PEDIATRIC ANESTHESIOLOGY

A Comprehensive Board Review

Edited by

KAI MATTHES · ANJOLIE E. LAUBACH
ELLEN WANG · T. ANTHONY ANDERSON

OXFORD

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EDITED BY

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PREFACE

Board certification in Pediatric Anesthesiology was established in 2013 and provides this dynamic subspecialty with a mechanism to formally recognize expertise in perioperative care for pediatric patients undergoing surgical and diagnostic procedures. The field of Pediatric Anesthesiology continues to expand and now includes the subspecialties of chronic pain management and ultrasound-guided regional anesthesia. Individuals who practice this discipline must complete a 4-year Anesthesiology residency followed by a 1- to 2-year Pediatric Anesthesiology fellowship. Additional training in pediatric cardiac anesthesia, intensive care, pain management, and regional anesthesia can be pursued as well.

This textbook was compiled as a high-yield study aid that will assist Anesthesiology residents, Pediatric Anesthesiology attending physicians, and certified registered nurse anesthetists (CRNAs) to rapidly consolidate knowledge in the fundamentals of this specialty while preparing for written certification in anesthesiology, pediatric subspecialty certification, and in the routine care of their patients.

The textbook follows the published American Board of Anesthesiology Pediatric Anesthesiology certification content outline. Major topics include basic sciences, organ-based clinical sciences, subspecialties, and special techniques. With more than 600 questions formatted according to the new American Board of Anesthesiology standards, this text includes a comprehensive review of each subtopic in the content outline. Each answer discussion provides a thorough overview of the subject and includes key points after each question, which allows for efficient review of the subject matter for rapid recall. Numerous figures and tables allow for efficient consolidation of key facts during review. Furthermore, references after each answer discussion provide readers with resources to major texts and seminal papers on each subject matter.

We are grateful to our contributing authors for sharing their expertise through the question-and-answer format employed in this textbook. Their efforts have made this project successful. We are also grateful for the support of Drs. Paul Hickey and Mark Rockoff of Boston Children's Hospital, whose support and encouragement made this endeavor possible. We are also indebted to the staff at Oxford University Press, particularly Andrea Seils and Rebecca Suzan.

We hope that you find *Pediatric Anesthesiology: A Comprehensive Board Review* a valuable addition to the materials used in preparation for the written certification examination as well as in the daily care of your patients.

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SECTION I

BASIC SCIENCE

1.

ANATOMY

Amber N. Borucki and Herodotos Ellinas

1. Compared to an adult airway, which anatomic difference of an infant airway is correct?

A. An infant's larynx is more anterior and caudad compared to the adult's.
B. An infant's narrowest portion of the upper airway is at the upper trachea below the cricoid cartilage.
C. An infant's epiglottis is flat, broad, and floppy compared to the adult's.
D. An infant's anterior portion of the vocal cords is attached caudad compared to the posterior portion.

2. Neonates require a higher dose of succinylcholine compared to adults. Which one of the following explains this finding?

A. Smaller proportion of fat distribution
B. Smaller muscle mass
C. Larger extracellular fluid volume
D. Larger protein binding

3. You are taking care of a 2-month-old, 4 kg boy for thoracotomy with lung resection for congenital cystic adenomatoid malformation (CCAM). Preoperative hematocrit is 28%. What would be the estimated blood loss if the intraoperative hematocrit is 21%?

A. 80 mL
B. 60 mL
C. 100 mL
D. 110 mL

4. What is the reason for administering a higher per kilogram dose of propofol in a child compared with an adult?

A. Smaller proportion of fat distribution
B. Smaller muscle mass
C. Larger protein binding
D. Larger volume of distribution

5. An 11-year-old, 90 kg boy with a body mass index (BMI) of 36 kg/m^2 is scheduled to undergo tonsillectomy and adenoidectomy. What would be the most important perioperative concern?

A. Postoperative nausea and vomiting
B. Postoperative respiratory depression
C. Gastroesophageal reflux
D. Hepatic enzymatic drug metabolism

6. An 1800 g, 2-day-old, 34-week premature male infant presents for repair of left congenital diaphragmatic hernia. A double-lumen umbilical venous catheter is in place for intravenous access. Which of the following statements describes proper technique for umbilical venous catheter placement?

A. Umbilical venous catheters may be placed if peritonitis is present.
B. The appropriate location of the tip of an umbilical venous catheter is at the junction of the inferior vena cava and the right atrium.
C. The ductus venosus is patent for catheter advancement for the first month of life.
D. If resistance is met during placement, the catheter should be left in its current location and only exchange transfusion can be performed.

7. A 6-month-old male presents for hypospadias repair. The anesthetic plan includes caudal epidural anesthesia. Which of the following statements describes the normal sacral anatomy of an infant?

A. The anterior superior iliac spines and the sacral cornua form an equilateral triangle used for caudal epidural anesthesia placement.
B. The sacral vertebrae are fused at this age.
C. The infant dural sac terminates at the level of the third sacral vertebrae.

D. The infant sacrum has a greater curvature (lordosis) than the adult sacrum.

8. A 5 kg, 3-month-old male patient presents for endoscopic sagittal suture removal due to craniosynostosis. The anesthetic plan includes general endotracheal anesthesia. Which of the following statements describes the infant airway?

A. The infant epiglottis is broad and angled parallel to the axis of the trachea.
B. The thyroid cartilage is the only complete ring of cartilage to encircle any part of the airway.
C. A more acute angle exists between the plane of the tongue and the plane of the laryngeal inlet in an infant.
D. In a preterm infant, the larynx is located at the middle of the fourth cervical vertebra.

9. A 5-year-old, 22 kg ASA 1 male presents for left inguinal hernia repair. The anesthetic plan includes general anesthesia augmented with an ilioinguinal nerve block for postoperative pain control. Which of the following statements describes the anatomy of the ilioinguinal nerve?

A. The ilioinguinal nerve is derived from the ventral rami of the L2 spinal nerve root.
B. After leaving the lumbar plexus, the ilioinguinal nerve courses posterior to the quadratus lumborum muscle.
C. The ilioinguinal nerve is derived from the dorsal rami of the L2 spinal nerve root.
D. The ilioinguinal nerve provides motor innervation to the internal oblique muscle.

10. An umbilical arterial line was placed in an 1100 g, 27-week premature male infant for blood sampling. Forty-five minutes after placement, blanching of the right lower extremity is observed. Which of the following complications of an umbilical arterial line has the patient developed?

A. Malpositioned catheter
B. Thromboembolic event
C. Vasospasm
D. Vessel perforation during placement

11. Percutaneous needle cricothyroidotomy and surgical cricothyroidotomy are both included in the difficult airway algorithm for emergency airway management in pediatric patients. Which of the following statements accurately describes their use?

A. Risk of injury to vital structures is considered to be the same using both the percutaneous and surgical techniques.
B. The percutaneous technique is more successful than the surgical technique.
C. Surgical cricothyrotomy is more rapidly performed than percutaneous cricothryotomy.
D. Percutaneous cricothyrotomy uses techniques familiar to nonsurgical trained physicians, which enhances their comfort level and speed.

12. A peripheral nerve block was performed at the elbow on a 14 kg, 2-year-old female for removal of a mass on the wrist. A total of 3 mL of 0.2% ropivicaine was injected 1 cm lateral to the biceps tendon along the intracondylar line. Which nerve was injected?

A. Ulnar nerve
B. Radial nerve
C. Median nerve
D. Musculocutaneous nerve

13. A 12-year-old female weighing 35 kg presents for resection of a right anterior thigh mass. The surgeon would like a peripheral nerve block performed for postoperative pain control. Which of following is the most appropriate regional block?

A. Fascia iliaca
B. Sciatic nerve
C. Lateral femoral cutaneous nerve
D. Iliohypogastric nerve

14. A 14-month-old previously healthy male was involved in a restrained motor vehicle accident. In the emergency room he was found to have a classic "seatbelt sign." A kidney, ureter, and bladder (KUB) X-ray obtained showed free air in the abdomen. He was urgently brought to the operating room for exploratory laparotomy. He had difficult intravenous access in the emergency room, and an intraosseous line was placed. Which of the following statements describes appropriate usage of an intraosseous line?

A. Intraosseous line placement may affect later tibial growth in children.
B. Complications such as cellulitis, abscess, fracture, and osteomyelitis occur in 11% of cases.
C. Contraindication if prior insertion of an intraosseous line in the extremity within 24 hours.
D. It should not be used for emergency resuscitation.

15. A 1-day-old, 2200 g, 35-week premature male infant with congenital diaphragmatic hernia presents urgently for repair. The anesthetic plan includes placement of a

preductal arterial line. Which of the following arteries will be suitable?

A. Right femoral artery
B. Umbilical artery
C. Left temporal artery
D. Left subclavian artery

16. A 14-month-old male presents for revision of a prior circumcision. The urologic surgeon asks you to place a penile nerve block for analgesia. Which of the following statements properly describes the innervation of the penis?

A. The dorsal penile nerve is derived from fibers of the perineal nerve branch of the pudendal nerve.
B. The pudendal nerve is derived from the ventral rami of the L4-S2 segments of the spinal cord.
C. The dorsal penile nerve divides into two branches, which separate at the level of the symphysis pubis.
D. Branches of the iliohypogastric nerve supply the skin at the root of the penis.

17. An 8-month-old, 9 kg male presents for thoracotomy and resection of a congenital cystic adenomatoid malformation on the left lung. The anesthetic plan includes placement of a left-sided paravertebral catheter for postoperative analgesia. Which of the following statements accurately describes the anatomy of the paravertebral space?

A. Sympathetic ganglia and rami communicantes are present in the paravertebral space.
B. The paravertebral space is continuous from T1 to L5, allowing passage of a catheter.
C. The anterolateral boundary of the paravertebral space is the visceral pleura.
D. The paravertebral space does not exist in the lumbar area.

18. An 11-year-old, 35 kg male presents for excision of a right foot ganglion cyst. The cyst is located on the lateral aspect of the foot immediately inferior to the lateral malleolus. An ankle block is planned for postoperative analgesia. Which of the following nerves supplies the sensory innervation to this dermatome?

A. The deep peroneal nerve
B. The sural nerve
C. The superficial peroneal nerve
D. The saphenous nerve

CHAPTER 1 ANSWERS

1. ANSWER: D

This question discusses the anatomic differences of the pediatric versus the adult airway. In **adults**, the **larynx** is located at the level **of C4-C5.** Based on magnetic resonance imaging (MRI) and computerized tomography (CT) confirmatory evidence, the **infant larynx** (up to 2 years of age) is located at the level **of C3-C4** and therefore **more cephalad than the adult location**.

The **narrowest portion of the upper airway in infants is at the level of the cricoid cartilage** (not below, as in Answer B), which was supported by a study of children <2 years of age by MRI and CT. More recent data, however, in children of ages 2 months to 13 years old indicate that the narrowest portion of the infant airway is the **glottis and the immediate subglottic area** and remains unchanged throughout childhood development. Despite data from this study, *Cote's Practice of Anesthesia for Infants and Children* (5th ed.) states that "the cricoid cartilage is functionally the narrowest portion of the upper airway and large diameter endotracheal tubes may meet resistance immediately below the cords (subglottic or cricoid ring region)."

The **epiglottis in an infant is narrower, shaped like the Greek letter omega,** and **angled away** from the axis of the trachea. Its position may cause difficulty with lifting the epiglottis during direct laryngoscopy.

In adults, the vocal cords lie perpendicularly to the trachea, whereas in **infants** the **vocal cords are angled inferiorly, which means that the anterior portion is attached caudad compared to the posterior portion**. This can provide more challenges during tracheal intubation, especially if the endotracheal tube is inserted via the nasal approach.

KEY FACTS

- There is controversy about the narrowest portion of the upper airway in infants described as the glottis or subglottis (cricoid cartilage) depending on the literature cited.
- The infant larynx (up to 2 years of age) is located at the level of C3-C4, which is more cephalad than the adult larynx located at the level of C4-C5.
- The infant larynx is more anteriorly located than the adult larynx.
- The infant epiglottis is narrower, shaped like the Greek letter omega, and angled away from the axis of the trachea.
- In an infant, vocal cords are angled inferiorly with the anterior portion attached caudad compared to the posterior portion.

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2. ANSWER: C

This question describes differences in volume of distribution between infants, children, and adults. The correct answer is C.

Drug absorption and distribution is affected by three components: total body water (TBW), total body fat, and total body protein (Table 1.1). TBW affects distribution of water-soluble medications such as antibiotics and muscle relaxants, including succinylcholine. **TBW is divided into** two compartments: **intracellular and extracellular,** both of which are **larger than in adults**. The percent of TBW in term infants is about 70%–80% and reaches adult composition of about 60% by the age of 12 years. The **additional percent of water** found in **infants** demands a **higher dosing of medications** such as **succinylcholine** to obtain the same effect as in adults.

Infants and children have a **smaller proportion of fat distribution** compared to adults with about **12% of body weight at term** versus 20%–25% **of adult body weight**. Medications that require redistribution to muscle or fat for resolution of clinical effects may have both a higher initial blood level and **prolonged duration of action (barbiturates, opioids)**. These effects may result in longer sedation and respiratory compromise.

Infants and children have **lower levels** of the two main plasma proteins **albumin and α_1-acid glycoprotein,** thus allowing for higher free fraction of medications and a stronger effect. Alteration in protein binding **affects** medications that are **acidic (highly protein bound) such as antiepileptics, local anesthetics, antibiotics, and midazolam**.

Table 1.1 COMPONENTS AFFECTING DRUG ABSORPTION AND DISTRIBUTION

	PRETERM	TERM	ADULT
Total body water (% body weight)	80	70	60
Muscle mass (% body weight)	15	20	50
Fat (% body weight)	3	12	20–25
Blood volume (mL/kg)	90	80	70

Succinylcholine is **used in neonates and children based on similar indications** as in adults (rapid sequence induction [RSI] for full stomach; i.e., acute appendicitis, severe gastroesophageal reflux, trauma, and pyloric stenosis). It is effective intramuscularly with complete muscle relaxation achieved in 3–4 minutes. As noted earlier, a **higher dose is needed to achieve a similar effect as in adults**; faster resolution of clinical effect is noted in infants and children and is due to faster clearance. Succinylcholine is metabolized by butyrylcholinesterase (plasma cholinesterase, pseudocholinesterase) and although the enzyme activity is lower in neonates, no clinical significance is noted. Contraindications for its administration are the same as for adults (i.e., trauma, burns, prolonged immobility, upper and lower motor neuron disorders, and history of malignant hyperthermia).

KEY FACTS

- Drug absorption and distribution is affected by three components: TBW, total body fat, and total body protein.
- TBW is greater in infants and children, and therefore higher doses of succinylcholine are required.
- Infants and children have a smaller proportion of fat distribution compared to adults, which may lead to prolonged duration of action for barbiturates and opioids.
- Infants and children have lower levels of plasma proteins of albumin and α_1-acid glycoprotein, which affects medications that are acidic (highly protein bound) such as antiepileptics, local anesthetics, antibiotics, and midazolam.

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3. ANSWER: A

This question outlines differences in blood volume in children compared to adults. The correct answer is A.

It is important to estimate blood volume for each child undergoing anesthesia in order to anticipate the need for replacement (see Table 1.2). Blood volume is higher in preterm and term infants compared to adults due to an increased plasma volume. In the **preterm infant, the blood volume is about 90–100 mL/kg, and it decreases with age to attain adult levels of about 60–70 mL/kg.** Data suggest that **obese children should be treated as having an adult-like blood volume of about 60–70 mL/kg** rather than a child equivalent of 70–80 mL/kg.

Table 1.2 ESTIMATES OF CIRCULATING BLOOD VOLUME

AGE	BLOOD VOLUME (ML/KG)
Preemie	90–100
Full-term newborn	80–90
3–12 months	75–80
3–6 years	70–75
>6 years	65–70

SOURCE: Adapted from Davis PJ. *Smith's Anesthesia for Infants and Children*. 8th ed. St. Louis, MO: Mosby; 2011:384 and 409.

Oxygen supply and demand dictate lowest hematocrit allowed for each individual. A child with a **severe respiratory disorder, central nervous system injury, or cyanotic heart disease** is in need of a higher hematocrit to maintain adequate oxygen-carrying capacity to prevent further compromise. **A premature infant will also require a higher hematocrit** to help prevent apnea of prematurity and its associated complications of bradycardia and failure to thrive.

To estimate blood loss from an initial hematocrit to a current hematocrit, we use the following formula:

$$\text{estimated blood loss (EBL)} = \text{blood volume} \times \text{weight} \times \left(\text{Hct}_{\text{init}} - \text{Hct}_{\text{curr}}\right) / \text{Hct}_{\text{init}}$$

In our case, estimated blood volume is 4 kg × 80 mL/kg, initial Hct is 28%, and current Hct is 21%; that is,

$$4 \times 80 \times (28 - 21)/28 = 4\,\text{kg} \times 80\,\text{mL/kg} \times 7/28 = 80\,\text{mL}$$

Remember that this number is only an estimate and actual hematocrit depends on both the rate of blood loss and the rate of fluid replacement with crystalloids and colloids.

KEY FACTS

- EBL = blood volume × weight × ($\text{Hct}_{\text{init}} - \text{Hct}_{\text{curr}}$)/$\text{Hct}_{\text{init}}$
- Premature newborn: 90–100 mL/kg
- Full-term newborn: 80–90 mL/kg
- 3 months–1 year: 75–80 mL/kg
- 3–6 years: 70–75 mL/kg

- >6 years: 65–70 mL/kg
- Obese children should be treated as having an adult-like blood volume of about 60–70 mL/kg.

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4. ANSWER: D

This question describes differences in volume of distribution between infants, children, and adults and describes the specific properties of propofol. Data in children show that the **volume of distribution for propofol is larger than in adults**.

Drug absorption and distribution is affected by three components: **TBW, total body fat, and total body protein**. TBW affects distribution of water-soluble medications such as antibiotics and muscle relaxants. TBW is divided into two compartments: intracellular and extracellular, both of which are larger than in adults. The percent of body water in term infants is about 70%–80% and reaches adult composition of about 60% by age 12 years old. The additional percent of water found in infants demands a higher dosing of medications such as succinylcholine to obtain the same effect as in adults.

Infants and children have a **smaller proportion of fat distribution** compared to adults with about 12% of body weight at term versus 20%–25% of adult body weight. Medications that require redistribution to muscle or fat for resolution of clinical effects may have both a higher initial blood level and prolonged duration of action (barbiturates, opioids). These effects may result in longer sedation and respiratory compromise.

Infants and children have lower levels of the two main plasma proteins albumin and α_1-acid glycoprotein, thus allowing for a higher free fraction of medications and a stronger effect. Alteration in protein binding affects medications that are acidic (highly protein bound) such as antiepileptics, local anesthetics, antibiotics, and midazolam.

Propofol is highly lipophilic with clinical effects dissipating due to rapid redistribution to vessel-rich organs and metabolism via the liver (conjugation to a water-soluble molecule) and excretion into the urine. In children, **higher doses are required both for induction (2–3 mg/kg)** and for maintenance of sedation (200–300 μg/kg per minute). **Context-sensitive half-time, however, is longer** in children than in adults with 1-hour infusion time of about 10 minutes instead of 6 minutes in adults and a 4-hour infusion of about 20 minutes instead of 10 minutes in adults.

KEY FACTS

- Volume of distribution for propofol is larger in children than in adults.
- Propofol is highly lipophilic with clinical effects dissipating due to rapid redistribution to vessel-rich organs and metabolism via the liver.
- Higher doses are required both for induction (2–3 mg/kg) and for maintenance of sedation (200–300 μg/kg per minute).
- Context-sensitive half-time for propofol is longer in children than in adults.

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5. ANSWER: B

This question outlines health problems associated with obesity. All of the answers are valid concerns in a young obese adolescent, but the most important one is **perioperative respiratory depression due to both predisposition for obstructive sleep apnea and the use of opioids** during tonsillectomy and adenoidectomy.

Postoperative nausea and vomiting is a concern, especially after this procedure, but is managed well with multidrug administration of ondansetron and dexamethasone. **Gastroesophageal reflux (GER) is prevalent among morbidly obese patients with 70% complaining of heartburn**. Data suggest that **neither the volume nor the acidity is increased in nondiabetic, fasting, obese patients without GER**. Fatty liver can affect metabolism of medications undergoing hepatic biotransformation, but in adolescents it is clinically not a significant risk, especially with no synthetic liver function changes and no clinical evidence of liver disease (e.g., bleeding, platelet dysfunction).

Obesity has become one of the most important health issues the United States faces today. Based on data from the National Health and Nutrition Examination Survey, about 17% (12.5 million) children and adolescents aged 2–19 years are obese. According to the Centers for Disease Control and Prevention (CDC), the best way to determine childhood overweight and obesity is by calculating

the BMI, which is equal to weight (kg) divided by height (m) squared. CDC child/adolescent growth charts and calculators are available to provide an age-specific percentile. **Overweight is defined as BMI >85th percentile and obesity as BMI >95th percentile**. Obesity diagnosed in early childhood not only persists in adolescence but also is maintained in adulthood with all of its associated comorbidities.

Side effects of obesity involve multiple systems. Cardiovascular disorders such as **long-term hypertension with left ventricular dysfunction** are seen as early as in **the adolescent years**; **dyslipidemia with adult coronary artery disease and peripheral vascular disease** are also prevalent. Respiratory compromise is a large component of morbidity with **decreased functional residual capacity (FRC), increased work of breathing, hypoxemia, obstructive sleep apnea,** and eventual **pulmonary hypertension, cor pulmonale, and heart failure**. **Metabolic syndrome with insulin resistance** and **type 2 diabetes mellitus** can be detrimental to the heart, kidneys, and brain. Gastrointestinal disorders include **cholelithiasis, GER,** and **fatty liver** (nonalcoholic steatohepatitis [NASH]). Neurologic problems include **pseudotumor cerebri** with persistent headaches requiring medical management and cerebrospinal fluid removal. Orthopedic issues include **slipped capital femoral epiphysis (SCFE)** and **Blount disease** (tibia vara).

Behavioral modification and dietary management are the main components of treatment in childhood obesity. Although medications and surgical management are the mainstay treatments in adults, few data are available in adolescents.

KEY FACTS

- Perioperative respiratory depression is due to both predisposition for obstructive sleep apnea and the use of opioids.
- GER is prevalent among morbidly obese patients with 70% complaining of heartburn; neither volume nor acidity is increased in nondiabetic, fasting, obese patients without GER.
- Overweight is defined as BMI >85th percentile and obesity as BMI >95th percentile.
- The comorbidities of obesity affect nearly every organ system.

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6. ANSWER: B

The umbilical vein is a convenient access site for placement of central venous catheters in newborns. The **majority of umbilical venous catheters are placed blindly** in the intensive care unit by neonatologists with a high rate of malposition. Although most anesthesia providers do not place these catheters themselves, it is extremely important to evaluate the location of umbilical venous catheters before usage in the operating room because infusion of fluids and medications through a malpositioned catheter may lead to life-threatening consequences.

The umbilical **cord contains one umbilical vein and two umbilical arteries**. The **umbilical vein** has thinner walls than the arteries, is usually located in the 12 o'clock position, and generally remains **patent for the first week of life**. The course of the umbilical vein begins at the umbilicus and ends at the liver edge, where the vein widens into an umbilical vein/portal vein confluence. This confluence connects to intrahepatic branches of the left portal vein and also to the ductus venosus. The **ductus venosus travels superiorly and joins with the hepatic vein, which enters the inferior vena cava at the level of T8-T10**.

Indications for placement of an umbilical venous catheter include the following: emergency access for medications in the delivery room, access for daily fluids/medications and blood draws in the intensive care unit, long-term access for low birth weight infants, exchange transfusion, and central venous pressure monitoring. Absolute **contraindications include omphalocele, omphalocitis, nectrotizing enterocolitis, and peritonitis** (Answer A).

Placement of the umbilical venous catheter should be performed under sterile conditions. A 3.5 or 5 French catheter is selected based on neonate size. The **catheter is advanced** under sterile conditions through (sequentially) **the umbilical vein, the ductus venosus, and finally the inferior vena cava**. The appropriate location of the catheter tip is at the junction of the inferior vena cava and the right atrium (Answer B). If resistance is met during placement, this may indicate that the catheter is in the portal system, has entered an intrahepatic branch of the portal vein, or that the ductus venosus may already be closed. The **ductus venosus is usually patent for 5–7 days after birth** (Answer C). In this situation the catheter should be pulled back into the umbilical vein to avoid direct administration of hyperosmolar or sclerosing medications into the portal venous system. The catheter then may be used for emergency medications and exchange transfusion only (Answer D). After placement of any umbilical venous catheter, a chest radiograph is necessary to confirm catheter tip location.

A feared complication of umbilical venous catheterization is placement of the tip of the catheter in an **intrahepatic portal venous location**. **Infusion of hyperosmolar or sclerosing solutions may lead to portal necrosis and eventual cirrhosis**. Other complications of umbilical

venous catheter usage include **portal thrombosis, infection, endocarditis, portal hypertension, pericardial effusion and tamponade, liver abscess, and systemic emboli**.

KEY FACTS

- The umbilical cord contains one umbilical vein and two umbilical arteries.
- The umbilical vein is thinner walled than the arteries, is at a 12 o'clock position, and remains patent for the first week of life.
- Absolute contraindications for an umbilical vein catheter include omphalocele, omphalocitis, nectrotizing enterocolitis, and peritonitis.
- The catheter is advanced sequentially through the umbilical vein, the ductus venosus, and finally the inferior vena cava.
- Avoid leaving the tip of umbilical venous catheter in the intrahepatic portal venous system.

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7. ANSWER: C

Caudal epidural anesthesia is the neuraxial technique used with highest frequency in children who require procedures below the level of the umbilicus. Single-shot or continuous techniques may be employed. Continuous techniques involve entrance of the epidural catheter at the sacrum and threading of the catheter to appropriate dermatome height. Knowledge of pediatric sacral anatomy is paramount to mastering both techniques.

The sacrum is a triangular structure that consists of five fused sacral vertebrae in the adult. During infancy and childhood the sacral vertebrae are not yet fused and instead are connected by hyaline cartilage. **Fusion of the vertebrae begins during the 20th year of life** (Answer B). The sacrum articulates with the coccyx inferiorly, the L5 vertebra superiorly, and the ilium bilaterally. In adults, the angle between the sacrum and L5 vertebrae is 130–160 degrees, and this contributes to significant lordosis. **Infants have decreased lumbar lordosis** compared to adults and **also less epidural fibrosis than adults** (Answer D). In infants, the sacrum is narrower and flatter than in adults and structurally less variable.

The **sacral cornua and the posterior superior iliac spines are the anatomical surface landmarks** used during caudal anesthesia (Answer A). Together they form an **equilateral triangle** with the **apex pointing to the sacral hiatus**. The sacral hiatus results from the absence of the laminae and spinous processes of the S5 and sometimes S4 vertebrae. The sacral hiatus is the entrance to the sacral canal. The sacral canal contains fat, connective tissue, the filum terminale, the dural sac that contains the cauda equina, and epidural vessels. In the **neonate, the dural sac ends at the S3-S4 vertebral level** (Answer C). **By 1 year of age, the dural sac arrives at its adult position of S1-S2**. One important difference between the adult and neonate during caudal anesthesia is that the approach to the subacrachnoid space from the sacral hiatus is more direct in neonates than in adults. Therefore, dural puncture is more frequent during epidural injection of neonates and infants.

Performance of caudal anesthesia begins with placement of the patient in lateral decubitus or prone position after sedation or general anesthesia has been instituted. The patient is prepped and draped sterilely. The posterior superior iliac spines and sacral cornua are palpated. Using these landmarks, the sacral hiatus is identified. The appropriate needle (depending on technique employed) is advanced through the subcutaneous tissue at a 45- to 75-degree angle until the needle "pops" through the sacrococcygeal ligament and into the sacral canal. The needle should then be advanced several millimeters into the sacral canal; however, care should be taken to not advance it too far because this may puncture the dural sac. Aspiration is performed for cerebrospinal fluid and blood. If aspiration is negative, a test dose is administered. Once a negative test dose is confirmed, local anesthetic can be injected directly into the epidural space. If a continuous epidural catheter will be placed, the catheter may be threaded to the appropriate location after a confirmed negative aspiration. A test dose is then performed through the catheter.

Sites of **misplacement of the needle during caudal anesthesia include the following: subperiosteum, bone marrow, posterior sacral ligaments, into a false hiatus, the anterior sacral wall and possibly pelvis, or into a lateral foramen**.

KEY FACTS

- The sacrum is a triangular structure that consists of five fused sacral vertebrae.
- During infancy and childhood the sacral vertebrae are not yet fused; they are connected by hyaline cartilage.
- Fusion of the vertebrae begins during the 20th year of life.
- The sacral hiatus results from the absence of the laminae and spinous processes of the S5 and sometimes S4 vertebrae.
- Landmarks of caudal anatomy are sacral cornua and the posterior superior iliac spines, which form an equilateral triangle with the apex pointing to the sacral hiatus.

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8. ANSWER: C

There are several fundamental differences between the adult and pediatric airway that are important to the practice of pediatric anesthesiology. These differences are based on physical alterations of anatomic structures that define the airway—the tongue, epiglottis, laryngeal inlet, and subglottis.

The **infantile tongue is large** in proportion to the oropharynx and has a tendency to fall backward and obstruct the laryngeal inlet during mask ventilation.

The shape of the **epiglottis in the infant is described as narrow, omega-shaped, firm, and angled away from the axis of the trachea** (Answer A). The adult epiglottis, however, is more often flat, broad, and floppy, and it is often angled parallel to the trachea.

The location of the larynx differs greatly from preterm neonate to term infant to adult. In the **preterm neonate, the glottic opening is located at mid-C3 vertebral level** (Answer D). In the **full-term infant, the glottic opening is located at the C3-C4 vertebral interspace**. In the **adult, the larynx is found at the C4-C5 vertebral interspace**. The anesthetic implications of a superior laryngeal position are great. With a cephalad position, a more acute angle exists between the plane of the tongue and the plane of the laryngeal inlet, thus making direct laryngoscopy more challenging (Answer C). The higher location of the laryngeal inlet in the premature neonate or term infant also leads to further glottic obstruction by the large infant tongue.

There are observed differences in the subglottic structures between adults and infants. Studies using MRI, CT scanning, and autopsy reports reveal that the **narrowest portion of the pediatric airway is located immediately subglottic, at the cricoid cartilage**. Therefore, the pediatric airway is described as "funnel shaped." The **cricoid cartilage is the only complete ring of cartilage to encircle** any part of the airway (Answer B), and thus it is subject to significant compression by ill-fitting endotracheal tubes. Compression of tracheal mucosa at this level can lead to significant edema, hyperemia, and mucosal damage. Resultant edema can narrow the already physiologically reduced subglottic area even further. The resistance produced by the pathological narrowing is equivalent to the inverse of the radius. In infants with a smaller anatomical subglottic radius, the increase in resistance is devastating and can lead to post-extubation croup. Therefore, the choice of an endotracheal tube with the appropriate diameter is essential in the pediatric population.

KEY FACTS

- The infantile tongue is large.
- The shape of the epiglottis in the infant is described as narrow, omega shaped, firm, and angled away from the axis of the trachea.
- In the preterm neonate the glottic opening is located at mid-C3 vertebral level.
- In the full-term infant, the glottic opening is located at the C3-C4 vertebral interspace.
- In adults, the larynx is located at the C4-C5 vertebral interspace.

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9. ANSWER: D

Inguinal nerve blocks are useful in patients undergoing procedures **involving the groin and inguinal canal** in particular. These blocks can be used as the primary anesthetic in adult inguinal hernia procedures. In pediatric patients, inguinal blocks are commonly used for postoperative pain control and are placed under general anesthesia.

Anesthesia of the inguinal region is obtained by blockade of the ilioinguinal and iliohypogastric nerves. **Both the ilioinguinal and iliohypogastric nerves arise from the lumbar plexus and consist of fibers from the ventral rami of the L1 spinal nerve root** (Answers A and C). The nerve then descends anterior to the quadratus lumborum muscle and iliacus muscles (Answer B).

Superomedial to the anterior superior iliac spine, both the ilioinguinal and iliohypogastric nerves pierce the transversus abdominus muscle and run between the internal oblique and the transversus abdominus. The nerves then run inferomedially and pierce the internal oblique and external oblique. Both nerves supply motor innervation to the internal oblique and transversus abdominus muscles (Answer D). The iliohypogastric nerve provides cutaneous sensation over the inguinal crease; the ilioinguinal nerve provides cutaneous sensation to the medial thigh and lateral scrotum/mons pubis.

The block is performed by first **identifying the anterior superior iliac spine (ASIS)**. A mark is drawn **2 cm medial and superior to the ASIS**. This will be the site of

insertion of the needle. After sterile prep and drape, a blunt needle is then introduced at a 45-degree angle to the skin and advanced cephalad through the external oblique (first pop) and then through the internal oblique (second pop). Local anesthetic is injected deep to the external and internal oblique in 1–2 mL aliquots after negative aspiration. The needle is then successively redirected and fanned first medially and then laterally in a similar fashion. **Complications include local anesthetic toxicity and bowel perforation**.

KEY FACTS

- Inguinal nerve blocks are useful in patients undergoing procedures involving the groin and inguinal canal.
- Both the ilioinguinal and iliohypogastric nerves arise from the lumbar plexus and consist of fibers from the ventral rami of the L1 spinal nerve root.
- The ilioinguinal and iliohypogastric nerves supply motor innervation to the internal oblique and transversus abdominus muscles.
- The iliohypogastric nerve provides cutaneous sensation over the inguinal crease.
- The ilioinguinal nerve provides cutaneous sensation to the medial thigh and lateral scrotum/mons pubis.
- Complications include local anesthetic toxicity and bowel perforation.

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10. ANSWER: C

The first cannulation of an umbilical artery was in the 1950s by Dr. Virginia Apgar. This technique has become a common method of arterial access in the neonate because the umbilical artery is a convenient site. Umbilical arterial catheters (UACs) are used mainly for the purpose of arterial blood pressure monitoring and arterial blood sampling. They can also be used in emergency situations for the administration of medications and for exchange transfusion.

Contraindications to the placement of an umbilical arterial catheter include the following: **peritonitis, necrotizing enterocolitis, omphalocele, omphalitis, acute abdomen, and local vascular compromise in the lower limbs or buttocks**.

Technique: Prepare and drape the umbilical stump and abdomen in sterile fashion. Cut the cord 1 cm above the umbilicus. Identify the two umbilical arteries—the vessels are thicker walled and are smaller than the vein. Cephalad traction is applied to the umbilical stump to aid in passage of the catheter. Dilation of the vessel is suggested by some texts. The catheter is then gently introduced into the artery (forceps may help). Aspiration confirms intraluminal placement. X-ray or ultrasound confirms tip location. Proper location of the catheter tip is extremely important in reducing complications. The **umbilical artery is a direct continuation of the internal iliac arteries**. Usually the catheter will pass into the aorta from the umbilical artery; however, it can occasionally pass into the femoral artery from the external iliac artery or into the gluteal arteries. These are inappropriate locations and can lead to thrombosis and loss of the extremity. The catheter can also be placed too high in the aorta and pass through the ductus arteriosus and into the pulmonary artery, making for misleading blood gas sampling.

Two catheter tip locations in the descending aorta have been evaluated and studied—the high position (T7-T9) and the low position (L3-L4). **High positions have been found by several studies to have an overall lower incidence of vascular complications**. The low position is difficult to maintain and may lead to malposition in the iliac arteries.

There are many complications related to placement of an umbilical arterial catheter. The complications are broken down into four groups: **malposition, vascular accidents, equipment-related errors, and other complications.**

Malpositioning errors include the following: peritoneal perforation, vessel perforation, false aneurysm, sciatic nerve palsy, misdirection of catheter into external/internal iliac artery, and hypoglycemia with catheter tip opposite celiac axis. Vessel perforation is often associated with resistance during placement, loss of blood return, and hypotension subsequent to the procedure (Answers A and D).

Vascular accidents include thrombosis, embolism, vasospasm, and air embolism. **Thromboembolic complications of UAC placement most often occur days to weeks** after placement of the catheter (Answer B). Embolism may occur to the lower extremity or buttocks and may lead to the loss of a limb. Embolization can also occur to the renal vasculature. This often results in sudden hypertension in the newborn. Infarction of the kidney may occur. Thrombosis of the aorta leads to an elevated afterload state that puts increased pressure on the developing heart. This may lead to congestive heart failure in the newborn. Vasospasm is a common complication of UAC placement. **Vasospasm is often seen within minutes to hours after placement and presents as blanching of the buttocks or lower extremity** (Answer C).

Equipment-related complications include transection of the catheter, breaking of the catheter, electrical hazard, and disconnection of the tubing.

Other complications include infection, necrotizing enterocolitis, cotton fiber embolus, Wharton jelly embolus, bladder injury, factitious hypernatremia, paraplegia, and sciatic nerve palsy.

KEY FACTS

- UACs are used for arterial blood pressure monitoring and arterial blood sampling, emergency administration of medications, and for exchange transfusion.
- Contraindications include peritonitis, necrotizing enterocolitis, omphalocele, omphalitis, acute abdomen, and local vascular compromise in the lower limbs or buttocks.
- The umbilical artery is a direct continuation of the internal iliac arteries.
- High positions (T7-T9) have been found by several studies to have an overall lower incidence of vascular complications.
- Complications include malposition, vascular accidents, and equipment- related errors.
- Thromboembolic complications of UAC placement most often occur days to weeks after placement.
- Vasospasm is often seen within minutes to hours after placement and presents as blanching of the buttocks or lower extremity.

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11. ANSWER: D

Percutaneous needle cricothyrotomy uses the Seldinger technique for vascular access to obtain entry to the airway in emergency situations. This procedure is part of the difficult airway algorithm when mask ventilation and intubation are not possible.

The basic procedure is performed by first placing the patient in the supine position with the head extended. This can be accomplished by placing a rolled towel under the patient's shoulders. This position allows palpation of the cricothyroid membrane and moves vital structures away from the midline. Assuming right-hand dominance, the left index finger is used to palpate the cricothyroid membrane. In an infant, this space is only 1 mm in size. Once the cricothyroid membrane is found, the left middle finger and thumb are used to stabilize the trachea for needle advancement. Using the right hand, an intravenous catheter attached to a syringe is then inserted through the cricothyroid membrane. During insertion, aspiration of air is performed. Once air is aspirated, the catheter is slid off the needle and the needle is discarded. A 3 mm adapter from a pediatric endotracheal tube can be attached to the catheter and passive oxygenation or ventilation can be initiated. It must be remembered that **percutaneous needle cricothyrotomy may not allow for adequate ventilation (depending on catheter size), and that passive oxygenation may only be performed in certain situations**. If jet ventilation is used, there is a high likelihood of barotraumas if proper precautions are not taken.

A standard 12- or 14-gauge angiocatheter can be used to perform the procedure. There are also multiple commercial kits available for pediatric patients. These kits include different specialized needles, guidewires, dilators, and endotracheal tube connectors. Some specialized needles come with plastic stoppers to limit the depth of needle insertion to prevent puncture of the posterior tracheal wall. Other kits include needles with dilators large enough to permit 3.0–5.0 ID tracheostomy tubes.

Complications of percutaneous needle cricothyrotomy include puncture of the carotid, internal and external jugular, posterior wall of the trachea, and esophagus.

In 1992, the American Heart Association recommended percutaneous needle cricothyrotomy over surgical cricothyrotomy as the method to obtain an emergency airway. Reasons for this decision include the belief that the procedure has the advantages of **increased safety and shorter procedural time with similar success rates of surgical cricothyrotomy**. Several studies were performed looking at the success rates of the two procedures in adults. The results showed there was no statistical difference between success rates of percutaneous needle cricothyrotomy and surgical cricothyrotomy (Answer B). Practitioners were surveyed and preferred the percutaneous method because it included techniques that even nonsurgical practitioners were more familiar with (Answer D). Also, it is believed that percutaneous procedure may cause less tissue injury and avoid complications of surgical cricothyrotomy (Answer A). **Complications of surgical cricothyrotomy include injury to the carotid, internal jugular, cricoid and thyroid cartilage, laryngeal stenosis, and permanent speech disruption**. Finally, it was found that most practitioners could perform percutaneous cricothyrotomy more rapidly than surgical cricothyrotomy.

KEY FACTS

- Percutaneous needle cricothyrotomy uses the Seldinger technique for vascular access to obtain entry to the airway in emergency situations.
- Percutaneous cricothyrotomy is the preferred technique to obtain a surgical airway.

- Complications of percutaneous needle cricothyrotomy include puncture of the carotid, internal and external jugular, posterior wall of the trachea, and esophagus.
- Complications of surgical cricothyrotomy include injury to the carotid, internal jugular, cricoid and thyroid cartilage, laryngeal stenosis, and permanent speech disruption.

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12. ANSWER: B

Peripheral nerve blocks performed at the elbow can create surgical anesthesia for procedures on the forearm and wrist. These blocks can also create surgical anesthesia for procedures on the hand; however, a wrist block may be more helpful and specific. Blocks that are performed at the elbow are also commonly used as rescue blocks to supplement incomplete surgical anesthesia of a brachial plexus nerve block.

The three main nerves to the forearm and hand can be blocked at the elbow: the radial nerve, median nerve, and ulnar nerve. They can be localized by peripheral nerve stimulation or ultrasound.

Blockade of the ulnar nerve (Answer A) at the elbow produces anesthesia of dorsal and ventral surface of the medial side of the hand and the fourth and fifth digit. Blockade of the ulnar nerve will also lead to loss of ulnar deviation and inability to flex the fourth and fifth fingers. In the elbow, the **nerve is located between the medial epicondyle of the humerus and the olecranon process of the ulna**. The nerve is easily identified at this location, as it is only covered by skin. Technique: The elbow is flexed, the ulnar groove is palpated, and a 27-gauge needle is advanced perpendicular to the skin along the nerve. Local anesthetic is injected (2–5 mL).

Blockade of the **median nerve** (Answer C) at the elbow produces anesthesia of the ventral medial surface of the palm, including the thumb and digits 2–4. It also produces anesthesia of the dorsal surface of the distal third of fingers 2–4. Loss of flexion at all metacarpophalangeal joints and extension of the interphalangeal joints of digits 2–3 is characteristic of median nerve block. The nerve also is responsible for opposition of the thumb and pronation and flexion of the wrist. Technique: The arm is first abducted and supinated. **A marking is made along the intercondylar line between the medial and lateral epicondyles on the anterior aspect of the elbow**. The brachial artery is identified along this line and a mark is made 1 cm medial from the brachial artery. The needle is advanced perpendicularly to the skin (can be done under ultrasound guidance), taking care not to enter the brachial artery. After negative aspiration, 2–5 mL of local anesthetic is injected.

Blockade of the **radial nerve** (Answer B) at the elbow produces anesthesia of the dorsal surface of the forearm and lateral hand. It also produces anesthesia of the dorsal surface of the proximal two-thirds of the lateral 3½ digits. Loss of extension of the wrist and lateral fingers is characteristic of radial nerve block. Technique: The arm is abducted and supinated. A line is drawn on the ventral surface of the elbow along the **intercondylar line between the medial and lateral epicondyles of the humerus**. The biceps tendon is located. A mark is placed **1–2 cm lateral to the biceps tendon**. A 27-gauge needle is advanced (with or without ultrasound guidance) perpendicularly to the skin. After negative aspiration, 2–5 mL of local anesthetic is injected.

The **musculocutaneous nerve is blocked in the upper arm** and not at the elbow (Answer D).

KEY FACTS

- The ulnar nerve at the elbow produces anesthesia of dorsal and ventral surface of the medial side of the hand and the fourth and fifth digit. Location of the nerve is between the medial epicondyle of the humerus and the olecranon process of the ulna.
- The median nerve at the elbow produces anesthesia of the ventral medial surface of the palm, including the thumb and digits 2–4. It also produces anesthesia of the dorsal surface of the distal third of fingers 2–4. The nerve is blocked 1cm medial from the brachial artery along the intercondylar line between the medial and lateral epicondyles on the anterior aspect of the elbow.
- The radial nerve at the elbow produces anesthesia of the dorsal surface of the forearm and lateral hand. It also produces anesthesia of the dorsal surface of the proximal two-thirds of the lateral 3½ digits. The nerve is blocked 1–2 cm lateral to the biceps tendon from the intercondylar line between the medial and lateral epicondyles of the humerus.

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13. ANSWER: A

The **fascia iliaca compartment block** is a commonly used peripheral nerve block for children undergoing

lower-extremity surgery. It is a modification of the femoral nerve block and is distinct from the "3 in 1" nerve block initially described by Winnie et al. in 1973. The **fascia iliaca compartment block** has the same lumbar plexus targets as the "3 in 1" nerve block—the **femoral nerve, obturator nerve, and lateral femoral cutaneous nerve (Answer C).** However, it is performed in a more lateral position with respect to the femoral artery, and it aims to disperse local anesthetic throughout the facial compartment formed by the fascia iliaca (interiorly), iliacus muscle (posteriorly), iliac crest (laterally), and the sacrum (medially). Because the block is performed further laterally than the "3 in 1" block, it is postulated that local anesthetic injection into the femoral artery is less common with the fascia iliaca compartment block.

Adult and pediatric studies comparing the fascia iliaca compartment block to the conventional "3 in 1" nerve block have shown that the fascia iliaca compartment block more consistently leads to surgical anesthesia of all three nerves. Previous studies of the "3 in 1" block reported inconsistent obturator nerve blockade. The fascia iliaca block has also been found to be more reliable in pediatric patients versus adult patients.

The **fascia iliaca nerve block is indicated for anterior thigh procedures, hip procedures, and knee procedures**.

The fascia iliaca block can be performed with a blind technique or using ultrasound guidance. The blind technique or "double pop" technique is performed more commonly in adults. During this technique, a line is drawn from the pubic tubercle to the anterior superior iliac spine. A mark is then made corresponding to the intersection of the lateral third of this line and a point 2 cm distal to the line. This is the site of injection. The needle is then advanced at an angle of 75 degrees until two "pops" or losses of resistance are felt. Loss of resistance occurs when passing through the fascia lata and the fascia iliaca. After negative aspiration, a large volume of local anesthetic is injected (abiding to local anesthetic dosing guidelines for toxicity). During ultrasound guidance, the needle is advanced with the tip of the needle aiming for the space between the fascia iliaca and the iliacus muscle. The goal is for local anesthetic deposition between these two structures. During a successful block, the local anesthetic is seen to move both laterally and medially in the fascial plane.

The **iliohypogastric nerve block is combined with a nerve block of the ilioinguinal nerve often for procedures such as hernia repair, orchidopexy, or hydrocele surgery**. This block provides anesthesia to the lower abdominal wall, groin, and root of the penis/mons pubis. The **obturator nerve provides sensation to the medial thigh and motor innervation of the adductor muscles of the thigh**. Blockade of the obturator nerve is usually combined with femoral and lateral femoral cutaneous nerve blocks in either the fascia iliaca block or the "3 in 1" block for procedures of the anterior and medial thigh. The **lateral femoral cutaneous nerve provides sensation to the lateral aspect of the thigh**. Blockade of this nerve alone can be used to diagnose and treat meralgia paresthetica. The lateral femoral cutaneous nerve is also blocked in combination with the femoral or sciatic nerve for procedures of the knee and to treat tourniquet pain. The **femoral nerve provides sensation to the anterior thigh, knee, and medial calf**. It provides motor innervation to muscles in the anterior thigh responsible for knee extension. This nerve can be blocked for procedures on the anterior thigh. It is commonly used in femoral shaft fractures in children.

KEY FACTS

- The fascia iliaca compartment block involves blockade of the femoral nerve, obturator nerve, and lateral femoral cutaneous nerve.
- The fascia iliaca nerve block is indicated for anterior thigh procedures, hip procedures, and knee procedures.
- The iliohypogastric nerve block is often combined with a nerve block of the ilioinguinal nerve for procedures such as hernia repair, orchidopexy, or hydrocele surgery.
- The obturator nerve provides sensation to the medial thigh and motor innervation of the adductor muscles of the thigh.
- The lateral femoral cutaneous nerve provides sensation to the lateral aspect of the thigh.
- The femoral nerve provides sensation to the anterior thigh, knee, and medial calf.

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14. ANSWER: C

Intraosseous infusion was first described in 1922. Its use in children became popular in the 1940s. Intraosseous infusion fell out of favor in the 1950s–1960s when disposable intravenous catheters were developed and techniques for intravenous catheter insertion improved. In the 1980s, multiple reports were published describing intraosseous infusion efficacy in the pediatric population. Intraosseous infusion is currently endorsed by both Pediatric Advanced Life Support (PALS) and Advanced Cardiac Life Support (ACLS) as a route for emergency fluid and drug administration when peripheral venous access fails (Answer D).

The bone marrow **of long bones contains veins that drain the medullary sinuses**. These veins drain into major veins of the lower and upper extremity and do not collapse in shock states. Therefore, placement of a catheter in one of these veins is readily performed and can lead to the delivery of emergency fluids and medications into large peripheral veins. **Common sites for intraosseous insertion include the tibia, femur, humerus, and sternum.**

Contraindications to placement of an intraosseous line include **long bone fracture, vascular injury to the chose extremity, prior orthopedic procedure on the chosen extremity, cellulitis**, and **prior insertion of intraosseous line** in the chosen extremity within a **period of 24 hours** (Answer C).

Intraosseous lines can be placed by manual insertion techniques, battery-powered drivers, or impact-driven devices (such as a bone injection gun). The technique for manual placement of a tibial intraosseous line will be discussed here:

1. Sterile prep of the tibia should be performed.
2. Palpate the tibial tuberosity.
3. Locate a point on the medical surface of the tibia that is 1–2 cm below and medial to the tibial tuberosity. This should be the site of needle puncture.
4. Using a short needle with a stylet (to prevent bone migration into the needle), puncture the mantle of the tibia at a 75-degree angle directed toward the feet. The angle is chosen to avoid injury to the epiphyseal plate.
5. Proper location is determined when there is loss of resistance upon entering the marrow.
6. Remove the stylet and connect the needle to an infusion line. Fluids show flow freely without extravasation.
7. Stabilize the needle. Some needles come with stabilization devices.
8. Observe for extravasation during entire use of intraosseous infusion line.

Complications of intraosseous infusion include cellulitis, fracture, abscess, and osteomyelitis. These **complications** have been reported in **less than 1% of cases**. Other complications include extravasation and compartment syndrome. Intraosseous lines, when placed properly, are not associated with bone growth defects later in life.

KEY FACTS

- Intraosseous insertion is endorsed by both PALS and ACLS as a route for emergency fluid and drug administration when peripheral venous access fails.
- Common sites for intraosseous insertion include the tibia, femur, humerus, and sternum.
- Contraindications to placement of an intraosseous line include long bone fracture, vascular injury to the chosen extremity, prior orthopedic procedure on the chosen extremity, cellulitis, and prior insertion of intraosseous within a period of 24 hours.

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15. ANSWER: C

The ductus arteriosus is a vascular structure that connects the proximal **descending aorta** to the roof of the left pulmonary artery. This connection diverts blood from the right ventricle away from the lungs in the fetal state. At birth, elevated oxygen tension leads to gradual constriction of the medial smooth muscle layer of the ductus arteriosus. **Functional closure usually occurs within the first 2 days of life**. Persistent patency of the ductus arteriosus may also occur. **Risk factors include prematurity, genetic disorders, infection, and congenital cardiac disorders**. In healthy infants <48 hours old and in cases of persistent ductus arteriosus, a transitional circulation is present. During this time the ductus arteriosus is partially to fully patent and will allow shunting of blood from left to right or right to left, depending on pulmonary versus systemic pressures.

The location of arterial line placement in infants with suspected patent ductus arteriosus is important. A preductal versus postductal placement may be advantageous to evaluate for intraoperative cardiac shunting. The exact location of the ductus arteriosus has been described as distal to the left subclavian takeoff, although this location may be variable depending on right- versus left-sided aortic arch and congenital cardiac anomalies. Studies have also been performed using pulse oximetry in neonates with patent ductus arteriosus demonstrating no difference in SpO_2 in the left upper extremity versus the right upper extremity.

Preductal arteries include the **right subclavian, right common carotid, and left common carotid.** Therefore, **preductal arterial puncture sites include the right radial artery, right brachiocephalic artery, right axillary artery, right subclavian artery, right temporal artery, and left temporal artery**.

The radial artery is the most common site of arterial pressure monitoring. Complications from its use include thrombosis, embolic phenomena, vasospasm, ischemia, and

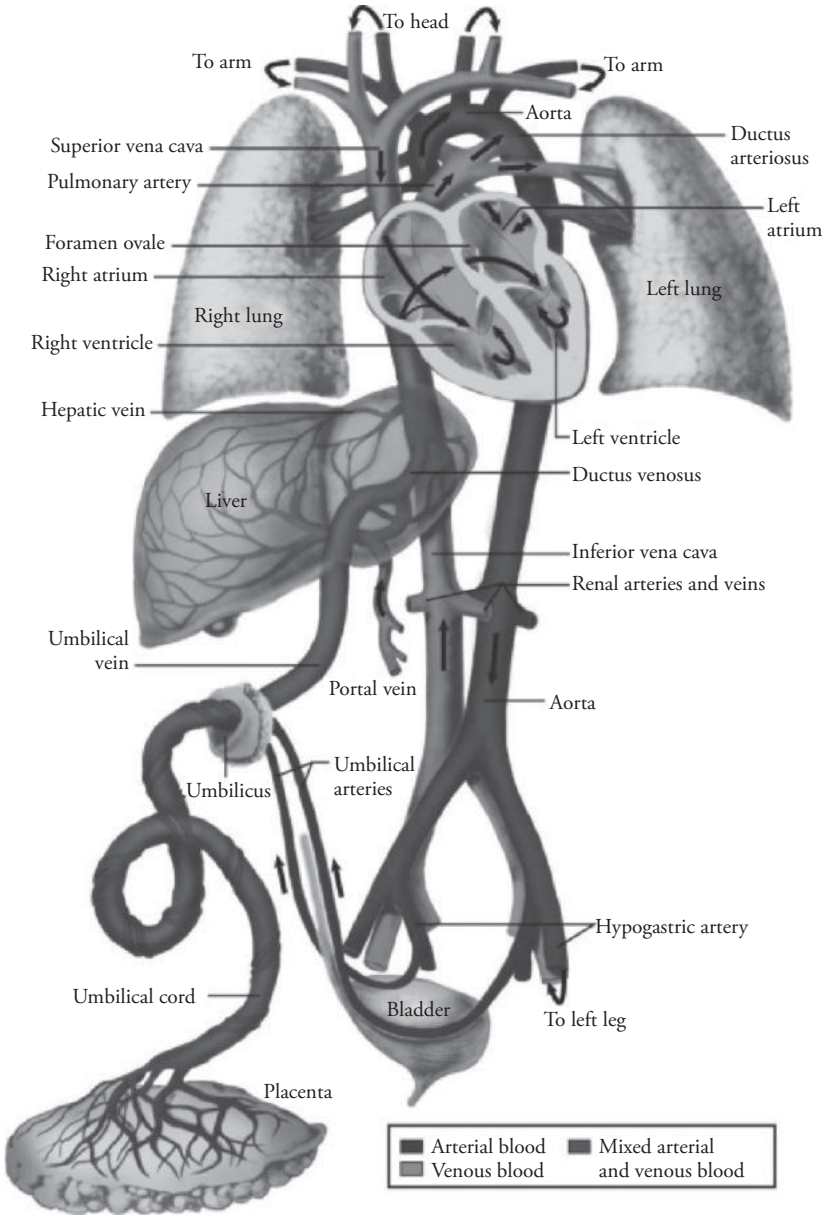

Figure 1.1 Course of the fetal circulation in late gestation. Notice the selective blood flow patterns across the foramen ovale and the ductus arteriosus. (From Greeley WJ, Berkowitz DH, Nathan AT. Anesthesia for pediatric cardiac surgery. In: Miller RD, ed. *Anesthesia*. 7th ed. Philadelphia, PA: Churchill Livingstone; 2010:2599–2652.)

infection. A modified Allen test is suggested prior to insertion of a radial arterial line.

Brachiocephalic, subclavian, and axillary arterial pressure monitoring are rare in the neonate, and they are often used when the radial artery is unable to be cannulated. Complications include pseudoaneurysm formation, thrombosis formation, ischemia of the limb, infection, and brachial plexus nerve injury (subclavian and axillary artery placement).

Temporal arterial pressure monitoring may be used when radial arterial monitoring is unavailable. Cerebral infarction has been described with this technique. Infarction is related to retrograde embolization of air or blood clot.

KEY FACTS

- The ductus arteriosus is a vascular structure that connects the proximal descending aorta to the roof of the left pulmonary artery.
- Functional closure usually occurs within the first 2 days of life.
- Risk factors for delayed closure include prematurity, genetic disorders, infection, and congenital cardiac disorders.
- Preductal arteries include the right subclavian, right common carotid, and left common carotid. Therefore, preductal arterial puncture sites include the right radial

artery, right brachiocephalic artery, right axillary artery, right subclavian artery, right temporal artery, and left temporal artery.

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16. ANSWER: C

The pudendal nerve is a **mixed motor and sensory nerve that provides sensation of the penis/clitoris, scrotum/vulva, perineum, and anus**. The pudendal nerve is derived from the ventral rami of the S2-S4 spinal segments (Answer B). After the nerve roots combine, the pudendal nerve leaves the pelvis through the greater sciatic foramen. It then reenters the pelvis via the lesser sciatic foramen and travels through the pudendal canal (a sheath of obturator fascia). In the pudendal canal, the nerve divides into the inferior rectal nerve, perineal nerve, and dorsal nerve of the penis/clitoris.

The **distal two-thirds of the penis derives its complete innervation from paired dorsal penile nerves**. **The dorsal penile nerve divides into two branches that separate at the level of the pubic symphysis** (Answer C). These branches then run laterally to the dorsal penile artery and terminate in the glans penis. **The root of the penis and the proximal one-third of the penis have shared innervated by both the dorsal penile nerve and the ilioinguinal nerve** (Answer D). Therefore, any **procedures performed on the proximal shaft or penoscrotal hypospadia repairs require caudal anesthesia**.

The perineal nerve is a branch of the pudendal nerve; however, its fibers separate early from the pudendal nerve during its course through the pudendal canal. The perineal nerve fibers do not contribute to innervation of the penis (Answer A).

KEY FACTS

- The pudendal nerve is a mixed motor and sensory nerve that provides sensation of the penis/clitoris, scrotum/vulva, perineum, and anus.
- The distal two-thirds of the penis receives its complete innervation from paired dorsal penile nerves.
- The dorsal penile nerve divides into two branches that separate at the level of the pubic symphysis.

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17. ANSWER: A

The paravertebral space is a triangular "potential space" that exists on either side of the vertebrae between the vertebral body, parietal pleura, and the transverse process. The borders of the paravertebral space are (1) anterolateral—the parietal pleura, (2) medial—the vertebral body and intravertebral disc, and (3) posterior—the transverse process and costotransverse ligament (Answer C).

The **paravertebral space is continuous from T1 to T12**. This space allows the spread of local anesthetic cranially and caudally from a single injection site, and it allows the passage of a catheter. Inferior to T12, the space is sealed off by the origin of the psoas muscle, which attaches to the vertebral body and transverse process. **A paravertebral block can still be performed in the cervical and lumbar region; however, each individual space must be blocked separately (Answers B and D)**. Superior to T1, the paravertebral space may communicate with fascial planes in the neck.

The paravertebral space is **continuous with the epidural space medially and the intercostal space laterally.** There is controversy about whether the paravertebral space communicates to the contralateral side via the prevertebral fascia because the fascia is tightly connected to the vertebral body with limited case reports of contralateral spread along the prevertebral fascia.

The paravertebral space contains many important neurovascular structures. After the thoracic spinal nerve roots leave the intervertebral foramen, they divide into dorsal and ventral rami. The dorsal rami supply the paravertebral muscles and skin of the back, and the ventral rami continue as intercostal nerves. Both the dorsal and ventral rami are present in the paravertebral space. Also present in this potential space are the **sympathetic chain ganglia** and their **sympathetic rami communicantes** that communicate with the intercostal nerve (Answer A).

The paravertebral regional nerve block is commonly used to induce unilateral anesthesia for thoracic and upper abdominal procedures in children. Its benefits include minimization of systemic opioids and their side effects, avoidance of complications and side effects associated with epidural anesthesia, and site-specific unilateral analgesia.

Placement of a paravertebral block or catheter has been performed using three different techniques, which include

the loss-of-resistance technique, nerve-stimulator-guided technique, and ultrasound-guided technique. In the loss-of-resistance technique, the paravertebral space is identified after the needle "walks off" the transverse process and punctures the costotransverse ligament, leading to a loss of resistance. In the nerve-stimulator-guided technique, the needle is advanced and muscle contractions of the corresponding level are sought as the primary endpoint. Using the ultrasound-guided technique, the needle is advanced under ultrasound guidance. Ultrasound use can be combined with the other two techniques for increased accuracy and safety.

Complications of paravertebral regional anesthesia include pleural puncture, pneumothorax, inadvertent epidural spread of local anesthetics, intercostal nerve block, and vascular injection.

KEY FACTS

- Paravertebral space is continuous from T1 to T12.
- The borders of the paravertebral space are anterolateral (the parietal pleura); medial (the vertebral body and intravertebral disc); and posterior (the transverse process and costotransverse ligament).
- Paravertebral space is continuous with the epidural space medially and the intercostal space laterally.
- Complications of paravertebral regional anesthesia include pleural puncture, pneumothorax, inadvertent epidural spread of local anesthetics, intercostal nerve block, and vascular injection.

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18. ANSWER: B

The ankle block is a common regional nerve block used for procedures involving the foot. To provide analgesia to the entire foot, five nerves must be blocked. The nerves are (1) the deep peroneal nerve, (2) the superficial peroneal nerve, (3) the sural nerve, (4) the tibial nerve, and (5) the saphenous nerve.

The **sciatic nerve divides in the popliteal fossa into the tibial nerve and the common peroneal (fibular) nerve**. The tibial nerve descends in the posterior compartment of the leg and divides posterior to the medial malleolus into medial and lateral plantar nerves. These nerves are mixed sensory and motor nerves. They supply motor innervation to the intrinsic muscles of the foot, except for the

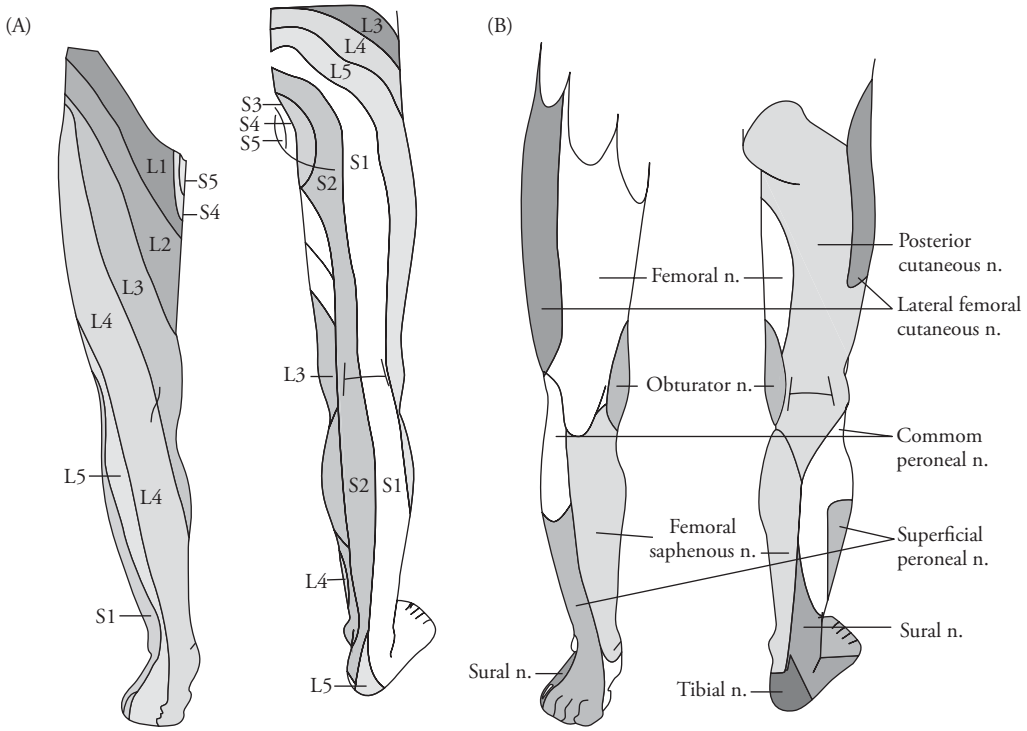

Figure 1.2 (*A*) Cutaneous distribution of the lumbosacral nerves. (*B*) Cutaneous distribution of the peripheral nerves of the lower extremity. (From Wedel DJ, Horlocker TT. *Miller's Anesthesia*. Philadelphia, PA: Churchill Livingstone; 2010:1639–74.)

extensor digitorum brevis. **They supply sensation to the sole of the foot and the plantar surface of toes 1–5, with the exception of the first web interspace (supplied by the deep peroneal nerve**).

The **common peroneal nerve divides** into the **superficial peroneal nerve and deep peroneal nerve**. The **superficial peroneal** nerve is a **sensory nerve** that supplies the **skin on the dorsum of the foot, including the dorsal aspect of toes 1–5,** with the **exception of the first web interspace**. The **deep peroneal nerve** is a **mixed motor and sensory nerve** that supplies **motor innervation to the extensor digitorum brevis.** It supplies **sensation to the first web interspace**.

The **sural nerve is composed of nerve fibers from both the common peroneal and tibial nerves**. This nerve enters the foot posterior to the lateral malleolus and supplies the sensory innervation to the lateral foot and lateral fifth digit.

The **saphenous nerve is a pure sensory nerve derived from the femoral nerve**. It passes anterior to the medial malleolus. It supplies sensory innervation to the medial side of the foot down to the first metatarsal.

The technique for an ankle block involves subcutaneous infiltration in the known locations of the five primary nerves that innervate the foot. This is essentially a ring block. Local anesthetic should be superficially injected:

1. Saphenous nerve—around the great saphenous vein near the medial malleolus
2. Superficial peroneal nerve—between the extensor hallucis longus tendon and the lateral malleolus
3. Deep peroneal nerve—lateral to the extensor hallucis longus tendon
4. Sural nerve—between the Achilles tendon and the lateral malleolus.
5. Tibial nerve—posterior to the posterior tibial artery behind the medial malleolus

KEY FACTS

- The tibal nerve supplies sensation to the sole of the foot and the plantar surface of toes 1–5, with the exception of the first web interspace (supplied by the deep peroneal nerve).
- The superficial peroneal nerve is a sensory nerve that supplies the skin on the dorsum of the foot, including the dorsal aspect of toes 1–5, with the exception of the first web interspace.
- The deep peroneal nerve is a mixed motor and sensory nerve that supplies motor innervation to the extensor digitorum brevis. It supplies sensation to the first web interspace.
- The sural nerve is composed of nerve fibers from both the common peroneal and tibial nerves. This nerve supplies the sensory innervation to the lateral foot and lateral fifth digit.
- The saphenous nerve is a pure sensory nerve derived from the femoral nerve. It supplies sensory innervation to the medial side of the foot down to the first metatarsal.

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2.

PHYSICS AND ANESTHESIA EQUIPMENT

James Peyton, Matthew C. Gummerson, Radhamangalam J. Ramamurthi, Albert Yeung, and Robert M. Brustowicz

1. Which of the following contributes to the dead space in a circle system?

A. CO_2 absorber
B. Breathing bag (reservoir)
C. Length of tubing from unidirectional valves to Y-piece
D. Distance from Y-piece to the terminal bronchioles

2. Which of the following is the correct arrangement of Mapelson breathing circuit components for the most efficient controlled ventilation (proximal to distal, with patient at distal end)?

A. Adjustable pressure-limiting (APL) valve, breathing bag, breathing tube, fresh gas inlet, mask
B. Breathing bag, breathing tube, fresh gas inlet, APL valve, mask
C. Breathing bag, APL valve, breathing tube, fresh gas inlet, mask
D. Fresh gas inlet, breathing bag, breathing tube, APL valve, mask

3. A 6-year-old girl undergoes bilateral ureteral reimplantation under general endotracheal anesthesia using 70% nitrous oxide, 27% oxygen, and 2.6% sevoflurane. Within a few minutes of emergence and extubation, she is transported to the postanesthesia care unit (PACU) spontaneously ventilating with oxygen delivered by face mask. However, the anesthesiologist fails to realize that the oxygen tank is empty. The patient's vital signs on arrival to the PACU are blood pressure 102/60 mm Hg, heart rate 87 beats/min, respiratory rate 16 breaths/min, and SpO_2 84%. On physical exam, she has clear, bilateral breath sounds with excellent tidal volumes and is resting comfortably. Which of the following is the most likely cause of the patient's low pulse oximeter reading?

A. Negative pressure pulmonary edema
B. Alveolar hypoventilation
C. Inadequate neuromuscular blockade reversal
D. Diffusion hypoxia

4. An 11-year-old male is undergoing a left hemicolectomy in Leadville, Colorado (elevation 10,152 feet; atmospheric pressure 523 mm Hg). If the patient is under general endotracheal anesthesia with isoflurane (with a perfectly calibrated variable-bypass vaporizer) set to deliver 1%, which of the following most accurately describes the changes seen at higher altitudes with isoflurane?

A. The percent concentration of isoflurane delivered will be higher than at sea level.
B. The percent concentration of isoflurane delivered will be lower than at sea level.
C. The partial pressure of isoflurane will be higher than at sea level.
D. The partial pressure of isoflurane will be lower than at sea level.

5. A 17-year-old girl has just undergone a laryngotracheal reconstruction under general anesthesia and is to be transported to the pediatric intensive care unit intubated. A Mapleson F (or Jackson-Rees modification of the Mapleson E or Ayre's T-piece) circuit is connected to a standard E-cylinder oxygen tank at the foot of the bed. The pressure gauge on the oxygen tank reads 1200 psi. How many minutes will the anesthesia provider have for transport before the oxygen tank is empty if the oxygen is flowing at 15 L/min?

A. 10 minutes
B. 25 minutes
C. 40 minutes
D. 55 minutes

6. A 29-week-old (postconceptual age) premature neonate admitted to the neonatal intensive care unit develops bilious vomiting, abdominal distention with a palpable mass, and rectal bleeding. The patient is intubated, resuscitated, and scheduled for an emergent exploratory laparotomy. On transport to the operating room a Mapleson F breathing circuit is used by the anesthesiologist. What advantage do Mapleson systems have over a circle system?

A. Decreased fresh gas flow requirement
B. Preservation of airway humidity
C. Decreased work of breathing
D. Increased dead space

7. A healthy 16-year-old male was an unrestrained passenger in a motor vehicle accident. He is undergoing an emergent exploratory laparotomy for perforated bowel and ruptured renal capsule. Other injuries include a 15% pneumothorax and a tibial plateau fracture. If 70% nitrous oxide were to be administered as part of the patient's general anesthetic, in which compartment would there be the most dramatic volume expansion?

A. Lumen of intestine
B. Pleural cavity
C. Endotracheal tube cuff
D. Middle ear cavity

8. An otherwise healthy, 3 kg full-term neonate is undergoing an open pyloromyotomy for pyloric stenosis. What is the most effective strategy for preventing hypothermia in this anesthetized infant during the surgical procedure?

A. Providing warm intravenous fluids
B. Placing a radiant warmer 90 cm above the infant
C. Utilizing a forced-air warming blanket
D. Utilizing a humidification device in the airway circuit

9. A 15-year-old female is scheduled for a thoracolumbar spinal fusion utilizing spinal cord neuromonitoring. Which of the following modalities directly monitors the integrity of ischemia-sensitive, alpha motor neurons in the anterior horn of the spinal cord?

A. SSEPs (somatosensory evoked potentials)
B. Epidural MEPs (lower lumbar epidural space-monitored motor-evoked potentials)
C. Neurogenic MEPs (peripheral nerve-monitored motor-evoked potentials)
D. CMAPs (compound muscle action potentials)

10. In which of the following clinical conditions or disease states will the patient's true arterial oxygen saturation be lower than what would be reported on a conventional pulse oximeter (assume using a correctly sized probe for the patient's age)?

A. Fetal hemoglobin
B. Hyperbilirubinemia
C. Carboxyhemoglobinemia
D. Sickle cell disease

11. A 13-year-old female is undergoing posterior spinal fusion for idiopathic scoliosis with somatosensory evoked potential (SSEP) monitoring. Which of the following changes is concerning for ischemia?

A. Increased amplitude, increased latency
B. Increased amplitude, decreased latency
C. Decreased amplitude, increased latency
D. Decreased amplitude, decreased latency

12. Describe the arterial line waveform in Figure 2.1:

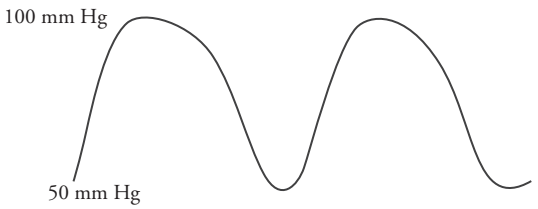

Figure 2.1 Arterial line waveform.

A. The trace is underdamped, but the systolic pressure reading will be the most accurate measurement.
B. The trace is overdamped, but the systolic pressure will be the most accurate measurement.
C. The trace is underdamped, but the mean pressure will be the most accurate measurement.
D. The trace is overdamped, but the mean pressure will be the most accurate measurement.

13. Which part of the cardiac cycle does the dicrotic notch on the arterial waveform correspond to?

A. Closure of the aortic valve
B. Opening of the aortic valve
C. Closure of the mitral valve
D. Opening of the mitral valve

14. A 75 kg 16-year-old boy has a 6 mm inner diameter cuffed oral endotracheal tube in situ. There is a large leak around the tube unless the cuff is significantly overinflated, and a decision is made to change the endotracheal tube using an airway exchange catheter and oxygen insufflation at 2 L/min. To what depth should the exchange catheter be inserted?

A. 5–6 cm above the carina
B. 2–3 cm above the carina

C. At the carina—stop when resistance is felt
D. 2–3 cm below the carina to ensure the exchange catheter does not migrate out of the trachea

15. Helium can be used to treat upper airway obstruction because:

A. It is used in combination with oxygen to produce a gas mixture with a lower density than air.
B. It is used in combination with oxygen to produce a gas mixture with a higher density than air.
C. It is used to encourage turbulent flow to improve gas exchange in the alveoli.
D. It is used with oxygen to produce a gas mixture with a higher viscosity than air.

16. In order to increase the clearance of CO_2 in a patient receiving high-frequency oscillatory ventilation (HFOV), how should you alter the ventilator settings?

A. Increase FiO_2
B. Decrease FiO_2
C. Increase amplitude, decrease frequency
D. Decrease amplitude, increase frequency

17. When using a bispectral index (BIS) depth of anesthesia monitor:

A. Adding nitrous oxide to the anesthetic gas mixture will decrease the BIS reading.
B. Adding an intravenous infusion of fentanyl to an inhaled anesthetic technique will lower the BIS reading.
C. Adding an intravenous infusion of propofol to an inhaled anesthetic technique will lower the BIS reading.
D. Adding an intravenous infusion of ketamine to an inhaled anesthetic technique will lower the BIS reading.

18. Perioperative hypothermia causes:

A. Increased oxygen consumption
B. Faster wound healing
C. Lower wound infection rates
D. Increased risk of bleeding

19. The observed $ETCO_2$—$PaCO_2$ difference in neonates is dynamic (not fixed) in the following condition:

A. Cyanotic heart disease
B. Acyanotic shunting lesions
C. Leak around endotracheal tube
D. Fast aspiration rate via the sample line

20. Which of the following is a correct statement regarding components of a pediatric circle breathing system?

A. The radius of curvature of the tubing will have no effect on compliance.
B. The length of the circuit will affect the dead space.
C. The presence of median septum at the Y piece will increase the dead space.
D. The size of the reservoir bag will have minimal effect on normocapnic ventilation.

21. The following is a correct statement about the Mapleson F (Jackson-Rees modification of Ayres T-piece) system and its variants:

A. $PaCO_2$ is independent of the minute ventilation at a given fresh gas flow.
B. It lacks a mechanism to retain humidity and temperature
C. $PaCO_2$ is independent of the fresh gas flow rate at a given minute ventilation.
D. The determinants of $PaCO_2$ are the same for spontaneous and controlled ventilation.

22. Which of the following is a correct statement about the desflurane vaporizer?

A. The desflurane vaporizer is not agent specific.
B. It lacks variable bypass
C. It is not to be used out of circuit
D. There is no temperature compensation.

23. Which of the following is a correct statement regarding CO_2 absorbers?

A. Sodalime does not regenerate its color.
B. Baralyme is a safer absorber.
C. Amsorb Plus contains $CaCl_2$.
D. Amsorb Plus produces Compound A on reaction with sevoflurane.

24. Which of the following will interfere with pulse oximeter readings?

A. Fetal hemoglobin
B. Skin color
C. Bilirubin
D. Methylene blue

25. On older anesthesia machines, the change in flow meter values can cause significant differences in the delivered minute volume to the patient. Which feature of newer anesthesia machines has made this effect negligent?

A. Piston-driven ventilator
B. Pneumatic bellow-driven ventilator
C. Compliance compensation
D. Fresh gas decoupling

26. Which of the following features differentiates near infrared spectroscopy from pulse oximetry?

A. Transmitters emitting different wavelengths of light
B. Movement artifact
C. Ambient light artifact
D. Higher signal strength

27. The following is a correct statement about an ultrasound transducer:

A. The transducer functions only as a receiver of ultrasound waves.
B. A linear array transducer has the best lateral resolution.
C. A curvilinear transducer produces a smaller image.
D. A curvilinear probe is used for transthoracic echocardiography.

28. Which of the following is a correct statement about processed electroencephalographic (EEG) monitoring in children?

A. The pediatric EEG does not vary with age.
B. EEG measures subcortical activity.
C. Epileptiform activity is not seen with sevoflurane anesthesia.
D. Processed EEG monitoring is not well validated in pediatric anesthesia.

CHAPTER 2 ANSWERS

1. ANSWER: D

Dead space is defined as the **portion of a tidal volume that does not undergo gas exchange**. As dead space increases, one must increase the delivered tidal volume if a specified amount of alveolar ventilation is desired.

A **circle system** is composed of several components, which together **allow lower gas flows, less waste of anesthetic agents, reduced loss of patient heat and humidity, and reduced environmental pollution,** as compared to Mapleson circuits. These components include a carbon dioxide absorber, breathing bag reservoir with adjustable pressure-limiting valve, inspiratory and expiratory unidirectional valves, corrugated tubing, and a Y-piece that can attach to a mask or endotracheal tube.

In a circle system, the presence **of unidirectional valves limits** the contribution of the ventilatory apparatus to the **anatomic dead space**. Only the **area distal to the Y-piece** that joins the inspiratory flow to the expiratory flow at the mask or endotracheal tube is significant. This small volume adds to the patient's **anatomic dead space**, which includes **the nose, mouth, oropharynx**, and airways from **the trachea through the terminal bronchioles**.

The CO_2 absorber and breathing bag are proximal to the unidirectional valves in a circle system and are therefore not exposed to mixing of inspired and expired gases. The unidirectional valves also prevent the mixing of inspired and expired gas proximal to the Y-piece, thereby eliminating the effect of the length of tubing, as exists in the Mapleson circuits. The only relevant addition to the patient's anatomic dead space is the distance from the Y-piece to the patient's airway.

KEY FACTS

- Dead space is defined as the portion of a tidal volume that does not undergo gas exchange.
- In a circle system, the presence of unidirectional valves limits the dead space; only the area distal to the Y-piece adds to the anatomic dead space.
- Anatomic deadspace is comprised of the nose, mouth, oropharynx, and airways from the trachea through the terminal bronchioles.

2. ANSWER: C

Even though they are not used as frequently as in the past, **Mapleson circuits** (see Figure 2.2) are simple, inexpensive, and lightweight. Since there is **no carbon dioxide absorption**, and **no unidirectional valves** are present, **rebreathing does occur** to some extent, although this can be limited by increasing fresh gas flow. The efficiency of the systems is related to the amount of fresh gas flow required.

Answer A refers to the **Mapleson F** or **Jackson-Rees** modification of the Mapleson E or Ayre's T-piece (APL valve, breathing bag, breathing tube, fresh gas inlet, mask). It is essentially a Mapleson E with **a breathing bag and APL** attached to the **proximal end** to allow controlled ventilation and gas scavenging. This type of circuit requires fresh gas flows of at least **2–3 times minute ventilation** for **spontaneous ventilation**, and at least **2 times minute ventilation** for **controlled ventilation**.

Answer B refers to the **Mapleson B** circuit (breathing bag, breathing tube, fresh gas inlet, APL valve, mask). This type of circuit requires fresh gas flows of at least **2 times minute ventilation** for **spontaneous ventilation**, and at least **2–2.5 times minute ventilation for controlled ventilation.**

Answer C refers to the **Mapleson D** circuit (breathing bag, APL valve, breathing tube, fresh gas inlet, mask). This circuit is the **most efficient** Mapleson circuit for

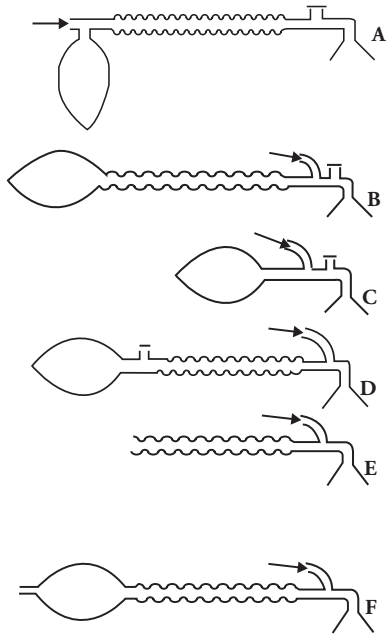

Figure 2.2 The five semiclosed anaesthetic systems listed by Mapleson (1954) together with the Jackson-Rees modification of Ayre's T-piece. (Reprinted with permission from Willis BA. Rebreathing in a T-piece: volunteer and theoretical studies of the Jackson-Rees modification of Ayre's T-piece during spontaneous respiration. *Br J Anaesth*. 1975;47:1239.)

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controlled ventilation, and it is reasonable for spontaneous ventilation. This type of circuit requires fresh gas flows of at least **2–3 times minute** ventilation for **spontaneous ventilation**, but only **1–2 times minute ventilation for controlled ventilation**.

The **Bain circuit** is a modification of the Mapleson D that allows the fresh gas to run through tubing within the breathing tube, allowing **warming of fresh gas** as it passes by expired gas. The fresh gas is still added to the circuit in the same place as with the Mapleson D, thereby allowing the Bain circuit to retain the positive aspects of the Mapleson D. Even though the modification adds to the size and weight of the apparatus, it results in **better retention of heat and humidity**.

Answer D refers to the **Mapleson A** (fresh gas inlet, breathing bag, breathing tube, APL valve, mask). This type of circuit requires the **least fresh gas flow** for **spontaneous ventilation**, needing only an amount **equal to minute ventilation** (~80/mL/kg per minute). It is the least favorable choice of the Mapleson circuits for controlled ventilation, requiring very high and unpredictable gas flows.

KEY FACTS

- The **Mapleson D** is the most efficient Mapleson circuit for controlled ventilation and is reasonable for spontaneous ventilation; requiring fresh gas flows of at least 2–3 times minute ventilation for spontaneous ventilation, but only 1–2 times minute ventilation for controlled ventilation.
- The **Bain circuit** is a modification of the Mapleson D that allows the fresh gas to run through tubing within the breathing tube, allowing warming of fresh gas as it passes by expired gas.
- The **Mapleson A** is the most efficient for spontaneous ventilation, requiring a fresh gas flow of only an amount equal to minute ventilation (~80/mL/kg per minute).
- Efficiency for **spontaneous** ventilation: Mapelson A > D > C > B ("*A D*og *C*an *B*ite")
- Efficiency for **controlled** ventilation: Mapelson D > B > C > A ("*D*og *B*ites *C*an *A*che")

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3. ANSWER: D

Causes of **postoperative hypoxemia** are numerous and include all of the answer choices, as well as numerous others. In this particular case, however, the most likely explanation is diffusion hypoxia.

Diffusion hypoxia refers to a scenario that can occur due to the **rapid elimination of nitrous oxide** into the alveoli following a nitrous oxide–based anesthetic. Nitrous oxide diffuses so quickly into alveolar air spaces that the diluted alveolar gas mixture can have **decreased partial pressures of oxygen and carbon dioxide**. In a patient breathing room air, this decrease in PAO_2 can lead to arterial hypoxemia. If supplemental oxygen is not provided, diffusion hypoxia can persist for 5–10 minutes following the anesthetic, and it can therefore contribute to arterial hypoxemia in the PACU.

Other causes of postoperative hypoxemia include atelectasis, V-Q mismatch, pulmonary edema, congestive heart failure, alveolar hypoventilation, aspiration, pulmonary embolus, shivering, sepsis, transfusion-related lung injury, ARDS, obesity, and patient conditions such as asthma or chronic obstructive pulmonary disease.

KEY FACTS

- Diffusion hypoxia is a result of the rapid elimination of nitrous oxide into the alveoli, diluting the alveolar oxygen and carbon dioxide.
- Increasing the fractional inspired oxygen concentration helps prevent diffusion hypoxia.

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4. ANSWER: A

Traditional **variable-bypass vaporizers** can be **used at any altitude** without changing the dialed setting of the vaporizer, despite the fact that the **actual volume percent delivered** is significantly **different** at higher elevations. This is due to the fact that the partial pressure of a particular anesthetic in the central nervous system seems to be responsible for the effect of the agent, rather than the volume percent/ concentration delivered. The **partial pressure** of an anesthetic agent required to anesthetize a patient **does not change with altitude**, and if the vaporizer continues to deliver a more or less fixed partial pressure, there is no need

for a change in the dialed output setting. Most conventional variable-bypass vaporizers already automatically compensate for this requirement in that the **output is actually a partial pressure**, not a percent concentration, even though percent concentration is labeled on the dial.

If looking at the actual volume percent output of a variable-bypass vaporizer, there is a significant increase with altitude—inversely proportional to the change in barometric pressure. For example, at an elevation of 10,000 ft (~3000 m), where atmospheric pressure is only about two thirds of the value at sea level, the increase in output from an isoflurane vaporizer almost doubles (if set to 1%, output is actually almost 2%).

In conclusion, when using a variable-bypass vaporizer at higher elevation, there is no need for compensation. The partial pressure required for anesthesia is constant, and the delivered partial pressure at altitude is almost the same as at sea level. Even though the percent concentration required for anesthesia increases, the vaporizer will already deliver a higher percentage concentration.

The same is not true for other types of vaporizers, such as the vaporizer used for delivery of desflurane. This type of vaporizer is a dual-circuit, gas/vapor blending vaporizer whose percentage output remains constant regardless of altitude. When using **desflurane** with a heated, pressurized vaporizer such as the Ohmeda Tec-6 or Drager D-vapor, the **concentration dial will need to be increased** in order to deliver adequate anesthesia to the patient at higher altitude.

KEY FACTS

- When using a variable-bypass vaporizer at high altitudes, the increased elevation can mostly be ignored.
- While the percent concentration required for anesthesia increases, a variable-bypass vaporizer will already deliver higher percentages at high altitudes.
- The partial pressure required for anesthesia remains constant at high altitude, and the delivered partial pressure at altitude is almost the same as at sea level with variable-bypass vaporizers.
- When using desflurane in a heated, pressurized dual-circuit vaporizer, the percent concentration dial setting must be increased on the vaporizer to deliver adequate anesthesia.

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5. ANSWER: B

A size E compressed gas cylinder containing oxygen weighs approximately 5.90 kg empty and 6.76 kg full. When **full**, it contains approximately **625 L of oxygen at a pressure of approximately 2000 psi** (see Table 2.1).

By using Boyle's law, one can estimate the amount of gas remaining in a cylinder. **Boyle's law** states that for a **fixed mass at a given temperature, the product of pressure and volume is constant**. Using this relationship, and given that oxygen exists only in a gaseous state within the cylinder, we can estimate the remaining volume in an oxygen cylinder as a proportion of the original volume.

1200 psi/2000 psi = x/625 L

This yields a value of 375 L. If the flow rate is 15 L/min, then there are 25 minutes remaining until the tank is empty (375/15).

KEY FACTS

Table 2.1 (REFERS TO QUESTION 5) COMPRESSED GAS CYLINDERS

GAS	COLOR		PRESSURE AT 70°F (PSI)	STATE IN CYLINDER	E CYLINDER CAPACITY (L)
	U.S.	INTERNATIONAL			
Oxygen	Green	White	1900–2200	Gas	625–660
Carbon dioxide	Gray	Gray	838	Liquid <88°F	1590
Nitrous oxide	Blue	Blue	745–750	Liquid <98°F	1590
Helium	Brown	Brown	1600–2000	Gas	496
Nitrogen	Black	Black	1800–2200	Gas	651
Air	Yellow	White and black	1800	Gas	625

SOURCE: Adapted with permission from Dorsch JA, Dorsch SE. *Understanding Anesthesia Equipment*, 5th ed. Wolters Kluwer/Lippincott Williams & Wilkins; 2008:9.

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6. ANSWER: C

Mapleson systems, also known as carbon dioxide washout circuits or flow-controlled breathing systems, **lack unidirectional valves** and **CO_2-absorbing devices**. There are six variations (See Figure 2.2), designated letters A–F—each with unique advantages. The Mapleson F and Mapleson D circuits are popular configurations. Each consists of a reservoir bag, corrugated tubing (Mapleson D), adjustable overflow valve, fresh gas inlet, and the patient connection. There are no separate inspiratory and expiratory limb. **These circuits rely on high fresh gas flows to circulate and eliminate CO_2 out of the circuit**. Rebreathing will occur when the inspiratory flow exceeds fresh gas flow. Composition of inspired gas will depend on how much rebreathing takes place and also varies depending on the use of controlled versus spontaneous ventilation. Monitoring of end-tidal CO_2 is the best method to determine optimal fresh gas flow. The relative simplicity of the systems **decreases the resistance and work of breathing**, especially during spontaneous ventilation. They also offer the advantage of **a decrease in dead space**. Furthermore, they are light, convenient, and inexpensive.

There are drawbacks to Mapleson systems, however. Their delivery of anesthetic vapors is inefficient and can pollute the surrounding atmosphere. Furthermore, these systems are **unable to preserve humidity of the inspired gases** from high fresh gas flows and lack of a humidifying component.

KEY FACTS

- **Mapleson circuits** are valveless, semiclosed partial rebreathing systems that minimize the work of breathing, especially for infants during spontaneous ventilation.
- Multiple configurations exist, each with certain advantages in terms of efficiency of rebreathing.
- Mapleson breathing circuits rely on high fresh gas flows for delivery of anesthetic vapors and elimination of carbon dioxide.
- Mapleson circuits consist of a reservoir bag, corrugated tubing, APL valve, fresh gas inlet, and the patient connection without separate inspiratory and expiratory limbs.
- Advantages of Mapleson systems include decreased work of breathing (especially during spontaneous ventilation) from the absence of valves, decreased dead space, relative convenience, and inexpensive cost.
- Disadvantages include rebreathing of large amounts of CO_2 if fresh gas flows are not adequate, inefficient delivery of anesthetic vapors with subsequent pollution, and loss of humidity with high gas flows.

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7. ANSWER: B

Nitrous oxide is a nonpolar, **highly soluble** gas that **easily diffuses through membranes**. The blood-gas partition coefficient of nitrous oxide is 0.46, making it **34 times more soluble than nitrogen** (coefficient 0.014). The greater solubility of nitrous oxide compared to nitrogen results in rapid diffusion of nitrous oxide along its concentration gradient: from the lungs into the blood, and then rapidly into air-containing spaces such as the bowel, pleural cavity, and others.

The difference in the blood-gas partition coefficients of nitrous oxide (0.46) and nitrogen (0.014) results in **preferential transfer of nitrous oxide into a compliant air-filled cavity** faster than nitrogen can exit. This results in rapid expansion of the air-filled space as nitrous oxide from the blood reaches equilibrium with the air-filled space, whereas nitrogen is only able to diffuse out slowly. Due to this phenomenon, use of nitrous oxide during gastrointestinal surgery and in patients with ileus or bowel obstruction is relatively contraindicated. Bowel gas volume can expand 2–3 times within the first 2 hours of administration of 75% nitrous oxide, which may cause harmful traction across anastomoses and worsening of intestinal obstruction symptoms.

A **pneumothorax** has been shown to rapidly and dramatically expand in volume with the use of nitrous oxide, **doubling in the first 10 minutes** and **tripling in 30–45**

minutes when a 75% nitrous oxide/oxygen mixture is used. Other functional disorders such as pneumoperitoneum, pneumopericardium, and pneumocephalus can also theoretically be worsened by nitrous oxide administration. However, the volume–pressure relations vary as these areas of the body have different tissue compliance. In general, *as compliance becomes greater* (as within the pleural cavity and bowel), the *volume* change will be greater; *as compliance becomes lower* (as within the skull and middle ear), the *pressure* change will be greater.

The rate at which the volume increases in air-filled cavities is affected by the solubility of the respired gas in the blood and the blood flow to the space or blood flow/space volume ratio. Other factors that affect rate of diffusion through any semipermeable membrane include temperature, molecular weight of the respired gas, permeability of the gas through (or the solubility in) the tissue composing the membrane, and the pressure gradient of the respired gas across the membrane.

The amount of gas diffusing into air-filled spaces depends on the transport capacity of the blood as given by the blood–gas partition coefficient of nitrous oxide and the membrane characteristics where the diffusion process takes place (i.e., whether the membrane is porous versus nonporous, silicone versus latex). For example, **lung tissue is both porous and highly compliant**, contributing to the rapid increase in size of a pneumothorax when a patient inspires a mixture of nitrous oxide and oxygen. Recent data suggest that nitrous oxide may even diffuse directly from the alveolar gas into the pleural space rather than being transferred by the blood via the circulation, contributing to the observation of rapid expansion in this space.

Other air-filled cavities that can expand with use of nitrous oxide include the middle ear cavity, endotracheal tube/LMA cuff, and the air-filled balloons of catheters (such as that of a Swan-Ganz pulmonary artery catheter). Nitrous oxide can also expand an iatrogenic-caused air-filled cavity such as an intracardiac air embolus. Pressure in air-filled endotracheal tube cuffs has been shown to increase during general anesthesia with nitrous oxide, which can exert excessive tracheal mucosal pressure even when the initial sealing pressure was satisfactory. The **largest increase in the endotracheal tube cuff pressure occurs during the first hour of anesthesia** and can contribute to ischemia of tracheal mucosa. With the advent of high-volume/low-pressure cuffs this has been attenuated, but the phenomenon still exists. The increase in volume in endotracheal cuffs is not as dramatic as compared to pleura or bowel, in part because the initial volume is so much smaller and the cuff not as compliant.

Nitrous oxide can diffuse into the middle ear cavity, which can be problematic when the Eustachian tube is not functioning properly. However, as described earlier, the middle ear is a noncompliant space and the pressure will increase much more than the volume.

KEY FACTS

- Nitrous oxide is 34 times more soluble in blood than nitrogen; this causes a preferential transfer of nitrous oxide into a compliant, air-filled cavity faster than nitrogen can exit, resulting in expansion of the air-filled space.
- Nitrous oxide rapidly and dramatically accumulates in the pleural space, with the potential to triple the volume of a pneumothorax within 45 minutes when administered at 75%.
- Bowel gas volume will also expand with the use of nitrous oxide, but not as dramatically (2–3 times in the first 2 hours of 75% nitrous oxide administration).
- Pneumoperitoneum, pneumopericardium, and pneumocephalus can also theoretically be worsened by nitrous oxide administration, but the volume increase may be less dramatic given the low compliance of these tissues.
- In general, *as compliance becomes greater* (as within the pleural cavity and bowel), the *volume* change will be greater; *as compliance becomes lower* (as within the skull and middle ear), the *pressure* change will be greater.
- Other air-filled cavities that may expand include the middle ear compartment (more deleterious with an occluded Eustachian tube), endotracheal tube/LMA cuffs, and catheter balloons filled with air.
- The rate at which volume increases in gas-enclosed spaces depends on the solubility of the respired gas in the blood, the blood flow to the space, and the blood flow/space volume ratio.

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8. ANSWER: C

Heat loss occurs through a variety of mechanisms in the operating room environment. **Initial heat loss** during

anesthesia is due to the transfer of heat from the central compartment/body core to the periphery/skin surface (**internal redistribution**). The **second phase** of heat loss is caused by **thermal imbalance**, which is a result of **decreased heat production** coupled with increased heat loss to the environment. These mechanisms for heat loss (by percent for a neonate in a thermonuclear environment) are **radiation (39%), convection (34%), evaporation (24%), and conduction (3%)**.

Radiant heat loss, defined as the function of **the temperature difference between the patient and the surrounding environment**, is the **major source of heat loss** in an anesthetized patient. Increasing the ambient operating room temperature is an effective means of minimizing radiant heat loss in an anesthetized newborn.

A **radiant warmer** can **help reduce cutaneous heat loss by 77%** during the induction of anesthesia and before the infant is prepped and draped. A radiant heater should be placed no closer than 90 cm from a patient's skin to avoid skin burns. In addition, prolonged use of radiant warmers may increase insensible losses. However, utilizing this device during the surgical procedure is impractical.

Convective heat loss is another major contributor to heat loss in the anesthetized infant. Convective heat loss is defined as the **transfer of heat from the body to air or liquid molecules flowing over it**. "Convective forced-air warmers are by far the most effective devices to maintain the temperature and increase the temperature of cold children" (Coté et al., 2009, p. 566).

Covering exposed skin surfaces not involved in the surgical field helps reduce radiant, convective, and evaporative heat loss. The **head comprises a large percentage of the total body surface area of an infant**, and therefore providing **head covering** is an effective means of preventing heat loss (as well as reducing oxygen consumption—23% in term neonates and 36% in preterm neonates).

Providing humidification of inspired gases can reduce convective and evaporative losses via the respiratory tract. Additionally, humidification will increase tracheal mucous flow and decrease damage to the trachea from dry inspired gases. The higher minute ventilation per kilogram of body weight in children makes airway humidification more effective in children than in adults.

KEY FACTS

- Initial heat loss in an anesthetized patient is through internal redistribution.
- Radiation 39%: transfer of heat between two objects of different temperatures that are not in contact with each other
- Convection 34%: transfer of heat to moving molecules such as air or liquid
- Evaporation 24%: heat loss from converting liquid (sweat, insensible water losses, liquids applied directly to skin) to a gaseous state
- Conduction 3%: heat transfer between two surfaces in direct contact
- Utilizing forced-air warmers is the most effective method of preventing heat loss during surgery in children.

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9. ANSWER: D

Somatosensory evoked potentials (SSEPs), also known as cortical SSEPs, **stimulate peripheral nerves and measure the response** using electrodes placed on the patient's scalp. The pathway of this signal starts in the **peripheral nerve, ascends the ipsilateral dorsal (sensory) column of the spinal cord**, crosses to the **contralateral side at the level of the brain stem**, and then continues to the **primary sensory cortex**. The impulses measured are sensory in nature but are used as a **surrogate to monitor for motor deficits** because of the proximity of the motor and sensory tracts in the spinal cord.

Motor evoked potentials (MEPs) are the neuroelectrical signals produced in response to electrical or magnetic pulse stimulation to the brain. MEPs can be measured by **direct transcranial stimulation of the motor cortex or by spinal cord stimulation**. With spinal cord stimulation, neurogenic MEPs measure the **conduction via the dorsal columns in a retrograde fashion** and are actually sensory in nature. Regardless of where the stimulation occurs, the responses to the stimulation are usually recorded distal to the surgical site.

When utilizing **epidural MEPs**, the recording electrodes are located in the **lower lumbar epidural space**. While epidural MEPs are the least effected by muscle relaxants, they **monitor conduction via the corticospinal tract** and therefore do not provide information about the condition of the anterior horn motor neurons. When utilizing neurogenic MEPs, the recording electrodes are near peripheral nerves but also do not accurately measure motor conduction.

When utilizing **compound muscle action potentials (CMAPs)**, the recording electrodes are located directly in peripheral muscles. CMAPs generated after **transcranial stimulation** are believed to be **exclusively transmitted via motor tract conduction** and thus **directly monitor the integrity of ischemia-sensitive, alpha motor neurons** in the anterior horn of the spinal cord. Unfortunately, these

responses are also exquisitely sensitive to common anesthetic agents.

KEY FACTS

- CMAPs are the preferred method for monitoring intraoperative spinal cord motor integrity; these are also very sensitive to anesthetic agents.
- SSEPs measure sensory pathways; although these are close to the motor pathways in the spinal cord, significant false-positive and false-negative changes have been reported.
- Epidural MEPs and neurogenic MEPs are not that accurate for monitoring intraoperative spinal cord motor integrity.

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Coté CJ, Lerman J, Todres ID, eds. *A Practice of Anesthesia for Infants and Children*. 4th ed. Philadelphia, PA: Saunders; 2009:640–2.

10. ANSWER: C

Pulse oximetry measures the **ratio of oxyhemoglobin to the sum of oxyhemoglobin and deoxyhemoglobin in the blood.** Utilizing spectrophotoelectric transmission pulse oximetry, the amount of light transmitted through tissue at two different wavelengths of light (**930 and 660 nm**) is measured. Readings below 70% tend to be inaccurate and may overestimate the actual amount of deoxyhemoglobin present in the blood. Other types of **hemoglobin (-F and -S) have a minimal effect** on the accuracy of pulse oximetry, as does hyperbilirubinemia (Answers A, B, and D).

Carboxyhemoglobinemia may cause an **overestimation** of the true arterial oxygen saturation (Answer C). In a patient who has carboxyhemoglobinemia, the photo **detector interprets carboxyhemoglobin as oxyhemoglobin**. In a similar fashion, **methemoglobinemia** causes arterial oxygen desaturation, but the pulse oximeter reading will be higher than the patient's actual arterial saturation. That is, the **degree of patient desaturation is underestimated** by the pulse oximeter. As one would expect, this disparity becomes greater during desaturation if the patient has high levels of methemoglobin in the blood.

Intravenous dyes like **methylene blue and indocyanine green** (as well as colored fingernail polish) can also affect the accuracy of pulse oximeter readings. In the presence of these substances, however, the patient's true **oxygen saturation is actually higher** than the monitor indicates.

When caring for small infants, one must be cognizant of the **"penumbra effect."** This phenomenon can occur when an adult clip-on probe is used on an infant's finger or toe. In this situation, the photo detector of the large probe will sense the motion of the patient's arterial pulsation and thus produce a believable pulse waveform, but a **large amount of light will be transmitted around** the digit of the infant, which will produce **an artificially elevated saturation reading**.

KEY FACTS

- Carboxyhemoglobinemia may cause a conventional pulse oximeter to overestimate a patient's true arterial oxygen saturation; the photo detector interprets carboxyhemoglobin as oxyhemoglobin.
- Methemoglobinemia causes arterial oxygen desaturation, but the pulse oximeter reading will be higher than the patient's actual arterial saturation.
- Other types of hemoglobin (-F and -S) have a minimal effect on the accuracy of pulse oximetry, as does hyperbilirubinemia.
- Intravenous dyes like methylene blue and indocyanine green (as well as colored fingernail polish) may cause a falsely low saturation reading on the pulse oximeter when the patient's true arterial saturation is higher.

REFERENCE

Coté CJ, Lerman J, Todres ID, eds. *A Practice of Anesthesia for Infants and Children*. 4th ed. Philadelphia, PA: Saunders; 2009:20,22,1116–8.

11. ANSWER: C

Somatosensory evoked potentials (SEPs or SSEPs) can be used to monitor for spinal cord injury during scoliosis surgery. It provides real-time, continuous assessment of spinal cord function and usually requires advanced practitioner training to utilize effectively. An SEP is a signal in the sensory pathway that is generated in response to stimulation of a sensory nerve. Typically in scoliosis surgery, a **peripheral nerve** (such as the median, peroneal, or posterior tibial nerve) is **stimulated at a fixed interval during a procedure**. The **resulting SEP can be recorded over the scalp or spine**. An intact neural pathway is required for an SEP to be generated. Intraoperative changes in the SEP during scoliosis surgery may indicate that this pathway has been jeopardized, either from ischemia or mechanical disruption/surgical retraction.

SEPs are described in terms of **polarity** (direction of the wave signal), **amplitude** (voltage difference between two peaks of opposite polarity), and **latency** (time measured from the application of the stimulus to the point of maximum amplitude of the evoked potential). SEPs are continuously repeated during surgery, with the **amplitude and latency compared to baseline values**. During periods of **ischemia, SEP amplitude decreases and latency**

increases. In general, **a reduction in amplitude of greater than 50%** and an **increase in latency of 10% is regarded as clinically significant**. SEPs are more reliable in patients with idiopathic scoliosis compared to those with neuromuscular scoliosis. SEPs only monitor the sensory pathway and provide no direct information about motor function or the anterior portions of the spinal cord. If SEP monitoring is equivocal, some advocate an intraoperative wake-up test to assess motor function.

SEPs are affected by both pharmacologic and physiologic variables. For intraoperative monitoring, the most important variables are anesthetic agents, blood pressure, oxygenation, and body temperature. **Volatile inhaled anesthetics produce dosage-dependent decreases in amplitude and increases in latency. Nitrous oxide alone decreases amplitude but has no effect on latency.** In general, intravenous anesthetic agents have less effect on SEPs. **Propofol, opioids, and dexmedetomidine appear to have minimal effects on SEPs.** Hypotension results in progressive decrease in amplitude with no change in latency. Hypoxia produces a decrease in amplitude similar to the change seen in ischemia. Both hypothermia and hyperthermia can cause perturbations in amplitude and latency.

KEY FACTS

- Somatosensory evoked potentials (SEPs or SSEPs) can be used to monitor for spinal cord injury during scoliosis surgery.
- During periods of ischemia, SEP amplitude decreases and latency increases.
- In general, a reduction in amplitude of greater than 50% and an increase in latency of 10% is regarded as clinically significant.
- Volatile inhaled anesthetics produce dosage-dependent decreases in amplitude and increases in latency.
- Nitrous oxide alone decreases amplitude but has no effect on latency.
- Propofol, opioids, and dexmedetomidine appear to have minimal effects on SEPs.

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12. ANSWER: D

Invasive blood pressure measurement was initially described in 1733 by an English Parson, Rev. Stephen Hales, when he published experiments he performed in 1727 measuring the height reached by blood pumped from a dog's heart after aortic cannulation. Noninvasive blood pressure measurement was first used during anesthesia by Cushing in 1901 and remains a minimum standard of monitoring during anesthesia.

The gold standard of blood pressure monitoring is an invasive intra-arterial reading of blood pressure. It relies on the principle of **hydraulic coupling, with a continuous stream of fluid being in direct contact with the arterial blood flow and a pressure transducer via an intra-arterial cannula and fluid column**. The pulsatile arterial flow moves a diaphragm within the transducer, which is connected to a **Wheatstone bridge system, using the changes in electrical resistance during expansion/compression of two pairs of wires to generate the changing electrical signal**, which is then displayed by the monitor.

Damping refers to anything that reduces the energy within an oscillating system. **An arterial line trace that shows optimal or critical damping will display a rapid upstroke of systolic pressure, a dicrotic notch,** and demonstrate the best balance between response rate to change and accuracy. **Causes of damping in an arterial line measuring system include:**

- Air bubbles
- Kinks in the tubing or cannula
- Three-way taps (stop-cocks)
- Changes in patient position
- Vasospasm
- Changes in compliance of the tubing

KEY FACTS

- Damping refers to anything that reduces the energy within an oscillating system.
- Optimal damping displays a rapid upstroke of systolic pressure, a dicrotic notch, and is balanced between response rate to change and accuracy.

REFERENCE

Hales, Stephen. Statical essays: containing haemastatics; or, an account of some hydraulick and hydrostatical experiments made on the blood and blood-vessels of animals. London: W. Innys, T. Woodward and J. Peele, 1733.

Ward M, Langton JA. Blood Pressure Measurement. *Contin Educ Anaesth Crit Care Pain* 2007;7(4):122–126.

13. ANSWER: A

The cardiac cycle refers to the events that occur from the beginning of one heartbeat to the next. It begins with **spontaneous activation of the sinus node in the right atrium**, near the entrance of the superior vena cava. There is a small delay in **the electrical impulse being conducted through the atria into the ventricles**, causing the atria to contract before the ventricles. This allows **the atria to forcibly eject blood into the ventricles prior to ventricular contraction and increase end diastolic volume of the ventricles**. During ventricular contraction the A-V valves (mitral and tricuspid) are closed, allowing blood to flow into the atria. The **increase in pressure within the ventricles causes the opening of the aortic and pulmonary valves, followed by the rapid isovolumic contraction of the ventricles ejecting blood into the aorta and pulmonary artery**. After ejection, **the ventricles relax until the decrease in pressure allows closure of the aortic and pulmonary valves**. The **closure of the aortic valve** causes a **transient rise in aortic pressure**, which is captured in the arterial line trace as the **dicrotic notch**.

This is summarized in Figure 2.3.

KEY FACTS

- Dicrotic notch closure of the aortic valve causes a transient rise in aortic pressure, which is captured in the arterial line trace as the dicrotic notch.

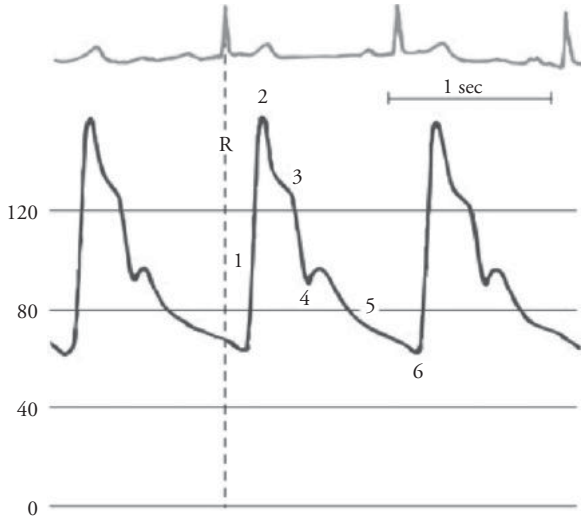

Figure 2.3 Normal arterial blood pressure waveform and its relationship to the electrocardiographic R wave. 1, Systolic upstroke; 2, systolic peak pressure; 3, systolic decline; 4, dicrotic notch; 5, diastolic runoff; 6, end-diastolic pressure. (From Mark JB. *Atlas of Cardiovascular Monitoring*. New York: Churchill Livingstone; 1998.)

REFERENCE

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14. ANSWER: B

Many techniques have been described for managing changes of endotracheal tubes, both intraoperatively and in intensive care unit (ICU) patients. In the difficult airway it may be vital to **keep access to the trachea** to enable replacement endotracheal tube over the exchange catheter, if direct viewing is impossible. It may also be desirable to provide **oxygen insufflation into the trachea** in patients with little physiological reserve. An airway exchange catheter (e.g., Cook or Aintree exchange catheter) is designed to do both of these things. It is a long, hollow tube that can be passed through an in situ endotracheal tube, while oxygen is insufflated down it to allow oxygenation while the existing endotracheal tube is removed and a new endotracheal tube railroaded over the exchange catheter into the trachea. The manufacturers' instructions state the **correct depth of insertion is 2–3 cm above the carina.**

If the exchange catheter is not inserted far enough, it may be displaced out of the trachea during tube exchange, resulting in misplacement of the endotracheal tube. If it is **inserted too far,** it can cause **direct trauma** to the lung parenchyma, with **tension pneumothoraces** and death possibly occurring.

It is also worth noting that due to the long, narrow gauge of the exchange catheters, using **high-flow oxygen should be avoided,** as the pressure generated at the distal end of the exchange catheter can be high enough to cut through muscle and connective tissue.

KEY FACTS

- Exchange catheters keep access to the trachea during replacement of an endotracheal tube and allow oxygen insufflation during endotracheal tube exchange
- Depth of insertion should be 2–3 cm above carina
- Tension pneumothoraces can result if an exchange catheter is inserted too far
- Avoid high-flow oxygen when using tube exchange catheters

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15. ANSWER: A

Gas flow may be described as **laminar, turbulent,** or in a **transitional state between laminar and turbulent**. The **most efficient** way for gas exchange to occur is **during laminar flow**. The **propensity** of a substance **to display laminar flow** is decided by its **Reynold's number**. This is a mathematical description of the substance's flow mechanics, incorporating the **density, speed of flow,** and the **diameter** of the tube it is flowing through, divided by the **viscosity of the substance.** The **lower the number**, the higher the likelihood of **laminar flow** occurring. If the Reynold's number is **<2000, then laminar flow is likely**, between 2000 and 4000 **transitional flow** is likely, and **>4000 turbulent flow** is likely.

Helium has a **similar viscosity** to **air,** but a significantly **lower density**. It is an inert and nonflammable gas. **Heliox** is usually a combination of **21% oxygen and 79% helium**. It is also available as a 30:70 mixture, but any increase from this may negate the purpose of using it. The presence of **helium increases the propensity for laminar flow** within the airways by lowering the Reynold's number of the inspired gas. This may **decrease the work of breathing and improve gas exchange**. Disadvantages include being unable to deliver high concentrations of inspired oxygen. However, if ventilation is significantly improved by the decrease in work of breathing and the increase in laminar flow, oxygenation may be improved, as illustrated by the alveolar gas equation. If the flow remains turbulent despite the presence of helium, there is also a possibility that overall gas flow will be improved due to the lower density.

Heliox use has been described in **upper airway obstruction, asthma, croup, epiglottitis, and chronic obstructive pulmonary disease**. It is also used in commercial air mixtures for diving.

KEY FACTS

- Gas flow may be described as laminar, turbulent, or in a transitional state between laminar and turbulent.
- The propensity of a substance to display laminar flow is decided by its Reynold's number.
- Helium has a similar viscosity to air, but a significantly lower density. It is an inert and nonflammable gas. Heliox is usually a combination of 21% oxygen and 79% helium.
- Helium increases the propensity for laminar flow within the airways by lowering the Reynold's number of the inspired gas, decreasing the work of breathing and improving gas exchange.
- Reynold's number = (Density × velocity of flow × diameter of tube)/Viscosity.

REFERENCES

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Reuben AD, Harris AR. Heliox for asthma in the emergency department: a review of the literature. *Emerg Med J.* 2004;21:131–5.

16. ANSWER: C

HFOV is often used in the neonatal ICU when conventional ventilation has not succeeded in maintaining adequate oxygenation/ventilation. It may produce **less ventilator-associated lung injury** and decrease the risk of developing chronic lung disease. The principle of HFOV is to **maintain a high mean airway pressure** and use **high frequency (2–15 Hz), small volume** (less than the patient's dead space) **breaths** to provide gas exchange. Mechanisms of gas exchange are complex and not fully understood, involving convection, laminar and turbulent flow, and molecular diffusion.

Amplitude is the measurement of the **pressure delivered above and below the mean airway pressure**. It is measured proximally in the circuit, so it will be attenuated by the size of the endotracheal tube and the patient's own airway resistance (with flow through the tube being proportional to the fourth power of the radius/tube length). **Increasing amplitude will increase the volume of lung expansion**, but it may lead to barotrauma and complications such as gas trapping and pneumothorax. **Decreasing the frequency** will also lead to **larger gas volumes** being exchanged per cycle and **thus lower CO_2**.

There is no clear evidence of improvement in outcome when compared to conventional ventilation in preterm neonates. Approximately 20% of premature neonates requiring mechanical ventilation will be placed on HFOV. A recent Cochrane meta-analysis demonstrated this lack of superiority; however, no evidence of harm was found. Two recent trials of HFOV in adults with acute respiratory distress syndrome (ARDS) showed no benefit, and a potential increase in mortality associated with HFOV. Its use in the adult ICU is decreasing, but it remains a mainstay of treatment of respiratory distress in the neonatal ICU. **CO_2 clearance is not linked to oxygenation** and **increasing the mean airway pressure may improve oxygenation** but will not improve CO_2 clearance.

KEY FACTS

- HFOV may produce less ventilator-associated lung injury and decrease the risk of developing chronic lung disease.
- The principle of HFOV is to maintain a high mean airway pressure and use high-frequency (2–15 Hz),

small-volume (less than the patient's dead space) breaths to provide gas exchange.
- Amplitude is the measurement of the pressure delivered above and below the mean airway pressure.
- CO_2 clearance is not linked to oxygenation and increasing the mean airway pressure may improve oxygenation but will not improve CO_2 clearance.

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17. ANSWER: C

The bispectral index (BIS) is the most widely studied depth-of-anesthesia monitor. It **combines power spectral analysis of the EEG signal with a phase relationship analysis** to give a number representing the changes within the EEG, from 0 (isoelectric) to 100 (fully awake). The algorithm used was created by retrospectively analyzing EEG data taken from anesthetized volunteers and correlating clinical features associated with loss of consciousness to the EEG signal. A Cochrane review in 2007 demonstrated a possible decrease in risk of awareness within high-risk patients; however, when compared to the use of end tidal anesthetic concentration monitoring, there is no difference in rates of awareness. One of the weaknesses of the BIS monitor is the **lack of response** that it has **to some commonly used anesthetic adjuncts, such as nitrous oxide, ketamine, and opiates.** The **BIS reading** does **correlate** closely to **Propofol plasma concentration** and **end tidal (ET) volatile agent** reading (i.e., it will decrease as the plasma concentration of propofol or the ET volatile concentration increases).

Other depth-of-anesthesia monitoring techniques used in clinical practice include the following:

- The isolated forearm technique where a tourniquet is inflated on the upper arm prior to giving muscle relaxants, preventing the drug from reaching the isolated forearm. Moving the fingers/hand to command is used as a surrogate for awareness.
- Narcotrend and M-Entropy use similar technology to BIS and are based on EEG.
- Auditory evoked potential monitoring uses **auditory stimulus** (provided by a loud 7 Hz click) via headphones to produce an **evoked potential within the cochlea**. This is then captured from changes in the EEG by digital averaging of the last 256 waveforms and an index number from 0–100 produced, with 0 being isoelectric and 100 fully awake.

KEY FACTS

- BIS combines power spectral analysis of the EEG signal with a phase relationship analysis to give a number representing the changes within the EEG.
- A Cochrane review in 2007 demonstrated a possible decrease in risk of awareness within high-risk patients; however, when compared to the use of end tidal anesthetic concentration monitoring, there is no difference in rates of awareness.

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Punjasawadwong Y, Phongchiewboon A, Bunchungmongkol N. Bispectral index for improving anaesthetic delivery and postoperative recovery. *Cochrane Database Syst Rev*. 2007;CD003843.

18. ANSWER: D

Perioperative hypothermia, defined as a core temperature **less than 36°C**, can have significant side effects. In operations lasting longer than 1 hour, it is recommended that temperature is measured and that active forced air warming devices are used to maintain core temperature. Immediately after the induction of anesthesia, core temperature will begin decrease due to several factors, including **loss of protective behaviors** (such as shivering and adding layers of clothing), **patient exposure, vasodilatation caused by anesthesia, the infusion of relatively cold intravenous fluids,** and the **decrease in metabolic rate associated with anesthesia**.

Heat is lost in several ways:

- Radiation (accounting for >60% of heat lost)
- Convection (accounting for approximately 25% of heat lost)
- Evaporation (accounting for approximately 5%–15% of heat lost)

Hypothermia can affect **coagulation** via **worsening platelet function**, **increasing fibrinolysis,** and **decreasing the effectiveness of temperature-dependent enzymes**

within the coagulation cascade. **Oxygen consumption decreases** by approximately 5%–10% **for every 1°C** that core temperature drops. **Shivering** can occur due to hypothermia, usually postoperatively, which can **increase oxygen consumption by** 40%–100%. **Wound healing** can be delayed, **wound infection rates can increase, and rates of myocardial ischemia** can increase due to perioperative hypothermia. Because of these effects, perioperative hypothermia has been recognized as a target to improve surgical outcomes internationally. Guidelines emphasizing the maintainence of perioperative normothermia have been produced in multiple countries, including the United States, United Kingdom and Ireland, Australia, and New Zealand.

KEY FACTS

- Perioperative hypothermia is defined as a core temperature less than 36°C.
- Hypothermia can affect coagulation via worsening platelet function, increasing fibrinolysis, and decreasing the effectiveness of temperature-dependent enzymes within the coagulation cascade.
- Wound healing can be delayed, wound infection rates can increase, and rates of myocardial ischemia can increase due to perioperative hypothermia.

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19. ANSWER: A

In neonatal ventilation, it is common to observe an $ETCO_2$-$PaCO_2$ difference, particularly when using a side stream capnometer, due to various mechanical and physiological reasons.

Mechanical causes include the following:

1. Leak around the uncuffed endotracheal tube
2. Sampling rate of the side stream capnometer, which is usually larger than the expiratory flow rate
3. The faster respiratory rate of a spontaneously breathing infant can have stacking effect on the sampling.

Most of the time the mechanical causes result in relatively fixed $ETCO_2$-$PaCO_2$ differences, which can be corrected by addressing the source of the issue.

Physiologic causes include states where the pulmonary blood flow is restricted or the parenchyma is diseased. Irrespective of the type of capnometer used (main stream or side stream), neonates with cyanotic-shunting congenital heart lesions and intrinsic parenchymal diseases will show an $ETCO_2$-$PaCO_2$ gradient that is dynamic.

In contrast, **acyanotic shunting lesions tend to show a relatively fixed relationship in the $ETCO_2$-$PaCO_2$ gradient.**

KEY FACTS

- An $ETCO_2$-$PaCO_2$ gradient is dynamic in the setting of cyanotic-shunting congenital heart lesions and intrinsic parenchymal diseases.
- Acyanotic shunting cardiac lesions tend to show a relatively fixed relationship in the $ETCO_2$-$PaCO_2$ gradient.

REFERENCE

Sandberg W, Urman R, Ehrenfeld J, eds. *The MGH Textbook of Anesthetic Equipment*. Philadelphia, PA: Churchill Livingstone; 2010:306.

20. ANSWER: D

The main purpose of a breathing system is to aid normocapnic ventilation by avoiding loss of tidal volume in the circuit itself and by minimizing mechanical dead space. To minimize the loss of tidal volume in the compliance of the tubing, **pediatric circle systems have a smaller radius of curvature of the tubing**, which, according to LaPlace's Law, renders them less distensible and thus decreasing the compression volume.

Mechanical dead space exists only where fresh and exhaled gases are mixed (i.e., at the Y-piece), irrespective of the length of the limbs of the circle. Dead space no longer exists when fresh and exhaled gases are completely separated. The dead space of the Y-piece in a circle system can be decreased by the addition of a median septum.

KEY FACTS

- In pediatric breathing systems, the size of the reservoir bag will have minimal effect on normocapnic ventilation as long as the fresh gas flow is adequate.
- The reservoir bag's role is to provide additional volume at times of peak inspiratory efforts, to augment the fresh gas flow.
- Mechanical dead space exists only where fresh and exhaled gases are mixed (i.e., at the Y-piece).
- Dead space no longer exists when fresh and exhaled gases are completely separated.

- The dead space of the Y-piece in a circle system can be decreased by the addition of a median septum.

REFERENCE

Sandberg W, Urman R, Ehrenfeld J, eds. *The MGH Textbook of Anesthetic Equipment*. Philadelphia, PA: Churchill Livingstone; 2010:297.

21. ANSWER: B

In the Mapleson F system, the addition of a reservoir bag helps one to "feel" the compliance of the lungs and also enables assisting or controlling the ventilation as needed (See Figure 2.2). Thus, it is ideally suited for pediatric use. But being a simple system, it lacks the ability to precisely control the $PaCO_2$, which changes both with minute ventilation and fresh gas flow rate. **At high fresh gas flow rates,** the minute ventilation determines the $PaCO_2$ as there is minimal or no dead space effect. **At high minute volume,** the fresh gas flow determines the $PaCO_2$.

During spontaneous ventilation, provided there is adequate expiratory pause and high fresh gas flow, there is minimal mixing of expired gases with the fresh gas, which helps to reduce the dead space effect and thus maintains $PaCO_2$ at a normal level.

During manual controlled ventilation, there is a possibility of variable expiratory pause, which can cause variable effect on dead space gas, which in turn can affect the $PaCO_2$.

Unlike the circle system, the Mapleson F system lacks the ability to retain humidity and temperature.

KEY FACTS

- The addition of a reservoir bag in the Mapleson F system enables assisting or controlling the ventilation as needed. Thus, it is ideally suited for pediatric use.
- It lacks the ability to precisely control the $PaCO_2$, which changes both with minute ventilation and fresh gas flow rate.
- The Mapleson F system also lacks the ability to retain humidity and temperature.

REFERENCE

Sandberg W, Urman R, Ehrenfeld J, eds. *The MGH Textbook of Anesthetic Equipment*. Philadelphia, PA: Churchill Livingstone; 2010:297.

22. ANSWER: B

The modern vaporizers can be defined as agent specific, out of circuit, flow over, variable bypass, and temperature compensated to describe the salient physical features involved in the design of the vaporizers. **Agent specificity is an important safety feature** to avoid filling a vaporizer with a wrong agent. This is achieved by having keyed index filling and color-coding for the vaporizer itself. Temperature compensation is usually by a bimetallic strip regulating the splitting ratio according to the operating temperature to maintain a constant vapor output. In the case of the desflurane vaporizer, temperature is maintained by an active heating device. Most of the modern vaporizers are designed to be used outside the circle system.

In most modern vaporizers, **having a variable bypass chamber helps to split the ratio of the fresh gas flow (FGF) entering the vaporizing chamber and the bypass chamber**. In essence, a fraction of the FGF entering the vaporizing chamber gets fully saturated with the vapor, which then mixes with vapor-free FGF at the ratio set by the vapor control dial to give the desired final concentration.

In contrast, **the desflurane vaporizer lacks the variable bypass**. This is due to the fact that desflurane is a vapor at standard room temperature of 23°C. A measured amount of desflurane vapor is added to the FGF, which is controlled by the differential pressure transducer and the flow control valves.

KEY FACTS

- The temperature of a desflurane vaporizer is maintained by an active heating device.
- It lacks the variable bypass due to the fact that desflurane is a vapor at standard room temperature of 23°C.

REFERENCE

Baum JA. New and alternative delivery concepts and techniques. *Best Pract Res Clin Anaesthesiol*. 2005;19(3):415–28.

23. ANSWER: C

The efficiency of the circle system depends on the ability of the CO_2 absorbent used to consistently remove the CO_2 from the expired gases. The **sodalime forms carbonates of sodium and calcium as the alkalis ($NaOH$ and $Ca(OH)_2$) react with the carbonic acid** (produced by the CO_2 reacting with water). As the sodalime reaches exhaustion, there is **accumulation of carbonic acid,** which changes the color of the **indicator dye from white to purple**. With time there is some regeneration of alkalis, which changes the color back to white.

Baralyme is unsafe, as it has been shown to **cause fire with sevoflurane** due to some ill-defined chemical reaction. Also both sodalime and baralyme can produce a significant amount of carbon dioxide by degrading the halogenated

inhalational agents like desflurane, enflurane, and isoflurane; the risk increases if the absorbers were run dry with high rates of fresh gas flow.

Amsorb Plus is the only currently available product in the United States. This does not have the strong alkalis like the sodalime. The color change on exhaustion is permanent with no regeneration. **Amsorb Plus has $CaCl_2$**, which is a humectant that helps to produce more water. **Amsorb Plus does not produce Compound A on reaction with sevoflurane**.

KEY FACTS

- The sodalime forms carbonates of sodium and calcium as the alkalis (NaOH and $Ca(OH)_2$) react with the carbonic acid.
- Baralyme is unsafe, as it has been shown to cause fire with sevoflurane.
- Amsorb Plus has $CaCl_2$, which is a humectant that helps to produce more water. Amsorb Plus does not produce Compound A on reaction with sevoflurane.

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Miller RD, Pardo M. *Basics of Anesthesia*. 6th ed. Philadelphia, PA: 2011.

24. ANSWER: D

The **pulse oximeter** works on the principle of differential absorption of red and infrared lights by hemoglobin and oxyhemoglobin. The transmitter emits **two different wavelengths (930 nm and 660 nm) of light** and the receiver, if positioned across the tissue of interest, receives the transmitted light after absorption by the hemoglobin molecules. There could be interference from ambient light, movement, and from the "penumbra effect," when the probe is too big for the finger (using an adult probe on an infant finger).

Intravenous dyes like methylene blue and indocyanine green can artificially lower the saturation values. **Methemoglobinemia also reduces the saturation values**, whereas **carboxyhemoglobin causes increase in the saturation values**. Increased levels of Copper(II) porphyrin, seen in bronze baby syndrome, has been shown to decrease the saturation value. Isosulfan blue, a dye used in identification of sentinel lymph nodes, is also shown to decrease the saturation readings.

Bilirubinemia, sickle cell disease, and fetal hemoglobin have minimal or no effect on pulse oximeter values.

KEY FACTS

- Methemoglobinemia reduces pulse oximeter saturation values.
- Carboxyhemoglobin increases pulse oximeter saturation values.

REFERENCE

Coté CJ, Lerman J, Anderson B, eds. *A Practice of Anesthesia for Infants and Children*. 5th ed. Philadelphia, PA: Saunders; 2013:1116–7.

25. ANSWER: D

When using **volume-controlled ventilation**, older anesthesia machines **deliver variable minute volumes** depending on the set fresh gas flow since the fresh gas flow gets added to the ventilator output. The **newer machines** avoid this by **decoupling the fresh gas flow and ventilator output**. So **changes in set fresh gas flows do not affect the ventilator-delivered minute ventilation**.

The fresh gas decoupling is done by a valve located between the fresh gas inflow and the ventilator circuit, which diverts the fresh gas flow to the reservoir bag during inspiration and back into the ventilator circuit during expiration; the expiratory valve also opens during expiration, removing the excess gases into the scavenging system. Figure 2.4 explains the function of the fresh gas decoupling valve both in inspiration (A) and expiration (B).

Older anesthesia ventilators do not have compliance compensation, which is the fraction of the delivered tidal volume that can be lost in mechanical components of the breathing system. Newer anesthesia ventilators not only have the ability to quantify the compliance of the breathing system but also can augment the delivered minute volume to compensate for that lost in the mechanical compliance of the breathing system.

KEY FACTS

- Newer anesthesia machines have a decoupled fresh gas flow and ventilator output so that the set fresh gas flow does not affect the ventilator-delivered minute ventilation.
- The fresh gas decoupling is done by a valve located between the fresh gas inflow and the ventilator circuit, which diverts the fresh gas flow to the reservoir bag during inspiration and back into the ventilator circuit during expiration.

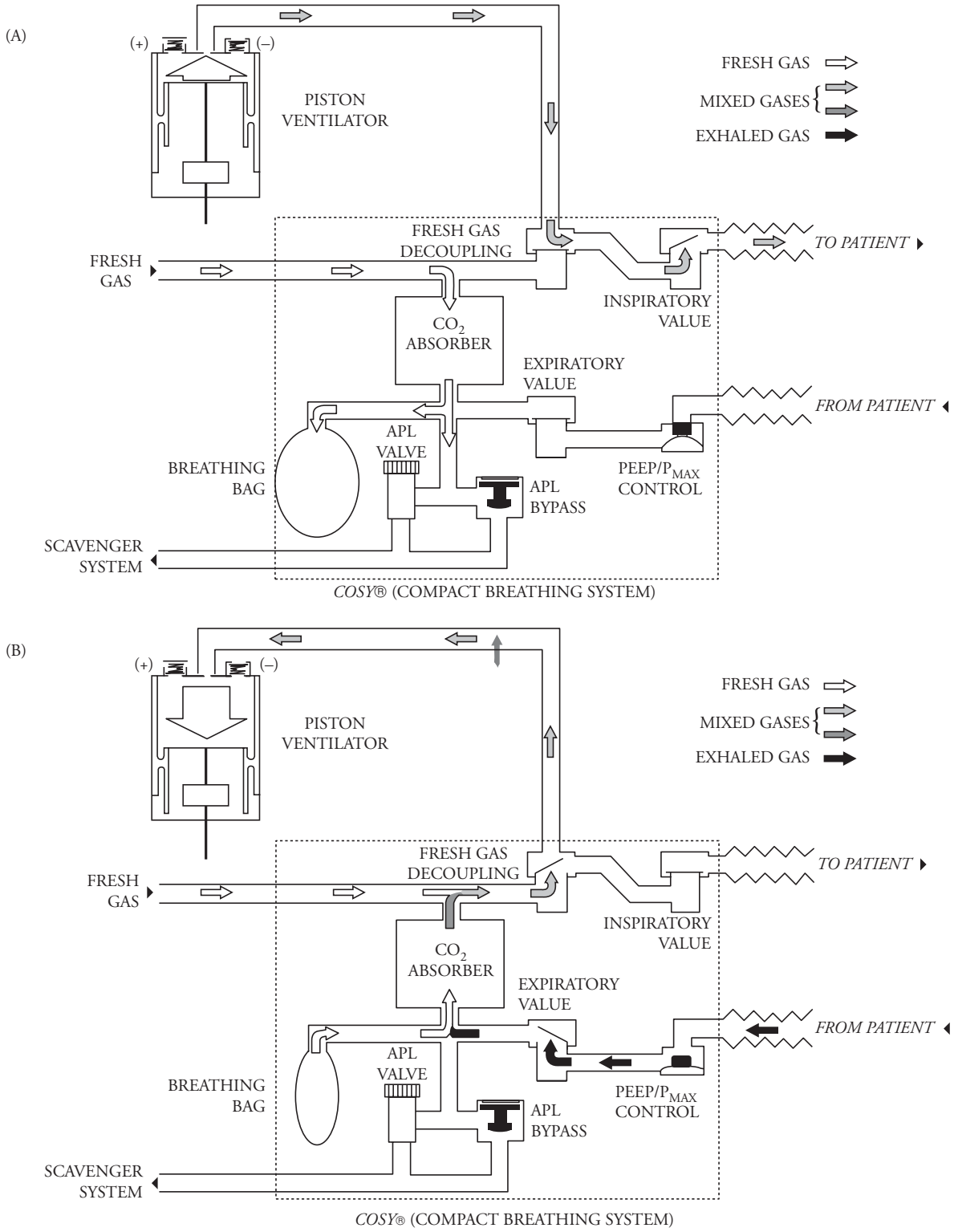

Figure 2.4 Explains the function of the fresh gas decoupling valve both in inspiration and expiration. (From Gunter JB, Ball J, Than-Win S. Preparation of the Dräger Fabius anesthesia machine for the malignant-hyperthermia susceptible patient. *Anesth Analg*. 2008 Dec;107(6):1936–45. Reprinted with permission.)

REFERENCE

Coté CJ, Lerman J, Anderson B, eds. *A Practice of Anesthesia for Infants and Children*. 5th ed. Philadelphia, PA: Saunders; 2013:1113.

26. ANSWER: D

Where the **pulse oximeter** is a useful trend of pulmonary function, cerebral oximetry trends the ratio of regional oxygen delivery and utilization and thus helps to detect cerebral ischemia. There is no standard of care for the use of NIRS-based cerebral oximetry in pediatric anesthesia, although it has its greatest presence in pediatric cardiac anesthesia.

Like pulse oximetry, **near infrared spectroscopy (NIRS)** uses the similar principle of light absorption by chromophores in the blood and tissues, namely hemoglobin, oxyhemoglobin, and cytochrome aa3. Both suffer from movement artifact and ambient light artifact.

Both use lights of different wavelengths, emitted by transmitters.

NIRS measures reflected light from arterial, venous, and capillary hemoglobin, whereas the pulse oximeter relies only on the pulsatile component; thus, **NIRS has the higher signal strength than the pulse oximeter**, as there is no need to subtract the pulsatile component. NIRS can be used as a monitor of regional organ oxygen saturation not just for the brain but also in other tissues like kidneys, free flaps, spinal cord, and so on.

KEY FACTS

- Near infrared spectroscopy (NIRS) uses the similar principle of light absorption by chromophores in the blood and tissues, namely hemoglobin, oxyhemoglobin, and cytochrome aa3.
- NIRS measures reflected light from arterial, venous, and capillary hemoglobin, whereas the pulse oximeter relies only on the pulsatile component.
- NIRS has the higher signal strength than the pulse oximeter, as there is no need to subtract the pulsatile component.

REFERENCE

Kasman N, Brady K. Cerebral oximetry for pediatric anesthesia: why do intelligent clinicians disagree? *Paediatr Anaesth*. 2011;21(5):473–8.

27. ANSWER: B

In the **linear array ultrasound transducer**, the **piezoelectric crystals** that transmit and receive the ultrasound beams are arranged in **a linear fashion and are sequentially fired, producing a rectangular image**. Since there is **minimal divergence of the beams**, this has the **best lateral resolution**.

Axial resolution is the ability to distinguish two objects that lie in a plane parallel to the direction of the US beam. Higher frequency transducers have better axial resolution.

Lateral resolution is the ability to distinguish two objects that lie in a plane perpendicular to the direction of the US beam. Lateral resolution is related to the US beam width. The narrower the US beam width, the greater the lateral resolution. High-frequency probes have narrower beam width, which allows for better lateral resolution.

The position of the narrowest part of the beam can be adjusted by changing the focal zone.

The curved surface of the curvilinear probes produces a wider image as the beams diverge from the probe. The divergent beam lacks the lateral resolution, mostly at the far field, due to loss of energy.

In the phased array transducer the beam diverges from a single point in the transducer, creating a much wider image. This enables the footprint to be small enough to place between the ribs and so it is used for transthoracic echocardiography.

KEY FACTS

- In the linear array ultrasound transducer, the piezoelectric crystals are arranged in a linear fashion and are sequentially fired, producing a rectangular image.
- Because there is minimal divergence of the beams, the linear array transducer has the best lateral resolution.

REFERENCES

Arbona FL, Khabiri B, Norton JA. Ultrasound basics for the busy novice practitioner. *Int Anesthesiol Clin*. 2011;49(4):34–51.
Coté CJ, Lerman J, Anderson B, eds. *A Practice of Anesthesia for Infants and Children*. 5th ed. Philadelphia, PA: Saunders; 2013:914–5.

28. ANSWER: D

Processed EEG monitoring relies on the principle of monitoring changing EEG waves of different amplitudes and frequencies at different states of awareness, wakefulness, light sleep, and deep sleep. Though there are studies to show strong validation of correlation of depth of anesthesia in adults, with different methods of monitoring of processed EEG signals, the evidence in pediatric anesthesia is lacking. One of the reasons is that the EEG signal characteristics are age specific; **from infancy to**

adolescence, different EEG waveforms are predominant at different stages of development:

- *From birth to 2 months*: Sleep spindles appear.
- *From 3 to 5 months:* alpha rhythm, with increasing frequency: from 4–6 Hz initially to 8–9 Hz by the age of 3.
- *From 3 to 10 years:* Alpha rhythm becomes more important and abundant, with voltage up to 60 μV, with an increasing reactivity; slow waves disappear, although they are seen occasionally in certain individuals in posterior leads.
- *From 10 to 14 years:* ample alpha rhythm, limited abundant theta, and slow patterns becoming less evident or more organized as posterior slow waves.
- *From 14 to 19 years*: Alpha rhythm predominates with reduced voltage to adult levels (50 μV), theta becomes more discreet, and posterior slow waves disappear. Asymmetry diminishes from its prior prominence in the very young.
- *After 19 years:* The tracing is that of the adult, although there may remain some theta activity. Posterior slow waves have generally disappeared.

It is important to note the ASA task force statement on the use of these processed EEG monitors for adult patients:

> Intraoperative monitoring of depth of anesthesia, for the purpose of minimizing the occurrence of awareness, should rely on multiple modalities, including clinical techniques (e.g., checking for clinical signs such as purposeful or reflex movement) and conventional monitoring systems (e.g., electrocardiogram, blood pressure, heart rate, end-tidal anesthetic analyzer, capnography). The use of neuromuscular blocking drugs may mask purposeful or reflex movements and adds additional importance to the use of monitoring methods that assure the adequate delivery of anesthesia. . . . It is the consensus of the Task Force that brain function monitoring is not routinely indicated for patients undergoing general anesthesia, either to reduce the frequency of intraoperative awareness or to monitor depth of anesthesia.

KEY FACTS

- Processed EEG monitoring relies on the principle of monitoring changing EEG waves of different amplitudes and frequencies at different states of awareness, wakefulness, light sleep, and deep sleep.
- The evidence for accurately processed EEG signals in pediatric patients under anesthesia is currently lacking.

REFERENCES

Constant I, Sabourdin N. The EEG signal: a window on the cortical brain activity. *Paediatr Anaesth*. 2012;22(6):539–52.

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3

PHARMACOLOGY

Lauren R. Kelly Ugarte, Daniel Agne, and Chul-Kyun Park

1. Infants may respond differently to medication dosages compared to adults because:

A. Infants have increased levels of albumin compared to adults.
B. The degree of protein binding of medications in infants is more than in adults.
C. There is increased free fraction of protein-bound medications compared to adults.
D. Alpha-1-acid glycoprotein concentration in infants is relatively higher than in adults.

2. Inhalation induction is more rapid in infants than in adults because infants have:

A. A greater fraction of cardiac output to the vessel-rich group
B. A decreased alveolar ventilation to functional residual capacity ratio
C. A decreased cardiac output.
D. An increased blood/gas solubility

3. Which patient requires the highest minimum alveolar concentration (MAC) of isoflurane?

A. A preterm neonate born at 35 weeks gestation on day of life 7
B. A full-term neonate on day of life 1
C. A full-term infant at 3 months of age
D. A 5-year-old child

4. Which patient requires the highest MAC of sevoflurane?

A. A full-term newborn on day of life 1
B. A former 32-week preterm infant at 1 year of age
C. A 5 year old
D. A 15 year old

5. A 2-year-old child with chronic rhinorrhea, upper respiratory infections, and partial nasal occlusion presents for an adenoidectomy. The most rapid and safe inhalation induction in this child prior to intubation for the adenoidectomy would include inhalation of:

A. 6% Sevoflurane with 2 L/min nitrous oxide and 2 L/min oxygen
B. 8% Sevoflurane with 4 L/min oxygen
C. 6% Desflurane with 2 L/min nitrous oxide and 2 L/min oxygen
D. 3 L Nitrous oxide and 1 L/min oxygen

6. Which medication is least likely to cross the blood–brain barrier in a 1-month-old infant?

A. Morphine
B. Fentanyl
C. Atropine
D. Neostigmine

7. An otherwise healthy 7-year-old child fell from his bike and sustained a significant head injury because he was not wearing a helmet. After 2 days of being intubated and sedated in the intensive care unit (ICU), his urine becomes dark and his labs show metabolic acidosis and increased potassium levels. The most likely cause of this is related to:

A. Dexmedetomidine infusion used for continuous sedation
B. Propofol infusion used for continuous sedation
C. Succinylcholine used for initial intubation
D. Midazolam used with intermittent bolusing for sedation

8. A 4 kg, 6-week-old infant with several days of vomiting has been diagnosed with pyloric stenosis. The

patient has been adequately resuscitated and brought to the operating room for a laparoscopic pyloromyotomy. The most appropriate analgesic for postoperative pain control is:

A. Remifentanil 2 μg/kg IV
B. Morphine 0.05 mg/kg IV
C. Ketorolac 0.25 mg/kg IV
D. Acetaminophen 40 mg/kg PR

9. A 3-year-old girl was playing with her sister's piggy-bank after dinner when she began drooling, crying, and coughing with some difficulty breathing. She is brought to the operating room to remove a foreign body from her esophagus. Her family history is significant for her mother and sister being "slow to wake up" with prolonged intubations from "an anesthesia medication" after tonsillectomies. Which medication should be avoided in this patient?

A. Succinylcholine
B. Remifentanil
C. Cistaracurium
D. Propofol

10. Succinylcholine is contraindicated for intubation in which of the following cases?

A. A 10-year-old child with Moyamoya disease who suffered a stroke 2 months ago without residual hemiparesis for tonsillectomy
B. A 2-year-old child who pulled a boiling pot off the stove and suffered a burn 2 hours ago requiring irrigation and debridement
C. A 3-year-old child with central core disease who requires a G-tube
D. A 6-year-old child with cerebral palsy, decreased function of the left lower extremity for tendon surgery

11. Many medications prolong neuromuscular blockade. Which of the following statements is true?

A. Steroids decrease the duration of neuromuscular blockade.
B. Aminoglycosides do not contribute to prolonged neuromuscular blockade.
C. Inhalational anesthetics increase metabolism of neuromuscular blockers and shorten the action of nondepolarizers.
D. Dexmedetomidine does not potentiate neuromuscular blockade in humans.

12. A neonate status-post esophageal atresia repair is intubated in the neonate intenstive care unit (NICU) and sedated with a fentanyl infusion. An appropriate dose of a medication is been given as a bolus and causes profound hypotension. Which medication is most likely implicated?

A. Fentanyl
B. Midazolam
C. Vecuronium
D. Pancuronium

13. A 10 kg, 1-year-old boy presents for a circumcision revision. Following an inhalation induction, IV access, and placement of a laryngeal mask airway (LMA), cefazolin is given as per surgeon request, which is infusing during the penile blockade. Suddenly, you notice a decrease in end tidal CO_2, decreased saturation, and difficulty with ventilation through the LMA. Blood pressure decreases by 10%. The electrocardiogram (EKG) remains normal. Which intervention is indicated to help with the clinical picture?

A. 10% Intralipid 2 mL/kg IV
B. 100 mg IV diphenhydramine
C. 5 μg IV epinephrine
D. 100 mg IV methyprednisolone

14. A 7-year-old girl with epilepsy was just started on a new antiepileptic medication and is presenting for a bilateral ureteral reimplant for vesicoureteral reflux. Which of the following statements about preoperative testing necessity is true?

A. A platelet count should be checked if the patient's home medication is lamotrigine
B. A serum sodium level should be checked if the patient's home medication is valproic acid
C. A serum sodium level should be checked if the patient's home medication is carbamazepine
D. A platelet count should be checked if the patient's home medication is levitiracetam

15. A 14-year-old girl with recurrent urinary tract infections (UTIs) is started on sulfamethoxazole and trimethoprim. She soon develops a rash and itchiness in her throat. Her antibiotic is changed and she is improving. Which of the following medications should be avoided in this patient in the future?

A. Celecoxib
B. Latex
C. Nitrofurantoin
D. Ketorolac

16. A 2-year-old boy presenting for an inguinal hernia repair has a strong family history of G6PD deficiency.

He has not been tested for the disease, but his preoperative labs are within normal limits and his physical examination is unremarkable. Which anesthetic medication contributes to oxidative stress?

A. Sevoflurane
B. Fentanyl
C. Propofol
D. None of the above

17. A 6-year-old boy with adenotonsillar hypertrophy and recurrent throat infections presents for tonsillectomy/adenoidectomy. The patient's history is remarkable only for familial long QT syndrome, for which he takes propanolol. Which medication would you avoid administering to him?

A. Oral midazolam
B. Succinylcholine
C. Propofol
D. Isoflurane

18. Which of the following is true regarding ketamine?

A. It cannot be given PO, PR, and IM.
B. It may cause excess salivation with bronchodilation while diminishing respiratory protective reflexes.
C. It cannot be used for rapid sequence induction in neonates.
D. Children are at lower risk for hallucinations and delirium than adults.

19. Which of the following medications is approved for perioperative pediatric use by the FDA?

A. Dopamine
B. Neostigmine
C. Succinylcholine
D. Ondansetron

20. A 15 kg child is coming in for inguinal herniorrhaphy. The general surgeon ordered an antibiotic for surgical infection prophylaxis. Which of the following intravenous antibiotic dosages is correct?

A. Ampicillin 25 mg/kg
B. Cefazolin 10 mg/kg
C. Clindamycin 10 mg/kg
D. Vancomycin 100 μg/kg

21. Which of the following skin-cleaning preparations is most appropriate for a spinal?

A. No skin cleaning preparation is needed.
B. 0.5% povidone-iodine
C. 0.5% chlorhexidine gluconate in 70% isopropyl alcohol
D. 10% isopropyl alcohol

22. Which of the following is true regarding ototoxicity of medications in neonates?

A. Aminoglycoside ototoxicity is higher in neonates than adults.
B. Rapid bolus administration of furosemide in the neonate causes less ototoxicity than the same dose given over several hours and has a better diuretic effect.
C. Ototoxicity due to diuretic administration in the neonate is often permanent.
D. The risk of hearing loss in neonates exposed to aminoglycosides has been found to be about 1.5%.

23. Which statement regarding local anesthetics is true?

A. Bupivacaine levels may be increased after repeated dosing in neonates compared to adults due to higher protein binding and higher clearance in neonates.
B. Bupivacaine is often used in neonatal regional anesthesia.
C. EMLA cream may reverse methemoglobinemia in neonates.
D. High levels of absorbed EMLA cream pose no risk of seizures in neonates.

24. Which of the following statements regarding dexamethasone use in pediatric patients is true?

A. Dexamethasone is not associated with avascular necrosis of the femoral head.
B. Dexamethasone has no effect on postoperative pain after tonsillectomy.
C. Dexamethasone increases postoperative nausea and vomiting in toddlers.
D. Dexamethasone has been associated with increased bleeding after tonsillectomy.

25. Critical incidents in pediatric anesthesia often involve medication errors. What is true regarding anesthesia-related medication error risks?

A. Giving a bolus on an infusion line may cause an unwanted drug effect.
B. Duplicate dosing of medications between the wards and the operating room is an uncommon issue in pediatric anesthesia.
C. Adults are subjected to more dosage errors than children.
D. Communication among care providers does not decrease drug errors.

26. When comparing term neonatal body composition to adult body composition, which of the following parameters increases as age increases?

A. Total body water (% body weight)
B. Extracellular fluid (% body weight)
C. Intracellular water (% body weight)
D. Total blood volume (mL/kg)

27. Hepatic clearance of fentanyl is most dependent on which of the following?

A. Hepatic blood flow
B. Plasma drug concentration
C. Induction of hepatic enzymes
D. Lipid solubility

28. A 1-year-old male is evaluated for pain in the recovery room after inguinal hernia repair. After a single dose of fentanyl the patient appears comfortable within minutes. An hour after the dose of fentanyl the patient appears uncomfortable again, and you decide to give morphine for longer duration of pain control. After a dose of morphine you notice it takes about 10 minutes before the patient appears comfortable. The rapid onset of fentanyl compared with morphine is secondary to:

A. Immature blood–brain barrier
B. Higher protein binding of morphine compared to fentanyl
C. Higher nonionized fraction of fentanyl compared to morphine
D. Higher lipid solubility of fentanyl compared to morphine

29. When comparing acetaminophen to ketorolac, which of the following characteristics is specific to ketorolac?

A. Opioid sparing effect
B. Anti-inflammatory effect
C. Inhibition of cyclooxygenase
D. Antipyretic effect

30. A 5-year-old male with a history of postoperative delirium/agitation after ear tube placement is scheduled to undergo a tonsillectomy and adenoidectomy. You plan on giving dexmedetomidine in an attempt to prevent postoperative delirium. The mechanism of action of dexmedetomidine most closely resembles which drug?

A. Midazolam
B. Ketamine
C. Clonidine
D. Propofol

31. In reference to question 30 above, the most likely side effect of dexmedetomidine is:

A. Apnea
B. Hypotension
C. Shivering
D. Tachycardia

32. An increase in which neonatal variable best explains the more rapid rise of the alveolar to inspired anesthetic partial pressures (F_A/F_I) in neonates compared to adults?

A. Alveolar ventilation to functional residual capacity ratio
B. Blood gas partition coefficient
C. Brain blood partition coefficient
D. Cardiac output

33. Which statement best describes sevoflurane pharmacodynamics?

A. MAC is highest at 8 months of age
B. MAC is less than additive with N_20 in infants
C. Sevoflurane is more potent than isoflurane
D. Sevoflurane is less potent than desflurane

34. The most relevant reason why desflurane is not commonly used for mask induction is because of:

A. Prolonged duration in stage II during induction
B. Tachycardia and hypertension during induction
C. Increased risk of laryngospasm
D. Increased risk of emergence delirium

35. Which opioid has a greater clearance in the neonatal period?

A. Fentanyl
B. Hydromorphone
C. Alfentanil
D. Remifentanil

36. An 8-year-old male with cerebral palsy and a history of lower-extremity contractures is undergoing adductor and psoas tendon lengthening. What is the most likely response to neuromuscular blockade?

A. Hyperkalemic response to succinylcholine
B. Resistance to nondepolarizing muscle relaxants
C. Sensitivity to nondepolarizing muscle relaxants
D. Resistance to succinylcholine

37. A 7-year-old male with a 22-gauge peripheral IV in place is scheduled to have removal of hardware after an

ORIF of a humerus fracture he sustained 1 year ago. He states that he is scared because it "burned his arm" when he went to sleep last time. The most effective prophylactic treatment for pain with propofol injection is:

A. IV fentanyl prior to propofol
B. IV lidocaine mixed with propofol
C. IV lidocaine with tourniquet on prior to propofol
D. Cold packs on the arm

38. A 20 kg, 5-year-old female presents for a left foot cuboid osteotomy. You plan on placing a popliteal-sciatic nerve block. Which of the following exceeds the maximum dose of local anesthetic in this patient?

A. 9 cc 0.5% ropivacaine
B. 9 cc 2% lidocaine with epinephrine 1:200,000
C. 15 cc 0.25% bupivacaine
D. 15 cc 0.25% bupivacaine with epinephrine 1:200,000

39. A 4-year-old male undergoing strabismus repair receives ondansetron at the end of surgery for postoperative nausea and vomiting (PONV) prophylaxis. The antiemetic effect of ondansetron is mediated by:

A. Central agonist of the 5-HT_3 receptor and H_1 receptor
B. Central and peripheral antagonist of the 5-HT_3 receptor
C. Mixed agonist/antagonist of 5-HT_3 and 5-HT_4
D. Central antagonist of the Neurokinin-1 receptors

40. A 4-year-old female with history of asthma and eczema is scheduled for umbilical hernia repair. She underwent an inhalation induction and placement of an endotracheal tube. Manual bag ventilation becomes difficult, requiring elevated peak pressures. Wheezing is heard bilaterally and a rash is seen on the patient's trunk. You notice that the blood pressure has dropped and believe that the patient is having an anaphylactic reaction. After calling for help and administering 100% oxygen the next best step is giving which medication?

A. Hydrocortisone
B. Diphenhydramine
C. Epinephrine
D. Albuterol

41. For a 20 kg patient undergoing an awake fiberoptic intubation, 3 mL of 4% lidocaine was given via nebulization. The patient's SpO_2 suddenly becomes 85%, and the patient starts to complain about having difficulty breathing. Heart rate and blood pressure are normal. What is the next step you should take?

A. Administer sodium thiosulfate.
B. Administer epinephrine.
C. Administer methylene blue.
D. Draw arterial blood gas.

42. A 2-year-old girl is brought to the hospital after being injured in a car accident. Her pupils are of different size. The surgeon asks you to administer mannitol. What is the risk of giving a bolus of mannitol over 5 minutes?

A. Brain herniation
B. Hypo-osmolality
C. Hyponatremia
D. Hypotension

43. What medication should be avoided during emergent craniotomy?

A. Hypertonic saline
B. Thiopental
C. Ketamine
D. Midazolam

44. A 3-year-old girl is presenting for vesicoureteral reflux needing ureteral reimplantation. General anesthesia is induced by mask with sevoflurane, an endotracheal tube is placed, and anesthesia is maintained with sevoflurane. What is the best postoperative pain management for this patient?

A. Hydromorphone 10 μg/kg bolus
B. Caudal block with 0.25% bupivacaine, 0.5 mL/kg
C. Caudal block with 0.25% bupivacaine, 1 mL/kg
D. Caudal block with 0.25% bupivacaine, 1.25 mL/kg

45. You are in the postanesthesia care unit (PACU) and see a patient vomiting. The bedside nurse informs you that the patient is a 14-year-old girl who just had inner ear surgery, and she has been vomiting since she woke up from anesthesia. She has received dexamethasone and ondansetron during the procedure. The nurse asks you what pharmacological treatment she should give next. What medication should you order?

A. Dexamethasone
B. Ondansetron
C. Metoclopramide
D. Promethazine

46. Which protein is primarily involved for protection of systemic toxicity from local anesthetics?

A. Serum albumin
B. Elastin

C. C-Reactive proteins
D. Alpha-1-acid glycoproteins

47. A 5-year-old girl with Trisomy 21 is coming in for an abdominal procedure. The patient has narrow-angle glaucoma. Which of these medications can be safely used for this patient?

A. Glycopyrrolate
B. Atropine
C. Scopolamine
D. Pilocarpine

48. A healthy 10-year-old, 40 kg patient is scheduled for anterior cruciate ligament (ACL) repair. During injection of local anesthetic for femoral nerve block, the patient suddenly starts to have convulsions. You suspect that the patient has systemic toxicity from local anesthetic. What would be your next step of action?

A. Administration of lipid emulsion 10%, 40 mL
B. Administration of lipid emulsion 10%, 60 mL
C. Administration of lipid emulsion 20%, 40 mL
D. Administration of lipid emulsion 20%, 60 mL

49. You are performing a rapid sequence induction on a full stomach patient with succinylcholine and propofol. After successful intubation, you decide to paralyze the patient with a second dose of succinylcholine prior to incision. What physiological signs are more likely to be seen after the second administration of succinylcholine?

A. Bradycardia
B. Tachycardia
C. Hypertension
D. Hypotension

50. Compared to older children, how does rocuronium's onset of action and duration differ in infants, respectively?

A. Same as children; shorter than children
B. Faster than children; shorter than children
C. Slower than children; longer than children
D. Slower than children; shorter than children

51. A patient presents with an inguinal hernia repair. During the interview, you obtain information from his parents that the patient has never undergone any type of surgeries and he gets a rash when given egg whites but not to egg yolk. Parents inform you that they have both had surgeries without any problems. How will you proceed?

A. Cancel surgery
B. Cancel surgery and send patient for skin prick testing.
C. Proceed with surgery but do not use propofol.
D. Proceed with surgery and use propofol.

52. You are consulted by a PICU physician regarding a 2-year-old patient who presented with high fever and seizures. The patient was intubated 2 days ago and has been on midazolam, propofol, and vecuronium infusion. She has suddenly developed metabolic acidosis and hyperkalemia. You suspect propofol infusion syndrome (PRIS). What is the known risk factor for developing PRIS?

A. Propofol infusion at 50 μg/kg per minute for 2 days
B. Patients with defect in lipid metabolism
C. Patients with seizure disorders
D. Patients with kidney disease

53. You are scheduled to perform scoliosis surgery on a 13-year-old boy with seizure disorder, acne, gastroesophageal reflux disease (GERD), and a history of liver transplant. He is on carbamazepine, erythromycin, omeprazole, and cyclosporine. After achieving muscle relaxation with rocuronium (1.2 mg/kg), the patient is successfully intubated. Twenty minutes later, as you are about to turn the patient prone, the patient starts to move again. Which drug explains why the patient moved?

A. Carbamazepine
B. Erythromycin
C. Omeprazole
D. Cyclosporine

54. Compared to other opioids, what is the characteristic that is different for a single bolus of remifentanil in neonates?

A. Smaller volume of distribution
B. Faster onset
C. Longer duration
D. Shorter half-life

55. An opiate-naïve patient complains that codeine that has been prescribed does not have any effect on her pain control. What metabolism process does codeine undergo?

A. Codeine is metabolized by CYP 2D6 to oxymorphone.
B. Codeine is metabolized by CYP 2D6 to hydromorphone.
C. Codeine is metabolized by CYP 2D6 to morphine.
D. Codeine is metabolized by CYP 2D6 to oxycodone.

CHAPTER 3 ANSWERS

1. ANSWER: C

Infants have immature livers, which do not produce the same amount of proteins, including albumin, as the mature liver (A). Many medications will bind to these proteins, so **the degree of protein binding of medications in infants is less than adults, thereby increasing the free form of medications** (B) (unbound medication). Also, **many medications that are highly protein bound in adults have less affinity in children**. Therefore, for a given dose, **neonates will have more free and available active drug levels** for pharmacologic action. Along the same lines, **alpha-1-acid glycoprotein concentration is less in infants than in adults** (D); therefore, medications that bind alpha-1-acid glycoproteins (i.e., lidocaine and alfentanil) will be more in the free form in infants (C).

KEY FACTS

- Infants produce less albumin and alpha-1-acid glycoprotein than adults.
- Infants have a decreased degree of protein binding of medications; therefore, the free form of medications is increased.

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2. ANSWER: A

The rate of inhalational anesthetic uptake is directly related to the ratio of alveolar ventilation (Av) to functional residual capacity (FRC). **The higher the Av/FRC ratio, the more rapid the rate of anesthetic rise and effect**. Children have three times the alveolar ventilation compared to adults, and this increased minute ventilation results in a more rapid inhalation induction (B). **Infants have a decreased FRC compared to adults**, which also increases the Av/FRC ratio. Infants have a higher cardiac output than adults (C). However, the rate of rise of an inhaled anesthetic is inversely related to changes in cardiac output, meaning lower cardiac output leads to a faster induction. **Neonates have a paradoxical reaction to inhaled anesthetics in that they have a high cardiac index and a quick response to induction with inhaled anesthetics.** This may be attributed to the 18% compared to 8% proportion of the cardiac output that infants send to the vessel-rich group compare to adults (A). Also, **the solubility of inhaled agents (D) is less in neonates in comparison to adults**, which is contributed to a rapid wash-in, and lower levels of cholesterol and proteins in the blood.

KEY FACTS

- Infants undergo a more rapid inhalation induction because of an increased alveolar ventilation, increased minute ventilation, and decreased FRC in comparison to adults.
- The solubility of inhaled agents is decreased in neonates in comparison to adults, contributing to a rapid wash-in, and lower levels of cholesterol and proteins in the blood.

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3. ANSWER: C

The MAC of isoflurane reaches its peak at 1–6 months of age. There is a steady increase to peak from <32 weeks postconceptual age and a steady decline thereafter.

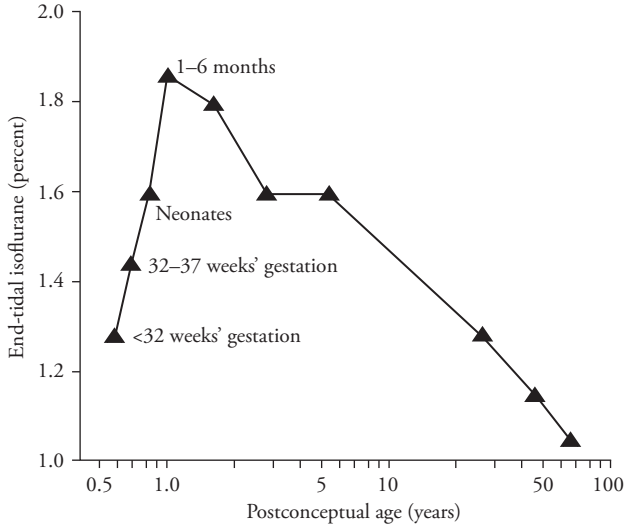

Figure 3.1 The minimum alveolar concentration (MAC) of isoflurane. (Reprinted with permission from Cote CJ, Lerman J, Todres ID, eds. *A Practice of Anesthesia for Infants and Children*. 4 ed. Philadelphia, PA: Saunders; 2009:107.)

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4. ANSWER: A

The MAC of sevoflurane is greatest in full-term newborns. MAC is 0.1% less in infants 1–6 months of age and drops 25% to 2.5% from 6 months to 10 years of age. MAC for sevoflurane was determined with 100% oxygen, observing for response to a single skin incision.

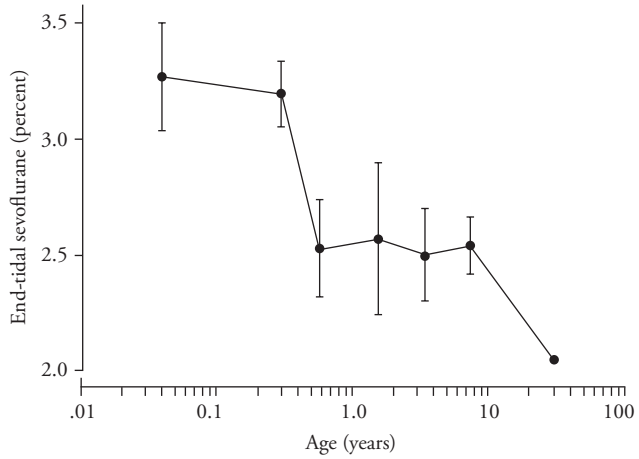

Figure 3.2 The minimum alveolar concentration (MAC) of sevoflurane. (Reprinted with permission from Cote CJ, Lerman J, Todres ID, eds. *A Practice of Anesthesia for Infants and Children*. 4 ed. Philadelphia, PA: Saunders; 2009:108.)

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5. ANSWER: B

Aside from halothane, sevoflurane is the least pungent inhalational anesthetic at 1 MAC. Sevoflurane is quite well tolerated for inhalation induction, and it may be dialed up to 8% for a healthy child during induction to "overpressure" the circuit and increase the rate of induction (B). **The spontaneously breathing child will self-regulate his or her breathing to decrease the risk of overdosing on this inhalational agent**; that is, at higher dosages, there is decreased minute ventilation. This safety measure is lost once controlled ventilation is instituted.

The rapidity of achieving a MAC of sevoflurane is decreased with the addition of nitrous oxide. It has been shown that 60% nitrous oxide decreases the MAC of sevoflurane by 20% (A).

Desflurane is more irritating than sevoflurane and is therefore not commonly chosen for an inhalation induction. It also has an increased rate of respiratory complications (C). While being noncaustic and pleasant to inhale, **nitrous oxide cannot reach 1 MAC and would be inadequate to achieve intubating conditions when used alone** (D). It is, however, a useful adjunct to initially relax children during induction at 50%–70% inhalational levels prior to introducing the more potent-smelling sevoflurane.

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6. ANSWER: D

Brain capillaries are impermeable to most ionized substances and macromolecules that are physically too large to pass through tight junctions between endothelial cells. Also, brain capillaries lack the ability for pinocytosis, thus decreasing the passage of many other substances into the brain. **In the newborn, the blood–brain barrier is not fully developed, and partially ionized medications, such as morphine, are able to cross into the brain** (A). Due to its lipophilic nature, fentanyl is able to pass through the blood brain barrier in all age groups (B). Atropine crosses the blood–brain barrier at all ages and high doses contribute to the neurologic effects of atropine (C). These effects are described as making one "mad as a hatter" with behavioral abnormalities, hallucinations, and delirium. **Neostigmine, with its quaternary ammonium group, is too large to pass through the blood–brain barrier (D).** This is important to be aware of in case there is a need to reverse the neurologic side effects of medications such as atropine and scopolamine. Reversal of neurologic effects of these medications is achieved with **physostigmine, as it lacks a quaternary ammonium group and is able to cross the blood–brain barrier**.

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7. ANSWER: B

The patient is most likely experiencing **propofol infusion syndrome**. **The use of propofol for prolonged periods of time in pediatric ICUs is contraindicated due to a rare syndrome of metabolic acidosis, heart failure, lipidemia, rhabdomyolysis, and death** (B). The exact cause is not known, but it is associated with higher dosing required for children, longer versus shorter infusions, and it is possibly linked to impaired fatty acid oxidation.

Though dexmedetomidine is only approved for infusions up to 24 hours in the United States, its side effects would not paint the clinical picture described in the question stem (A). Dexmedetomidine's side effects are related to its function as an alpha-2 agonist and are cardiovascular in nature, include high or low blood pressure correlated with dosing, a decrease in heart rate associated with dosing, and significantly increased blood pressure when glycopyrrolate is given with it.

Succinylcholine may cause rhabdomyolisis if used for intubation in a patient with neuromuscular disease or malignant hyperthermia, or detrimental hyperkalemia in a patient with >8% of his or her body burned, prolonged sickness or limb disuse, decreased renal excretion of potassium, or those at risk of malignant hyperthermia (C). **A newly denervated state in patients leads to proliferation of acetylcholine receptors in the muscles, which contributes to a large release of potassium from muscles when succinylcholine is given.** Clinically significant hyperkalemia does not occur until 1–3 days after a crush injury, stroke, or burn. In relation to the stem question, hyperkalemia and rhabdomyolysis would occur in an at-risk patient upon dosing of the medication and not appear 2 days after a single dose of succinylcholine.

Midazolam used for sedation may lead to respiratory depression, especially when combined with opiates (D). It has also been associated with myoclonus and apnea in preterm NICU patients and may contribute to intraventricular hemorrhages but not the clinical picture noted in the stem.

KEY FACTS

- Prolonged infusion of propofol is contraindicated due to the risk of propofol infusion syndrome.
- Propofol infusion syndrome can lead to metabolic acidosis, heart failure, lipidemia, rhabdomyolysis, and death.
- A crush injury, stroke, or burn leads to increased release of potassium from muscles when succinylcholine is given 1–3 days after the initial insult.

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8. ANSWER: D

Neonates with pyloric stenosis are very sensitive to opiate medications and can have postoperative apnea due to increased narcotic sensitivity (B). A laparoscopic approach to the pyloric stenosis uses small incisions that seem to be less painful than the open approach, and use of local anesthetics at the incision sites provides adequate relief. Remifentanil is a poor choice due to its rapid half-life and possible contribution to increased pain if a long-acting pain medication is not administered (A). While it is not an opiate, **ketorolac's safety in patients less than 6 months of age has not been confirmed** and may not be ideal in this patient due to age and immature organ systems (C). **Ketorolac also has significant affects on hematologic, renal, and gastrointestinal (GI) function.** Acetaminophen is an adequate analgesic for this procedure and does not contribute to respiratory depression (D). **Acetaminophen dosing ranges from 20 to 40 mg/kg PR perioperatively and a loading dose of 40 mg/kg is safe. Acetaminophen should not exceed 100 mg/kg total dosing per day due to risk of potentially fatal hepatic toxicity**.

KEY FACTS

- Neonates with **pyloric stenosis** are very sensitive to opiate medications and can have postoperative apnea due to increased narcotic sensitivity.
- Ketorolac also has significant affects on hematologic, renal, and gastrointestinal (GI) function.

- Acetaminophen dosing ranges from 20 to 40 mg/kg PR perioperatively and a loading dose of 40 mg/kg is safe. Acetaminophen should not exceed 100 mg/kg total dosing per day due to risk of potentially fatal hepatic toxicity.

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9. ANSWER: A

This patient would be considered a full stomach and would require intubation for the endoscopic foreign body removal. A rapid sequence induction is indicated in this case to prevent aspiration. Succinylcholine has a rapid onset and is rapidly metabolized, which makes it useful for a short case that does not require prolonged paralysis. However, it is possible that the patient's family members have pseudocholinesterase deficiency, which would cause prolonged paralysis after an intubating dose of succinylcholine. **This prolonged action of succinylcholine is due to an inherited lack of plasma cholinesterase, the enzyme that breaks down succinylcholine** (A).

Remifentanil is hydrolyzed by nonspecific blood and tissue esterases and is not a substrate for plasma cholinesterase, so it can be considered for use in a rapid sequence induction for a short case (B). Of note, esmolol is also broken down by nonspecific cholinesterases, and butyrylcholinesterase (pseudocholinesterase) does not play a significant role in its breakdown. **Cisatracurium is broken down by enzymatic hydrolysis independent of plasma cholinesterase and spontaneous degradation in plasma and tissue at normal body temperature, also known as Hofmann elimination**, which accounts for 77% of total body clearance (C). Cisatraciurium can be used for a rapid sequence induction but requires a higher dose. Its duration of action would be longer than that of succinylcholine, but most patients should be able to be reversed with neostigmine in a timely fashion. Propofol is not contraindicated for this child (D).

KEY FACTS

- Prolonged action of succinylcholine can occur due to an inherited lack of plasma cholinesterase, the enzyme that breaks down succinylcholine.
- Remifentanil is hydrolyzed by nonspecific blood and tissue esterases and is not a substrate for plasma cholinesterase.
- Cisatracurium is broken down by enzymatic hydrolysis independent of plasma cholinesterase and spontaneous degradation in plasma and tissue at normal body temperature, also known as Hofmann elimination.

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10. ANSWER: C

Central core disease is strongly correlated with malignant hyperthermia risk, and patients with this should be managed with a clean technique, which includes the avoidance of inhaled anesthetics (other than nitrous oxide) as well as depolarizing neuromuscular blockers such as succinylcholine (C). Hyperkalemic response to succinylcholine may be exaggerated in certain patients and lead to cardiac arrest. This includes patients with unhealed skeletal muscle injuries, crush injuries, extensive burns, stroke with disuse, bedbound patients, and spinal cord transections. Strokes or transient ischemia attacks that have no residual deficits such as decreased strength or limb use do not pose an increased threat of hyperkalemia (A). Also, **timing of an injury or loss of use is important, as the risk for a hyperkalemic response increases with time and peaks a week or more after the initial insult**. Accordingly, an injury just 2 hours old will not have a significant impact on potassium release from muscle or body cells, and there are no reports of this occurring in the first 48 hours after a burn (B). If greater than 8% of the body surface is burned, it places a patient at risk and most cardiac arrests in these patients have happened 20–50 days after the insult. **The presumed mechanism of hyperkalemic response to succinylcholine in such patients is a proliferation of extra-junctional receptors and increased sites of potassium leakage.** This needs some time to develop. Although people with cerebral palsy may have disuse of their extremities, they are not susceptible to hyperkalemia if no additional injuries are sustained (D).

KEY FACTS

- Central core disease is strongly correlated with malignant hyperthermia.
- Patients should be managed with a clean technique, which includes the avoidance of inhaled anesthetics (other than nitrous oxide) as well as depolarizing neuromuscular blockers such as succinylcholine.

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11. ANSWER: D

Prolonged muscle weakness has been reported in intubated ICU patients who receive neuromuscular blocking agents and corticosteroids (A). Many patients had no known risk factors for increased weakness, and such myopathies were associated with elevated creatine kinase levels, with EMG studies showing myopathic changes, normal sensation and nerve conduction, and reduced deep tendon reflexes.

Aminoglycosides are known potentiators of neuromuscular blockage (B). This blockade cannot be reversed with medications such as neostigmine, but calcium may attenuate it as the antibiotics are involved in antagonizing calcium ions associated with propagation of nerve impulses.

Inhalational agents potentiate neuromuscular blockade in a dose-related fashion and also accelerate the onset of Phase II blockade (C). Desflurane may have a greater potentiating effect than sevoflurane. The mechanism is not clear, but it may involve halogenated agents acting at the nicotinic receptor on the neuromuscular junction, which has a dose-dependent effect.

Dexmedetomidine produces muscle flaccidity in animal models, but there is no evidence that it potentiates neuromuscular blockade in humans (D).

KEY FACTS

- Prolonged muscle weakness has been reported in intubated ICU patients who receive neuromuscular blocking agents and corticosteroids.
- Aminoglycosides can potentiate the effect of neuromuscular blocking agents.
- Inhalational agents potentiate neuromuscular blockade in a dose-related fashion.
- Dexmedetomidine does not potentiate neuromuscular blockade in humans.

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12. ANSWER: B

There is an apparent interaction between midazolam and fentanyl in neonates when one medication is bolused during an infusion of the other that leads to profound hypotension (B). A fentanyl bolus upon a fentanyl infusion should not cause profound hypotension, if dosed appropriately (A). This is common practice. Fentanyl is often chosen as an anesthetic adjunct in neonates and children for its cardiovascular stability, although it can be associated with decreased heart rate and chest wall/glottic rigidity when given in large boluses. **Vecuronium is a muscle relaxant that typically lacks adverse cardiovascular effects, even when given in large doses** several times the usual clinical dose (C). Pancuronium is often used with fentanyl due to their complementary side effects and would not be expected to cause profound hypotension in this case (D). **There is an association of increased vagal tone with large boluses of fentanyl, which may affect cardiac output in neonates** who depend on heart rate for cardiac output due to their fixed stroke volume. **Pancuronium has a vagolytic effect**, and this raise in heart rate would be beneficial in the setting of large fentanyl boluses to offset the decreased heart rate that may occur.

KEY FACTS

- There is an apparent interaction between midazolam and fentanyl in neonates when one medication is bolused during an infusion of the other that leads to profound hypotension.
- Vecuronium is a muscle relaxant that typically lacks adverse cardiovascular effects, even when given in large doses.
- There is an association of increased vagal tone with large boluses of fentanyl, which may affect cardiac output in neonates.
- Pancuronium has a vagolytic effect.

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13. ANSWER: C

The clinical picture is most likely **allergic reaction** to the antibiotic though local anesthesia toxicity should be on the differential. A normal EKG makes the likelihood of local anesthesia toxicity less likely (A). Treatment for local anesthesia toxicity is intralipid. Local anesthesia toxicity is most severe if bupivacaine is used due to its direct binding to myocardial muscle cells. The dosing for intralipid is 1.5 mL/kg of 20% intralipid, which may be bolused up to 3 times and then an infusion of 0.25 mL/kg per minute up to 0.5 mL/kg per minute. Benadryl or diphenhydramine is used in the treatment of anaphylaxis in 1 mg/kg IV dosing to block histamine release (B). **The most important medication for treatment of anaphylaxis is epinephrine as it acts to stabilize mast cell degranulation as well as to augment blood pressure** (C). Epinephrine may be given IV titrated to effect or intramuscularly usually to the thigh 0.01 mL/kg of 1:1000 concentration. Subcutaneous administration is no longer recommended. Early treatment with epinephrine can be lifesaving. IV corticosteroids are also part of the treatment of anaphylaxis, and solumedrol dosed at 2 mg/kg is appropriate (D). IV medications are important as well as ample IV fluid administration during a case of anaphylaxis. Albuterol would also be an appropriate adjunct for bronchodilation in the setting of bronchospasm related to anaphylaxis. One should also consider intubating the patient to secure the airway as airway swelling may occur. Of note, the most common medication to cause allergic reaction in a pediatric study in France was vecuronium.

KEY FACTS

- Local anesthetic systemic toxicity is unlikely in the setting of a normal EKG.
- The most important medication for treatment of anaphylaxis is epinephrine as it acts to stabilize mast cell degranulation as well as to augment blood pressure.

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14. ANSWER: C

Lamotrigine (lamictal) is an alternative to valproic acid with fewer side effects, although it is not as effective for myoclonic seizures. Lamotrigine is also used to stabilize moods. It can cause severe rash, fatigue, and impaired cognition, but severe medical side effects are not common (A). However, lamotrigine is not commonly used in children as the risk of developing a life-threatening rash is 1 in 50 patients. Valproic acid (Depakote) is a broad spectrum antiepileptic medication and is most effective for generalized seizures; it has been the called the gold standard for treating many new-onset pediatric seizures. **Valproic acid can significantly affect platelet function as well as cause side effects, including alopecia, weight gain, tremor, GI upset, and liver toxicity in infants**. Carbamazepine (Tegretol) is an effective medication for partial seizures. **It affects sodium channels and can lead to low platelet and sodium levels.** Its propensity to cause hyponatremia by antidiuretic effects has made carbamazepine a treatment for some cases of diabetes insipidus. Carbamazepine may

also cause rashes, including Stevens-Johnson syndrome. **Oxcarbazepine (Trileptal) is similar to carbamazepine and may have fewer side effects though the risk for hyponatremia may be higher and sodium levels should be checked in these patients.** Many patients are now taking levitiracetam (Keppra) as it is a broad-spectrum antiepileptic that has few side effects and does not cause as may memory problems as the other antiepileptics. It also is less likely to have drug–drug interactions (D).

KEY FACTS

- Lamotrigine is not commonly used in children due to the risk of a life-threatening rash in 1 out of 50 patients.
- Valproic acid can significantly affect platelet function as well as cause side effects, including alopecia, weight gain, tremor, GI upset, and liver toxicity in infants.
- Carbamazepine can lead to hyponatremia and thrombocytopenia.

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15. ANSWER: A

This patient appears to have an **allergic reaction to Bactrim**. Bactrim is a sulfa drug and the sulfonamides were the first antimicrobial agents used effectively to treat infectious diseases. It is currently used as a first-line treatment for UTIs due to its coverage of urobacteria and its low cost. Common allergic reactions to this class include the spectrum of benign to malignant rashes, nausea, and vomiting. In this case, many **anesthesiologists believe avoidance of drugs in this class would be prudent**. Celecoxib (Celebrex), a selective cyclo-oxygenase-2 inhibitor, is a diaryl-substituted pyrazole derivative containing a sulfonamide substituent. Because of this structural component, **celecoxib is contraindicated for use in patients who have demonstrated allergic reactions to sulfonamides** (A). One study showed that of 969 patients with an allergic reaction after a sulfonamide antibiotic, almost 10% had an allergic reaction after subsequently receiving a sulfonamide nonantibiotic. It is interesting to note that in this study, the risk of allergic reactions was increased after receiving penicillin. The authors found the risk of an allergic reaction after the receipt of a sulfonamide nonantibiotic was lower among patients with a history of hypersensitivity to sulfonamide antibiotics than among patients with a history of hypersensitivity to penicillins. The authors also found that the association between hypersensitivity after the receipt of sulfonamide antibiotics and a subsequent allergic reaction after the receipt of a sulfonamide nonantibiotic is most likely to be due to a predisposition to allergic reactions rather than to cross-reactivity with sulfonamide-based drugs. **Bactrim should be used with caution in patients with G6PD, renal and hepatic impairment, and patients on Coumadin and glipizide**. **Patients with allergies to kiwis and bananas and with a history of urinary tract manipulation, such as those with spina bifida or myelomeningocele or frequent exposure to latex should avoid latex exposure** (B). Macrobid (nitrofurantoin) is an alternate to Bactrim for treatment of UTIs and side effects include, cough, malaise, and rarely pulmonary fibrosis if used long term (C). Ketorolac has no association with Bactrim allergy (D).

KEY FACTS

- Celecoxib, a selective cyclo-oxygenase-2 inhibitor contains a sulfonamide substituent.
- Because of this structural component, celecoxib is contraindicated for use in patients who have demonstrated allergic reactions to sulfonamides.

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16. ANSWER: D

Glucose-6-phosphatase dehydrogenase (G6PD) deficiency is the most common enzyme defect in the world and is most common in people from areas where malaria is endemic, as well as their relatives, due to its protective

effects in malarial disease. **Exposure to oxidative drugs put patients with G6PD deficiency at risk for hemolytic crisis, with symptoms/signs including cyanosis, headache, body pains, jaundice, myoglobinuria, and anemia.** This usually manifests 2–3 days after exposure to the offending agents. If not recognized, this could lead to severe neurologic complications. Often, the laboratory signs will be evident prior to the clinical signs because the clinical signs relate to red blood cell breakdown. When a patient is under anesthesia, it is difficult to recognize a hemolytic reaction, so avoidance of offending medications to prevent a reaction is the primary means of caring for a patient with G6PD deficiency. Also a high index of suspicion is needed if such a patient is anesthetized and presenting with hypotension, jaundice, and so on. Free hemoglobin in plasma and urine can be measured as evidence of hemolysis. **Treatment would include discontinuing the offending agent and maintaining urine output.** There are varying degrees of reactions to many medications found on "trigger" lists on the Internet and in literature, and some listed may be used without issue. Anesthesia medications studied in vivo such as codeine derivatives, propofol, fentanyl, and ketamine have been found to be safe in G6PD (B, C). Isoflurane, sevoflurane, diazepam, and midazolam have been studied and found to have an inhibitory effect on G6PD activity in vitro, but ketamine and prilocaine did not. Although the inhalational agents were found to inhibit G6PD in vitro, inhalational agents are often used without sequelae in G6PD deficiency (A). No thorough studies have found acetaminophen, used in therapeutic doses, to be contraindicated in this disease, but there is a report of acetaminophen overdose being implicated in hemolysis. It is also important to avoid hypothermia, acidosis, hyperglycemia, and infection in these patients as such stressors may induce hemolytic crisis as well. For the most part it is prudent to avoid high doses of aspirin, high doses of prilocaine (found in EMLA cream), sulfonamide and nitrofurantoin antibiotics, antimalarials, glyburide, hydralazine, methylene blue, nitrates, nitroprusside, vitamin K, chloramphenicol, and quinine.

KEY FACTS

- Patients with G6PD deficiency are at risk for hemolytic crisis, with symptoms/signs including cyanosis, headache, body pains, jaundice, myoglobinuria, and anemia.
- Anesthesia medications such as codeine derivatives, propofol, fentanyl, and ketamine have been found to be safe in G6PD.
- Isoflurane, sevoflurane, diazepam, and midazolam have been found to have an inhibitory effect on G6PD activity in vitro, but they are often used without sequelae in G6PD deficiency.

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17. ANSWER: B

Patients with long QT syndrome (QTc >0.440 seconds) are at risk for malignant arrhythmias, including torsades de point and ventricular fibrillation. Beta-blockers do not completely protect against torsades in the perioperative period and care must be taken not to contribute to prolongation of the QT interval. **Emotional stress and auditory stimuli may contribute to prolongation of the QT interval**; thus, premedication with midazolam would not be contraindicated (A). Some medications can contribute to autonomic effects and lengthening of the QT interval and may increase the risk of an arrhythmia. **Medications used perioperatively that are in this group include** succinylcholine (due to autonomic effects and potassium release), ketamine (due to sympathomimetic effects), atropine, and glycopyrrolate (which lead to unopposed sympathetic tone) (B). Droperidol carries a black box warning for prolonging QT and ondansetron is on the list of medications that contribute to torsade de pointes; thus, patients receiving ondansetron should be monitored closely.

Propofol has minimal effect on the QT interval and has even been found to help reverse the prolongation of the QT interval in healthy patients exposed to sevoflurane (C). Sevoflurane is thought to be safe in long QT syndrome, especially in patients being treated with beta blockers, but it does prolong the QT interval; isoflurane does it to a lesser extent (D).

KEY FACTS

- Medications to be avoided in patients with prolonged QT syndrome include succinylcholine (due to autonomic effects and potassium release), ketamine (due to sympathomimetic effects), atropine, and glycopyrrolate (which lead to unopposed sympathetic tone).

- Sevoflurane prolongs QT but is thought to be safe in patients with prolonged QT syndrome, especially if patients are being treated with beta blockers.
- Isoflurane prolongs the QT interval to a lesser extent than sevoflurane.

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18. ANSWER: D

Ketamine can be used for as a premedication, sedative, induction agent as well as an analgesic adjunct. It can be given orally, rectally, intravascularly, and intramuscularly to achieve rapid effects (A). It produces a **trancelike cataleptic state with amnesia and analgesia** and can be used as a sole agent for procedures such as bone resetting and suture placement. It **has bronchodilatory effects** and has a **stable cardiovascular profile** with a low incidence of cardiac arrhythmias, and when an IV induction is performed with midazolam and ketamine, there is remarkable cardiovascular stability (B). Ketamine does **cause sympathomimetic effects** with increased heart rate, blood pressure, and respiratory rate, but respiratory protective reflexes are preserved and it is **rare to cause apnea** and airway obstruction. Side effects also include centrally mediated **excess salivation**, which may need treatment with an anticholinergic (B). **Emergence phenomena** related to ketamine include sensation of **floating; vivid, scary dreams; and hallucinations**. Adults carry a 2- to 10-fold risk of emergence phenomena compared to children (D). Benzodiazepines help to attenuate emergence phenomena. IM administration is less likely to have emergence phenomenoa and children under 10 years old are least likely to be bothered by it.

KEY FACTS

- Ketamine produces a trancelike cataleptic state with amnesia and analgesia
- Ketamine produces bronchodilatory effects and has a stable cardiovascular profile
- Ketamine produces sympathomimetic effects with increased heart rate, blood pressure, and respiratory rate
- Side effects also include centrally mediated excess salivation, which may need treatment with an anticholinergic

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19. ANSWER: C

The FDA is a governmental agency that works to state intended indications, dosing, and age limitations for medications. They base their approvals on evidence from clinical trials mainly performed by pharmaceutical companies. **A majority of medications used in children have not been approved by the FDA for use in children and their use is thus considered "off label."** Anesthesiologists administer medications based on clinical experience rather than from data provided by controlled clinical trials. This is an accepted practice because withholding such medications is not deemed appropriate. Some of the most commonly used medications that are not approved for people younger than 18 years old include neostigmine (though vecuronium is approved) (B), hydromorphone, dopamine (A), and ondansetron (D). Some medications are approved for limited use in pediatrics with age restrictions (see Tables 3.1 and 3.2). **Children younger than 1 year of age have the most restricted list of medications available to them** and thus are most often treated with medications that are not FDA approved. **Succinylcholine is approved for use in pediatrics (C), though it carries a restricted use warning from the FDA due to its association with hyperkalemia and malignant hyperthermia**. The FDA recommends succinylcholine to only be used in certain pediatric situations such as full stomach, laryngospasm, or difficult airway situations.

KEY FACTS

- A majority of medications used in children have not been approved by the FDA.

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Table 3.1 PEDIATRIC FDA-LABELING STATUS FOR DRUGS REGULARLY ADMINISTERED BY ANESTHESIOLOGISTS TO PEDIATRIC PATIENTS (YOUNGER THAN AGE 18 YEARS)

FDA-APPROVED FOR ALL AGES	NOT FDA-APPROVED FOR PATIENTS UNDER 18 YEARS
Acetaminophen	Aminocaproic acid
Adenosine	Amiodarone
Ampicillin	Butorphanol
Atropine	Cefotetan
Clindamycin	Clonidine
Desflurane	Codeine sulfate
Dexamethasone	Dexmedetomidine
Diphenhydramine	Dobutamine
Docusate	Dopamine
Epdedrine	Esmolol
Epinephrine[a]	Granisetron
Furosemide	Hetastarch/NaCl solution
Gentamicin	Hydromorphone
Heparin	Ketoprofen
Insulin	Ketorolac[c]
Lidocaine	Labetalol
Magnesium	Methadone
Magnesium sulfate	Milrinone
Midazolam[b]	Malbuphine
Morphine	Naltrexone
Naloxone	Neostigmine
Nictric oxide	Nitroglycerin
Nitroprusside	Norepinephrine
Nortriptyline	Odansetron[d]
Pancuronium	Oxycodone
Pentobarbital	Oxymorphone
Phenobarbital	Oxytocin
Phenylephrine	Polyethylene glycol
Phenytoin	Potassium chloride
Propranolol	Pregabalin
Prostaglandin E1	Procainamide
Remifentanil	Protamine
Sevoflurane	Ropivacaine
Sodium bicarbonate	Scopolamine
Sodium chloride	Thiopental
Succinylcholine	Tizanidine

(*continued*)

Table 3.1 CONTINUED

FDA-APPROVED FOR ALL AGES	NOT FDA-APPROVED FOR PATIENTS UNDER 18 YEARS
Sufentanil	
Vancomycin	
Vasopressin	
Vecuronium	

[a] For asthma, epinephrine inhalation approved for age 4 years and older; all ages for other indications.

[b] Midazolam is approved for treatment of anxiety and sedation during mechanical ventilation; midazolam oral syrup for procedural sedation is approved for patients older than 6 months.

[c] Ketorolac is not approved for treatment of pain in children but is approved for treating pain and other disorders of the eye as an ophthalmic solution.

[d] Ondansetron is approved for the treatment of chemotherapy-induced nausea and vomiting in children but is not approved for postoperative nausea and vomiting prophylaxis.

FDA, United States Food and Drug Administration; NaCl, sodium chloride.

Table 3.2 DRUGS WITH AGE-LIMITED PEDIATRIC FDA-LABELED INDICATIONS THAT ARE REGULARLY ADMINISTERED BY ANESTHESIOLOGISTS

AGE GROUP WITH FDA-LABELED INDICATIONS	ANESTHETICS/ ANALGESICS	OTHER COMMONLY USED DRUGS
≥1 month	Cisatracurium Diazepam[a] (seizure treatment) Methohexital (>1 month)	Cefazolin
≥2 months	Propofol (maintenance)	
≥3 months	Rocuronium[b]	
≥4 months		Cefoxitin
≥6 months	Diazepam (anxiety) Ibprofen[c]	
≥1 year	Codeine phosphate	
≥2 years	Fentanyl Isoflurane	Albuterol Dolasetron Granisetron hydrochloride Promethazine
≥3 years	Chloroprocaine (>3 years) Gabapentin Haloperidol Propofol (induction)	
≥6 years	Hydrocodone	Metoprolol[d]
≥10 years	Etomidate	
≥12 years	Alfentanil Amitriptyline Bupivacaine Lorazepam	Mannitaol terbutaline
≥16 years	Ketamine	Glycopyrrolate[e]
≥17 years		Modafinil

[a] Diazepam injectable has FDA-approved labeling to treat seizures in children 1 month and older.

[b] Not approved for use in rapid sequence intubation.

[c] IV formulation of ibuprofen only approved for patients 17 years or older.

[d] Metoporlol succinate is labeled for use in children 6 years and older; the oral formulation (metoprolol tartrate) is not labeled for pediatric use.

[e] Glycopyrrolate has FDA-approved labeling for oral administration only in children age 3 years and older.

FDA, United States Food and Drug Administration.

20. ANSWER: C

Perioperative antibiotic prophylaxis is important in decreasing the risk of perioperative infections. **Administration of antibiotics should occur within 60 minutes of surgical incision in order to have a therapeutic level of circulating medication**. Redosing should occur if the procedure lasts **longer than two half-lives** of the medication. For uncomplicated hernia repair there is no clear medication that works best as it is considered a clean procedure. If the surgeon elects to provide antibiotic coverage, it is generally recommended to cover the patient with a **first-generation cephalosporin**. If the patient has a history of **MRSA**, it is acceptable to use **vancomycin** for coverage as well. In cases **of beta-lactam allergy**, **clindamycin and vancomycin** are acceptable alternatives. As for pediatric dosing of perioperative antibiotics in the stem question: **Ampicillin is dosed 50 mg/kg** and ampicillin-sulbactam is dosed off of the ampicillin component with redosing recommended every 2 hours (A). **Cefazolin is dosed at 30 mg/kg** and redosed every **4 hours** (B). **Clindamycin is dosed 10 mg/kg** and redosed every **6 hours** (C). **Vancomycin is dosed 15 mg/kg** with redosing every **4 to 8 hours** (D). Initial dosing of vancomycin should occur within 2 hours of incision as the medication requires 1 hour to infuse to reduce the risk of hypotension and skin-related reactions.

KEY FACTS

- Administration of antibiotics should occur within 60 minutes of surgical incision in order to have a therapeutic level of circulating medication.
- Ampicillin is dosed 50 mg/kg, Cefazolin is dosed at 30 mg/kg, Clindamycin is dosed 10 mg/kg, Vancomycin is dosed 15 mg/kg.

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21. ANSWER: C

Skin is colonized with many microorganisms, including staphylococci and pseudomonas. Placing a spinal involves traversing the skin and subcutaneous tissues with a needle to end up in the cerebral spinal fluid. In addition to using a sterile field and dress, it is prudent to use a skin antiseptic prior to placing a spinal in order to decrease infectious complications. There are three common skin antiseptics used: iodine/iodophor, chlorhexidine, and alcohol solutions.

Iodine-based preparations are often used because they work to **oxidize skin contaminants** after crossing through cell walls. They are **bacteriostatic** in nature. They are effective against gram positives (including MRSA), gram negatives, tubercle bacillus, fungi, and viruses. A 10% povidone-iodine is a standard solution. Allergic reaction may occur in people allergic to certain dyes and shellfish.

Iodine-based preparations are not recommended for use in the very young children due to their highly permeable skin and skin surface-to-weight ratio, and in rare cases (burn victims and neonates) absorption has caused significant morbidity. **The increased absorbance of iodine-based disinfectants may also lead to thyroid suppression.**

Chlorhexidine is often used to clean the skin prior to surgical and needle manipulation. **Its mechanism of antisepsis is due to binding negative charges in bacterial walls and disrupting the osmotic equilibrium, and it provides widespread coverage, including yeasts and viruses**, though its efficacy on fungal coverage is not as good as iodine- or alcohol-based solutions. Overall, chlorhexidine has been shown to be very effective in decreasing skin colonization. One study showed that in skin prepped with chlorhexidine, positive skin culture was lower than in iodine-based and alcohol-based skin preparation, with an absolute risk reduction (ARR) of 0.25 and a relative risk reduction (RRR) of 71. It is not FDA approved for use in lumbar puncture; however, it has been shown to be safe and effective in adults for skin preparation prior to spinal insertion without increased neurologic risk. It is even used in newborns as a total body cleansing solution to decrease infection rates in nurseries, and it has been shown that with whole body cleansing there are low levels of absorption and no significant harmful effects.

Alcohol-based skin preps work to rapidly **lyse cell walls through denaturation of proteins** and alcohol-based products cover microbes similar to iodine-based products. The concentration of the alcohol confers efficacy more than the type of alcohol used. Because of its rapid antiseptic effects, alcohol is often mixed with other skin antiseptics in order to get the benefit of both solutions and to prolong the efficacy of other solutions. Alcohol **is highly flammable**; thus, it must be dry for at least 3 minutes prior to manipulation with any sort of cautery in order to decrease this risk. Alcohol that is pooled and in touch with infant skin for significant periods of time can cause burns; younger neonates are more susceptible to these burns and alcohol-based cleansers should **never be used on infants less than 28 weeks** due to significant risk to the delicate skin.

KEY FACTS

- Iodine-based preparations are not recommended for use in very young children due to their highly permeable skin and skin surface-to-weight ratio.

- The increased absorbance of iodine-based disinfectants may also lead to thyroid suppression.
- Alcohol-based cleansers have rapid antiseptic effects, but is highly flammable and can cause burns. They should never be used in infants less than 28 weeks.

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22. ANSWER: D

Neonates exposed to **aminoglycosides** and **loop diuretics** are at risk for **ototoxicity** resulting in hearing impairment or deafness. Neonatal exposure to aminoglycosides is often for treatment of illnesses such as bacterial meningitis or for coverage of patients on extracorporeal membrane oxygenation. It has been found that the incidence of ototoxicity is less in neonates than in adolescents and adults, and several studies show the incidence is around 1.5% in neonates who received aminoglycosides (A and D). Hearing loss often **occurs within the first weeks** after exposure and is more likely when patients are exposed to **supratherapeutic** levels and for longer durations of exposure. There are no data on the incidence of hearing loss associated with loop diuretic exposure and the mechanism is not clear, but there is an association with increased risk with rapid administration of such diuretics (B). **Furosemide** is the **most commonly used loop diuretic in infants,** and it has been shown that a **rapid bolus (over 5 minutes) causes more ototoxicity** than an **infusion over 8 hours**; peak serum concentrations are significantly higher with bolus administration. When used for diuresis, continuous IV infusion of loop diuretics is more effective than intermittent bolusing. With this in mind, a bolus rate of administration for >120 mg dose at <4 mg/min is safe and for doses <120 mg an infusion rate of 0.5mg/kg per minute is recommended. It is interesting to note that **the hearing damage associated with bolus dosing of furosemide is often reversible** (C). In addition to contributing to ototoxicity, furosemide may contribute to **dilation of the ductus arteriosus** due to its stimulation of prostaglandin E2 synthesis, and it should be used with caution in preterm neonates. Preterm neonates also have variable metabolism of furosemide, and drug accumulation is possible with repeated dosing, which increases the risk of late-onset deafness in such patients. Concomitant use of loop diuretics and aminoglycosides increases ototoxic side effects, but noise trauma does not seem to have such an effect.

KEY FACTS

- The incidence of ototoxicity of aminoglycosides is less in neonates (1.5%) than in adolescents and adults.
- Furosemide causes more ototoxicity if given as bolus rather than infusion.
- Hearing damage associated with bolus dosing of furosemide is often reversible.

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23. ANSWER: B

Bupivacaine is the most common local anesthetic used in pediatric regional anesthesia (B). **It has a high free concentration per dose due to lower protein binding capacity and lower clearance in neonates compared to their adult counterparts** (A). **Neonates** have lower plasma concentrations of alpha-1-acid glycoprotein, which would bind the local anesthetic, and these low plasma concentrations lead to a **relative increase in the amount of unbound circulating drug**. With more unbound drug circulating, the therapeutic, as well as toxic, effects are higher. Compound this with a decreased ability to metabolize and clear bupivacaine, and accumulation can occur during infusions or repeated dosing.

Eutectic mixture of local anesthetics (EMLA) cream must be used cautiously in neonates due to their more permeable skin and their higher skin surface-to-weight ratio compared to older children. They are at risk for

significant absorption of the **lidocaine and prilocaine** medication components, and high levels of **these medications may induce seizures and methemoglobinemia**, respectively (C and D). The association between prilocaine and methemoglobinemia has generally restricted prilocaine use in infants and children to the EMLA with size-appropriate dosing due to this concern.

KEY FACTS

- Bupivacaine has a high free concentration per dose due to lower protein binding capacity and lower clearance in neonates compared to adults.
- EMLA cream must be used cautiously in neonates due to their more permeable skin and their higher skin surface-to-weight ratio compared to older children.
- The association between prilocaine and methemoglobinemia has generally restricted prilocaine use in infants and children.

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24. ANSWER: D

Avascular necrosis of the femoral head is a known complication of **corticosteroid** therapy in patients with **acute lymphoblastic leukemia** and other patients exposed to high doses of steroids (A). Avascular necrosis as a complication of steroid use is seen in children from 1.5 to 10 years old, with a **peak incidence from 4 to 9 years old**. Use of **dexamethasone** (Decadron) is not thought to be detrimental in limited use for tonsillectomy surgery and is found to decrease postoperative pain, nausea, and vomiting (B and C). Its use is considered standard of care in many institutions for tonsillectomy and its adverse effects and cost appear negligible. Children who receive a single intraoperative dose of dexamethasone (dose range = 0.15 to 1.0 mg/kg) are half as likely to vomit in the first 24 hours postoperatively compared to children receiving placebo. Routine use of the medication in five children would be expected to result in one less patient experiencing posttonsillectomy emesis. It has also been shown that increasing dexamethasone dosage from 0.05 mg/kg up to 0.5 mg/kg significantly decreases postoperative pain medication use and the need for postoperative nausea treatments with the increasing dosages. There has, however, been an **association of increased postoperative bleeding with dexamethasone (Decadron) use in tonsillectomy** (D), with bleeding occurring in higher dosages (0.5 mg/kg). One study was stopped early due to the association of bleeding with need for reoperation in patients receiving 0.5 mg/kg of dexamethasone.

KEY FACTS

- High-dose corticosteroid therapy may lead to avascular necrosis of the femoral head.
- Dexamethasone (Decadron) is found to decrease postoperative pain, nausea, and vomiting.
- There has been an association of increased postoperative bleeding with dexamethasone (Decadron) use in tonsillectomy.

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25. ANSWER: A

Medication errors occur for many reasons. It is very important to be thoughtful in medication administration in order to decrease undesirable results. In small babies, infusion lines may carry opiates or vasoactive medications, and it is important to realize that bolusing through an infusion line could lead to a bolus of the medication in that line (A). Along the same line, when propofol or opiates are in an IV line on transport, there could be complications of late-onset resedation during transport, in the PACU or on the floor. It is a crucial recommendation that pediatric IV lines be flushed and cleared of any unnecessary medications, while being monitored, and prior to transfer to other care providers. In an analysis of critical incidents related to medication administration in pediatric anesthesia, **the duplication of dosing between the operating room and the wards was found to be the most common** (B). This finding is important as it raises awareness for the importance of handoffs and clear documentation that is readily accessible to all teams in the hospital (D). **Drug substitution, name mix-ups, and dosage errors in pediatric anesthesia are reportedly more common than in adults** (C). It is always

important to be vigilant with dilutions of medications, clearly labeling medications and administering medications over appropriate time intervals. Administration of incorrect medications, inappropriate doses, untimely schedules, and inadequate infusion rates are all found to be problems. For this reason, protocols are put in place and the importance of double-checking orders and administration of medications is warranted especially with medications that are not commonly used or medications that could cause significant harm with wrong administration. Additional risk can be reduced by making medication vials dissimilar, having the pharmacy make particular dilutions, actually using calculators to work out small doses, and following drug charts.

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26. ANSWER: C

Body composition plays an important role in volume of distribution as well as disposition of drugs. The differences seen between the term infant and adult show that **as age increases, total body water, extracellular fluid, and blood volume all decrease (A, B, and D). Intracellular water, muscle mass, and fat all increase with age** (C). The difference in body composition is even more pronounced in the preterm infant. Volume of distribution (Vd) of water-soluble drugs is larger in term and preterm infants secondary to the increased total body water percentage. An increased Vd in neonates results in a larger initial per kilogram dose to achieve the same effect as seen in adults. Lower body fat percentage in infants results in a lower Vd of lipophilic drugs. Lower muscle mass in infants results in reduced redistribution to muscle and a more prolonged duration of action compared to adults.

KEY FACTS

- Total body water, extracellular fluid, and blood volume decrease with age.
- Intracellular water, muscle mass, and fat increase with age.

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27. ANSWER: A

Hepatic clearance of a drug is the extraction ratio times the liver blood flow. Hepatic extraction ratio refers to the fraction of drug entering the liver that is removed in one pass through the liver. The highest extraction ratio possible is one, which would correspond with the liver extracting 100% of a drug passing through the hepatic circulation. **Drugs with high extraction ratios have a high percentage of the drug removed by the liver. Examples of drugs with high extraction ratios are fentanyl, bupivacaine, lidocaine, ketamine, propofol, naloxone, and metoprolol**. Therefore, clearances of drugs with high extraction ratios are most dependent on hepatic blood flow **(A)** as most of the drug is efficiently extracted after passing through the liver and induction of hepatic enzymes will have little effect on increasing clearance. Clearances of drugs with low hepatic extraction ratios are most dependent on the liver's ability to metabolize the drug and hepatic clearance is increased by induction of hepatic enzymes (C). **Examples of drugs with a low extraction ratio are methadone, diazepam, alfentanil, coumadin, and phenytoin**. While lipid solubility increases volume of distribution, it does not have a direct effect on hepatic clearance (D). Hepatic clearance is independent of plasma drug concentration (B).

KEY FACTS

- Drugs with a high extraction ratio have a high percentage of the drug removed by the liver.
- Clearances of drugs with a high extraction ratio are most dependent on hepatic blood flow.
- Examples of drugs with high extraction ratios are fentanyl, bupivacaine, lidocaine, ketamine, propofol, naloxone, and metoprolol.
- Examples of drugs with a low extraction ratio are methadone, diazepam, alfentanil, coumadin, and phenytoin.

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28. ANSWER: D

Opiates receptors are located in the central nervous system (CNS) and therefore opiates must pass through the blood–brain barrier (BBB) to reach their site of action. The BBB is made up of endothelial cells with tight junctions that prevent the transit of ions and water-soluble substances. Lipid-soluble substances and water diffuse freely across the

BBB, whereas water-soluble substances, large molecules, and ions penetrate poorly. While morphine has been shown to be more permeable in the neonatal period of animal models, adult BBB permeability is achieved by 2 months of age (**A**). **High lipid solubility is the most important factor, allowing transit of opiates across the BBB. Fentanyl has a high lipid solubility, allowing rapid transit across the BBB and rapid onset of action, while morphine has a low lipid solubility, resulting in a slower transit across the BBB, slower onset of action, and increased duration of action (D)**. Protein binding also plays an important role in the amount of free drug available to cross the BBB. Morphine is less protein bound than fentanyl and does not explain the rapid onset of fentanyl (B). Lower protein binding in the neonatal period can increase the free morphine available to cross the BBB, resulting in a more rapid onset in neonates compared to adults; however, fentanyl still has a more rapid onset in the neonatal period secondary to the high lipid solubility. Fentanyl does not have a higher nonionized fraction compared to morphine (C).

KEY FACTS

- Fentanyl has a high lipid solubility, allowing rapid transit across the BBB and rapid onset of action.
- Morphine has a low lipid solubility, resulting in a slower transit across the BBB, slower onset of action, and increased duration of action.

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29. ANSWER: B

Acetaminophen and ketorolac are both analgesics used in the perioperative setting. Both have been shown to have an **opioid-sparing** and **antipyretic effect (A and D).** The action of paracetamol at a molecular level is unclear but could be related to the production of reactive metabolites by the peroxidase function of COX-2, which could deplete glutathione, a cofactor of enzymes such as PGE synthase. While both acetaminophen and ketorolac inhibit cyclooxygenase (COX) (C), resulting in decreased conversion of arachidonic acid to prostaglandins, **only ketorolac exhibits a significant anti-inflammatory effect (B)**. COX-2 inhibition is responsible for the anti-inflammatory effect. Prostaglandins responsible for gastric protection, platelet function, and regulation of renal blood flow are produced by COX-1. Inhibition of COX-1 results in decreased gastric protection, platelet inhibition, and reduced renal blood flow. Risk of postoperative bleeding in the setting of ketorolac-induced platelet dysfunction should be addressed prior to administration. Another potential adverse effect of ketorolac is impaired bone healing in the setting of orthopedic procedures, especially spinal fusions. Acetaminophen site of action is central, while ketorolac has both central and peripheral sites of action.

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30. ANSWER: C

Dexmedetomidine is an α_2-agonist with eight times the selectivity for the α_2 receptor compared to clonidine (C). Dexmedetomidine affinity for α_2 receptor compared to α1 receptor is 1600:1. **CNS α_2 receptor activation results in sedation, analgesia, and anxiolysis, all of which are mediated by suppression of the sympathetic nervous system secondary to hyperpolarization of noradrenergic neurons**. Sedation is mediated by α_2 receptor activation at the locus ceruleus as well as inhibition of ascending norepinephrine pathways. Analgesic effects are mediated primarily at the level of the spinal cord. Hemodynamic effects are mediated at the autonomic ganglia, resulting in bradycardia and hypotension. Dexmedetomidine has been shown to be effective in preventing emergence agitation. Midazolam and propofol both facilitate GABA receptor activation (A and D). Ketamine is an NMDA receptor antagonist (B).

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31. ANSWER: B

Dexmedetomidine has been shown to be effective in preventing emergence agitation. Dexmedetomidine is an α_2-agonist with eight times the selectivity for the α_2 receptor compared to clonidine. CNS α_2 receptor activation results in sedation, analgesia, and anxiolysis, all of which are mediated by suppression of the sympathetic nervous system secondary to hyperpolarization of noradrenergic neurons. Sedation is mediated by α_2 receptor activation at the locus ceruleus as well as inhibition of ascending norepinephrine pathways. Analgesic effects are mediated primarily at the level of the spinal cord. **Hemodynamic effects are mediated at the autonomic ganglia, resulting in bradycardia and hypotension (B and D)**; however, hypertension occurs less frequently, secondary to direct vasculature smooth muscle contraction when dexmedetomidine is used at high doses. Hypertension has also been reported when anticholinergic drugs are used to treat dexmedetomidine-induced bradycardia. Dexmedetomidine does not cause postoperative shivering and has actually been shown to be effective in treating postoperative shivering (C). Dexmedetomidine does not cause respiratory depression or apnea (A).

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32. ANSWER: A

The rate of increase in F_A/F_I (also called wash-in) describes the time to reach equilibrium between inspired and alveolar anesthetic partial pressures and is determined by (1) delivery of anesthetic to the lungs and (2) uptake of anesthetic by the blood and tissues.

FACTORS AFFECTING DELIVERY

1. **Inspired concentration**: This variable is independent of age.
2. **Alveolar ventilation and FRC:** The ratio of alveolar ventilation to functional residual capacity (Va/FRC) is the most important variable determining the delivery of anesthetic to the lungs. **Va/FRC is higher in neonates (5:1) compared to adults (1.5:1) and most responsible for more rapid rise in F_A/F_I seen in neonates (A)**. The higher Va/FRC in neonates is due to relative increased alveolar ventilation secondary to an increased metabolic rate and a decreased FRC secondary to decreased alveolar compliance and increased chest wall compliance.

FACTORS AFFECTING UPTAKE

1. **Solubility:** The most important factor affecting uptake is solubility; specifically blood:gas partition coefficient and brain:blood partition coefficient. Table 3.3 lists the blood:gas and brain:blood solubility of inhaled agents for neonates and adults. Blood:gas solubility is decreased in the neonatal period secondary to lower serum cholesterol and protein compared to adults (B). **Less soluble agents (lower blood:gas and brain:blood partition coefficient) have less uptake from alveoli and result in a more rapid equilibrium between alveolar and inhaled partial pressure.** More soluble agents (increased blood:gas and brain:blood partition coefficient) would result in a more soluble agent and a slower rise F_A/F_I rather than more rapid (B and C).
2. **Venous to alveolus partial pressure gradient:** Decreased brain:blood partition coefficient results in less tissue uptake, higher venous blood anesthetic partial pressure, and a lower pressure gradient between venous blood and alveolus. The net effect is a more rapid rise of F_A/F_I. Brain:blood partition coefficient is decreased in neonates due to increased water content and decreased lipid and protein concentrations.

Table 3.3 PHARMACOLOGY OF INHALED ANESTHETICS

SOLUBILITY	HALOTHANE	ENFLURANE	ISOFLURANE	SEVOFLURANE	DESFLURANE
$\lambda_{b/g}$ adults	2.4	1.9	1.4	0.66	0.42
$\lambda_{b/g}$ neonates	2.14	1.78	1.19	0.66	—
$\lambda_{brain/b}$ adults	1.9	1.3	1.6	1.7	1.2
$\lambda_{brain/b}$ neonates	1.5	0.9	1.3	—	—

3. **Cardiac output:** As cardiac output increases, pulmonary blood flow also increases, resulting in more anesthetic uptake from the alveolus, slowing the rise in F_A/F_I (D). However, a greater percentage of cardiac output supplies the vessel-rich group in the neonate compared to the adult. Increased percentage of blood flow to the vessel-rich group (rather than increased cardiac output alone) results in a more rapid equilibration between brain tissue and alveolus, resulting in a faster rise in F_A/F_I.

While more soluble agents more clearly illustrate pharmacokinetics of wash-in, the principles are still present to a lesser degree with less soluble agents.

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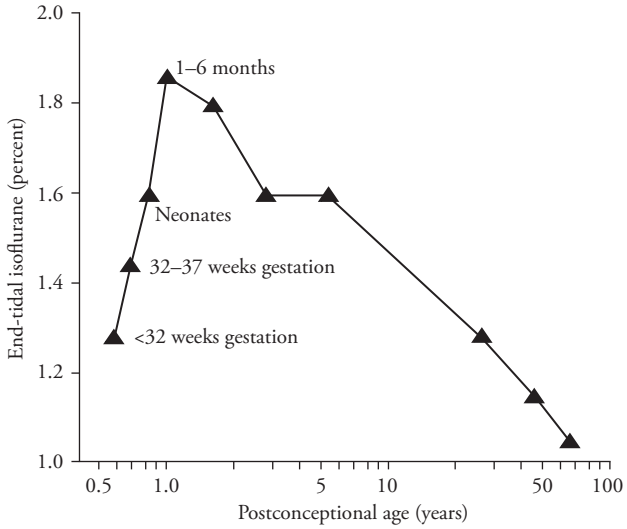

Figure 3.3 The minimum alveolar concentration (MAC) of isoflurane in preterm and full-term neonates, infants, and children. MAC increased with gestational age in infants younger than 32 weeks gestation (1.3%), reaching a zenith in infants 1 to 6 months of age of 1.87% and decreased thereafter with increasing age to adulthood. Postconceptional age is the sum of the gestational age and postnatal age in years. (Data from Cameron CB, Robinson S, Gregory GA. The minimum anesthetic concentration of isoflurane in children. *Anesth Analg*. 1984;63:418–20 and LeDez KM, Lerman J. The minimum alveolar concentration (MAC) of isoflurane in preterm neonates. *Anesthesiology*. 1987;67:301–7. Reprinted with permission.)

33. ANSWER: B

Sevoflurane is an inhaled anesthetic frequently used for mask inductions secondary to its nonpungent odor compared with other volatile anesthetics currently used in practice. Sevoflurane has a relatively low solubility (blood:gas partition coefficient = 0.66), which allows a rapid induction and emergence. **Minimum alveolar concentration (MAC) of sevoflurane is the highest in the newborn period and remains unchanged until about 6 months of age at which point MAC decreases by ~25% (A). The MAC of desflurane and isoflurane both peak between 3 and 6 months.** MAC of inhalational anesthetics is often described as additive; however, **N_2O combined with sevoflurane or desflurane is less than additive in children**. Studies showed that 60% N_2O only decreased the MAC of sevoflurane by 20% (B).

MAC represents the potency of inhalational agents. **Potency in decreasing order are (with neonatal MAC in parenthesis): isoflurane(1.6)>sevoflurane(3.3)>desflurane(9)>N_2O(~104) (C and D)**

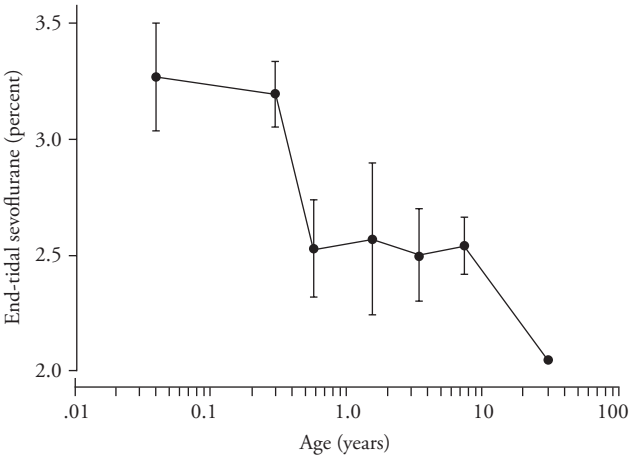

Figure 3.4 The minimum alveolar concentration (MAC) of sevoflurane in neonates, infants, and children. MAC is greatest in full-term neonates (3.3%), less in infants 1–6 months of age (3.2%), and then decreases 25%, to 2.5%, for all infants and children 6 months to 10 years of age. Age is postnatal age in years. MAC of sevoflurane in adults, 30 years of age, shown for completeness. All MAC measurements were performed with sevoflurane in 100% oxygen using a single skin incision. (Data from Lerman J, Sikich N, Kleinman S, Yentis S. The pharmacology of sevoflurane in infants and children. *Anesthesiology*. 1994;80:814–24. Reprinted with permission.)

KEY FACTS

- The MAC of desflurane and isoflurane peak between 3–6 months of age.
- N_2O combined with sevoflurane or desflurane is less than additive in children.
- The potency of inhalational anesthetics in decreasing order is as follows: isoflurane (1.6) > sevoflurane (3.3) > desflurane (9) > N_2O (~104).

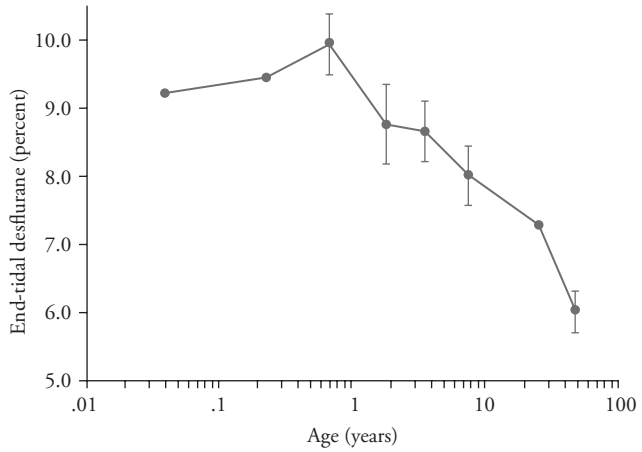

Figure 3.5 The minimum alveolar concentration (MAC) of desflurane in neonates, infants, and children. MAC in full-term neonates of 9.2% increased slowly during infancy, reaching a zenith in infants 6 to 12 months of age of 9.9% and decreased thereafter with increasing age to adulthood. All MAC measurements were performed with desflurane in oxygen using a single skin incision. (Data from Taylor RH, Lerman J. Minimum alveolar concentration of desflurane and hemodynamic responses in neonates, infants, and children. *Anesthesiology*. 1991;75:975–9. Reprinted with permission.)

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34. ANSWER: C

Desflurane is a volatile inhalational anesthetic with the lowest solubility of any of the volatile agents, resulting in rapid wash-in and wash-out. The rapid onset is a good characteristic for inhalation induction and would lead to a decreased amount of time in stage II, not a prolonged duration of stage II (A). Despite the rapid wash-in time, **desflurane is a poor choice for inhalational induction due to the increased airway reactivity in response to the pungent odor. Bronchospasm, laryngospasm, and breath holding are all significantly increased when desflurane induction is attempted (C).** Hemodynamic effects of desflurane are similar to isoflurane and sevoflurane with a 20%–30% decrease in mean arterial pressure. Tachycardia and increased blood pressure have been described with rapid increase in desflurane concentration, but this is not what precludes the use of desflurane as an induction agent (B). While all of the volatile anesthetics are known to cause emergence delirium, sevoflurane has a higher incidence of emergence delirium compared to desflurane (D).

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35. ANSWER: D

Remifentanil is a synthetic opioid with rapid onset and brief elimination half-life of about 3–6 minutes. Remifentanil is metabolized by plasma and tissue esterases, which are present and mature at birth (D). **Remifentanil is** the only opioid that has **increased rather than reduced clearance in the neonatal period.** Tolerance and hyperalgesia have both been described with remifentanil infusions. Chest wall rigidity and vocal cord closure have been described with bolus doses of remifentanil. All other opioids rely on hepatic and/or renal clearance for elimination of the drug (A, B, and C). Hepatic enzymatic activity (CYP3A4) and hepatic blood flow are both reduced in the neonatal period, leading to reduced hepatic extraction, metabolism, and clearance of drug. Reduced glomerular filtration rate leads to a reduced renal clearance of drugs and metabolites.

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36. ANSWER: B

Cerebral palsy (CP) is a neuromuscular disorder of movement relating to abnormal development or injury to the developing brain. CP is not a primary disorder of the neuromuscular junction; however, changes at the neuromuscular junction occur, including the upregulation of immature acetylcholine (ACh) receptors. Nondepolarizing muscle relaxants are competitive agonists at ACh receptors. **Conditions with upregulation of ACh receptors result in resistance to nondepolarizing muscle relaxants because more receptors must be blocked (B).**

Sensitivity to nondepolarizing muscle relaxants occurs in conditions with downregulation of ACh receptors such as myasthenia gravis (C). Succinylcholine works by binding ACh receptors and causing muscle action potential, resulting in fasciculations. The muscle is not able to repolarize because succinylcholine cannot be metabolized by acetylcholinesterases. Return of muscle function occurs as succinylcholine diffuses away from the receptor. Fasciculations result from muscle depolarization with potassium release. Succinylcholine normally causes an increase in potassium by 0.5 mEq/L. **Hyperkalemia can result when succinylcholine is used in conditions with increased extrajunctional immature ACh receptors, including burns, spinal cord injury, stroke, and prolonged immobilization.** Hyperkalemia also occurs after succinylcholine use in Duchenne's muscular dystrophy due to potassium leak from muscle breakdown. CP does have an increased number of immature ACh receptors; however, the receptors are located close to neuromuscular junction rather than widespread and cause weak-to-no effect to augment the response to succinylcholine (A and D). One theory to explain the lack of substantive hyperkalemic response to succinylcholine in patients with CP is that the muscles are never fully developed or functionally innervated.

KEY FACTS

- Conditions with upregulation of ACh receptors result in resistance to nondepolarizing muscle relaxants.
- The use of succinylcholine can lead to hyperkalemia in conditions with increased extrajunctional immature ACh receptors, including burns, spinal cord injury, stroke, and prolonged immobilization.

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37. ANSWER: C

Pain upon injection of propofol is common and likely the result of **nociceptive effect of propofol in the outer aqueous layer not covered by lipid micelles**. Pain is more common when injected into small peripheral veins. Multiple strategies have been in an attempt to prevent pain on injection and **IV lidocaine with tourniquet on 30–60 seconds prior to propofol injection proved to be the most effective (C).** Propofol lidocaine mix and fentanyl prior to propofol injection are about equally effective at preventing pain (A and B). Cold packs on the arm proved least effective.

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38. ANSWER: B

Local anesthetic (LA) toxicity is a potentially life-threatening complication of regional anesthesia. CNS and cardiac toxicity both occur with CNS symptoms normally preceding cardiac symptoms. However, bupivacaine has a lower threshold for cardiac toxicity than other LA, resulting in the potential for cardiac symptoms to occur at the same time or precede CNS toxicity. Ropivacaine, a long-acting LA, has less cardiac toxicity because it is only L-enantiomers, which have lower affinity for cardiac sodium channels. **The maximum dose of ropivacaine is 3 mg/kg** or 60 mg in this patient. A dose of 9 cc of 0.5% ropivacaine contains 45 mg of ropivacaine and does not exceed the maximum dose (A). Maximum dose of lidocaine is dependent on the presence of epinephrine in the solution. Epinephrine causes local vasoconstriction and decreases systemic uptake. **The maximum dose of lidocaine is 5 mg/kg without epinephrine and 7 mg/kg with epinephrine**. A dose

Table 3.4 MAXIMUM RECOMMENDED DOSES AND DURATION OF ACTION OF COMMONLY USED LOCAL ANESTHETICS

LOCAL ANESTHETIC	MAXIMUM DOSE (MG/KG)*	DURATION OF ACTION (MINUTES)†
Procaine	**10**	**60–90**
2-Chloroprocaine	**20**	**30–60**
Tetracaine	**1.5**	**180–600**
Lidocaine	**7**	**90–200**
Mepivacaine	**7**	**120–240**
Bupivacaine	**2.5**	**180–600**
Ropivacaine	**3**	**120–240**

* Maximum doses of local anesthetics. Doses of amides should be decreased by 30% in infants younger than 6 months of age. When lidocaine is being administered intravascularly (e.g., during intravenous regional anesthesia), the dose should be decreased to 3 to 5 mg/kg; there is no need to administer long-acting local anesthetic agents for intravenous regional anesthesia, and such a practice is potentially dangerous.

† Duration of action is dependent on concentration, total dose, site of administration, and the child's age.

of 9 cc 2% lidocaine contains 180 mg of lidocaine, which exceeds the maximum dose of lidocaine with epinephrine in this patient (140 mg maximum dose) (B). **Bupivacaine has a maximum dose of 2.5 mg/kg with and without epinephrine**. A dose of 15 cc 0.25% bupivacaine contains 37.5 mg, which is below the maximum dose of 50 mg in this patient (C and D). While maximum doses are recommendations, **other factors affecting toxicity should be taken into consideration, including location of block, age and hepatic function (in reference to plasma protein binding and metabolism, which are impaired in neonates), and duration of infusion/speed of injection**.

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39. ANSWER: B

Risk factors for PONV in the pediatric population include (1) age greater than 3 years, (2) duration of procedure greater than 30 minutes, (3) strabismus surgery, and (4) history of PONV in the patient or first-degree relative. PONV has multiple treatment strategies. Ondansetron is a selective serotonin receptor antagonist blocking the serotonin receptor subtype 5-HT_3 located centrally in the chemoreceptor trigger zone and peripherally in the abdominal vagal afferents (B). Common side effects of ondansetron are QT prolongation and headache. Multiple H_1 receptor antagonists have antiemetic effects and include diphenhydramine (Benadryl), proclorperazine (Compazine), and promethazine (Phenergan). Sedation is a common side effect of H_1 blockers, which limits use in the postoperative period. Metoclopramide and droperidol both have antiemetic activity secondary to dopamine receptor antagonism (A). **Metoclopramide is an antagonist of the Dopamine D2 receptor and is also an agonist on serotonin 5-HT4 receptors and causes weak inhibition of 5-HT3 receptors (C)**. It produces prokinetic effects of the GI tract secondary to enhancement of acetylcholine activity at GI tract smooth muscle muscarinic receptors. Extrapyramidal symptoms are a potential side effect of metoclopramide. Metoclopramide is much less effective than ondansetron at preventing PONV. Droperidol prolongs QT interval and has resulted in torsades de pointes when used in high doses; however, risk of torsades at lower antiemetic doses has been questioned. **Neurokinin-1 receptor antagonists (aprepitant)** block substance P both centrally and in the GI tract (D). While postoperative reduction in nausea is similar to ondansetron, reduction in postoperative vomiting is significantly reduced. Routine use of aprepitant is limited by cost.

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40. ANSWER: C

Perioperative anaphylaxis most commonly occurs at induction with the most likely offending agent being muscle relaxants followed by latex and antibiotics. Atopy, asthma, eczema, and previous allergic/anaphylactic reaction are risk factors. Anaphylaxis results from IgE-mediated hypersensitivity reaction causing degranulation of mast cells that releases histamine along with other vasoactive proinflammatory substances. Vasodilation, bronchoconstriction, and increased vascular permeability result in the symptoms of anaphylaxis. **The most important first step in treatment is hemodynamic support and bronchodilation, as well as mast cell stabilization, all of which are accomplished with epinephrine (C).** Depending on the severity of hemodynamic collapse, epinephrine can be given intramuscularly or intravenously. The β_2 and α_1 agonist effects of epinephrine will treat the bronchoconstriction and vasoconstriction, respectively. Albuterol has β_2 agonist effects, but it would not be the next step in treatment for the reasons listed earlier (D). The anti-inflammatory effects of hydrocortisone are often delayed 4–6 hours and while indicated in the treatment of anaphylaxis would not be the next best step (A). Diphenhydramine, an H_1 blocker, is also used in the treatment of anaphylaxis with varying degrees of success but does not treat the most life-threatening symptoms of anaphylaxis and therefore would not be the next best step (B). Volume resuscitation is also an important step in treating vasodilation following mast cell degranulation.

KEY FACTS

- The most common etiology of intraoperative anaphylaxis is the administration of muscle relaxants followed by latex exposure and antibiotic administration.
- The first step in treatment is to administer epinephrine to accomplish hemodynamic support and bronchodilation, as well as mast cell stabilization.

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Randall F. Clinical Complications in Pediatric Anesthesia. in Gregory. *Gregory's Pediatric Anesthesia*. 5th ed. 1177–80.

41. ANSWER: C

During performance of an awake fiberoptic intubation, it is important to anesthetize the patient's oropharynx well in order to keep the patient comfortable. However, anesthesiologists must be cognizant of maximum allowed local anesthetic dose for the patient's weight. The maximum dose of lidocaine is 5 mg/kg without epinephrine and 7 mg/kg with epinephrine.

This patient is suffering from **acute methemoglobinemia from nebulized lidocaine**. The calculated dose of lidocaine that the patient has received is (40 mg/mL × 3 = 120 mg), which is over the patient's upper limited of recommended dose.

Sodium thiosulfate is used as an antidote for **cyanide poisoning**. It enhances the conversion of cyanide to thiocyanate, which is renally excreted. Thiosulfate has a somewhat delayed effect and thus is typically used with sodium nitrite for faster antidote action (A). Administering epinephrine would not be the first step that needs to be taken since the patient is hemodynamically stable (B). The patient is symptomatic with respiratory distress. It would not be advisable to waste time drawing an ABG prior to starting treatment (D).

Since the issue is most likely due to a toxic dose of lidocaine for the patient, methylene blue would be the first-line treatment (C). The initial dose can be 1–2 mg/kg over 5 minutes and the total dose should not exceed 7–8 mg/kg. **Methylene blue works by accelerating the enzymatic reduction of methemoglobin by NADPH-methemoglobin reductase**. The response is usually rapid and the dose may be repeated in 1 hour. However, it is important to remember that if any patient has G6PD deficiency, methylene blue should not be used since it can cause hemolysis. Other treatments include ascorbic acid (2 mg/kg), hyperbaric oxygen chamber, and exchange transfusions.

KEY FACTS

- Methylene blue is used to treat methemoglobinemia by accelerating the enzymatic reduction of methemoglobin by NADPH-methemoglobin reductase.
- Sodium thiosulfate is used as an antidote for cyanide poisoning. It enhances the conversion of cyanide to thiocyanate, which is renally excreted.

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42. ANSWER: D

Administering mannitol may help reduce intracranial pressure (ICP) and thus decrease the size of the brain. Mannitol decreases ICP by decreasing blood viscosity. However, it also transiently increases the cerebral blood flow and oxygen transport. It also reduces ICP by withdrawing water from the brain parenchyma. Starting doses (0.25–0.5 mg/kg intravenously) raise serum osmolality by approximately 10 mOsm. It takes about 20 to 30 minutes for this osmotic effect of the drug to develop. **If given too rapidly, mannitol can cause transient hypotension** (D).

It is also imperative to know that repeated doses **may increase serum osmolality to >320 mOsm** (B).

Since mannitol has properties of reducing ICP, it would be unlikely that administration of this medication will cause brain herniation (A).

Due to increase in free water loss after mannitol administration, hypernatremia rather than hyponatremia is a known complication (C).

Another possible treatment is hypertonic (3%) saline. It has been used more recently in the treatment of elevated ICP in patients with traumatic and nontraumatic cerebral edema because **sodium does not cross the blood–brain barrier quickly and its osmolar gradient is similar to mannitol**.

KEY FACTS

- Mannitol can cause transient hypotension if given rapidly.
- Mannitol may increase serum osmolality.

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Pollay M, Fullenwider C, Roberts PA, et al. Effect of mannitol and furosemide on blood-brain osmotic gradient and intracranial pressure. *J Neurosurg*. 1983;59:945.

43. ANSWER: C

In order to decrease ICP, **3% saline** and **mannitol** have been used successfully (A). Fisher et al. reported on 18 pediatric patients with traumatic brain injury who were enrolled in a double-blind, crossover study to compare the effects of 3% saline and 0.9% saline infusions on elevated ICP. The authors found that mean ICP was lowered by 4 mm Hg for 2 hours after the transfusion in the group that received 3% saline without changes in central venous pressure or renal

function. For the group who received 0.9% saline, ICP remained unchanged.

Barbiturates have some advantages in neurosurgical patients, since this class of drugs does lower both cerebral blood flow (CBF) and the cerebral metabolic rate for oxygen ($CMRO_2$) (B). A bolus of thiopental reduces ICP for 5–10 minutes. Pentobarbital can also effectively reduce ICP. Rectal administration of metholhexital will induce a light sleep in most children and can help decrease ICP by preventing agitation.

Intravenous or intramuscular midazolam is another possibility for a particularly anxious, uncooperative child who refuses oral premedication (D). Most intravenous sedatives decrease CBF and ICP.

Ketamine is a potent cerebral vasodilator; thus, it increases CBF, which can cause sudden increases in ICP (C). Therefore, ketamine should be avoided in patients with increased ICP.

KEY FACTS

- Hypertonic saline and mannitol have been used successfully to decrease ICP.
- Ketamine is a potent cerebral vasodilator; thus, it increases CBF, which can cause sudden increases in ICP.
- Barbiturates lower both CBF and the cerebral metabolic rate for oxygen ($CMRO_2$).

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44. ANSWER: C

Vesicoureteral reflux (VUR) is one of the most common abnormalities of the urinary tract in children and is present in about 25%–50% of those who have UTIs. In a patient undergoing vesicoureteral reimplantation, one must understand where the incision will be and where pain may refer to.

The classic surgical approach for vesicoureteral reflux is an open procedure in which the affected ureters are reimplanted into the bladder wall, re-creating a normal muscle flap valve.

This involves a lower abdominal incision and 3 to 4 hours of surgery.

A dose of 10 μg/kg hydromorphone is a large dose (A). When given as a bolus rather than a continuous infusion, it may cause apnea. In addition, the patient's pain will not be managed as well as regional anesthetic.

The dosage prescription scheme of Armitage for caudal blocks that was published many years ago still remains the most dependable.

With 0.5 mL/kg, all sacral dermatomes are blocked (B).

With 1.0 mL/kg, all sacral and lumbar dermatomes are blocked (C).

With 1.25 mL/kg, the upper limit of anesthesia is at least midthoracic (D).

However, when 1.25 mL/kg is injected, there is a danger of excessive rostral spread (above T4); it is therefore preferable not to administer more than 1.0 mL/kg of local anesthetic.

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Dalens B, Hasnaoui A. Caudal anesthesia in pediatric surgery: success rate and adverse effects in 750 consecutive patients. *Anesth Analg*. 1989;68:83–9.

45. ANSWER: D

Prophylaxis for postoperative nausea and vomiting (PONV) is recommended for patients undergoing inner ear surgery, strabismus surgery, because **incidence of PONV in untreated patients is 40%–90%.** When postoperative nausea and vomiting (PONV) occurs, treatment should be administered with an antiemetic from a pharmacologic class that is different from the prophylactic drug initially given.

If no prophylaxis was given, the recommended treatment is a low-dose 5-HT3 antagonist. It is also recommended that **if PONV occurs within 6-hour postoperatively, patients should not receive a repeat dose of the prophylactic antiemetic (A and B)**.

Repeating the medication given for PONV prophylaxis within the first 6 hours after the patient has left the PACU has not been shown effective. If more than 6 hours has elapsed, it may be possible to achieve some effect with a second dose of a 5-HT antagonist or butyrophenone (droperidol or haloperidol); however, this has not been demonstrated in clinical trials and should only be attempted if triple therapy (scopolamine, ondansetron, and dexamethasone) has been used for prophylaxis.

A second administration of dexamethasone (A) or transdermal scopolamine is not recommended for use as rescue agents. Metoclopramide is a gastroprokinetic agent and is used to treat PONV and gastroesophageal reflux disease. It has a black box warning regarding the adverse drug reaction of tardive dyskinesia (C). Promethazine (or Phenergan) is an H_1 blocker and has antiemetic properties

(D). However, it may be inappropriate in children under the age of 2 because of risk of airway compromise.

No benefit was demonstrated with the use of anticholinergic medications or with gastric content evacuation before emergence from anesthesia.

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46. ANSWER: D

Local anesthetics can be absorbed to cause toxic effects in human. These effects range from tinnitus and metallic taste to seizure and cardiovascular collapse. **There are two major proteins in the body that help to bind the local anesthetics: serum albumin and alpha-1-acid glycoprotein**. Serum albumin has a low affinity for local anesthetics, and many other medications can competitively bind to the sites. Moreover, during the first month of life, plasma levels of serum albumin are low. This is especially true for premature and fasted infants. Therefore, the protection offered by serum albumin against systemic toxicity of local anesthetics is low (A).

Elastin is a protein in connective tissue that is elastic and allows many tissues in the body to resume their shape after stretching and contraction. It does have a role in binding local anesthetics (B).

C-reactive protein is mainly used as a marker of inflammation and it does not have a role in binding local anesthetics (C).

α1-acid glycoproteins have high affinity for local anesthetics (5,000–10,000 times greater than that of albumin). Having such high affinity makes alpha-1-acid glycoproteins effective at protecting patients from systemic toxicity (D). Of note, plasma concentration of alpha-1-acid glycoproteins is very low at birth (0.2–0.3 g/L) and does not reach adult level before age 1. Given the fact that both of these proteins' plasma concentration is low at birth, it is imperative to decrease the maximum dose of local anesthetic administered.

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47. ANSWER: D

Narrow-angle glaucoma is caused by contact between the iris and trabecular meshwork, which in turn obstructs outflow of the aqueous humor from the eye. This contact between iris and trabecular meshwork may gradually damage the function of the meshwork until it fails to keep pace with aqueous production, and the pressure rises.

Because some children with trisomy 21 have narrow-angle glaucoma, atropine must be administered cautiously because it might worsen the glaucoma (B). **All anticholinergic agents (atropine, glycopyrrolate, scopolamine) cause mydriasis**, where pupil dilation causes increased obstruction of aqueous humor drainage from the eye. Atropine is metabolized in the liver by N-demethylation followed by conjugation with glucuronic acid. The kidneys eliminate half of the drug. The elimination half-life in healthy adults is about 3 hours, whereas that in term neonates it is 12 hours.

Glycopyrrolate (5 to 10 μg/kg) is a synthetic quaternary ammonium compound with potent anticholinergic properties. It offers advantage over atropine and scopolamine because of its quaternary structure, which limits crossing the blood–brain barrier. It is contraindicated in patients with glaucoma (A).

Scopolamine is a tertiary amine with greater CNS effects than atropine, causing sedation and amnesia. It has moderate antiemetic activity. To minimize the relatively high incidence of side effects, the transdermal dosage form has been developed for nausea and vomiting; however, its use is generally limited to teenagers so as to avoid potential toxicity.

In clinical practice, scopolamine is usually limited to those situations that require sedation. Scopolamine is also contraindicated in patients with glaucoma (C).

The central sedative effects of both atropine and scopolamine may be antagonized with physostigmine.

Pilocarpine is a parasympathomimetic agent that produces miosis and a fall in intraocular pressure (IOP) that is thought to result from an increase in aqueous humor outflow (D); thus, pilocarpine can be used safely in patients with glaucoma. Of note, at recommended dosages, side effects are rare but may include GI disturbances and diaphoresis.

KEY FACTS

- Anticholinergic agents cause mydriasis, which leads to obstruction of aqueous humor drainage from the eye and are therefore contraindicated in patients with glaucoma.
- Pilocarpine is a parasympathomimetic agent that causes miosis and a decrease in IOP that is thought to result from an increase in aqueous humor outflow.

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48. ANSWER: D

Intralipid (Baxter Healthcare) is a sterile, nonpyrogenic fat emulsion prepared for intravenous administration as a source of calories and essential fatty acids. Its main ingredients include soybean oil, glycerine, water, and egg yolk phospholipids. Possible side effects of Intralipid include fat emboli, allergic reactions, thrombophlebitis, hypertriglyceremia, and pulmonary hypertension.

The exact mechanism of lipid emulsion reversing local anesthetic toxicity is currently unclear. It is proposed that lipid emulsion creates a "lipid sink" where bupivacaine partitions preferentially into lipid globules.

The current recommendation from both the Association of Anaesthetists of Great Britain and Ireland and the American Society of Regional Anesthesia and Pain Medicine is a **bolus dose of 1.5 ml/kg over 1 minute of 20% Intralipid** (D) **and start an infusion of 15 mL/kg per hour**. After 5 minutes, if hemodynamic stability is not restored, two repeat boluses may be given every 5 minutes and the infusion rate may be increased to 30 mL/kg per hour. The maximum cumulative dose should not exceed 10 ml/kg over the first 30 minutes.

KEY FACTS

- Intralipid 20% is a sterile, nonpyrogenic fat emulsion for the treatment of local anesthetic toxicity.
- It is given as a bolus dose of 1.5 ml/kg over 1 minute followed by an infusion of 15 mL/kg per hour.

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49. ANSWER: A

Succinylcholine consists of two acetylcholine molecules linked together. Succinylcholine stimulates both **muscarinic and nicotinic cholinergic receptors**. Stimulation of muscarinic receptors within the sinus node results in numerous bradyarrhythmias, including sinus bradycardia, junctional rhythms, ventricular escape, and asystole (A).

Cardiac arrhythmias frequently follow intravenous administration. This was especially more frequent when halothane was used. Barbiturates have been shown to decrease the central vagal activity; thus, induction of thiopental can decrease the muscarinic effects of succinylcholine.

Prior intravenous administration of atropine reduces the incidence of arrhythmias. However, the same reduction was not seen with intramuscular administration of atropine as a premedication. **Cardiac sinus arrest may follow the first dose of succinylcholine but is more common after repeated bolus administration; such arrest may occur in children of any age**.

Although the incidence of bradycardia is low in older children, there are case reports of teenagers having severe bradycardia or cardiac arrests after succinylcholine administration without atropine. Therefore, atropine should probably be given intravenously just before the first dose of succinylcholine in all children, including teenagers, unless there is a contraindication to tachycardia.

KEY FACTS

- Succinylcholine stimulates muscarinic and nicotinic cholinergic receptors.
- Cardiac sinus arrest may follow the first dose of succinylcholine but is more common after repeated bolus administration.

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50. ANSWER: C

A comparison of infants with older children regarding their response to nondepolarizing muscle relaxants shows that **infants are generally more sensitive** to these drugs and that their **response varies** to a greater degree. Taivainen and colleagues showed that rocuronium's potency is greater in infants than in children, but **its onset is faster in children (C)**.

Although the initial dose per kilogram needed for neuromuscular blockade is often similar for children of all ages, **the greater volume of distribution and reduced renal or hepatic function of infants result in a slower rate of excretion and hence a prolongation of effect** (C). Neuromuscular blockade occurs at a lower blood concentration.

KEY FACTS

- Infants are more sensitive to rocuronium, but onset is fastest in older children.
- Infants have a greater volume of distribution and reduced renal or hepatic function, which results in a slower rate of excretion and hence a prolongation of effect of rocuronium.

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Taivainen T, Meretoja OA, Erkola O, et al. Rocuronium in infants, children and adults during balanced anaesthesia. *Paediatr Anaesth*. 1996;6:271–5.

51. ANSWER: D

Propofol (2,6-diisoprophylphenol) are lipid suspensions that contain lecithin/phophatide and soy oil. Interestingly, there is no consensus on contraindications for propofol. Warning labels differ among countries for the same formulation of propofol supplied by the same company. The 2009 guidelines on suspected anaphylactic reactions associated with anesthesia published by the Association of Anesthetists of Great Britain and Ireland claim **there is no evidence that propofol should be avoided in egg- or soy-allergic patients** but suggest a cautious approach is required in such patients. In the United States, there is no food allergy warning for the use of propofol. However, in Australia, labels warn of reactions in egg- or soy-allergic individuals.

Propofol contains egg lecithin lipids derived from heated egg yolk. Egg lecithin is typically used as a natural stabilizer in food preparations. Egg lecithin has been reported to contain residual egg yolk but no egg white proteins. Therefore, this patient should be able to safely receive propofol (D).

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52. ANSWER: B

The major concern with propofol is the potential for propofol infusion syndrome (PRIS). **PRIS is usually diagnosed when a patient has been on high-dose propofol infusion (greater than 70 μg/kg per minute) for a prolonged period of time (usually more than 48 hours) who also has insidious onset of lactic acidosis, hyperkalemia, rhabdomyolysis, cardiac failure, or renal failure (A).**

Patients who have PRIS may deteriorate even further, causing cardiovascular collapse that is refractory to all resuscitative efforts. Interestingly, patients may also manifest PRIS with sudden onset of bradycardia that is refractory to usual treatments.

Although no such cases have been reported in healthy children during routine anesthesia care, there has been a case report of a child with a genetic defect in lipid metabolism who had received approximately 150 μg/kg per minute for 6.5 hours during scoliosis repair. This case report suggests caution in the use of propofol in children with known defects in lipid metabolism. Moreover, this may include some forms of mitochondrial disease. However, it should be noted that propofol has been used safely in many children with mitochondrial disease. Therefore, it is **most likely that patients with lipid metabolism defect may be at risk** (B).

Other risk factors include concomitant catecholamine inotrope infusions or high-dose corticosteroids and sepsis.

Another case report included a 5-year-old undergoing an arteriovenous malformation resection when an unexplained metabolic acidosis was detected after 6-hour propofol infusion. When the infusion stopped, the signs of PRIS also resolved.

Diagnosis of PRIS is challenging. Laboratory studies have shown that blood concentrations of malonylcarnitine and C5-acylcarnitine are increased. These compounds are known to inhibit carnitine palmitoyl transferase and the transfer of LCT into mitochondria.

KEY FACTS

- PRIS has been associated with high-dose propofol infusion (greater than 70 μg/kg per minute) for a prolonged period of time (usually more than 48 hours).

- PRIS has insidious onset of lactic acidosis, hyperkalemia, rhabdomyolysis, cardiac failure, or renal failure.
- Patients with lipid metabolism defects are more likely at risk.

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53. ANSWER: A

The effects of **chronic anticonvulsant therapy (CAT)** have made administering neuromuscular blockade more challenging. Richard and colleagues demonstrated that patients who have been on CAT resulted in faster 25% and 75% recovery of the first twitch. Moreover, Wright and colleagues have shown that the duration of action of vecuronium on patients who have been on chronic phenytoin administration is reduced. The clearance of vecuronium was typically increased by 138%. They concluded that **patients on CAT reduce the effects of neuromuscular blockade** by mechanisms that include both increased metabolism and reduced sensitivity of the patient to circulating concentration of vecuronium.

Our patient is on multiple medications that induce CYP P450. Although omeprazole is one of the inducers, it is less likely than carbamazepine to cause increased metabolism of rocuronium (A and C). This is most likely the reason why the patient had moved only 20 minutes after a large dose of muscle relaxation.

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54. ANSWER: D

Most of the opioids have highly variable pharmacokinetic properties in the neonatal period. Due to immature hepatic and renal systems in neonates, there is a large phamacokinetic variability. Note that unlike with virtually all other medications, **remifentanil's half-life is shorter in neonates than in older children** (D); this is most likely due to elimination of remifentanil by nonspecific plasma and tissue esterases (C). Moreover, neonates have a larger volume of distribution compared to older children, which probably factors into shorter half-life (A).

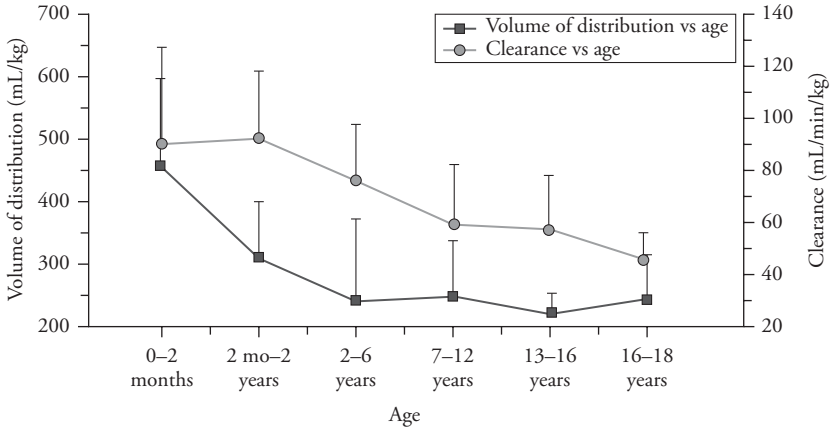

Figure 3.6 Remifentanil's volume of distribution and clearance. (Reprinted with permission from: Miller RD, Eriksson LI, Fleisher L, Wiener-Kronish J, Young WL. *Miller's Anesthesia*. 7th ed. Philadelphia, PA: Churchill Livingstone; 2009. Ross AK, Davis PJ, Dear Gd GL, et al. Pharmacokinetics of remifentanil in anesthetized pediatric patients undergoing elective surgery or diagnostic procedures. *Anesth Analg*. 2001;93:1393–401.)

The importance of this observation is that developmental immaturity of liver and renal function does not affect the pharmacokinetics of remifentanil.

Remifentanil does not have the fastest onset of action. Alfentanil has a faster onset than remifentanil (B).

As seen in Figure 3.6, during the first few months of life, the volume of distribution changes drastically due to both anatomic growth and physiologic maturation of the body.

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Ross AK, Davis PJ, Dear Gd GL, et al. Pharmacokinetics of remifentanil in anesthetized pediatric patients undergoing elective surgery or diagnostic procedures. *Anesth Analg*. 2001;93:1393–401.

55. ANSWER: C

Oral forms of opioids such as codeine, hydrocodone, and oxycodone have an oral bioavailability of approximately 60%. They have an onset time of 20 minutes and have half-lives ranging from 2.5 to 4 hours.

Hydrocodone and oxycodone have intrinsic analgesic property after being ingested. However, **codeine is a prodrug**; it must be metabolized into the active form of morphine (C) by the liver's **cytochrome P450 (CYP) 2D6 isoenzyme**. In patients with normal CYP 2D6, approximately 10% of codeine is metabolized into morphine. Unfortunately, approximately 7% of the American population has a complete or partial enzymatic deficiency of 2D6, making it impossible for them to metabolize codeine into morphine. This is the most likely scenario for our opiate-naïve patient who is not getting adequate analgesia from codeine.

On the other hand, approximately 3% to 5% of the US population are **rapid metabolizers,** which may cause morphine toxicity due to acute increased plasma level of morphine. Currently, there is no way to predict who is a poor or rapid metabolizer.

Morphine is also effective when given orally, but only about 20% to 30% of an oral dose reaches the systemic circulation. Therefore, when converting a patient's intravenous morphine dose to oral maintenance therapy, one must multiply the intravenous dose by a factor of 3 to 4 to provide comparable analgesic efficacy.

KEY FACTS

- Codeine is a prodrug and must be metabolized into the active form of morphine by the liver's cytochrome P450 (CYP) 2D6 isoenzyme.
- Approximately 3% to 5% of the US population are rapid metabolizers, which may cause morphine toxicity due to an acute increased plasma level of morphine.

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SECTION II

ORGAN-BASED BASIC AND CLINICAL SCIENCES

4.

RESPIRATORY SYSTEM

Anjali Koka, Elizabeth C. Eastburn, and Raymond Park

1. Formation of alveoli in the human lung begins at:

A. Gestational week 39
B. Gestational week 36
C. Gestational week 24
D. Gestational week 16

2. Compared to adults, infants have increased chest wall compliance due to:

A. Stiff ribs
B. Poorly developed intercostal muscles
C. High content of type I muscle fibers in the diaphragm
D. High elastic recoil of the lung

3. Compared to a normal adolescent, airway closure in a normal infant is due to:

A. Higher functional residual capacity per kilogram
B. Higher total lung capacity per kilogram
C. Higher closing capacity
D. Higher lung elasticity

4. In children, what is the effect of postextubation croup on trachea size and airflow resistance?

A. Trachea diameter decreases and resistance increases to the second power.
B. Trachea diameter decreases and resistance decreases to the second power.
C. Trachea diameter decreases and resistance increases to the fourth power.
D. Trachea diameter decreases and resistance decreases to the fourth power.

5. The presence of fetal hemoglobin causes a _____ in hemoglobin's affinity for oxygen. In normal adults a _____in hemoglobin affinity occurs with decrease in pH.

A. Increase, increase
B. Increase, decrease
C. Decrease, decrease
D. Decrease, increase

6. The P50 (mm Hg) for an infant older than 3 months is:

A. 19
B. 27
C. 30
D. 40

7. In the neonate, pulmonary surfactant increases:

A. Alveolar surface tension
B. Lung compliance
C. Work of breathing
D. Pulmonary vascular resistance

8. At birth, as the lungs expand with air, which of the following increases:

A. Pulmonary vascular resistance
B. Pulmonary blood flow
C. Right Atrial pressure
D. Surfactant production

9. Which of the following best describes LaPlace's equation:

A. The pressure within a sphere is directly proportional to surface tension and inversely related to the size of the sphere.
B. At a constant pressure, the volume of a gas will vary directly with temperature.
C. The diffusion rate of a gas across a fluid membrane is proportional to the difference in partial pressure, proportional to the area of the membrane, and inversely proportional to the thickness of the membrane.
D. The amount of gas dissolved in a solution is proportional to the partial pressure of the gas.

10. Why do infants develop hypoxemia on induction more readily than adults?

A. Higher P50
B. Higher oxygen consumption
C. Higher dead space to tidal volume ratio
D. Lower dead space to tidal volume ratio

11. In a spontaneously breathing normal infant, lung ventilation is:

A. Greatest in the base
B. Greatest in the dependent regions
C. Greatest in the nondependent regions
D. Same throughout the lung

12. A 2.4 kg neonate is placed in the lateral decubitus position for resection of a congenital cystic adenomatoid malformation. When single-lung ventilation is instituted, the infant desaturates with oxygen saturations in the low 80s. The reason for this desaturation can be explained by:

A. Infants have a higher oxygen requirement.
B. Infants have increased perfusion differences between dependent and nondependent lungs.
C. Due to greater chest wall compliance, infants generally have higher functional residual capacity in the dependent lung.
D. Infants have a greater functional advantage of the dependent diaphragm.

13. A 4-year-old, 16 kg patient is scheduled for video-assisted thoracoscopic surgery for a biopsy of lung tissue. The surgeon is requesting single-lung ventilation of the right lung. Which of the following would be the most appropriate option for single-lung ventilation in this patient?

A. Single-lumen endotracheal tube (ETT)
B. Bronchial blocker (BB)
C. Double-lumen tube (DLT)
D. Univent endotracheal tube

14. A 14-year-old female presents to the operating room for biopsy of supraclavicular lymph nodes associated with an anterior mediastinal mass. Prior to induction of anesthesia, which of the following is the most appropriate next step?

A. Review chest X-ray and lab work
B. Rigid bronchoscope available in room
C. 48 hours of glucocorticoids prior to the procedure
D. Placing the patient in the supine position

15. For patients with pectus excavatum or pectus carinatum deformities:

A. The Nuss procedure is equally successful in patients of all ages.
B. They do not generally have cardiorespiratory symptoms
C. They do not generally have other comorbidities
D. Have worsening of defects during adolescence

16. Which of the following is the most appropriate treatment for a 3 year-old, 12 kg boy with a history of snoring and an apnea hypopnea index (AHI) of 18 during nocturnal polysomnography?

A. Initiation of continuous positive airway pressure (CPAP)
B. Encourage weight loss
C. Tonsillectomy and adenoidectomy
D. No treatment needed

17. Which of the following changes in pulmonary function would be the first to manifest in an otherwise healthy patient with increasing spinal curvature due to idiopathic scoliosis?

A. Respiratory acidosis measured by arterial blood gas
B. Decreased vital capacity
C. Decreased FEV1
D. Decreased FRC

18. An 8-month-old male in respiratory distress is brought into the emergency room by his parents. On physical exam the patient is tachypneic with sternal retractions and he has perioral cyanosis. His parents report that he has had a cough for the past few days with a low-grade temperature.
The best initial treatment is:

A. Bronchoscopy
B. Intubation in the operating room
C. Antibiotics
D. Racemic epinephrine

19. A previously healthy 18-year-old 50 kg female patient was admitted to the intensive care unit with acute gallstone pancreatitis. She is febrile and hypotensive, requiring fluid boluses and inotropic support. One day later she has required increasing support to maintain oxygen saturations greater than 91%. She is currently breathing at a rate of 45 times a minute on a 100% nonrebreathing face mask. An arterial blood gas is obtained which shows the following: pH 7.21, PCO_2 36, and PaO_2 64. Which of the following is the next appropriate step in management?

A. Administration of a diuretic, as respiratory symptoms are due to volume overload
B. Echocardiogram to rule out ventricular dysfunction as cause of hypotension and dyspnea
C. Intubation with pressure support ventilation with titration to maintain oxygen saturation >98%
D. Intubation with volume control ventilation target tidal volumes 300–400 mL

20. A 4-week-old infant presents to the emergency room with an increased work of breathing that has been present since birth. On physical exam inspiratory stridor is noted. Which of the following is the most likely diagnosis of inspiratory stridor in this patient?

A. Subglottic stenosis
B. Laryngeal papilloma
C. Laryngomalacia
D. Vocal cord paresis

21. A flow-volume loop in a child with a bronchogenic cyst would most likely show:

A. Normal inspiratory and normal expiratory phase
B. Normal inspiratory phase and abnormal expiratory phase that improves after administration of bronchodilators
C. Abnormal inspiratory phase and normal expiratory phase
D. Normal inspiratory phase and abnormal expiratory phase not improved with bronchodilator administration

22. A 17-year-old patient with cystic fibrosis presents for a functional endoscopic sinus surgery for recurrent nasal polyps and chronic sinus disease. Which of the following is likely to be included in this patient's medical history?

A. Dilated aortic root
B. Imperforate anus
C. Developmental delay
D. Infertility

23. You are called to the emergency room for assistance with airway management in a 2 year-old child who presented in respiratory distress. On exam he has increased work of breathing, significant anxiety, and he is drooling. On exam lung sounds are clear, and a chest X-ray is normal. He has been otherwise well and is afebrile. His parents report that he was in his usual state of health and playing by himself in his room 30 minutes prior to presentation. The most likely cause of respiratory distress in this patient is:

A. Actue asthma exacerbation
B. Epiglottitis
C. Aspirated foreign body
D. Foreign body in the esophagus

24. A 7 year-old, 25 kg patient with a history of asthma develops severe bronchospasm soon after induction of anesthesia for a tonsillectomy. Which of the following is the best ventilation choice for this patient?

A. Tidal volume 150 cc, respiratory rate 30, I:E ratio 2:1
B. Tidal volume 150 cc, respiratory rate 20, I:E ratio 1:3
C. Titrate tidal volumes and respiratory rate to achieve normal $EtCO_2$ and SpO_2 of >98%
D. Tidal volume 250 cc, respiratory rate 20, I:E 1:1

CHAPTER 4 ANSWERS

1. ANSWER: B

Lung development begins in the first few weeks of gestation and continues through the **first decade of life**. The lung is an outgrowth of the **foregut ventral wall**. In the embryonic period, lung buds begin to form. The alveolar membranes and mucous glands of the lung are formed from endodermal tissue. The cartilage, muscles, and elastic tissue of the lung are formed from mesenchymal tissue. The next stage of lung development, the **pseudoglandular stage**, is characterized by **formation of bronchi** and **branching of the airway to terminal bronchiole**. In the **cannicular stage, acinus** formation begins. Thus, airway structures distal to the terminal bronchioles necessary for gas exchange develop from this point on. In the **saccular stage** there is **continued intra-acinar** development and formation of **alveolar ducts and sacs**. **Alveoli** development from the terminal air spaces begins at **36 weeks gestation** and continues after birth. The **majority** of **alveolar development occurs after birth in the first 12 months**. Both the number and size of the alveoli increase.

Pulmonary vessels (arteries and veins) that accompany the **bronchial tree form by 16 weeks gestation**. **Vascularization** of the terminal air spaces occurs at **26 to 28 weeks gestation**. Although the air space wall is still thick, this formation of a capillary network is sufficient for pulmonary gas exchange.

KEY FACTS

- A surface for gas exchange begins to develop by 24 weeks gestation and continues to develop well into childhood.
- Alveoli development begins at 36 weeks gestation with the majority of development in the first year of life.
- Embryonic stage: Usually complete by 7 weeks gestation, lung bud formation.
- Pseudoglandular stage: 7 to 17 weeks gestation, airway branching complete.
- Cannicular stage: 17 to 24 weeks gestation, acinus development; by the end of this stage surfactant production begins and a viable gas exchange surface forms.
- Saccular stage: 24 weeks to term, continued development of the gas exchange surface.

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2. ANSWER: B

Infants have **poorly developed intercostal muscles** and **accessory muscles of respiration**. In infants the **diaphragm** does most of **the work of breathing** and the **ribs have high cartilage** content and extend horizontally from the vertebral column. **Accessory muscles contribute little** to chest expansion due to chest characteristics. Additionally, the **intercostal muscles** are **only partially developed**.

Neonates exhibit retractions during rapid eye movement sleep due to chest wall stiffness. Preterm infants can exhibit retractions during all stages of sleep. Young children can exhibit **paradoxical chest movement** with **respiratory distress (upper airway obstruction or intercostal muscles depression)**. Increased use of the diaphragm to maintain tidal volumes can lead to diaphragmatic fatigue or respiratory failure in the preterm infant.

The **diaphragm** muscle contains **type I (slow twitch) muscle fiber**. These slow twitch muscle fibers **prevent fatigue**. The diaphragm of a **preterm** infant has **less than 10% of type I muscle fibers**. This is much less than the diaphragm of a **term** infant, which has approximately **25% of type I muscle fibers,** and an **adult, which has 50%**.

The elastic properties of the lung are expressed as **compliance—the volume change per unit pressure change (tidal volume per transpulmonary pressure)**. Lung compliance depends on size. **Specific compliance** refers to the **compliance per unit volume of lung**; specific lung compliance is **constant throughout childhood**.

Infants have **very high chest wall compliance**. By **1 year of age** the **chest wall stiffens** and **compliance decreases** and nearly equals lung compliance. As the chest wall stabilizes, **FRC is maintained passively**. Elastic recoil of the lung increases throughout childhood, peaking at adolescences and subsequently declining due to deterioration of pulmonary elastic fibers.

KEY FACTS

- In infants the main muscle of respiration is the diaphragm. The diaphragm contains less type I muscle fibers and thus fatigues easily.
- In infants chest wall compliance is high and decreases with age due to muscle and skeletal development.
- In infants lung compliance is low and increases during childhood due to lung elastic tissue development.

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3. ANSWER: C

During **exhalation, small airways close, causing air trapping**. **Closing volume** is the lung volume at which **terminal airways** begin to **collapse**. Closing capacity is the **sum of closing volume and reserve volume**. **Infant and children** have a **high closing capacity**; the closing capacity is within the tidal breath, which can lead to **atelectasis** and **airway collapse** during **normal respiration**. In infants and children, airway closure is a result of decreased outward recoil of the chest and decreased cartilage in the distal airways to resist inward lung recoil. **Closing capacity decreases with age** as the muscles of respiration and lung elastic tissue develop. However, after **adolescence and through adulthood closing capacity begins to increase as a result of decreased lung elasticity with aging**.

Functional residual capacity (FRC) is the volume of gas remaining in the lungs at the end of a normal expiration. Functional residual capacity **per kilogram is similar among all ages**. FRC is the volume in the lungs when the passive outward recoil of the chest is balanced with the passive inward recoil of the lung.

Infants have very low outward chest recoil and also low inward lung recoil. Thus, the **FRC of infants at static conditions (general anesthesia or apnea) is only about 10% of TLC**. This does not allow for adequate gas exchange due to airway closure and atelectasis. Infants and children maintain a **larger dynamic FRC through early cessation of exhalation**.

Box 4.1 **MAINTENANCE OF FUNCTIONAL RESIDUAL CAPACITY IN YOUNG INFANTS**

- Sustained tonic activities of inspiratory muscles throughout the respiratory cycle
- Breaking of expiration with continual but diminishing diaphragmatic activity
- Narrowing of the glottis during expiration
- Inspiration starting in midexpiration*
- High respiratory rate in relation to expiratory time constant*
- All mechanisms of sustaining FRC are lost with anesthesia or muscle relaxant.

* Create PEEPi or autoPEEP.
SOURCE: Motoyama EK, Davis PJ. *Smith's Anesthesia for Infants and Children*. 7th ed. St. Louis: Elsevier Mosby; 2006:44.

Total lung capacity (TLC) is the volume of air contained in the lungs at the **end of a maximal inspiration**. Adults have a larger total lung capacity than infants. This is because TLC is effort dependent and adults have well-developed muscles of respiration. **TLC increases with age** until about **5 years of age** when it reaches about 80–90 mL/kg. In healthy children, TLC correlates with height.

Infants have low lung elasticity due to poorly developed lung elastic tissue.

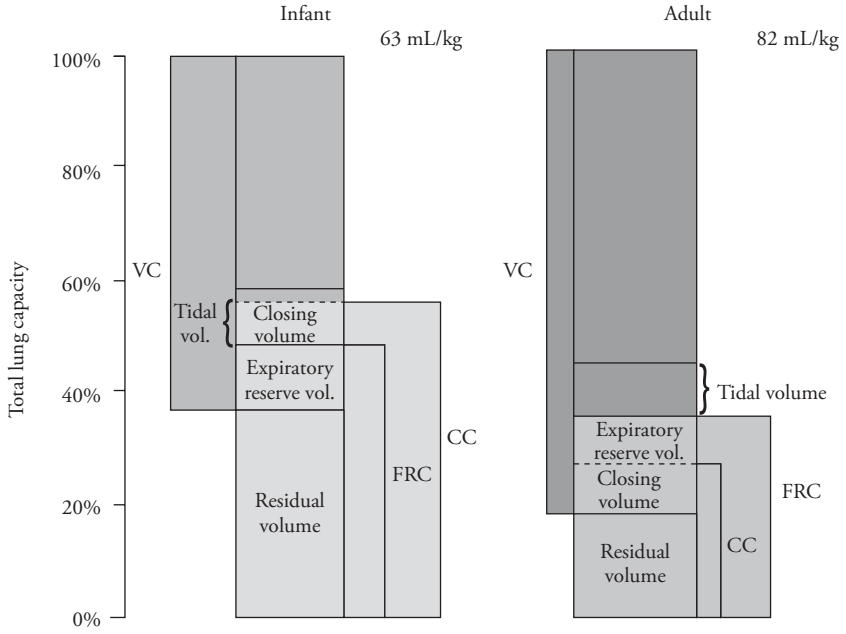

Figure 4.1 Lung volumes in infants and adults. Note that, in infants, tidal volume breathing occurs at the same volume as closing volume. CC, closing capacity; FRC, functional residual capacity; VC, vital capacity. (Modified from Nelson NM. Respiration and circulation after birth. In: Smith CA, Nelson NM, eds. *The physiology of the newborn infant*. Springfield, IL: Charles C Thomas; 1976:207. As cited in: Marciniak, B. *Practice of Anesthesia for Infants and Children*. Philadelphia, PA: Saunders; 2013.)

KEY FACTS

- Infants have a high closing capacity that is near FRC. This makes them prone to airway collapse and atelectasis. Closing capacity decreases during childhood due to chest development.
- Functional residual capacity per kilogram is similar among all ages (30 mL/kg).
- Adults have a larger total lung capacity than infants (82 mL/kg vs. 63 mL/kg)

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West JB, ed. *Respiratory Physiology: The Essentials*. 5th ed. Philadelphia, PA: Williams & Wilkins; 1990:101.

4. ANSWER: C

Postextubation croup, or **subglottic edema**, is the result **of airway swelling**. Infants and children are more prone to croup than adults because of anatomical airway differences. Due to the small size of the pediatric airway, even **minimal airway edema decreases the tracheal lumen and increases airflow resistance**. The **narrowest** portion of a child's airway is at the level of **the cricoid cartilage**. This area is at risk for internal tracheal mucosal injury during tracheal intubation. A small amount of airway edema can cause obstruction and compromise airflow. **Risk factors** for postextubation croup include **tight-fitting ETTs, traumatic intubation, tracheal trauma from position changes, age between 1 and 4 years, recent upper respiratory tract infection, and a history of croup**. A **leak** around the ETT **of less than 25 cm H_2O** decreases the risk factor for postextubation croup.

The **incidence** of postextubation croup is about **1%.** Croup usually **begins within 3 hours of extubation**. Mild cases can be treated with **humidified oxygen**. More severe cases may require **nebulized racemic epinephrine**. Racemic epinephrine can be **repeated after 2 hours**. Severe cases should be observed for an extended period of time or admitted to the hospital for continued observation and treatment. Additionally, **dexamethasone** is used to **reduce airway edema in postextubation croup**. The efficacy of corticosteroids to prevent postextubation croup is controversial.

Hagen-Poiseuille's law states that a small decrease in airway diameter results in a four-fold increase in resistance to flow in the trachea. A small degree of tracheal edema can cause significant obstruction in infants and children due to their overall small trachea size.

$$R = (8\eta L) / (\pi r^4)$$

where R is resistance η is air viscosity, L is length of airway, and r is radius of the trachea.

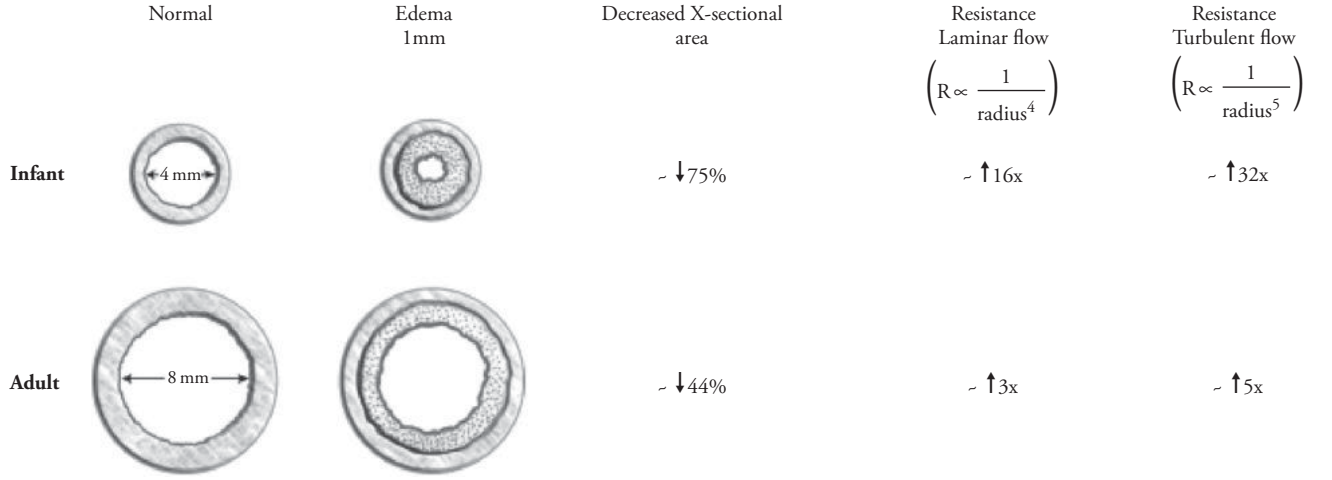

Figure 4.2 Relative effects of airway edema in an infant and an adult. The normal airways of an infant and an adult are presented on the left. Edematous airways display 1 mm of circumferential edema, reducing the diameter of the lumen by 2 mm. Notice that resistance to airflow is inversely proportional to the radius of the lumen to the fourth power for laminar flow (beyond the fifth bronchial division) and to the radius of the lumen to the fifth power for turbulent flow (from the mouth to the fourth bronchial division). The net result in an infant with a 4 mm diameter airway is a 75% reduction in cross-sectional area and a 16-fold increase in resistance to laminar airflow, compared with a 44% reduction in cross-sectional area and a 3-fold increased resistance in an adult with a similar 2 mm reduction in airway diameter. With turbulent airflow (upper airway), the resistance increases 32-fold in the infant but only 5-fold in the adult. (Reprinted with permission from Litman RS, Fiadjoe JE, Stricker PA, Coté CJ. *Practice of Anesthesia for Infants and Children*. 5th ed. Philadelphia, PA: Saunders; 2013.)

KEY FACTS

- Airway edema after postextubation croup is due to internal tracheal mucosal injury that decreases the tracheal lumen and increases airflow resistance.
- According to Hagen-Poiseuille's law, the change in airflow resistance resulting from a reduction in airway diameter is directly proportional to the airway radius elevated to the fourth power.

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5. ANSWER: B

Oxygen transport is determined by the **affinity of hemoglobin for oxygen**, **blood oxygen content**, and **cardiac output**. Hemoglobin-oxygen affinity depends on the **type of hemoglobin present**. **Fetal hemoglobin is 70% of total hemoglobin in the neonate**. Fetal hemoglobin reacts less with 2,3-diphosphoglycerate and thus has **increased oxygen affinity** and **decreased oxygen delivery to the tissue**.

Its presence can **shift the oxygen dissociation curve to the left**. The oxygen dissociation curve is a graph that shows the percent saturation of hemoglobin at various partial pressures of oxygen. It has a sigmoid shape, which reflects the cooperative nature of oxygen binding to hemoglobin.

Other factors that shift the oxygen dissociation curve to the **left** include **decreased temperature, increased pH, and decreased 2,3-diphosphoglycerate levels**. These factors **increase hemoglobin's affinity for O_2**

Oxygen content (CaO_2) of blood is expressed by the equation:

$$CaO_2 = Hb \times 1.39 \times SaO_2/100 + 0.003(PaO_2)$$

where Hb is hemoglobin, SaO_2 is oxygen saturation, and PaO_2 is partial pressure of oxygen.

Oxygen is carried in the blood, where it is dissolved and combined with hemoglobin. The amount of dissolved oxygen is small and relatively constant, but it is determined by the partial pressure of oxygen (PaO_2). As the **PaO_2 increases,** the amount of **dissolved oxygen increases**. This is described by Henry's law that states that the amount of gas dissolved in a solution is directly proportional to the partial pressure of that gas above the solution.

In the blood, oxygen combines reversibly with hemoglobin to form oxyhemoglobin. Each molecule of hemoglobin combines with four molecules of oxygen. **The affinity of hemoglobin for oxygen differs with age because the species of hemoglobin varies with age**.

The most efficient way to increase oxygen-carrying capacity is to increase cardiac output. Chronic hypoxemia leads to increased red blood cell production; the increase occurs slowly over several weeks.

KEY FACTS

- Oxygen transport is determined by the affinity of hemoglobin for oxygen, blood oxygen content, and cardiac output.
- Fetal hemoglobin has increased oxygen affinity and decreased oxygen delivery to the tissue.
- The affinity of hemoglobin for oxygen differs with hemoglobin species as well as temperature, pH, CO_2, and 2,3-diphosphoglycerate levels.
- The most efficient way to increase oxygen-carrying capacity is to increase cardiac output.

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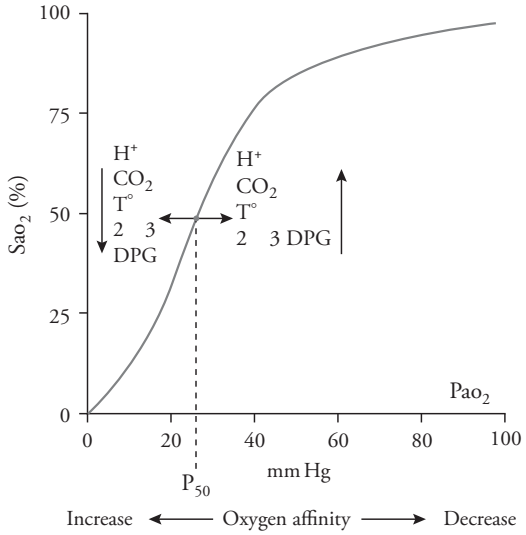

Figure 4.3 Relative effects of airway edema in an infant and an adult. (Reprinted with permission from Motoyama EK, Davis PJ, eds. *Smith's Anesthesia for Infants and Children*. 7th ed. St. Louis, MO: Elsevier Mosby; 2006:61.)

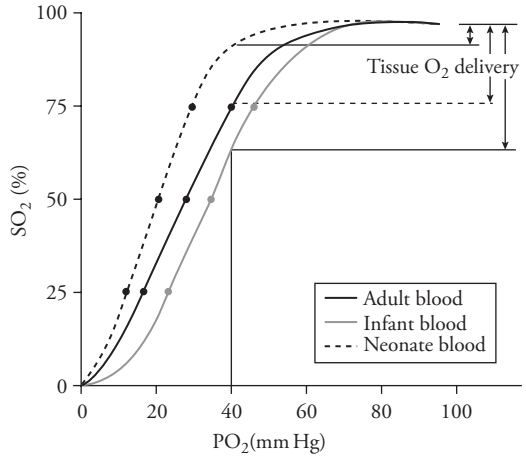

Figure 4.4 (Reprinted with permission from Motoyama EK, Davis PJ, eds. *Smith's Anesthesia for Infants and Children*. 7th ed. St. Louis, MO: Elsevier Mosby; 2006:62.)

6. ANSWER: C

The **P50 is the partial pressure of oxygen (PO_2) of whole blood at 50% oxygen saturation (SO_2)**. It indicates the **affinity of hemoglobin for oxygen**. The **blood of normal adults has a SO_2 of 50%** when **PO_2 is 27 mm Hg at 37°C and a pH of 7.4**. **Neonates** have a **lower P50 (19 mm Hg)** because of lower 2,3-diphosphoglycerate (2,3-DPG) level. They also have lower oxygen delivery to the tissue. By **3 months of age**, the total hemoglobin level decreases (**physiologic anemia of infancy**) and **adult hemoglobin replaces fetal hemoglobin**. Additionally, 2,3-DPG levels rise and the P50 increases to a high of 30 mm Hg during childhood, indicating increased delivery of oxygen to tissue.

In the blood, oxygen combines reversibly with hemoglobin to form oxyhemoglobin. Each molecule of hemoglobin combines with four molecules of oxygen. The affinity of hemoglobin for oxygen differs with age. Neonates have a **higher percentage of fetal hemoglobin and thus a higher oxygen-hemoglobin affinity**. The higher **affinity allows fetal hemoglobin to extract oxygen** from maternal adult hemoglobin. For different oxygen dissociation curves, the affinity of hemoglobin for oxygen increases with decreasing P50.

The characteristics of hemoglobin-oxygen affinity and oxygen delivery are different in children than adults. **Infants have a higher P50 (30 mm Hg) than adults (27 mm Hg)**. Oxygen delivery to the tissue may be the same for both infants and adults at different hematocrits—a lower hematocrit in infants versus adults. Conversely, **neonates have a lower P50 (19 mm Hg) than adults (27 mm Hg),** and equivalent tissue oxygen delivery may require a higher neonate hematocrit.

Table 4.1 COMPARISON OF NORMAL RESPIRATORY VALUES IN INFANTS AND ADULTS

PARAMETER	INFANT	ADULT
Respiratory frequency	30–50	12–16
Tidal volume (mL/kg)	7	7
Dead space (mL/kg)	2–2.5	2.2
Alveolar ventilation (mL/kg per minute)	100–150	60
Functional residual capacity (mL/kg)	27–30	30
Oxygen consumption (mL/kg per minute)	7–9	3

SOURCE: From Barash PG, Cullen BF, Stoelting RK. *Clinical Anesthesia*. 5th ed. Philadelphia, PA: Lippincott Williams & Wilkins; 2006:1187.

KEY FACTS

- The P50 is the PO_2 of whole blood at 50% SO_2.
- The P50 in adults is 27 mm Hg,
- The P50 in neonates is about 19–24 mm Hg (erythrocytes have high oxygen affinity and poor oxygen tissue delivery),
- The P50 of infants is 30 mm Hg (erythrocytes have low oxygen affinity and good oxygen tissue delivery).
- For different oxygen dissociation curves, the affinity of hemoglobin for oxygen increases with decreasing P50.

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7. ANSWER: B

Pulmonary surfactant decreases surface tension, increases lung compliance, and decreases work of breathing. Type 2 alveolar pneumocytes produce pulmonary surfactant. These cells are found on the **alveolar surface**. Surfactant is formed intracellularly on the lamellar bodies and expelled to the alveolar surface by exocytosis. Surfactant **production begins at about 24 weeks gestation**. The alveolar lining is 80% phospholipids and 10% lipoproteins. Phosphatidylcholine (PC) makes up 70% of the phospholipids. Dipalmitoylphosphatidylcholine, a type of PC, comprises the majority of PC and is surface active. Surfactant is secreted into the alveolar fluid and lines the alveoli. The amount of PC increases toward term. Surface-active proteins are important in the alveolar stability of neonates, increasing lung compliance and decreasing atelectasis. Used surfactant lipids are taken up and recycled or broken down by type 2 pneumocytes.

Lipoproteins, or surfactant proteins, are made in type 2 alveolar pneumocytes and **Clara cells**. Some proteins are hydrophilic and likely play a role in **the lung's**

immunity system by binding microorganisms. Other proteins are hydrophobic and enhance the stability of surfactant phospholipids. The amount of surfactant phospholipids and lipoproteins increases late in gestation.

Corticosteroids, among other medications, can **accelerate surfactant production**. Corticosteroids are administered routinely to pregnant women before the delivery of preterm infants to help mitigate respiratory distress at birth. Additionally, surfactant replacement therapy via ETT decreases morbidity and mortality in premature infants. It can also be used in disease states like persistent pulmonary hypertension of the newborn (PPHN) and acute respiratory distress syndrome (ARDS).

KEY FACTS

- Pulmonary surfactant decreases surface tension, promotes stability of the alveoli, and prevents the transudation of fluid into the alveoli. These factors combine to increase lung compliance and decrease work of breathing.
- Pulmonary surfactant is made by type 2 alveolar pneumocytes and functions to stabilize the alveolar membrane.
- Corticosteroids are given to pregnant women 24 to 48 hours before delivery of preterm infants.

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West JB, ed. *Respiratory Physiology: The Essentials*. 5th ed. Philadelphia, PA: Williams & Wilkins; 1990:93–8.

8. ANSWER: B

At birth, as the lungs expand with air, **pulmonary vascular resistance decreases and pulmonary blood flow increases**. The increase in pulmonary blood flow increases the left atrial pressure. The right atrial pressure decreases because blood can now flow into the pulmonary arteries. This results in a change in the pressure gradient across the atria, allowing the foramen ovale to close.

The transition from fetal to neonatal circulation is dependent on many factors, including the ability of the lungs to expand with air in which surfactant plays a key role. In the perinatal period, **pulmonary surfactant** increases to help **stabilize** the **terminal airspaces** that were previously filled with fluid.

Type II pneumocytes produce surfactant. Pulmonary surfactant is secreted into alveoli, forming an alveolar lining. The lining reduces surface tension and stabilizes terminal air spaces. **Surface tension** forces tend to **collapse alveoli** and draw fluid into the alveoli from the capillaries. Surfactant reduces surface tension by **opposing the normal attracting forces between surface molecules**. Surfactant functions to **(1) lower surface tension; (2) promote stability of the alveoli; and (3) prevent the transudation of fluid in alveoli**.

Surfactant production begins around **24 to 26 weeks gestation**. The presence of pulmonary surfactant greatly influences lung expansion and pulmonary gas exchange in the neonate. Inadequate pulmonary surfactant can cause poor lung expansion, leading to an inadequate ventilation/perfusion balance. **Decreased surfactant causes decreased lung compliance**, increased **atelectasis**, and **increased transudation within the alveol**i. Viability begins around 24 weeks gestation coinciding with surfactant production and increased lung surface area for gas exchange. Neonates with certain lung pathologies such as PPHN, congenital diaphragmatic hernia, and ARDS have decreased surfactant and are prone to respiratory problems.

KEY FACTS

- At birth **pulmonary vascular resistance decreases, pulmonary blood flow increases**, which in turn increases left atrial pressure and decreases right atrial pressure.
- Pulmonary surfactant promotes lung expansion and pulmonary gas exchange in the neonate.
- Three main functions of pulmonary surfactant include (1) lower surface tension; (2) promote stability of the alveoli; and (3) prevent the transudation of fluid in alveoli.
- Viability coincides with an adequate surface for gas exchange and surfactant production around 24 weeks gestation.

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9. ANSWER: A

Type II pneumocyte cells secrete surfactant, composed of phospholipids and proteins, into the alveolar membrane, coating the surface. A sphere generates a pressure that can be predicted by LaPlace's equation. The LaPlace equation describes the pressure within a sphere in relation to surface tension and size of the sphere:

$$P = 2T/r$$

where P is pressure, T is surface tension, and r is radius of sphere.

Pressure is higher in spheres with smaller radii; thus, if two spheres are connected to a common tube, the smaller sphere has the higher surface tension. The smaller sphere would empty into the larger sphere and then collapse. Surfactant reduces surface tension by opposing the normal attracting forces between surface molecules. **Surfactant contains both hydrophobic and hydrophilic groups**. At the air–water interface of the alveoli, the hydrophilic groups face the water and the hydrophobic groups face the air. The **decrease in surface tension produced by pulmonary surfactant increases lung compliance and decreases work of breathing**.

Charle's law states that at a constant pressure, the volume of a gas will vary directly with the absolute temperature:

$$V_1T_2 = V_2T_1$$

Fick's law states that the diffusion rate of a gas across a fluid membrane is proportional to the difference in partial pressure, proportional to the area of the membrane, and inversely proportional to the thickness of the membrane. The total membrane surface area in the lung is about 100 square meters and has a thickness of less than a millionth of a meter. It is a large effective gas exchange surface.

Henry's law states that the **amount of gas dissolved in a solution is proportional to the partial pressure of the gas**. The solubility of the gas is expressed as a constant. The law helps predict the amount of gas that will go into solution. It describes gas exchange in the lung.

KEY FACTS

- Pulmonary surfactant decreases surface tension that decreases the pressure within the alveoli and increases lung compliance.
- LaPlace's equation describes the pressure within a sphere in relation to surface tension and size of the sphere: P = 2T/r.
- Fick's law states that the diffusion rate of a gas across a fluid membrane is proportional to the difference in partial pressure, proportional to the area of the membrane, and inversely proportional to the thickness of the membrane.
- Charle's law states that at a constant pressure, the volume of a gas will vary directly with the absolute temperature.
- Henry's law states that the amount of gas dissolved in a solution is proportional to the partial pressure of the gas.

REFERENCE

West JB, ed. *Respiratory Physiology: The Essentials*. 5th ed. Philadelphia, PA: Williams & Wilkins; 1990:94, 168.

10. ANSWER: B

Infants and children become **hypoxemic** much more quickly than adults because of **smaller oxygen reserves and higher oxygen requirements**. **General anesthesia decreases** their **functional residual capacity (FRC)**, reducing their oxygen reserve severely. FRC is a balance between the inward recoil of the lung and the outward recoil of the chest wall. The opposing forces create a negative pleural pressure of –5 cm H_2O in adults. Infants have a **compliant chest wall** and **lower outward recoil** of the chest wall. The inward recoil of infants is slightly less than adults. In infants, the FRC with general anesthesia, muscle relaxation, or central apnea is only 10%–15% of TLC. **This low FRC is below closing capacity and can result in small airway closure**.

The **oxygen consumption** of an infant is much higher than that of an adult, as is the metabolic rate per kilogram. Thus, infants and children have higher oxygen demand per kilogram of body weight because of their higher metabolic rate. Oxygen consumption in the **neonate** is **6 to 8 mL/kg per minute** compared to the oxygen consumption of an **adult** of **3 mL/kg per minute**.

Infants require a **higher alveolar ventilation to meet the high metabolic demand**. They **increase** their **respiratory rates** to **increase their minute ventilation (tidal volumes** are relatively constant). Also, infants have a **high cardiac output (up to 250 mL/kg per minute)** to satisfy the metabolic demand.

The **dead space to tidal volume (Vd/Vt) ratio** in normal lungs is approximately constant (0.3) from infancy to adulthood. Tidal volume and functional reserve capacity per kilogram is the same for infants and adults.

KEY FACTS

- Increased oxygen consumption leads to more hypoxemia in infants and children compared to adults.
- In infants, chest wall relaxation (i.e., general anesthesia) lowers functional residual capacity to less than closing capacity.
- Infants have a high alveolar ventilation and respiratory frequency.
- Dead space to tidal volume ratio is the same in infants and adults.
- Tidal volume and functional reserve capacity per kilogram are the same in infants and adults.

REFERENCES

Barash PG, Cullen BF, Stoelting RK, eds. *Clinical Anesthesia*. 5th ed. Philadelphia, PA: Lippincott Williams & Wilkins; 2006:1187.

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Table 4.2 HEMOGLOBIN REQUIREMENTS FOR EQUIVALENT TISSUE OXYGEN DELIVERY

		HEMOGLOBIN FOR EQUIVALENT O_2 DELIVERY (MM HG) (G/DL)						
	P50							
Adult	27	7	8	9	10	11	12	13
Infant >6 months	30	5.7	6.5	7.3	8.2	9.0	9.8	10.6
Neonate <2 months	24	10.3	11.7	13.2	14.7	16.1	17.6	19.1

SOURCE: Data calculated from Motoyama EK et al. Functional basis of childhood anemia [abstract]. *Am Soc Anesthesiology* 1974;283. In: Motoyama EK, Davis PJ, eds. *Smith's Anesthesia for Infants and Children*. 7th ed. St. Louis, MO: Elsevier Mosby; 2006:63.

11. ANSWER: C

Gravity affects the **distribution of ventilation and perfusion in the lung**. In adults in the upright position, **transmural pressure at the apex of the lung** is **higher than at the base of the lung**. During spontaneous respirations in adults, **ventilation is distributed preferentially** to **dependent** regions of the lung. This is also seen in the lateral decubitus position; **the lower lung has greater ventilation than the upper lung**.

Conversely, infants with unilateral lung disease in the **lateral decubitus position have better oxygenation in the nondependent lung.** This paradoxical distribution of ventilation in infants and children may be caused **by increased chest wall compliance**. The **dependent lung has a low pleural pressure** and **tends to collapse** due to the infants' soft compressible rib cage. Airway closure tends to shift ventilation to nondependent parts of the lung. This situation is similar to that seen in the ventilated adult, with **nondependent regions better ventilated** and **dependent regions better perfused**.

Adult pulmonary hemodynamics, the effect of gravity and the characteristics of the upright lung are explained by West's concept of three lung zones. This was later modified to four lung zones. **In Zone 1, arterial pressure is less than alveolar pressure**. Pulmonary capillaries are collapsed and there is no perfusion. In **Zone 2, arterial pressure is greater than alveolar pressure and venous pressure is less than alveolar pressure**. Thus, capillary perfusion depends on the arterial to alveolar pressure gradient. In **Zone 3, arterial and venous pressures are greater than alveolar pressure**. Capillary perfusion is independent of airway pressure. In **Zone 4, pulmonary blood flow is reduced at the base of the lung due to increased interstitial pressure**.

Thus, in spontaneously breathing **adults**, **ventilation is distributed preferentially to dependent lung areas**. Perfusion follows a similar distribution. Hence, ventilation and perfusion are well matched in the adult. In an **upright lung** the ventilation to perfusion **(V/Q) ratio** is **higher at the apex** and **lower at the base**. For normal gas exchange the balance of regional distribution of ventilation and blood flow needs to be maintained.

In contrast, **ventilation in infants** is normally **distributed to nondependent regions of the lung**. **Perfusion is evenly distributed** throughout the lung due to the smaller anterior-posterior diameter that decreases the effect of gravity. This leads to an **increased V/Q mismatch as compared to adults**.

KEY FACTS

- The distribution of ventilation and perfusion is different in children compared to adults.
- In adults, gravity affects ventilation and perfusion distribution with both distributed preferentially to dependent lung regions.
- In infants and small children, ventilation is greater in nondependent regions of the lung, and perfusion is evenly distributed throughout the lung.
- In adults, the V/Q ratio in an upright lung is higher at the apex and lower at the base.
- Infants have a larger V/Q mismatch as compared to adults because of differences in the regional distribution of perfusion and ventilation.

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West JB, ed. *Respiratory Physiology: The Essentials*. 5th ed. Philadelphia, PA: Williams & Wilkins; 1990:41, 61.

12. ANSWER: A

Several factors contribute to worsened oxygenation in infants while in the lateral decubitus position compared with adults. Compared with adult patients, **infants have an extremely compliant chest wall** that, in the dependent position, cannot support the underlying lung, leading to a **decrease in functional residual capacity (FRC).** If there is enough reduction in **FRC** such that it **approaches residual volume**, there is an **increased likelihood of airway closure** during normal tidal ventilation leading to **shunting and desaturation**.

Also, due to the smaller size of infants, **the hydrostatic gradient** between the dependent and nondependent lungs is **reduced,** thereby **minimizing** the **favorable increase in perfusion to the dependent, ventilated lung** that would be more pronounced in larger patients.

In the lateral decubitus position, the dependent diaphragm has a mechanical advantage due to "loading" from the abdominal hydrostatic gradient. In infants, the **pressure**

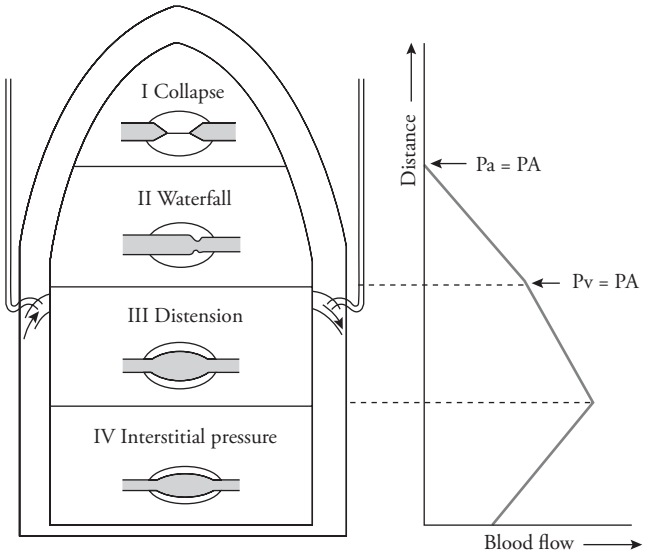

Figure 4.5 Four zones of lung perfusion. Zone I has no flow because alveolar pressure exceeds pulmonary arterial pressure, thereby collapsing alveolar vessels. Zone II is present when pulmonary arterial pressure exceeds alveolar pressure and both are greater than pulmonary venous pressure. This is termed the vascular waterfall, because flow is unaffected by downstream (pulmonary venous) pressure. Zone III is characterized by a constant driving force, the difference between pulmonary arterial and venous pressure. Both are greater than alveolar pressure. Flow increases throughout zone III, even though driving pressure is constant because the absolute pressures lower in the lung distend the vessels to a greater extent, thereby lowering resistance. Zone IV has less flow per unit lung volume, probably because of the increased parenchymal pressure surrounding pulmonary vessels. (From Hughes JMB et al. Effect of lung volume on the distribution of pulmonary blood flow in man. *Respir Physiol*. 1968;4:58. In: Motoyama EK, Davis PJ, eds. *Smith's Anesthesia for Infants and Children*. 7th ed. St. Louis, MO: Mosby; 2006:62.)

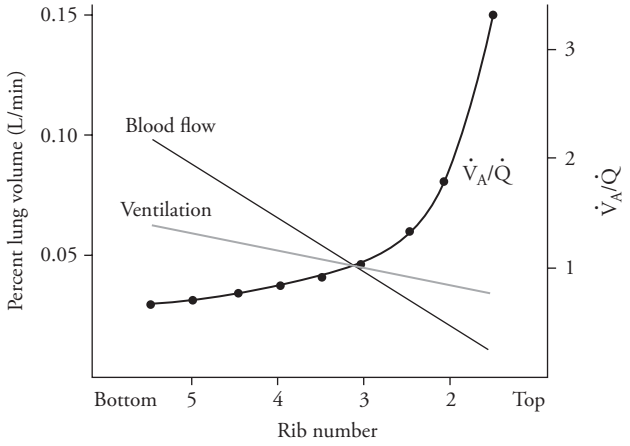

Figure 4.6 Effect of vertical height (expressed as the level of the anterior ends of the ribs) on ventilation and pulmonary blood flow (left ordinate) and the V/Q ratio (right ordinate). (Reprinted with permission from West JB. *Ventilation/Blood Flow and Gas Exchange*. 2nd ed. Oxford, UK: Blackwell Scientific; 1970. In: Motoyama EK, Davis PJ, eds. *Smith's Anesthesia for Infants and Children*. 7th ed. St. Louis, MO: Elsevier Mosby; 2006:62.)

gradient to the dependent diaphragm is reduced and with it the **functional advantage of the dependent diaphragm.** Lastly, because infants have a much higher baseline **oxygen requirement of approximately 6–8 mL/kg per minute compared with adult consumption rates of 2–3 mL/kg per minute**, they are also much more prone to desaturation.

KEY FACTS

- Due to differences in body structure and size, infants are more prone to desaturation in the lateral decubitus position than adults.
- Infants also have a greater tendency toward desaturation due to their higher baseline rate of oxygen consumption compared with adults.
- Infants: 6–8 mL/kg per minute oxygen consumption
- Adults: 2–3 mL/kg per minute oxygen consumption

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Cote CJ, Lerman J, Anderson B, eds. *A Practice of Anesthesia for Infants and Children*. 5th ed. Philadelphia, PA: Saunders; 2013:277–8.

13. ANSWER: B

The age-appropriate uncuffed ETT size for a 4 year old is 4.5 mm with an outer diameter of 6.2 mm. The **smallest available DLT is 26 Fr**, which has a corresponding **outer diameter of 8.7 mm**. This patient is an average-sized 4 year old; therefore, even a 26 Fr DLT would likely be too large for this patient as would a Univent tube. A single-lumen ETT and a BB would both be potential options for this patient. However, since **right-sided ventilation** is requested, due to **the proximal takeoff** of the **right upper lobe** (RUL), there is a much higher likelihood of RUL obstruction if a single-lumen tube is used for lung isolation rather than a BB.

Table 4.3 outlines recommended tube selection for single-lung ventilation in children.

Table 4.4 is a brief overview of the advantages and disadvantages of the available techniques for providing single-lung ventilation.

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Table 4.3 TUBE SELECTION FOR SINGLE-LUNG VENTILATION IN CHILDREN

TUBE SELECTION FOR SINGLE-LUNG VENTILATION IN CHILDREN

AGE (YEARS)	ETT (ID MM)	BB (F)	UNIVENT (FUJI SYSTEMS CO, TOKYO)	DLT (F)
0.5–1	3.5–4.0	2		
1–2	4.0–4.5	3		
2–4	4.5–5.0	5		
4–6	5.0–5.5	5		
6–8	5.5–6.0	5	3.5	
8–10	6.0 cuffed	5	3.5	26
10–12	6.5 cuffed	5	4.5	26–28
12–14	6.5–7.0 cuffed	5	4.5	32
14–16	7.0 cuffed	5, 7	6.0	35
16–18	7.0–8.0 cuffed	7, 9	6.0	35,37

BB, bronchial blocker; DLT, double-lumen tube; ETT, endotracheal tube; F, French Size; ID, inner diameter.

14. ANSWER: B

Anterior mediastinal masses can include neoplasms of the lung, mediastinum, and pleura. Common primary tumors are from non-Hodgkin and Hodgkin lymphoma. Patients with anterior mediastinal masses often present with signs and symptoms related to airway and vascular compression such as **dyspnea, orthopnea, pain, coughing, or superior vena cava (SVC) syndrome**. Commonly, tissue will need to be obtained in order to establish a correct diagnosis.

Preoperative evaluation should include studies such as **computed tomography (CT), echocardiography, and flow-volume loops** to aid in delineating the extent of compression of surrounding structures. It should be noted that CT scans, which are static images, may not always identify dynamic airway or vascular compression. If any diagnostic modalities reveal airway or circulatory compression (SVC or pulmonary outflow tract), serious consideration should be given to attempting to obtain the tissue biopsy under only local anesthesia. One study demonstrated that clinical features predictive of perianesthesia **complications** in children with mediastinal mass included **orthopnea, upper body edema, great vessel compression, and main-stem bronchial compression**.

However, if obtaining a **tissue biopsy under local anesthesia** is not an option, a short course of **chemotherapy, radiation, or steroids** can be considered to **shrink** the **tumor burden** and the risk of life-threatening airway or vascular compression under general anesthesia. The benefit of tumor regression from any of these interventions should

Table 4.4 ADVANTAGES AND DISADVANTAGES OF THE AVAILABLE TECHNIQUES FOR PROVIDING SINGLE-LUNG VENTILATION

	ADVANTAGES	DISADVANTAGES
Single-lumen ETT	- Simple technique - Aside from fiberoptic bronchoscope, no need for additional equipment	- Failure to provide adequate seal if using uncuffed ETT. This may lead to incomplete collapse of operative lung and fail to protect the ventilated lung from cross contamination from the operative lung - Hypoxemia secondary to potential obstruction of the upper lobe bronchus, in particular when the right mainstem is intubated
Bronchial blocker	- Ability to provide CPAP or suctioning to operative lung if open-tip bronchial blocker is used - Improved lung isolation more than uncuffed ETT due to complete seal	- Inability to provide CPAP or suctioning operative lung if closed tip bronchial blocker is used - Low-volume and high-pressure cuff that can potentially damage airway - Possible hyoxemia during placement, though this may be mitigated with adapters that allow ventilation during fiberoptic bronchonscopy-assisted placement - Potential for complete tracheal occlusion if blocker is displaced proximally into the trachea
Univent tube	- The bronchial blocker is attached to the main ETT; therefore, displacement of the blocker is much less likely to occur - The blocker tube has a small lumen that can allow gas to egress, suction, or apply CPAP - The blocker tube can be removed at the conclusion of the case to allow for conventional ventilation techniques without the need to exchange for an ETT	- Due to the large cross-sectional area occupied by the blocker channel, the Univent tube has a relatively large outer diameter relative to its inner diameter - Smaller Univent tubes have a disproportionally high resistance to gas flow - The blocker balloon has a low-volume and high-pressure cuff that can potentially damage airway
Double-lumen ETT	- Ability to isolate either lung with properly placed DLT - Ease of suctioning or applying CPAP to operative lung	- Need to change to single-lumen ETT if postoperative ventilation is required - Difficult placement in patients with difficult airway

CPAP, continuous positive airway pressure; ETT, endotracheal tube.

be weighed against the possibility of decreasing the substrate available for correct tissue diagnosis.

Even in children with an anterior mediastinal mass without any evidence of cardiorespiratory compromise, **induction of anesthesia can be associated with airway obstruction and hemodynamic collapse**. A history from patients and parents of the optimal position where clinical symptoms are minimized can be lifesaving knowledge, should the patient decompensate intraoperatively.

It is recommended that **spontaneous ventilation** be maintained during induction either via an inhalational, or carefully titrated IV induction as this offsets the natural tendency of the anterior mass to collapse onto and thereby compress the surrounding structures such as the pulmonary arteries, SVC, and respiratory tract. The **decrease in chest wall tone** as a result of **neuromuscular blockade can increase the risk of airway compression**. Likewise, placing the child in **lateral decubitus** or with the **head of the bed elevated** can also mitigate cardiovascular and respiratory compression. Should hemodynamic or respiratory collapse occur, use of **rigid bronchoscopy** by a skilled practitioner or changing **position to lateral or prone can be lifesaving**. If these measures are not effective in relieving the effects of the anterior mediastinal mass, **use of extracorporeal membrane oxygenation (ECMO) and cardiopulmonary bypass** should be considered.

KEY FACTS

- Even patients with asymptomatic anterior mediastinal masses can develop respiratory and cardiovascular compromise during induction of anesthesia.
- Spontaneous ventilation should ideally be maintained during induction of anesthesia to offset the tendency of the anterior mediastinal mass to collapse and compress surrounding structures.
- Preoperative workup in patients with an anterior mediastinal mass should carefully delineate the extent of compression of adjacent structures.
- A short course of chemotherapy, radiation, and steroids can shrink tumor burden but at the expense of decreasing tissue available for diagnosis.

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Hammer, G. Anaesthetic management for the child with a mediastinal mass. *Pediatric Anesth*. 2004;14:98–102.

15. ANSWER: D

Similar to other congenital skeletal abnormalities such as scoliosis, **pectus deformities** tend to **worsen during periods of rapid skeletal growth** such as during **adolescence**. Though the etiology of pectus deformities is not entirely clear, there is approximately a **35% rate of familial occurrence** and it is associated with **Marfan** and **Poland** syndrome. Though most patients with pectus deformities do not have associated cardiorespiratory symptoms, **20%–60% can have underlying mitral valve prolapse.** For patients who have reduced functional status related to their pectus deformity, **echocardiography and pulmonary function testing** may be of benefit.

Classically, pectus deformities were repaired via an open (Ravitch) procedure that involved an anterior chest wall incision, sternal osteotomy, and resection of involved costochondral cartilage. However, the open procedure has been largely supplanted by the Nuss procedure. The Nuss procedure evolved from the insight that because even older chronic obstructive disease patients could remodel their chest wall to the classic "barrel chest" of this patient population, it should be possible to reshape the chest wall of younger patients, who have much more pliable cartilage without the need for costochondral excision and sternotomy. The classic Nuss procedure involved bilateral midaxillary incisions followed by introduction of a pectus bar that is turned 180 degrees after insertion such that the concavity of the bar is posterior, and the pectus excavatum deformity is "pushed" anteriorly. More recent refinements to the Nuss procedure have included the use of **thoracoscopy to guide mediastinal dissection** and pectus bar insertion. The Nuss procedure has resulted in less blood loss, shorter operating times, and quicker recovery than the traditional open procedure. Due to the increased force exerted by the ribcage of older patients, they appear to be at higher risk for displacement of support bars used for surgery.

Patients require general anesthesia and epidurals can be used for postoperative analgesia. Though complications are rare during the Nuss procedure, there have been reports of significant injury to adjacent mediastinal structures, and the anesthesia provider should be prepared for these albeit rare, but possibly catastrophic events.

Postoperatively, patients who have undergone the Nuss procedure may present with **complications** from the surgery that may require intervention such as **pectus bar displacement, pleural effusion, thoracic outlet syndrome, infectious complications, pericarditis, sternal erosion of the pectus bar, direct cardiac injury, and anterior thoracic pseudoaneurysms**. Patients typically present after several years for removal of the pectus bar, which is generally an uncomplicated procedure; the anesthesia provider should consider that there have been reports of the pectus bar becoming adherent to the pericardium or lungs, leading to sudden, profound bleeding following removal.

KEY FACTS

- Pectus deformities tend to worsen during periods of rapid growth such as adolescence.

- There is a **35% rate of familial occurrence** and is associated with **Marfan** and **Poland** syndrome
- Most patients with pectus deformities do not have associated cardiorespiratory symptoms, though **20%–60% can have underlying mitral valve prolapse**
- Complications during pectus repair are unusual, but they can be associated with high morbidity due to injury to adjacent mediastinal structures.
- The pectus bar can in rare cases become adherent to pericardium and the lungs, leading to profound bleeding following its removal.

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16. ANSWER: C

The patient mentioned earlier has moderate **obstructive sleep apnea syndrome (OSAS)**. OSAS occurs when there are **transient periods of upper airway obstruction** that then lead to **hypoxemia, hypercapnea, and usually sleep disturbance**. The usual signs of OSAS are **snoring**, **gasping**, and **frequent awakening**. Long-term sequelae of OSAS include **cognitive and behavioral problems**, **poor growth**, and **systemic and pulmonary hypertension**.

Diagnosis of OSAS can only be made by nocturnal polysomnography (sleep study). During a sleep study electroencephalography (EEG), electrooculography(EOG), electromyography (EMG), chest wall, abdominal wall movement, nasal/oral airflow, end tidal CO_2, and pulse oximetry are monitored. The apnea hypopnea index **(AHI) measures the number of episodes of apnea and hypopnea in an hour (mild OSAS, 5–15 episodes/hr; moderate OSAS, 15–30 episodes/hr; severe OSAS, >30 episodes/hr).** Certain medical conditions can predispose patients to OSA. This includes disease states that result in hypotonia, as in **muscular dystrophy**, or discoordination of airway musculature, **obesity**, and **Trisomy 21**. In pediatric population the initial treatment of OSA is tonsillectomy and adenoidectomy. This is usually curative, but further treatment may be needed, especially in patients with other causes of OSA, as in patients with obesity or hypotonia.

Anesthetic management of patients with OSAS should include a careful airway examination; consideration should be given to preoperative echocardiogram if the OSAS is chronic and untreated. These patients may be difficult to mask ventilate due to their habitus and upper airway obstruction on induction. They also may be difficult to intubate. When planning for extubation, residual volatile anesthetics and neuromuscular blockers can even further decrease airway tone. Patients should be extubated awake, and if their disease is significant enough, they may be immediately transitioned to CPAP after extubation. A **multimodal approach to analgesia** (regional anesthesia, NSAIDS, acetaminophen) should be considered, as **opioids can cause somnolence, decreased respiratory drive, and alteration of the carbon dioxide response curve,** which can all exacerbate and potentiate episodes of airway obstruction. Postoperatively these patients should have **continuous monitoring for apnea and pulse oximetry**. If the patient uses CPAP at home, he or she will need to use it postoperatively. The intensive care unit may be needed postoperatively based on the degree of OSA or the type of surgery the patient is having.

KEY FACTS

- OSAS occurs when transient periods of upper airway obstruction lead to hypoxemia, hypercapnea, and sleep disturbance.
- AHI measures the number of episodes of apnea and hypopnea in an hour (mild OSAS, 5–15 episodes/hr; moderate OSAS, 15–30 episodes/hr; severe OSAS, >30 episodes/hr).

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17. ANSWER: B

Scoliosis is lateral curvature of the spine. Adolescent idiopathic scoliosis is the most common type, and more frequently seen in females. Neuromuscular scoliosis is the second most common, followed by congenital and miscellaneous. Neuromuscular scoliosis is associated with a neurologic or muscular disease. Some causes of neuromuscular scoliosis are cerebral palsy, muscular dystrophy, polio, and myelomeningocele.

Once **spinal curvature begins to exceed 60 degrees, pulmonary function tests begin to demonstrate a decrease in vital capacity**. **Pulmonary restriction** may not become clinically apparent until **thoracic curvature of 100 degrees** or more is present. However, some patients with idiopathic scoliosis may have pulmonary symptoms out of proportion to the severity of their scoliosis. The **more levels involved in the thoracic curve,** the **more pronounced the pulmonary impairment**. Changes in FEV or in arterial blood gas may not be seen until severe curve develops. Surgical correction is recommended for curves greater than 40 degrees, especially in patients who have not reached skeletal maturity.

Patients with forced vital capacity <30% of predicted may require prolonged postoperative intubation. Additionally, patients with neuromuscular scoliosis may have other coexisting factors such as recurrent respiratory infections, aspiration, and poor ability to clear secretions, which will also greatly impact their perioperative and postoperative course.

KEY FACTS

- Once spinal curvature begins to exceed 60 degrees, pulmonary function tests begin to demonstrate a decrease in vital capacity.
- Pulmonary restriction may not become clinically apparent until thoracic curvature of 100 degrees.
- The more levels involved in the thoracic curve, the more pronounced the pulmonary impairment.
- Patients with forced vital capacity <30% of predicted may require prolonged postoperative intubation.

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18. ANSWER: D

The patient described has symptoms of croup. **Croup** is a **viral illness** that has a **gradual onset**. Patients usually have a **barking cough due to subglottic edema**. Management is supportive; it is uncommon for these patients to require hospitalization and intubation, and it is rarely life-threatening. **Humidified air and racemic epinephrine** are effective treatments for dyspnea that may occur.

In comparison, **acute epiglottitis** is **a rapid-onset,** life-threatening **bacterial infection**. It leads to **supraglottic edema** that can progress to **total airway obstruction**. Patients are usually **toxic appearing**, with a **high fever**. In order to maintain patent airway, patients may be sitting up and leaning forward in a **tripod position**. Often the patient will be **drooling** with the **tongue protruded**. The initial treatment is **intubation** and should be done in the **operating room** with teams and equipment needed for complex airway management. Airway manipulation will worsen the supraglottic edema, so extreme care must be taken during intubation. If complete airway obstruction occurs, **rigid bronchoscopy**, **cricothyrotomy**, or **tracheostomy** may be needed to obtain an artificial airway. Induction of anesthesia in a child with acute epiglottitis should be done to **minimize patient anxiety** and to **maintain spontaneous respirations.**

KEY FACTS

- Croup: viral illness with gradual onset; symptoms of barking cough due to subglottic edema
- Treatment for croup is supportive: racemic epinephrine, humidified oxygen
- Acute epiglottitis: rapid-onset, life-threatening bacterial infection; supraglottic edema with possible progression to total airway obstruction; tripod posture, drooling, toxic appearing
- Initial treatment for acute epiglottitis: intubation

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Table 4.5 **CROUP VERSUS ACUTE EPIGLOTTITIS**

	CROUP	EPIGLOTTITIS
Etiology	Viral	Bacterial (*H. influenza, Streptococcus*)
Age	<3 years old	2–7 years old
Affected area	Subglottic	Supraglottic
Fever	None to low grade	High
Onset	Days	Hours
Symptoms	Barking cough, hoarse voice, tachypnea	Dysphagia, drooling, slow quiet breathing, tripod position
Treatment	Humidified oxygen, racemic epinephrine	Intubation, antibiotics
Neck X-ray findings	Steeple sign	Thumb print

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19. ANSWER: D

The patient described has acute pancreatitis leading to sepsis and has developed **acute respiratory distress syndrome (ARDS)**. Clinical features of ARDS are **hypoxemia, PaO_2/FIO_2 < 200**, and **bilateral infiltrates on chest X-ray** that is **not due to a cardiac cause** (pulmonary wedge pressure <18). Burns, sepsis, trauma, transfusion-related lung injury, and aspiration can all cause ARDS. There is no specific treatment for ARDS; management is supportive. However, the precipitating cause of the ARDS should be treated (i.e., antibiotics for sepsis).

Impaired oxygenation is a result of **diffuse alveolar injury** leading to disruption of the alveo-capillary membrane leading to **vascular permeability and inflammatory infiltration**. The affected alveoli are difficult to expand and ineffective at gas exchange. As the process is patchy throughout the lung, there are **areas of unaffected lung parenchyma**. With initiation of positive pressure ventilation, the unaffected and affected alveoli will display variable expansion. Therefore, if high-pressure ventilation is used, the distribution of the pressure will not be uniform throughout and the **lungs can be at risk of barotrauma**. Ventilatory management should include keeping **tidal volumes low (~6 mL/kg)**, **maximizing PEEP**, and using the **lowest possible FIO_2**. With the reduced minute ventilation, the patient will most likely have elevated $PaCO_2$. **Permissive hypercapnia** is an expected consequence of ventilator management in ARDS.

KEY FACTS

- Clinical features of ARDS are hypoxemia, PaO_2/FIO_2 < 200, and bilateral infiltrates on chest X-ray that are not due to a cardiac cause (pulmonary wedge pressure <18).
- Diffuse alveolar injury leads to vascular permeability and inflammatory infiltration.
- Ventilator management includes low tidal volumes (<6 mL/kg), maximizing PEEP, lowest possible FIO_2, and permissive hypercapnea.

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20. ANSWER: C

Stridor is a **high-pitched sound** produced by **airflow turbulence** due to **narrowing or obstruction** of the **upper airway**. Stridor is usually inspiratory but may also be biphasic or expiratory in nature. Stridor can vary from sounding like a squeak to a whistling noise. If the stridor is a result of **supraglottic** or **glottis obstruction**, it is present on **inspiration**. **Biphasic** stridor is thought to be a result of obstruction **below the level of the glottis**. Finally, **expiratory stridor** is caused by lesions occurring in the **distal trachea or mainstem bronchi**.

Laryngomalacia is the most common cause of stridor, occuring in about **80% of infants** with stridor due to a congenital laryngeal anomaly. Patients with laryngomalacia have **inspiratory, low-pitched stridor**. The pathophysiology of laryngomalacia is thought to be related to **neuromuscular hypotonia**.

Most cases of laryngomalacia will **resolve on their own before age 2**. Intervention may be required if the stridor is associated with other congenital abnormalities, cyanosis, apnea, or feeding difficulties.

Gastroesophogeal reflux disease may contribute to laryngomalacia by altering laryngeal reflexes and causing mucosal swelling.

The other choices listed may also cause stridor but are less common than laryngomalacia.

Subglottic stenosis in an infant can be **congenital** or more likely is the result of a **prolonged intubation**. If due to prolonged intubation, the laryngeal mucosa can be easily traumatized, leading to chronic changes in airway diameter. Repeated intubations, traumatic intubation, inappropriately large ETTs, or over inflated ETT cuffs may lead to mucosal damage and place the patient at risk of developing subglottic stenosis. Congenital subglottic stenosis is usually due to malformation of the cricoid cartilage, and it is defined as a **cricoid diameter of less than 3.5 mm**.

Vocal cord paresis is another cause of stridor in the neonate. This stridor is described as **inspiratory or biphasic with a high-pitched musical quality**. The causes of vocal cord paresis can range from idiopathic, birth trauma, central or peripheral neurologic diseases, or thoracic diseases or procedures.

KEY FACTS

- Stridor is a high-pitched sound produced by airflow turbulence due to narrowing or obstruction of the upper airway.
- Supraglottic or glottis obstruction: inspiratory stridor
- Obstruction below level of vocal: biphasic stridor
- Obstruction of distal trachea or mainstem bronchi: expiratory stridor
- Laryngomalacia is the most common cause of stridor; inspiratory, low- pitched stridor resolves by 2 years of age.

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21. ANSWER: D

A fixed airway obstruction will cause flattening of both the inspiratory and expiratory portions of the flow-volume loop. Examples include tracheal or subglottic stenosis, and neck masses causing external compression of the extrathoracic trachea.

A variable intrathoracic obstruction will manifest as flattening of the expiratory part of the flow-volume loop. Examples include intrathoracic tracheal malacia, bronchogenic cysts, or other distal tracheal lesions/masses.

A variable extrathoractic lesion tends to obstruct on inhalation more so than exhalation and will result in flattening of the inhalation component of the flow-volume loop. Examples include laryngomalacia and tracheomalacia of the trachea above the thoracic inlet and vocal cord abnormalities.

KEY FACTS

- Fixed airway obstruction: flattening of both inspiratory expiratory portions of flow-volume loop
- Variable intrathoracic obstruction: flattening of the expiratory part of the flow-volume loop
- Variable extrathoractic lesion: flattening of the inhalation component of the flow-volume loop

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22. ANSWER: D

Cystic fibrosis (CF) is a disease caused by a **genetic mutation on chromosome 7** that encodes for the protein-cystic fibrosis transmembrane conductance regulator (CFTR). The disease is inherited in an **autosomal recessive** manner. The abnormal protein causes altered chloride and ion transport across **epithelial cell membranes**, which affects the **major exocrine glands** in the body. These exocrine glands can have changes such as **increased mucus viscosity, secretion of excessive electrolytes, and abnormal mucociliary clearance**.

The organ systems involved and the severity of the disease are variable among patients. The following changes can, and do, occur:

Respiratory: Chronic cough, increased sputum, bronchiectasis, atelectasis, infiltrates, hyperinflation, wheezing, air trapping, nasal polyps, sinus disease, clubbing, hemoptysis, pneumothorax, infection, or colonization with bacteria such as *Staphlococcus areus, Hemophilus influenzae*, or *Pseudomonas aeruginos*.

Cardiovascular: Cor pulmonale.

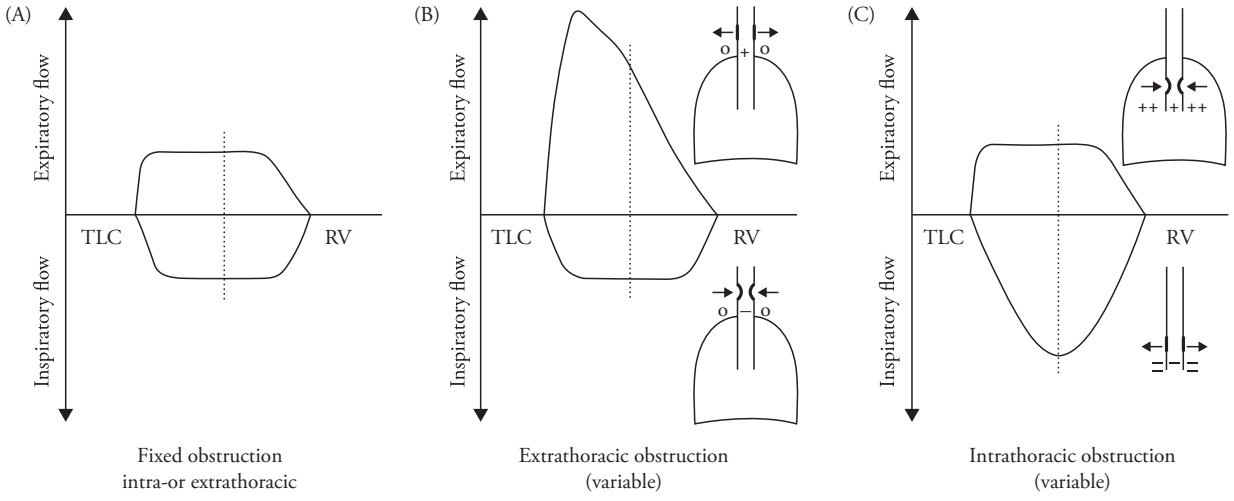

Figure 4.7 Flow-volume curves in fixed and variable obstruction. Fixed upper airway obstruction, variable extrathoracic obstruction, variable intrathoracic obstruction. (Reprinted with permission from Gurvitch DL. Thyrotoxicosis. In: Yao FF, ed. *Yao's and Artusio's Anesthesiology*. 6th ed. Philadelphia, PA: Lippincott Williams & Wilkins; 2008.)

Gastrointestinal: Pancreatic exocrine deficiency affecting intestinal malabsorption, carbohydrate intolerance leading to insulin-dependent diabetes, meconium ileus.

Hepatobiliary: Focal biliarycirrhosis leading to progressive liver damage and liver cirrhosis; gallbladder involvement is common.

Urogenital: Males: obstructive azoospermia causing infertility; females: abnormal mucus may act as a barrier to sperm penetration.

Musculoskeletal: Osteopenia/osteoporosis, pulmonary hypertrophic osteoarthropathy.

Integument: Chronic salt loss.

Social: The severity of the disease and the rate of decline can obviously place significant psychological stress on patients and their families. CF can greatly impact their quality of life.

The respiratory system is the main cause of morbidity and mortality in CF patients. Thick mucus results in obstruction of the small airways. Bronchial obstruction ultimately leads to inflammation and puts the lungs at risk for infection. The long-standing infection and inflammation leads to bronchiectasis. The usual respiratory findings in patients with CF are recurrent and chronic infection, chronic cough, and wheezing. As the disease progresses, the chronic cough is often paroxysmal and productive.

The goals of treatment of CF are to maintain growth and nutrition, slow the decline of pulmonary function, and to support measures to maintain a reasonable quality of life.

KEY FACTS

- CF is an autosomal recessive disease caused by a genetic mutation on chromosome 7.
- CF alters chloride and ion transport across epithelial cell membranes, which affects the major exocrine glands in the body.
- CF involves increased mucus viscosity, secretion of excessive electrolytes, and abnormal mucociliary clearance.

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23. ANSWER: D

Esophageal foreign body ingestions usually occur in children between the ages of **6 months and 3 years**. Only about 10%–20% of foreign bodies will require **procedural intervention** for removal. Most will pass through the gastrointestinal tract spontaneously. Esophageal foreign bodies tend to lodge in areas of physiologic narrowing and **can cause airway compression** if the foreign body is lodged at the level of the **cricoid cartilage** or the **carina**.

Airway foreign body aspiration, similarly to foreign body ingestion, commonly occurs between the ages of **1 and 3 years**. About 95% of foreign bodies will lodge in the right mainstem bronchus. Patients can present with **wheezing, persistent cough, abnormal voice, and stridor**. If there is complete or near complete obstruction of the airways, **tachypnea, cyanosis, and unconsciousness** will occur. Chest X-ray may be normal or display air trapping.

Anesthetic management in both esophageal and airway foreign bodies depends on the clinical status of the patient, the location of the object, and the length of time it has been in place. A major point of discussion is whether to control ventilation or to **maintain spontaneous ventilation**. Often in the presence of an airway foreign body, regardless of NPO time, the goal of induction of anesthesia is to maintain spontaneous ventilation. This can be achieved with volatile anesthetics or with a TIVA technique. In cases of **complete airway occlusion, needle cricothyroidotomy and transtracheal jet ventilation** may also bypass the obstruction. Endotracheal intubation with the goal of using the ETT to push the object into the right mainstem may allow the left lung to be ventilated.

The differential diagnosis of upper airway obstruction includes the following:

- Airway foreign body
- Esophageal foreign body

Infectious processes:

- Tracheitis
- Epiglottitis
- Croup
- Retropharyngeal abscess
- Peritonsiallar abscess
- Mononucleosis
- Trauma and burns

Edema:

- Anaphylaxis
- Hereditary angioedema
- Vocal cord dysfunction

KEY FACTS

- An esophageal foreign body (6 months–3 years old) can cause airway compression if at the level of the cricoid cartilage or the carina.

- Airway foreign body aspiration (1–3 years old): symptoms of wheezing, persistent cough, abnormal voice, and stridor, tachypnea, cyanosis, and unconsciousness
- The goal of anesthetic management for airway foreign bodies is to maintain spontaneous ventilation.

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24. ANSWER: B

Asthma is one of the most common chronic diseases of childhood. The most common symptoms of asthma are **wheezing and cough**. The pathophysiology of asthma includes **chronic inflammatory changes, airway hyperresponsiveness, and bronchoconstriction**, causing **reversible obstruction**. Cold weather, exercise, seasonal and environment allergens, tobacco smoke exposure, and viral upper respiratory infections are all common precipitating factors for developing an acute asthma exacerbation. Beta-2 receptors are found in the smooth muscle of the airways. Activation of Beta-2 receptors leads to bronchodilatation. Asthma is classified by severity. **Severity** is determined **by frequency of symptoms** and by **measuring FEV1**. Long-term pharmacologic management is guided by severity.

Preoperative evaluation of a patient with asthma should include an understanding of the **severity of the patient's disease, current medications, provoking factors, and establishing the time of the most recent acute event**. Patients should be counseled to continue their usual medications leading up to surgery. Postponing elective surgeries during an acute or very recent asthma exacerbation may be warranted.

Induction and emergence from anesthesia should be designed to limit airway irritation. LMA use instead of ETT use, consideration for deep extubation, and maintenance of a deep plane of anesthesia are strategies used in the perioperative period to avoid bronchospasm. Intraoperatively, patients with asthma may require **ventilation strategies to account for increased airway resistance**. Intraopertive bronchospasm can be treated **with inhaled beta agonists**. **Volatile anesthestics** such as isoflurane or sevoflurane **produce bronchodilatation** and **suppress airway reflexes**. They can be helpful during intraoperative management of an asthma exacerbation. If there is little or no response to inhaled beta agonists, **systemic corticosteroids** should be administered. **Epinephrine is a potent beta agonist** and should be given intravenously in **severe refractory asthma.** During an acute intraoperative event, mechanical ventilation goals should allow for a **long expiratory time**. In a severe case of bronchospasm the main goal of ventilation should be to maintain at least **low normal oxygenation**. Aggressive attempts at ventilating to normalize PCO_2 may result in barotrauma or air trapping. If the patient has a long history of steroid use, he or she may be at risk for iatrogenic adrenal insuffiency in the perioperative period and may require stress dose steroids.

KEY FACTS

- Asthma: pathophysiology includes chronic inflammatory changes, airway hyperresponsiveness, bronchoconstriction, and reversible obstruction.
- Severity is determined by frequency of symptoms and by measuring FEV1.
- Ventilation strategies need to account for increased airway resistance using longer expiratory times.

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5.

CARDIOVASCULAR SYSTEM

Audrius Zibaitis, Tomas Walsh, David A. August, Jamie Rubin, Vincent Collard, Hayden Nguyen, Scott Pritzlaff, and Annette Schure

1. Vascular rings and an interrupted aortic arch are caused by an abnormal development of which of the following embryologic aortic arches?

A. Aortic arches I and II
B. Aortic arches III and IV
C. Aortic arches II and IV
D. Aortic arches IV and VI

2. The largest decrease in pulmonary vascular resistance occurs at what age?

A. In utero between 32 and 36 weeks
B. At birth
C. At 4–6 weeks of age
D. At 6 years of age

3. Which of the following statements regarding the fetal circulation is correct?

A. The fetal circulation is a serial circulation.
B. The combined fetal cardiac output is about 400–425 mL/kg per minute.
C. The left ventricle is the dominant ventricle, providing 60% of the cardiac output.
D. The stroke volume of the right ventricle is about 0.7 mL at term.

4. A transitional atrioventricular (AV) canal is best described by which of the following statements:

A. It is the result of L-looping of the heart tube during the early embryological stages.
B. It is an incomplete AV canal with a primum atrial septic defect (ASD) and a small ventricular septic defect (VSD).
C. It is often associated with a cleft in the tricuspid valve.
D. It has a common AV valve with five bridging leaflets.

5. Which of the following statements describes the pathophysiology of a complete AV canal?

A. Right-sided outflow tract obstruction with right-to-left shunt and cyanosis
B. Ratio of pulmonary blood flow to systemic blood flow dependent on pulmonary and systemic vascular resistances
C. Adequate systemic perfusion is dependent on the presence of a patent ductus arteriosus (PDA).
D. Left-sided outflow tract obstruction with left-to-right shunting and pulmonary overcirculation

6. Which of the following types of total anomalous pulmonary venous return (TAPVR) is most commonly associated with decreased pulmonary venous blood flow?

A. Supracardiac type
B. Cardiac type
C. Infracardiac type
D. Mixed type

7. Endocarditis prophylaxis is indicated for which of the following procedures?

A. Upper endoscopy in 2-year-old boy with muscular VSD
B. Cardiac catherization in 1-year-old boy status post repair of Tetralogy of Fallot at age 2 months
C. Dental rehab procedure in 3-year-old girl status post ASD device closure 8 months ago
D. Dental rehab procedure in 3-year-old girl status post surgical VSD closure 5 months ago without evidence of residual defect

8. Which of the following statements regarding the cardiovascular manifestations in patients with Williams syndrome is true?

A. It is most often associated with subvalvular and valvar pulmonary stenosis,
B. It is commonly associated with endocardial cushion defects.
C. It is an arteriopathy involving mostly the supravalvular ascending aorta, often including coronary ostia and coronaries, but also other arteries.
D. The severity of cardiovascular disease is easily assessed by a preoperative echo.

9. Which of the following statements regarding cardiopulmonary bypass (CPB) in infants and children is correct?

A. Deep hypothermic arrest can be safely used for periods >60 min.
B. Hyperglycemia is common and often requires treatment with insulin.
C. CO_2 is often added to the CPB in order to facilitate alpha stat acid base management.
D. Hemodilution has significant implications for rheology and coagulation.

10. A 5-year-old healthy boy, 25 kg, is undergoing a dental rehab procedure under general anesthesia. After an uncomplicated procedure under isoflurane maintenance, he is reversed with neostigmine and glycopyrrolate. During suctioning of the oropharynx, just prior to extubation, the electrocardiogram (ECG) tracing suddenly changes (see Fig. 5.1).

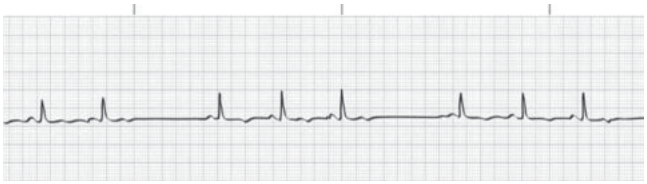

Figure 5.1 Torsades de pointes. (From Brown JD, Lim L, Koning S. Voriconazole associated torsades de pointes in two adult patients with haematological malignancies. *Med Mycol Case Rep*. 2014;4:23–5.)

Which of the following could be appropriate in this situation?

A. Dantrolene 500 mg IV
B. Lipid emulsion 12.5 mL IV
C. Procainamide 375mg IV push
D. Magnesium 0.6–1.2g IV

11. You are managing a 2-week-old preterm infant with a corrected gestational age of 30 weeks for an inguinal hernia. After a successful induction including propofol 3 mg/kg, you note a decrease in arterial blood pressure. You suspect it might be secondary to myocardial depression from the propofol.

Which of the following is a characteristic of the immature myocardium?

A. Reduced number of mitochondria
B. Decreased tolerance to ischemia
C. Limited glycogen storage
D. Rapid ATP depletion

12. A child is being delivered by cesarean section. Which of the following statements is correct regarding his physiology?

A. In utero, the partial pressure of oxygen is 30 mm Hg in the umbilical arteries.
B. In utero, most of the blood from his superior vena cava (SVC) crosses the foramen ovale into the left atrium.
C. The ductus arteriosus will be anatomically closed within 48 hours.
D. The foramen ovale will remain anatomically patent in infancy.

13. You are performing an inhaled induction using sevoflurane and nitrous oxide in a term neonate with a right-to-left intracardiac shunt. The $ETCO_2$ remains stable at 35 during the induction. Which of the following statements is the most accurate to describe the impact of the right-to-left shunt on the wash-in (F_A/F_I) of this inhaled induction?

A. With a right-to-left shunt, using halothane would provide a more rapid wash-in.
B. With a right-to-left shunt, the maximum depth achieved during an inhaled induction is increased.
C. With a right-to-left shunt, the sevoflurane partial pressure in the pulmonary veins is reduced.
D. With a right-to-left shunt, a change in cardiac output would have no effect on the F_A/F_I.

14. You are asked to deliver anesthesia to a 3-week-old requiring a transluminal balloon valvuloplasty of his severely stenotic aortic valve. The echocardiogram demonstrates a hypertrophied left ventricle with low-normal function, with a transaortic valve gradient of 70 mm Hg. Which of the following induction agents would provide the most hemodynamically stable condition for the intubation?

A. Sevoflurane 6%
B. Propofol 3 mg/kg
C. Ketamine 2 mg/kg
D. Etomidate 0.2 mg/kg

15. You are managing a 2-year-old child in the intensive care unit who underwent a resection of large subaortic

muscle band creating severe left ventricular outflow track obstruction. Following an uneventful surgery, he was brought to the intensive care unit with a single vasodilator agent used as treatment for his hypertension. On postoperative day 2, his blood pressure is starting to rise on increasing doses of that same vasodilator. He also demonstrates an increased mixed venous oxygen saturation and a new metabolic acidosis. Which vasodilator is being used in this child?

A. Esmolol
B. Inhaled nitric oxide
C. Sodium nitroprusside
D. Hydralazine

16. You are asked to provide anesthesia for a 3-year-old boy with a large unrepaired ventricular septal defect having a tonsillectomy and adenoidectomy. He has frequent upper respiratory tract infections. He is small for his age. During the mask induction using sevoflurane in 100% oxygen, his vital signs are the following: heart rate 130 beats/min, blood pressure 65/38, and an oxygen saturation of 99%. Which of the following would be your next intervention?

A. Bolus 20 mL/kg of normal saline IV
B. Decrease FiO_2 of oxygen to 0.21
C. Hyperventilate to $ETCO_2$ of 35 mm Hg
D. Give phenylephrine 1 μg/kg IV

17. A child with prenatally diagnosed dextro-transposition of the great arteries with intact ventricular septum is born by cesarean section. The child is immediately transferred to the neonatal intensive care unit. In the intensive care unit, the preductal saturation is 60% and the postductal saturation is 85%. Which of the following statements is true regarding his particular physiology?

A. There is right atrial hypertension.
B. There is retrograde blood flow in the aorta.
C. There is a restrictive intra-atrial communication.
D. The coronary arteries are located on the pulmonary arteries.

18. A 2-month-old presents for a g-tube insertion for failure to thrive. He was born with tricuspid atresia type Ib and was palliated at birth with a 4 mm modified Blalock-Taussig shunt. His vital signs are an oxygen saturation of 70%, a respiratory rate of 30, and a blood pressure of 70/35 mm Hg. Which of the following is correct regarding his coronary perfusion?

A. The coronary perfusion is derived from the modified Blalock-Taussig shunt.
B. The coronaries are perfused by retrograde flow from the modified Blalock-Taussig shunt.
C. The Blalock-Taussig shunt decreases the diastolic aortic blood pressure.
D. The coronary perfusion only occurs during systole.

19. You are asked to provide anesthesia for a 5-day-old term infant with an acute volvulus. As you are evaluating the child, you learn that he has suffered meconium aspiration. His echocardiogram shows an anatomically normal heart but with persistent pulmonary hypertension of the newborn with right-to-left shunting at the level of the foramen ovale. Which of the following therapeutic interventions would help manage the pulmonary hypertension intraoperatively?

A. Prostaglandin E1
B. Inhaled nitric oxide
C. Hypothermia to 34°C
D. 100% oxygen

20. You are evaluating a 7-year-old boy with Trisomy 21 awaiting dental extractions. At 2 months of age, he had a ventricular septal defect closure with Gore-tex as well as a transannular patch using pericardium. On his recent echocardiogram, there is evidence of a small, hemodynamically insignificant residual ventricular septal defect. He is allergic to penicillin (angioedema). What would be your preferred choice for antibiotic prophylaxis to be given 30–60 min prior to the procedure?

A. Amoxicillin 50 mg/kg IV
B. Azithromycin 50 mg/kg IV
C. Clindamycin 20 mg/kg IV
D. Ciprofloxacin 10 mg/kg IV

21. A 9-year-old boy is brought to the operating room for an emergency appendectomy. During your preoperative evaluation, you are informed by the parents that he is followed in cardiology for a hypertrophic cardiomyopathy. He is clinically asymptomatic with no history of syncope, palpitation, or chest pain. On exam, you note a prominent apical impulse with a 4/6 systolic ejection murmur louder with Valsalva. Which of the following medications would most likely be part of his medical therapy?

A. Metoprolol
B. Digoxin
C. Spironolactone
D. Enalapril

22. A 7-year-old boy has presented to the emergency department with dyspnea and tachypnea. He also complains of fatigue, loss of weight, and night sweats. His

vitals signs are as follows: a heart rate of 140 beats/min, a blood pressure of 72/35 mm Hg, an oxygen saturation of 96% on room air, and a respiratory rate of 40 breaths/min. The emergency room team suspects a pericardial effusion secondary to a possible lymphoma. Which of the following could be a sign found in a patient with tamponade?

A. Pulsus tardus et parvus
B. Pulsus bisferiens
C. Pulsus paradoxus
D. Pulsus alternans

23. A 1-day-old female is born with intracardiac lesions detected on prenatal ultrasound. A brain magnetic resonance image (MRI) has been ordered by the neonatologist for probable diagnosis of tuberous sclerosis complex. The patient is transferred from the neonatal intensive care unit to the MRI scanner on room air and without apparent distress. What is the appropriate action?

A. Induction with propofol 2 mg/kg and rocuronium 1 mg/kg
B. Delay case for further assessment
C. Inhalational induction with oxygen and sevoflurane
D. Sedation using dexmedetomidine

24. A 4-year-old male with long QT syndrome is undergoing general anesthesia for left orchiopexy. The patient has been followed by a pediatric cardiologist in the outpatient setting and is currently taking oral propanolol. What is an appropriate management for this patient?

A. Premedication with ketamine 4 mg/kg PO to relieve anxiety and stress
B. Place an IV while awake for induction in order to quickly treat arrhythmia.
C. The procedure can be performed in an outpatient surgery unit because the patient is currently taking oral beta-blocker.
D. Keep temperature at 37°C during surgery.

25. A 13-year-old female with idiopathic cardiomyopathy is undergoing general anesthesia for an orthotopic heart transplant. Following separation from cardiopulmonary bypass with milrinone and epinephrine infusions, the following is noted: a heart rate of 98 beats/minute, a radial blood pressure of 72/38, a central venous pressure of 18 mm Hg, and a distended right ventricle noted on direct visualization. The most prudent intervention would be:

A. Start inhaled nitric oxide
B. Request for a volume bolus through the aortic cannula
C. Start phenylephrine infusion to improve systemic blood pressure
D. Atrial pacing at 120 beats/minute

26. A 2-day-old newborn with diagnosis of Tetralogy of Fallot and absent pulmonary valve presents for complete surgical repair. Patient has significant respiratory distress requiring intubation and positive pressure ventilation in the cardiac intensive care unit. What would be the most likely potential complication after a successful complete repair?

A. Respiratory failure secondary to tracheobronchomalacia
B. Right ventricle failure
C. Significant pulmonary hypertension
D. Pulmonary edema related to overcirculation

27. A 7-day-old newborn with hypoplastic left heart syndrome (HLHS) presents for Norwood stage I palliation with a modified Blalock-Taussig shunt (mBTS). Prostaglandin E1 (PGE1) infusion is infusing at 0.01 μg/kg per minute. Vitals include spontaneous respiration rate of 40–50 breaths/min, heart rate of 149 beats/min, blood pressure 53/29 mm Hg, preductal oxygen saturation of 89%, lactate 0.8 mmol/L, and urine output of 0.5 mL/kg per hour overnight. What is the appropriate care for this patient?

A. Oxygen supplement via facemask for transport to the operating room
B. Give 20 cc/kg fluid bolus for marginal blood pressure and low urine output upon arrival to the operating room.
C. Avoid hypocapnea during transport and prior to CPB
D. Give packed red blood cells for Hct 35% prior to CPB

28. A 6-day-old boy with HLHS is undergoing Norwood stage I palliation with a modified Blalock-Taussig shunt. While coming off CPB with milrinone and epinephrine infusions, excessive hypoxemia is noted despite maximal ventilatory support. Heart rate at 150 beats/min, arterial blood pressure of 60/32 mm Hg, VBG of pH 7.36, PCO_2 43 mm Hg SvO_2 17 mm Hg HCO_3 25 mEq/L, lactate 1.6 mEq/L, and Hct 33% after modified ultrafiltration. What is the next appropriate intervention?

A. Increase inotropic support.
B. Transfuse to keep Hct > 40%.
C. Hyperventilate to achieve hypocarpnia.
D. Give sodium bicarbonate.

29. A 9-year-old with Williams syndrome is undergoing general anesthesia for repair of supraaortic and suprapulmonary stenoses. Upon coming off CPB with milrinone and epinephrine infusions, the patient shows evidence of hypotension despite escalating inotropic support. Soon after, the ECG shows evidence of ST depression with trending bradycardia. What is the most appropriate intervention?

A. Give epinephrine IV bolus.
B. Come back onto bypass.
C. Give red blood cells for better oxygen-carrying capacity.
D. Start nitric oxide to better support the RV.

30. A newborn with interrupted aortic arch undergoes complete repair and arch reconstruction. Which strategy can be used to decrease risk of neurological injuries during and after deep hypothermic circulatory arrest?

A. Hemodilution with hematocrit of 15%
B. Alpha stat blood gas strategy
C. Prevent hyperthermia immediately post circulatory arrest.
D. Give calcium.

31. A 6-month-old male with Trisomy 21 status post VSD patch closure 2 weeks ago presents for pacemaker placement. His underlying rhythm is shown in Figure 5.2. What should be the appropriate mode for epicardial pacing?

A. AAI
B. VOO
C. AOO
D. DDD

Figure 5.2 Functional SA node with AV Block.

32. A 1-day-old male with critical aortic stenosis presents to cath lab for hemodynamics and transluminal balloon valvuloplasty. The patient is breathing spontaneously on room air with a heart rate of 140 bpm and a noninvasive blood pressure of 60/29. PGE1 is running at 0.01 μg/kg per minute. What is an appropriate action for management?

A. Induction with propofol 2 mg/kg, fentanyl 1 μg/kg, and rocuronium 1 mg/kg
B. Conscious sedation with ketamine 0.5 mg/kg boluses to maintain hemodynamics
C. Turn off PGE1 because it can cause apnea and may lead to diastolic runoff.
D. Support cardiac contractility using dopamine infusion during the procedure.

33. A 21-year-old female with a history of Trisomy 21 and unbalanced atrioventricular septal defect status post nonfenestrated Fontan completion is undergoing general anesthesia for cardiac MRI. The patient is having dyspnea on exertion. Labs are within normal limit with hematocrit of 35%. Prior to induction of an anesthesia using etomidate, fentanyl, and rocuronium, what would be the most appropriate action?

A. Control potential reflex tachycardia with esmolol 1 mg/kg.
B. Start a dopamine infusion.
C. Reduce FiO_2 to prevent pulmonary overcirculation.
D. Give red blood cells to improve oxygen-carrying capacity.

34. You are called to assist a previously healthy 9-month-old male admitted for symptoms of upper respiratory infection. Upon arrival, the patient appears obtunded with continuous monitoring showing low oxygen saturation and decreasing heart rate. What is the most appropriate immediate intervention?

A. Intravenous (IV) epinephrine
B. Chest compressions
C. Supplemental oxygen and assist ventilation
D. Obtain autonomic external defibrillator (AED) device

35. Intraoperative considerations for children undergoing cardiac transplant include which of the following:

A. Permissive hypercarbia prior to placing patient on cardiopulmonary bypass
B. Preferential use of epinephrine and isoproterenol over atropine and ephedrine for chronotropic and inotropic support
C. Maintenance of anesthesia with isoflurane and nitrous oxide
D. Routine placement of a pulmonary artery catheter over use of transesophageal echocardiography for intraoperative monitoring

36. Which of the following is a critical test used to determine suitability for cardiac transplant:

A. Pulmonary Vascular Resistance Index
B. Holter monitoring
C. Echocardiogram
D. Chest radiograph

37. The most common significant arrhythmia seen in infants and children is:

A. Long QT syndrome
B. Ventricular tachycardia
C. Supraventricular tachycardia
D. Ventricular fibrillation

38. Proper management of a child with a pacemaker in the operating room includes which of the following?

A. Avoidance of unipolar cautery
B. Positioning of the indifferent plate for electrocautery close to the pacemaker so the device is between the electrodes
C. Interrogation and activation of rate-responsive features prior to surgery
D. Use of a harmonic scalpel or battery-operated hot wire hand-held cautery

39. The most common primary cardiac tumor in children is:

A. Atrial myxomas
B. Cardiac fibromas
C. Rhabdomyomas
D. Teratomas

40. Cardiac tumors in children:

A. Are usually only found in the left atrium
B. Always require surgical excision, especially rhabdomyomas
C. Have been associated with congenital abnormalities such as tuberous sclerosis
D. May impact ventricular filling but are not associated with arrhythmias

41. A 6-year-old girl with known hypertrophic cardiomyopathy (HCM) is presenting for inguinal hernia repair. She is followed by a pediatric cardiologist and is otherwise well. She has no difficulty participating in school activities. Optimal anesthetic management of this child with HCM would include the following:

A. Heart rate control with calcium channel blockers and β blockers as required
B. Permissive hypotension on induction
C. Decreasing preload with diuretics
D. Infusion of inotropes during surgery

42. An important characteristic that distinguishes dilated cardiomyopathy (DCM) from hypertrophic cardiomyopathy (HCM) includes:

A. Patients with DCM typically have a volume-loaded, poorly contractile ventricle.
B. HCM is frequently caused by a genetic defect, whereas DCM is only acquired.
C. Increasing preload in DCM is the hallmark treatment for acute symptom control.
D. Beta blockade is contraindicated in DCM but not in HCM.

43. In a child with known pulmonary hypertension, which of the following factors may lead to acute right ventricular failure if not adequately managed in the perioperative period:

A. Alkalemia
B. Hypocarbia
C. Transmitted positive airway pressure
D. Hyperthermia

44. Inhaled nitric oxide (NO) may be utilized in cases of refractory persistent pulmonary hypertension of the newborn (PPHN). The mechanism by which NO decreases hypoxemia is related to:

A. Increased levels of cAMP in systemic vasculature
B. Nonselective vasodilation of pulmonary vasculature
C. Induction of phosphodiesterase activity
D. Increased levels of cGMP in smooth muscle

45. Routine prophylactic administration of antibiotics prior to surgical procedures is recommended in which situation?

A. A 13-year-old with congenital heart disease undergoing a genitourinary or gastrointestinal procedure
B. A 9-month-old infant born with ventriculoseptal defect, which was completely without prosthetic material or residual defect repaired at 2 months of life
C. A 10-year-old with a history of cardiac transplantation and known valvulopathy
D. A 3-year-old child with recurrent episodes of *Staphylococcus* pharyngitis

46. Diagnostic criteria for Kawasaki disease in a child with persistent fever include which of the following:

A. Hepatosplenomegaly
B. Bilateral exudative conjunctivitis
C. Oral changes including strawberry tongue
D. Aseptic meningitis

47. The following is true of children afflicted by myocarditis:

A. Approximately one-half of patients with overt heart failure eventually will require heart transplantation.
B. Herpes viruses are the most common cause of this disease.
C. Aggressive therapy with inotropic agents is the gold standard treatment.
D. Cardiac biopsy reveals myocyte necrosis and degeneration.

48. Rheumatic heart disease:

A. Results from infection by group B nonhemolytic *Streptococcus*
B. Typically occurs in children ages 1 to 5 years of age
C. Occurs in approximately 50% of children with their first attack of rheumatic fever
D. Frequently involves the valves of the right heart

49. Anesthetic management for a child presenting acutely with a malignant pericardial effusion includes:

A. Induction with propofol
B. Expeditious use of positive pressure ventilation if possible
C. Infusion of catecholamines such as dopamine or isoproterenol
D. Fluid restriction to avoid prevent pulmonary edema

50. Pulsus paradoxus seen in pericardial effusion and tamponade:

A. Can be defined as a decrease in systolic blood pressure >10 mm Hg during exhalation
B. Suggests significant impairment in systolic ejection of the left ventricle
C. Is associated with tachycardia and peripheral vasoconstriction
D. Is seen in a majority of patients with chronic effusion

51. A 3-month old, 6 kg male infant is undergoing Stage 1 ("Norwood Procedure") of the Fontan palliation for hypoplastic left heart syndrome. The patient has been on a PGE1 infusion since birth. After induction, vitals show a pulse of 160 beat per minute, blood pressure of 58/35 mm Hg, and SpO_2 of 75%. Which of the following actions should be taken to prevent decompensation of the infant?

A. Increase the FiO_2 since this patient is already hypoperfused due to arterial-venous admixing
B. Hypoventilate to lower pulmonary vascular resistance
C. Allow hypoxemia and hypercarbia
D. Cannulate for ECMO

52. A 36-week fetus is scheduled to undergo EXIT procedure to facilitate airway access due to a cervical teratoma found on prenatal ultrasound. The mother is induced and intubated uneventfully. The uterine incision is made, and a moment later, the anesthesiologist attempts to place an endotracheal tube in the fetus. Which of the following is the most important aspect of obstetric anesthesia to ensure safe delivery of the infant?

A. Avoidance of maternal muscle relaxant to ensure fetal tone is maintained
B. Maintaining uterine tone to prevent maternal hemorrhage and fetal hypoxia
C. Ensuring full relaxation of the uterus to facilitate delivery
D. Full delivery of the infant to ensure adequate access to the airway

53. A 2-year-old girl with Tetralogy of Fallot is being induced for cardiac surgery. Her blood pressure falls on induction and she appears cyanotic. Her legs are raised off the table and phenylephrine is administered as a bolus. The benefit of phenylephrine in this circulation is derived from:

A. Reduction of afterload to facilitate forward flow
B. Decreasing right-to-left shunting, allowing for improved outflow of oxygenated blood
C. Allowing more blood to be sent to the pulmonary arteries by increasing right-sided venous return
D. Inotropic stimulation of myocardium

54. Which of the following best describes the effects of dopamine on the pediatric heart?

A. Dopamine has no chronotropic effects.
B. Dopamine has a predictable effect for a given dose.
C. Dopamine does not cause clinically significant arrhythmias.
D. Dopamine causes increased renal and mesenteric perfusion.

55. A 37-week newborn weighing less than 1500 grams at birth is classified as:

A. Low birth weight (LBW) infant
B. Large for gestational age (LGA) infant
C. Preterm infant
D. Very low birth weight (VLBW) infant

56. When does a full-term infant have the highest heart rate at rest?

A. First 24 hours after birth
B. Three months after birth

C. One month after birth
D. Six months after birth

57. A 1-hour-old infant is taken emergently to the operating room for fasciotomy for compartment syndrome after being delivered with the cord wrapped around the right foot. Which of the following best describes the transitional circulation of a 1-hour-old infant?

A. There is reversed flow in the ductus arteriosus compared to fetal circulation.
B. The ductus venosus is completely closed.
C. There is flow from right to left through the foramen ovale.
D. Pulmonary arterial resistance is not affected by hypercapnia.

58. A 6-month-old, 10 kg infant is taken to the operating room for suspected intussusception. The infant is febrile, tachycardic, and irritable. Just prior to induction, the ECG tracing shows a change in heart rhythm from normal sinus rhythm to supraventricular tachycardia. Which of the following is an appropriate treatment?

A. Defibrillation with 2 J/kg
B. Amiodarone 1–2.5 mg/kg
C. Adenosine 0.1 mg/kg
D. Magnesium sulfate 25–50 mg/kg

59. A 6-year-old child goes on to cardiopulmonary bypass (CPB) for repair of a congenital bicuspid aortic valve. Which of the following agents or techniques is the most likely to cause serious complications during CPB?

A. Isoflurane induction
B. Nitrous oxide
C. Sevoflurane
D. Desflurane

60. A 1-month-old infant with critical aortic stenosis is undergoing induction of anesthesia for aortic valve repair. The major problem with using ketamine in this patient comes from risk of:

A. Poor analgesia
B. Dysphoria
C. Tachycardia and arrhythmia
D. Hypersalivation

61. A 16-year-old runner collapses during a half-marathon. He is transferred to a tertiary care center, where he is in stable condition. Transesopageal echocardiography shows ventricular hypertrophy. The left ventricular outflow tract displays obstruction, with moderate mitral regurgitation and systolic anterior motion of the mitral valve. Before the procedure is completed, the patient begins to cough and move spontaneously. He develops sinus tachycardia to 140 and his blood pressure falls to 70/40. Immediate treatment with which of the following is likely to restore systolic blood pressure?

A. Esmolol
B. Adenosine
C. Phenylephrine
D. Lidocaine

62. A 6-year-old child with Down syndrome is taken into the GI suite for upper endoscopy to investigate chronic abdominal pain and gastroesophageal reflux. The child has a known ventricular septal defect, but it has not been well characterized and no records are available. He has grown well and the parents report he plays well with his older brother. Assuming the case proceeds, which of the following is most likely to manifest during IV induction?

A. Induction is likely to be faster since there is a right-to-left shunt.
B. There is likely a left-to-right shunt, which will have little bearing on induction speed.
C. Eisenmenger's syndrome is a major concern.
D. Ventricular septal defect has no bearing on induction speed.

63. Which statement regarding the pulmonary vascular development is correct?

A. Pulmonary vasculature development is complete at birth.
B. Pulmonary vasculature development is complete after the first few years of life.
C. Pulmonary hypertension episodes do not happen in full-term neonates.
D. Persistent fetal circulation rarely causes life-threatening issues.

64. Which features are characteristic of the neonatal heart?

A. Myocytes comprise 50% of neonatal heart elements versus 60% in the adult heart.
B. Sarcoplasmic reticulum and T tubule network are well developed.
C. Contains an increased number of mitochondria
D. Increased dependence on extracellular ionized calcium for contractile performance

65. A premature infant is delivered at 34 weeks gestation. Vitals signs are pulse 170, blood pressure 55/35, and respiratory rate 40. The main reason why inotropic medications are less helpful in infants is:

A. Rapid heart rate creates nonlaminar flow, which limits output.
B. The heart is stiff and already pumps at near-maximal output.
C. The immature B1 receptors do not respond to inotropic medications.
D. Strong vagal tone limits the response to exogenous administration.

66. A 1-day-old infant starts crying and develops central cyanosis. Patient is noted to have abnormal facies and cleft palate. Venous blood sample reveals low serum calcium level. Transthoracic cardiac ultrasound study shows severely narrowed pulmonary artery, right ventricular hypertrophy, a large VSD, and overriding aorta. Which of the following medications are indicated for this patient?

A. Prostacyclin
B. Epinephrine
C. Prostaglandin E1
D. Inhaled nitric oxide

67. An intraoperative transesophageal echocardiography is shown in Figure 5.3. What is the diagnosis?

A. Atrial septal defect
B. Ventricular septic defect
C. Systolic anterior motion
D. Tetralogy of Fallot

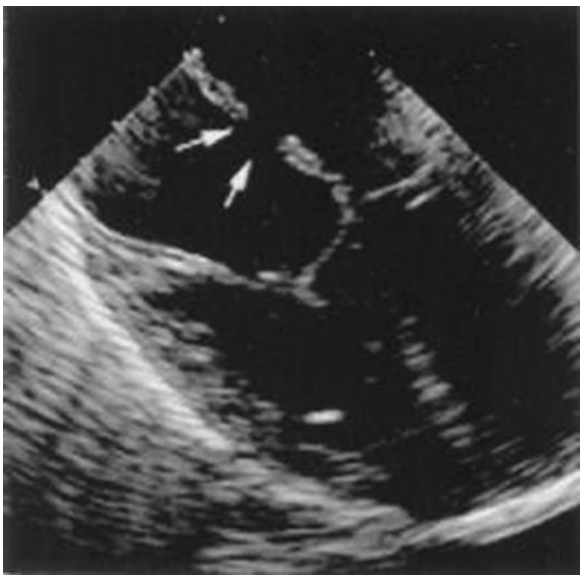

Figure 5.3 Central defect in the atrial septum (arrows), typical of a secumdum atrial septal defect, seen in the midesophageal four-chamber view. (From Perrino AC, Reeves ST, eds. *A Practical Approach to Transesophageal Echocardiography*. New York, NY: Lippincott, Williams and Wilkins; 2003: Rouine-Rapp K and Miller-Hance WC. Chapter 18. Transesophageal Echocardiography for Congenital Heart Disease in the Adult. Page 288. Reprinted with permission.)

68. An 8-year-old girl presents to the preop anesthesia clinic for evaluation of the need for periprocedural antibiotics for work on an impacted molar. She has a history of congenital heart disease. Records indicate she had an atrial septal defect that was repaired with a Teflon graft when she was 9 months old. Which of the following describes the most appropriate choice regarding her antibiotics selection?

A. Oral amoxicillin is indicated.
B. Vancomycin is indicated due to the Teflon graft.
C. Antibiotics are required if dental prosthetics are to be installed.
D. Antibiotics are not indicated.

69. A healthy 25-year-old woman at term gestation with a normal fetus undergoes rapid sequence induction and intubation for suspected placental abruption. Which of the following medications, when administered via IV to the mother, is a major concern with regard to the newborn?

A. Propofol
B. Remifentanil
C. Succinylcholine
D. Rocuronium

70. A 12-month-old, 10 kg male presents for circumcision. Shortly after injection of 20 mg bupivicaine 0.25% with epinephrine into the caudal space, ventricular tachycardia develops. Local anesthetic systemic toxicity is suspected. CPR is begun and intralipid is administered. Which of the following most accurately describes the reason for cardiovascular collapse?

A. Activation of parasympathetic tone resulting in conduction irregularity
B. Sodium channel blockade
C. Anaphylactic response
D. Hyperkalemia from muscular toxicity

71. A 16-year-old girl has a history of heart transplantation at age of 11 due to restrictive cardiomyopathy. Which of the following is the most likely cause of death at 12 years following transplant?

A. Infection
B. Rejection
C. Coronary artery disease
D. Multiorgan failure

72. An otherwise-healthy 16-year-old child is taken emergently to the operating theater immediately after suffering a 50% total body burn from a house fire. Rapid sequence induction is performed, including paralysis

succinylcholine 3 mg/kg coadministered with atropine 0.02%. Which of the following is true regarding use of succinycholine in this situation?

A. The risk of myoglobinuria from succinylcholine is increased in this patient.
B. In new burns, the risk of hyperkalemia from succinylcholine increases.
C. Succinylcholine is probably safe for use in this patient.
D. Cisatracurium would be a better choice of neuromuscular blocker.

73. Which of the following are normal ECG patterns of healthy infants as compared to adults?

A. Prolonged PR interval
B. Inverted right precordial T waves
C. Wider QRS complexes
D. Prolonged QT interval

74. Predictors for increased mortality in propofol infusion syndrome (PRIS) include:

A. Female gender
B. Patients older than 18 years
C. A propofol infusion lasting more than 48 hours
D. Respiratory acidosis

75. Which of the following patients would require bacterial endocarditis prophylaxis before a dental procedure under anesthesia?

A. A child who had surgical patch-repair of an ASD 1 year ago
B. A child who had a device closure of an ASD in the cardiac catheterization lab 8 months ago
C. A child who had surgical ASD repair 2 years ago whose echocardiogram shows a leak at the patch site
D. A child with left-to-right flow through an unrepaired ASD

76. A newborn is undergoing repair of transposition of the great arteries. The surgeon plans to use deep hypothermic circulatory arrest (DHCA) during the repair. Which statement about arterial blood gas (ABG) management during DHCA in pediatric heart surgery is true?

A. Using pH-stat management may require raising the sweep gas rate.
B. DHCA results in a more acidotic pH on the ABG.
C. Alpha-stat management provides better neurological outcomes than pH-stat.
D. If pH-stat management is used, arterial blood gas samples are heated to 37 degrees before analysis.

77. A newborn is undergoing deep hypothermic circulatory arrest (DHCA) to facilitate repair of a congenital heart defect. Which of the following is true regarding the effects of DHCA on neurodevelopmental outcome?

A. Ice packs should be applied to the patient's head during cooling and DHCA.
B. Methylprednisolone given immediately before DHCA improves neurological outcome.
C. The surgeon should limit DHCA intervals to 40 minutes at a time.
D. Significantly worse neurodevelopmental outcomes occur when DHCA exceeds 12 minutes.

78. A 3-year-old, 15 kg boy is undergoing a Fontan procedure. During chest closure, he is allowed to breathe spontaneously. An arterial blood gas taken 15 minutes later shows $PaCO_2$ = 61 mm Hg and pH = 7.27. What is the most appropriate ventilation strategy?

A. Continue spontaneous ventilation, which is optimal for Fontan patients
B. Volume-controlled ventilation with tidal volume (Vt) 160 mL, respiratory rate (RR) 20 breaths/min, inspiratory:expiratory (I:E) ratio 1:2, positive end-expiratory pressure (PEEP) 10, and fractional inspired oxygen (FIO_2) 100%
C. Volume-controlled ventilation with Vt 80 mL, RR 18, I:E 1:3, PEEP 5, and FIO_2 100%
D. Pressure-controlled ventilation with peak inspiratory pressure 16 cmH_2O, RR 30, I:E 1:1, PEEP 5, and FIO_2 100%

79. Which of the following statements is true for a neonate undergoing repair of a cyanotic heart lesion compared to an adult undergoing coronary artery bypass grafting (CABG)?

A. The minimum perfusion pressure on cardiopulmonary bypass can be lower in the neonate than in the adult.
B. Dilutional effects from the pump prime are approximately 25% for the adult and 75% for the neonate.
C. Although neonatal-sized bypass cannulae are smaller, they are placed in the same locations as for an adult.
D. Ultrafiltration is frequently used in both adult and neonatal heart surgery.

80. Which statement about the hybrid procedure for hypoplastic left heart syndrome is correct?

A. Ductal stenting, pulmonary artery banding, and creation of an unrestricted intra-atrial septum must be done during the same procedure.
B. The pulmonary artery bands are tightened according to an age- and weight-based formula.
C. During chest closure, inspired oxygen is liberalized to 100%.
D. Hemodynamic instability often occurs during pulmonary artery banding.

81. A 15-year-old male with newly diagnosed Wolff-Parkinson-White syndrome presents for laparoscopic appendectomy. He is not currently on any medications and is otherwise healthy. Upon insufflation of the abdomen he develops a wide complex tachycardia (heart rate 170 beats/min). Blood pressure is 110/70 mm Hg. Which of the following is the best medication to terminate the tachyarrhythmia?

A. Adenosine
B. Procainamide
C. Esmolol
D. Verapamil

82. A 1-year-old is placed on veno-arterial ECMO due to failure to wean from cardiopulmonary bypass after surgical repair of Tetralogy of Fallot. An arterial blood gas 30 minutes later shows pH 7.32, PCO_2 52 mm Hg, PO_2 223 mm Hg. Which of the following actions would reduce this patient's $PaCO_2$?

A. Increase the pump flow rate.
B. Increase the sweep gas rate.
C. Reduce the pump flow rate.
D. Increase the recirculation fraction.

83. A 1-year-old is undergoing surgical repair of Tetralogy of Fallot. Nasal intubation is difficult and requires multiple attempts. Shortly after the endotracheal tube is placed and end-tidal CO_2 is confirmed, the patient abruptly desaturates. Blood pressure is 80/50 mm Hg, and pulse is 120 beats/min. Which of the following would be the best treatment?

A. Milrinone 50 μg/kg
B. Dopamine infusion, 5 μg/kg per minute
C. Albumin 5%, 10 mL/kg
D. Epinephrine 5 μg/kg

84. A 1-year-old child is undergoing elective repair of Tetralogy of Fallot. Her baseline oxygen saturation is 100%. Which of the following would be true regarding the effect of Tetralogy of Fallot on the induction of anesthesia?

A. No significant change in the speed of induction
B. Significantly slower inhalational induction
C. Significantly faster intravenous induction
D. Significantly faster inhalational induction

85. A 580 g, 26-week post-gestational age premature neonate on high-frequency oscillatory ventilation is undergoing repair of a PDA via thoracotomy. Over the course of 15 minutes, the oxygen saturation drops from 95% to 82%. To improve the saturation, the most appropriate management is:

A. Increase the oscillation amplitude to better recruit alveoli.
B. Immediately switch to a conventional ventilator.
C. Request that the surgeon remove the retractor to allow lung expansion.
D. Place a 3 French Fogarty balloon catheter as a bronchial blocker.

86. A 1-week-old full-term newborn who has pulmonary atresia with an intact ventricular septum (PA/IVS) is undergoing a diagnostic cardiac catheterization in preparation for surgery. Shortly after induction, the blood pressure falls from 68/50 mm Hg to 52/30 mm Hg. Pulse-oximetry reads 82%. Which would be the *most* appropriate way to improve blood pressure?

A. Administer a normal saline bolus to raise filling pressures.
B. Reduce the inspired oxygen to limit "pulmonary steal" flow through multiple aortopulmonary collaterals.
C. Give nitroglycerin to decompress the right ventricle and reduce wall-tension related ischemia.
D. Initiate a prostaglandin E1 (PGE1) infusion.

87. A 30-year-old male with cholelithiasis needs a laparoscopic cholecystectomy. He has a history of Tetralogy of Fallot with total repair in infancy. Which of the following abnormalities is he most likely to have?

A. Tricuspid stenosis
B. Pulmonary regurgitation
C. Aortic stenosis
D. Mitral regurgitation

88. A 3-year-old is getting a ventricular septal defect repair. During cardiopulmonary bypass, the regional oxygen saturation displayed on the near-infrared spectroscopy (NIRS) monitor drops from 75% to 58%. Which of the following actions would increase the saturation measured by the NIRS monitor?

A. Reducing the amount of volatile agent added into the bypass circuit
B. Warming the patient from 35°C to normal body temperature
C. Lowering the cardiopulmonary bypass pump flow
D. Reducing the sweep gas rate

89. A 24-year-old woman adopted from another country presents with severe knee pain and is also discovered to have a VSD with Eisenmenger physiology. In planning the anesthesia for her upcoming repair of a complete anterior cruciate ligament tear, which statement is true?

A. Phenylephrine should be avoided due to its pulmonary vasoconstrictive constrictive effects.
B. A mixture of air and oxygen may be used.
C. Regional anesthesia is avoided due to increased perioperative mortality.
D. Her cardiac output should be monitored with a pulmonary artery catheter during surgery.

90. A 4-year-old 15 kg male with Williams syndrome presents for a robotic-assisted laparoscopic bilateral ureteral reimplantation for vesicoureteral reflux. His most recent echocardiogram demonstrates mild supravalvular aortic stenosis, moderate left ventricular hypertrophy, and normal biventricular function. Anesthesia is induced with inhaled sevoflurane and intravenous access is obtained. After 20 mg of propofol is given to facilitate intubation, deep ST-segment depressions are noted on the ECG, followed quickly by bradycardia and pulseless electrical activity. What is the *most* likely etiology for this cardiovascular collapse?

A. Myocardial ischemia associated with undiagnosed coronary artery anomalies
B. Acute right ventricular failure associated with undiagnosed pulmonary hypertension
C. Complete left ventricular outflow tract obstruction
D. SVT secondary to an undiagnosed accessory conduction pathway

91. A 2-year-old boy with Trisomy 21 (Down syndrome) is undergoing repair of a transitional atrioventricular canal defect. Shortly after inhalational induction with sevoflurane, his heart rate falls from 110 to 70 beats/min. Blood pressure is 70/55 mm Hg, and oxygen saturation is 100%. What is the most appropriate management?

A. No treatment indicated
B. Phenylephrine, 1 μg/kg IV
C. Glycopyrrolate, 10 μg/kg IV
D. Reduce the inspired oxygen fraction from 100% to 21%

92. A 1-week-old, full-term baby with infracardiac-type total anomalous pulmonary venous return is separating from cardiopulmonary bypass after full repair. This patient will likely have:

A. Pulmonary overcirculation
B. Inability to tolerate rapid administration of 20 mL/kg of blood products
C. Need for urgent balloon atrial septostomy
D. Ventricular escape rhythms

93. Modified ultrafiltration (MUF) in pediatric heart surgery produces which of the following effects?

A. Lower systemic vascular resistance
B. Long-term reduction of inflammatory cytokines
C. Reduced intraoperative bleeding
D. Increased hematocrit

94. A 14-year-old patient with hypertrophic obstructive cardiomyopathy presents for septal myomectomy. Induction of general anesthesia proceeds uneventfully, but after incision the patient's heart rate jumps from 70 to 110 beats/min, and blood pressure falls to 75/30 mm Hg. Which of the following interventions could actually worsen hemodynamic status of the patient?

A. 500 mL IV bolus of normal saline
B. 10 mg of IV ephedrine
C. 25 mg of IV esmolol
D. 80 μg of IV phenylephrine

95. A full-term, 3 kg child is undergoing a Norwood (Stage 1) operation for hypoplastic left heart syndrome. During the first several minutes after separating from bypass, the oxygen saturation falls from 80% to 68%. $PaCO_2$ is 40 mm Hg, blood pressure is 49/39 mm Hg, pulse is 120 beats/min, and mixed-venous saturation is 32%. Which of the following actions would be the most appropriate treatment?

A. Inhaled nitric oxide at 20 parts/million
B. Increased the inspired oxygen fraction to 100%
C. Dopamine infusion at 8 μg/kg per minute
D. Hyperventilate to achieve a $PaCO_2$ <30 mm Hg

96. An 8-month-old male presents for repair of a large perimembranous VSD. Preoperative echocardiogram demonstrates some pulmonary hypertension and left-to-right flow across the VSD. After an unexpectedly challenging intubation, the oxygen saturation remains at 87% despite confirmation of endotracheal tube placement and adequate ventilation with 100% oxygen and sevoflurane. Which

intervention is most likely to improve this patient's oxygen saturation?

A. Increasing the positive end-expiratory pressure (PEEP)
B. Administering a bolus of phenylephrine
C. Decreasing minute ventilation
D. Administering a blood transfusion

97. An 8-day-old, 3.5 kg female with transposition of the great arteries is undergoing an arterial switch operation. The patient has been off bypass for 20 minutes on dopamine and nitroglycerin infusions. After administering 10 mL/kg of packed red blood cells, the blood pressure rapidly begins to fall. Echocardiogram demonstrates acute onset of global myocardial dysfunction. LA pressure is 10 mm Hg, systolic blood pressure is 35 mm Hg, and RV pressures are increasing. Which of the following is the most appropriate intervention?

A. Stop the nitroglycerin infusion.
B. Aspirate blood from the central line.
C. Administer IV lasix.
D. Administer IV atropine.

98. A 3-week old, full-term male with preductal coarctation of the aorta is scheduled for full repair with resection of the narrowed portion and end-to-end anastomosis. Which of the following interventions will most likely decrease his risk of postoperative paraplegia?

A. Mild hypothermia (34°C–35°C)
B. Administration of furosemide (Lasix) prior to aortic cross clamp
C. Maintenance of femoral mean arterial pressure above 30 mm Hg
D. Hyperventilation to maintain $PaCO_2$ of 25–30 mm Hg

CHAPTER 5 ANSWERS

1. ANSWER: D

During the fourth and fifth week, the most distal part of the truncus arteriosus, called the aortic sac, branches into several symmetric aortic arches, which accompany the pharyngeal arches and their respective cranial nerves. **The arches develop from top to bottom and are not all present at the same time**. They terminate in a left and right dorsal aorta. Theoretically there are six symmetric arches: **arch I develops into the maxillary arteries**, **arch II into the hyoid and stapedial arteries,** and **arch III into the common carotid artery and the first part of the internal carotid artery**. The development of **arch IV is more complex: the left side forms the aorta between the left common carotid artery and the left subclavian artery, and the right side the proximal part of the right subclavian artery**. This explains the different course of the left and right recurrent laryngeal nerves. **Arch V is rudimentary in humans**, either never developing or regressing early. **Arch VI connects with the lung buds. The proximal part of arch VI forms the pulmonary arteries; the distal part regresses on the right, and on the left it forms the ductus arteriosus**. **Abnormal developments of the arches IV and VI form the basis of vascular rings and right-sided, double, and interrupted aortic arches.**

KEY FACTS

- Theoretically there are six symmetric arches.
- The arches develop from top to bottom and are not all present at the same time. They terminate in a left and right dorsal aorta.
- Abnormal developments of the arches IV and VI form the basis of vascular rings and right-sided, double, and interrupted aortic arches.

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2. ANSWER: B

The most dramatic decrease in pulmonary vascular resistance occurs at birth when the lungs are expanded during the first few breaths and exposed to higher levels of oxygen. **Oxygen is a very potent pulmonary vasodilator** (via release of endothelial-derived substances like nitric oxide and prostacyclins). At the same time the ductus arteriosus constricts and, with loss of the low resistance placenta, the systemic vascular resistance increases, reducing the shunt flow and increasing the pulmonary blood flow significantly.

In utero, the lungs are fluid filled and collapsed. In the hypoxic fetal environment (PO_2 in umbilical vein 30 mm Hg), the pulmonary vascular resistance is high, in midgestation about 10 times higher than 24 hours after an uneventful birth, most likely due to immature vasculature and hypoxic pulmonary vasoconstriction.

Over the course of the first few months of life, the pulmonary vascular resistance continues to decrease. Progressive remodeling of the pulmonary vasculature is characterized by increasing arborization with changes in the alveoli/arteriole ratio (from 20:1 at birth to 12:1 at 2 years) but also thinning of the medial muscle layer and extension into the periphery. **During the initial remodeling phase the highly muscularized pulmonary vessels are extremely reactive to a variety of stimuli, especially acidosis, hypoxia, and stress/pain.** A second nadir is reached at about 6–8 weeks, a time when patients with large ventricular septal defects or complete atrioventricular canals typically become increasingly symptomatic and present with congestive heart failure.

The maturation of the pulmonary vasculature continues well into the school years but at a much slower pace.

KEY FACTS

- The most dramatic decrease in pulmonary vascular resistance occurs at birth.
- A second nadir is reached at about 6–8 weeks.
- Oxygen is a very potent pulmonary vasodilator (via release of endothelial-derived substances like nitric oxide and prostacyclins).
- In utero, the lungs are fluid filled and collapsed.
- Over the course of the first few months of life, the pulmonary vascular resistance continues to decrease.

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3. ANSWER: B

To meet the metabolic demands for growth in a hypoxic environment, **the combined fetal cardiac output (CO) is**

approximately 400–425 mL/kg per minute, three times as high as in the adults.

The fetal circulation can be described as a parallel circulation with several shunts (foramen ovale and ductus arteriosus). Both ventricles contribute to the systemic output, **only 10%–15% of the CO reaches the lungs.** After birth the circulation is transitioned to a serial system: two separate pumps, the right and the left ventricle, each supporting a different circulation, pulmonary and systemic circulation with variable resistances. The deoxygenated blood is first pumped through the pulmonary circulation, oxygenated, and then the complete cardiac output is returned to the next pump, the left ventricle, and pumped into the systemic circulation.

The fetal parallel circulation imposes an increased workload for the right ventricle. **At term, 60% of the combined fetal cardiac output is provided by the right ventricle**, which is the dominant one.

Fetal ultrasound studies have shown that the **stroke volumes of the ventricles slowly increase during the gestation**, from 0.7 mL for the right ventricle and left ventricle at 20 weeks to about 7.6 mL for the right ventricle and 5.2 mL for the left ventricle at term.

KEY FACTS

- The combined fetal CO is approximately 400–425 mL/kg per minute, three times as high as in the adults.
- The fetal circulation can be described as a parallel circulation with several shunts (foramen ovale and ductus arteriosus).
- Only 10%–15% of the CO reaches the lungs.
- At term, 60% of the combined fetal cardiac output is provided by the right ventricle.

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4. ANSWER: B

Atrioventricular septal defects are the result of a defective endocardial cushion formation during the early stages of the embryological development (fifth week). They can be described as incomplete or complete and balanced or unbalanced AV canals:

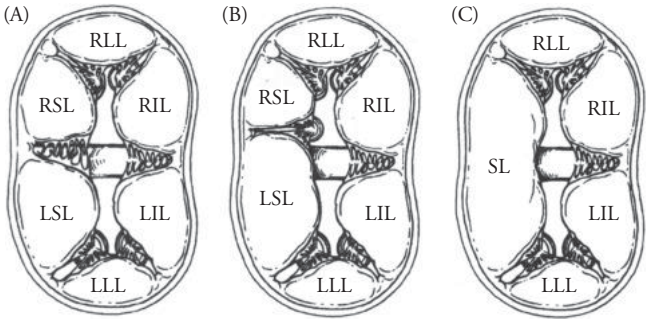

Figure 5.4 Main Rastelli Type variants of complete atrioventricular canal based on the anatomy of the superior (anterior) common leaflet. (From Jacobs JP, Burke RP, Quintessenza JA, Mavroudis C. Congenital Heart Surgery Nomenclature and Database Project: ventricular septal defect. *Ann Thorac Surg*. 2000;69(4 Suppl.):S36–43.)

Incomplete AV canal: Atrial and/or ventricular defect in association with divided atrioventricular valves with two separate orifices and some degree of abnormal leaflets, typically a cleft in the anterior mitral valve leaflet resulting in some degree of mitral valve insufficiency

Partial AV canal: Only primum ASD present
Transitional AV canal: Primum ASD and small VSD

Complete AV canal: Primum ASD and large VSD associated with a common atrioventricular valve with five leaflets. The location of the chordal attachments of the anterior bridging leaflet determines the so-called Rastelli Type (A, B, or C), with C being the most common.

D- and L-looping of the straight heart tube during days 23–28 are the basis for the position of the right and left ventricles and therefore for the orientation of the chambers and left-right asymmetry. This plays a role in the development of the L-TGA, the physiological corrected form of transposition of the great arteries. With ongoing growth of the heart tube and both ends fixed in place, there is bending and looping to one side, usually to the right side, creating the D-loop where the bulbus cordis, later to become the RV, is located on the right side. Occasionally the tube bends to the left, forms an L-loop, and now the bulbus cordis ends up on the left side of the heart.

KEY FACTS

- Atrioventricular septal defects are the result of a defective endocardial cushion formation during the early stages of the embryological development (fifth week).
- D- and L-looping of the straight heart tube during days 23–28 are the basis for the position of the right and

left ventricles and therefore for the orientation of the chambers and left-right asymmetry.
- Incomplete AV canal: Atrial and/or ventricular defect in association with divided atrioventricular valves with two separate orifices and some degree of abnormal leaflets
- Complete AV canal: Primum ASD and large VSD are usually associated with a common atrioventricular valve with five leaflets

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5. ANSWER: B

Complete AV canal defects are often classified as "left-to-right shunts," but they can also be described as "mixing lesions," even though they are not the classical single-ventricle mixing lesions. The defect in the atrial and ventricular septum is usually so large that there is significant mixing of deoxygenated systemic venous blood and oxygenated pulmonary venous blood in the area between the four chambers. **The ratio of pulmonary to systemic cardiac output (Qp/Qs) is dependent on the pulmonary and systemic vascular resistances.** With **decreasing pulmonary vascular resistance over the first few weeks** after birth, this ratio is shifted toward the pulmonary circulation, **leading to pulmonary overcirculation** with pulmonary edema and poor systemic circulation. Most infants will show signs and **symptoms of congestive heart failure within the first 3–4 weeks of life**. The increased pulmonary blood flow and exposure to high pressures can result in pulmonary hypertension and early remodeling of the pulmonary vasculature (pulmonary vascular occlusive disease [PVOD]).

Answer A describes the pathophysiology of Tetralogy of Fallot (RV outflow tract obstruction, VSD, overriding aorta, and RV hypertrophy).

Answer C refers to ductal dependent lesions like hypoplastic left heart syndrome or critical aortic stenosis.

Answer D is characteristic for critical aortic stenosis or coarctation of the aorta and a coexisting VSD.

KEY FACTS

- Complete AV canal defects are often classified as "left-to-right shunts," but they can also be described as "mixing lesions."
- The ratio of pulmonary to systemic cardiac output (Qp/Qs) is dependent on the pulmonary and systemic vascular resistances.
- Most infants will show signs and symptoms of congestive heart failure within the first 3–4 weeks of life.
- The increased pulmonary blood flow and exposure to high pressures can result in pulmonary hypertension and early remodeling of the pulmonary vasculature.

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6. ANSWER: C

Total anomalous pulmonary venous return (TAPVR) is a description for congenital heart defects where **all four pulmonary veins fail to connect to the left atrium but drain instead via remnants of the fetal venous system (vertical veins) into the SVC, IVC, or RA, resulting in a left-to-right shunt**. Obviously, **an intracardiac right-to left shunt is necessary to maintain cardiac output**. There are several anatomic variations of TAPVR: supracardiac (≈40%), cardiac (≈25%), infracardiac (≈25%), and mixed types (≈5%–10%), depending on the location of the anomalous connection. TAPVR is an isolated cardiac defect in about 60%, but one third are associated with complex anomalies, especially heterotaxy syndromes. The clinical presentation is **often complicated by some degree of pulmonary venous obstruction**, particularly in the infracardiac type (at the diaphragmatic hiatus or junction of the IVC/portal vein), leading to significant pulmonary hypertension, poor cardiac output, and increasing acidosis.

KEY FACTS

- Total anomalous pulmonary venous return (TAPVR) is a congenital cardiac condition in which all four pulmonary veins fail to connect to the left atrium but drain instead via remnants of the fetal venous system (vertical veins) into the SVC, IVC, or RA, resulting in a left-to-right shunt.
- An intracardiac right-to left shunt is necessary to maintain cardiac output.
- The clinical presentation is often complicated by some degree of pulmonary venous obstruction.

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7. ANSWER: D

The latest update of the American Heart Association guidelines for the prevention of infective endocarditis, published in 2007, shifted the focus toward **patients with the highest risk of adverse outcomes from endocarditis**. (See Box 5.1.)

According to these guidelines, endocarditis prophylaxis is not recommended for simple VSDs (Answer A) and upper endoscopies, catherizations without placements of prosthetic material or devices, and completely repaired congenital heart disease (CHD) more than 6 months ago without evidence of residual defects (Answer B). Patients who had an interventional ASD device closure only require prophylaxis during the first 6 months (Answer C). The patient in Answer D had a surgical VSD closure with prosthetic material just 5 months ago and is scheduled for a dental procedure, so she clearly falls into the high-risk category and should receive endocarditis prophylaxis.

Box 5.1 CARDIAC CONDITIONS ASSOCIATED WITH THE GREATEST RISK OF ADVERSE OUTCOMES FROM ENDOCARDITIS FOR WHICH ANTIBIOTIC PROPHYLAXIS BEFORE DENTAL PROCEDURES IS REASONABLE

Prosthetic cardiac valve or prosthetic material used for cardiac valve repair

Previous endocarditis

Congenital heart disease (CHD)[a]

- Unrepaired cyanotic CHD, including palliative shunts and conduits
- Completely repaired CHD with prosthetic material or device, whether placed by surgery or catheter intervention, during the first 6 months after the repair.
- Repaired CHD with residual defects in the site or adjacent to a site of a prosthetic patch or prosthetic device (which inhibit endothelialization)[b]

Cardiac transplantation recipients who develop cardiac valvulopathy

[a]Except for the conditions listed, antibiotic prophylaxis is no longer recommended for any other form of CHD.
[b]Prophylaxis is reasonable because endothelialization of prosthetic material occurs within first 6 months.
SOURCE: Modified from *Circulation*. 2007:116:1736–1754.

KEY FACT

- The latest update of the American Heart Association guidelines for the prevention of infective endocarditis, published in 2007, shifted the focus toward patients with the highest risk of adverse outcomes from endocarditis.

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8. ANSWER: C

Williams syndrome (WS), also called Williams-Beuren syndrome, was first described in 1961 by JCP Williams from New Zealand and is characterized by a combination of congenital heart defects (supravalvular aortic and pulmonary stenosis), developmental delay, and distinctive personality traits and facial features (elfin face). It has an incidence of about 1:20,000 and is caused by a spontaneous deletion on chromosome 7q11.23, resulting in an elastin arteriopathy. The smooth muscle cells of patients with WS are elastin deficient (only 15% of normal elastin content). Hypertrophic muscle cells with increased collagen content lead to thickening of the arterial media and obstructive hyperplastic intimal lesions. **The main cardiac feature is the supravalvular aortic stenosis** with tubular narrowing of the ascending aorta. A characteristic "hourglass narrowing" of the aorta can often be seen at the sinotubular junction. Coronary, renal, and mesenteric arteries can also be involved. Approximately 80% of WS patients have additional peripheral pulmonary artery stenosis, or less common central pulmonary artery stenosis. The resulting pathophysiology can be best described as **bilateral ventricular hypertrophy from bilateral outflow obstructions with increased risk for myocardial ischemia and sudden death due to decreased coronary perfusion and/or increased myocardial oxygen consumption.** The coronary blood flow can be compromised by multiple factors: loss of windkessel effect with reduced diastolic pressures, diastolic dysfunction of hypertrophied ventricles, ostial obstructions by thickened valve leaflets, and coronary arteriopathy with multiple stenotic areas. Unfortunately,

there is no correlation between the degree of supravalvular obstruction and coronary involvement, and echocardiograpy, the routine screening tool for ventricular function, hypertrophy, and outflow obstruction, is very insensitive for assessment of coronary blood flow. MRI and CT are promising new modalities, but for now cardiac catherization with coronary angiography is still the "gold standard." Obviously, in small and developmentally delayed children, all these imaging studies require some form of sedation or anesthesia. And there multiple case reports of sudden death and failed resuscitation attempts during sedation and general anesthesia in patients with WS. The best approach is a careful risk/benefit discussion prior to elective procedures and meticulous attention to myocardial oxygen consumption and coronary perfusion pressures during the perioperative phase.

KEY FACTS

- The main cardiac feature of Williams syndrome is supravalvular aortic stenosis with tubular narrowing of the ascending aorta.
- The resulting pathophysiology can be best described as bilateral ventricular hypertrophy from bilateral outflow obstructions with increased risk for myocardial ischemia and sudden death due to decreased coronary perfusion and/or increased myocardial oxygen consumption.

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9. ANSWER: D

For **congenital cardiac surgery** the extracorporal circuit has to be adjusted to a wide range of age groups and size variations (1.5 kg premie to 100 kg adolescent or adult). Infants and children have **smaller circulating blood volumes, higher oxygen consumption rates, and often highly reactive pulmonary vascular beds**. In addition, neonates and infants have **labile thermoregulation and immature organ systems** with multiple implications for ischemic tolerance and inflammatory response. Many complex repairs require a bloodless operative field, which can be difficult to achieve in the presence of intra- or extracardiac shunts, aortopulmonary collaterals, or otherwise increased pulmonary venous return.

Hemodilution: The relatively large bypass prime volumes compared to the circulating blood volume in infants and children lead to significant hemodilution. Even with the newest technology, the **minimum prime volume for circuits allowing full support in neonates at normothermia** is 220 mL, 180 mL if the arterial filter is excluded. The disadvantages of hemodilution clearly outweigh the benefit of improved viscosity at low temperatures: anemia with decreased oxygen-carrying capacity, reduced levels of plasma proteins and clotting factors leading to tissue edema and coagulopathy, electrolyte imbalances, and exaggerated release of stress hormones and complement activation.

Table 5.1 DIFFERENCES BETWEEN ADULT AND PEDIATRIC CARDIOPULMONARY BYPASS (CPB)

PARAMETER	ADULT	PEDIATRIC
Estimated blood volume	65mL/kg (4–5 L for 70 kg)	<10 kg: 85mL/kg (285 mL for 3 kg)
Dilution effects on blood volume	25%–33%	100%–200%
Addition of whole blood or packed red blood cells to prime	Rarely	Usually
Oxygen consumption	2–3 mL/kg per minute	6–8 mL/kg per minute
Full CPB flow at 37°C	50–75 mL/kg per minute	150–200 mL/kg per minute for <3 kg
Minimum CPB temperature	Rarely <25°C–32°C	Commonly 15°C–20°C
Use of total circulatory arrest or regional low flow perfusion	Rare	Common
Perfusion pressures	50–80 mm Hg	20–50 mm Hg
Acid-base management	Mainly Alpha stat	Alpha stat and/or pH-stat
Measured $PaCO_2$ differences	30–45 mm Hg	20–80 mm Hg
Glucose regulation • Hypoglycemia • Hyperglycemia	 Rare (major hepatic injury) Common; treated with insulin	 Common—reduced stores Less common—risk for rebound hypoglycemia

SOURCE: Modified from Lake L, Booker PD. *Pediatric Cardiac Anesthesia*. 4th ed. Philadelphia, PA: Lippincott, Williams & Wilkins; 2005; DiNardo JA, Zvara DA. *Anesthesia for Cardiac Surgery*. 3rd ed. Oxford, UK: Blackwell; 2008.

Acid-Base Management: **During hypothermia**, the dissociation constant of water increases, resulting in decreased levels of hydrogen and hydroxyl ions. During hypothermic cardiopulmonary bypass two completely different strategies for pH management can be used: alpha-stat or pH stat: **Alpha-stat** is named after the alpha imidazole rings of histidine, one of the major blood buffers that maintain chemical neutrality despite changing temperatures. During **alpha-stat management**, the pH is adjusted to be 7.4 and not corrected to the respective temperature. This strategy seems to preserve intracellular electrochemical neutrality as well as enzymatic function and improve metabolic recovery during rewarming. In contrast, using the **pH stat strategy**, as do hibernating animals, CO_2 is added to achieve a pH of 7.4 corrected to the patient's actual temperature. Despite increased intracellular acidosis and enzyme dysfunction, experimental studies have shown some advantages of pH stat, including improved cerebral perfusion, more homogenous cooling, and better oxygen delivery.

Deep Hypothermic Arrest: In the past, deep hypothermic arrest (DHCA) with rapid cooling to 18°C and removal of all cannulas for 45 to 60 minutes was considered to be the standard technique for complex neonatal repairs. Over the years, numerous studies demonstrated the potential hazards and negative effects on the neurological development. There is no absolutely safe time for circulatory arrest.

KEY FACTS

- Infants and children have smaller circulating blood volumes, higher oxygen consumption rates, and often highly reactive pulmonary vascular beds.
- Neonates and infants have labile thermoregulation and immature organ systems with multiple implications for ischemic tolerance and inflammatory response.
- Even with the newest technology, the minimum prime volume for circuits allowing full support in neonates at normothermia is 220 mL, 180 mL if the arterial filter is excluded.
- During hypothermia, the dissociation constant of water increases, resulting in decreased levels of hydrogen and hydroxyl ions.
- During alpha-stat management, the pH is adjusted to be 7.4 and not corrected to the respective temperature.
- Using the pH-stat strategy, CO_2 is added to achieve a pH of 7.4 corrected to the patient's actual temperature.

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10. ANSWER: D

The ECG shows a form of **polymorphic VT called "torsades de pointes"** characteristic of prolonged QT syndrome. **Magnesium**, 25–50 mg/kg IV, is the treatment of choice for "torsades de pointes" VT, which is usually unresponsive to defibrillation and other antiarrhythmics. Amiodarone and procainamide may lead to further QT prolongation with disastrous effects. Malignant hyperthermia and local anesthetic toxicity are less likely in this scenario, and the suggested doses are wrong:

Dantrolene: Initial dose 2.5 mg/kg; can be repeated up to 10 mg/kg

Lipid Emulsion 20%: Initial bolus dose 1.5 mL/kg, followed by infusion 0.25 mL/kg per minute. The bolus may be repeated once or twice to restore circulation. Double the infusion rate to 0.5 mL/kg per minute if blood pressure remains low. Continue the infusion for at least 10 min after attaining circulatory stability. The recommended upper limit is 10 mL/kg lipid emulsion over the first 30 min (from ASRA LAST checklist).

Procainamide: Pediatric Intravenous Dosing: Loading dose: 3 to 6 mg/kg *over 5 minutes* (not to exceed 100 mg per dose), may be repeated every 5 to 10 minutes to a maximum total loading dose of 15 mg/kg; do not exceed 500 mg in 30 minutes. Maintenance dose: Continuous IV infusion: 20 to 80 μg/kg per minute; maximum dose: 2 g/day.

KEY FACTS

- A form of polymorphic VT is called "torsades de pointes" and is characteristic for prolonged QT syndrome.
- Magnesium, 25–50 mg/kg IV, is the treatment of choice for "torsades de pointes" VT, which is usually unresponsive to defibrillation and other antiarrhythmics.

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Kies S, Pabelick CM, Hurley HA, White RD, Ackerman MJ. Anesthesia for patients with congenital long QT syndrome. *Anesthesiology*. 2005;102:204–10.

Roden DM. Long QT syndrome. *N Engl J Med*. 2008;358:169–76.

11. ANSWER: A

The **immature myocardium** differs from the adult myocardium based on its cytoarchitecture, metabolism, and

function. It possesses fewer mitochondria and its sarcoplasmic reticulum is underdeveloped. The sarcoplasmic reticulum is incapable of rapid release and uptake of calcium. This makes it more dependent on extracellular calcium levels to achieve its contractility. Furthermore, the immature myocardium is **composed proportionally of more connective tissue and water rather than contractile elements,** leading to an overall decreased contractility.

The **metabolism of the immature myocardium** is based mainly on carbohydrates and lactate as primary energy sources. This is different from the adult myocardium, which uses primarily free fatty acids as its source of ATP and has limited glycogen stores and glycolytic function. In contrast, the immature myocardium possesses a **larger glycogen storage** capacity and is **capable of anaerobic glycolysis** for ATP production. With decreased nucleotidase activity, the immature myocardium is provided with more ATP precursor, which limits the depletion of ATP. Overall, this gives the immature myocardium a better tolerance to ischemia with rapid recovery of function.

When comparing the function of the immature myocardium to the adult myocardium, it is found that it has **limited capacity to increase its cardiac output in response to an increased preload**. It also has a decreased tolerance to afterload. The **autonomic innervation** is immature with a parasympathetic dominance and an incomplete sympathetic innervation.

KEY FACTS

- The immature myocardium possesses fewer mitochondria and its sarcoplasmic reticulum is underdeveloped compared to the adult myocardium.
- The immature myocardium is composed proportionally of more connective tissue and water rather than contractile elements, leading to an overall decreased contractility.
- The metabolism of the immature myocardium is based mainly on carbohydrates and lactate as primary energy sources.
- When comparing the function of the immature myocardium as compared to the adult myocardium, it is found that it has limited capacity to increase its cardiac output in response to an increase preload.
- The autonomic innervation is immature with a parasympathetic dominance and an incomplete sympathetic innervation.

REFERENCE

Coté CJ, Lerman J, Anderson B, eds. *A Practice of Anesthesia for Infants and Children*. 5th ed. Philadelphia, PA: Saunders; 2013:357.

12. ANSWER: D

In utero, **both ventricles provide systemic blood flow and a variety of fetal connections** allow for mixing of oxygenated and deoxygenated blood. The relatively oxygenated placental blood arriving from the umbilical vein with a PO_2 of 30 mmHg divides equally to pass either through the liver or via the ductus venosus to reach the inferior vena cava. Oxygenated blood from the ductus venosus reaches the inferior vena cava, allowing it to be directed across the foramen ovale into the left atrium by the Eustachian valve. This oxygenated blood then passes through the left ventricle and aorta to supply the head, chest, and upper extremities.

The **deoxygenated blood returning from the superior vena cava and the coronary sinus is directed through the right ventricle and into the pulmonary artery**. The

Table 5.2 CHARACTERISTIC DIFFERENCES BETWEEN THE IMMATURE AND THE ADULT MYOCARDIUM

IMMATURE MYOCARDIUM	ADULT MYOCARDIUM
• Fewer mitochondria and SR • Poorly formed T tubules • Limited contractile elements and increased water content • Dependence on extracellular calcium for contractility	• Organized mitochondrial rows, abundant SR • Well-formed T tubules • Increased number of myofibrils with better orientation • Rapid release and reuptake of calcium via SR
• Carbohydrates and lactate as primary energy sources • Increased glycogen stores and anaerobic glycolysis for ATP • Decreased nucleotidase activity, retained ATP precursors • Better tolerance to ischemia with rapid recovery of function	• Free fatty acids as primary source for ATP • Limited glycogen stores and glycolytic function • Increased 5′-nucleotidase activity, rapid ATP depletion • Less tolerance to ischemia
• Decreased compliance • Limited CO augmentation with increased preload • Decreased tolerance to afterload • Immature autonomic innervation: parasympathetic dominance, incomplete sympathetic innervation	• Normally developed tension • Able to improve CO with increased preload and to maintain CO with increasing afterload

majority of this blood is returned to the descending aorta via the ductus arteriosus and only approximately 8%–10% of the total cardiac output passes through the high-resistance pulmonary circulation. Blood in the descending aorta with a PO_2 of approximatively 15% either supplies the umbilical artery to be reoxygenated by the placenta or continues to supply the lower extremities. The fetal circulation therefore runs in parallel, the left ventricle providing 35% and the right 65% of cardiac output. Fetal cardiac output is therefore measured as a combined ventricular output.

During the transition from fetal to postnatal circulation, the **lung expansion decreases the pulmonary vascular resistance and increases the pulmonary blood flow**. This increases the left atrial pressure. Simultaneously, the removal of the placenta and the increase in blood oxygen content lead to umbilical vessel constriction and increased systemic vascular resistance. Blood flow through the ductus venosus is suddenly reduced, causing its passive closure over 3 to 7 days. This reduced blood return to the inferior vena cava as well as the increased left atrial pressure causes the foramen ovale to close functionally within the first breath of life. The foramen ovale will be completely closed in 50% of children by 5 years.

The **decrease in pulmonary artery pressure and increase in systemic vascular resistance will also reverse the flow across the ductus arteriosus** from left to right. Unlike the passive closure of the ductus venosus, the ductus arteriosus is affected by blood oxygen content and circulating prostaglandins. The ductus arteriosus will have functionally (but not anatomically) closed in 58% of normal full-term infants by 2 days of life and in 98% by day 4. Within 2 to 3 weeks, functional constriction is followed by a process of ductal fibrosis, resulting in a band-like structure called the ligamentum arteriosum.

Any stimulus such as hypoxia, acidemia, or structural anomaly can increase pulmonary vascular resistance and potentially reopen the ductus arteriosus or foramen ovale. This allows a right-to-left shunt, which worsens hypoxia. This effect is seen in persistent pulmonary hypertension of the newborn.

KEY FACTS

- In utero, both ventricles provide systemic blood flow and a variety of fetal connections allow for mixing of oxygenated and deoxygenated blood.
- The deoxygenated blood returning from the superior vena cava and the coronary sinus is directed through the right ventricle and into the pulmonary artery.
- During the transition from fetal to postnatal circulation, the lung expansion decreases the pulmonary vascular resistance and increases the pulmonary blood flow.
- The decrease in pulmonary artery pressure and increase in systemic vascular resistance will also reverse the flow across the ductus arteriosus from left to right.

REFERENCE

Coté CJ, Lerman J, Anderson B, eds. *A Practice of Anesthesia for Infants and Children*. 5th ed. Philadelphia, PA: Saunders; 2013:355–6.

13. ANSWER: C

Wash-in is the rate of increase of the partial pressures of alveolar to inspired anesthetic (F_A/F_I). Six factors affect the wash-in of inhaled anesthetics. The first three factors **influence the delivery of anesthetic to the lungs**: inspired concentration, alveolar ventilation, and functional residual capacity. The last three factors **influence the uptake of anesthetic from the lungs**: cardiac output, the alveolar to venous partial pressure gradient, and the solubility. For the F_A/F_I to reach equilibration, the rate of delivery of anesthetic to the lungs must substantially exceed its removal from the lungs. When comparing infant to adult, four factors explain the **faster wash-in**: the greater fraction of the cardiac output distributed to the vessel-rich group, the greater ratio of alveolar ventilation to functional residual capacity, the reduced tissue/blood solubility, and the reduced blood/gas solubility.

The **more rapid increase in F_A/F_I of insoluble anesthetics compared with soluble anesthetics** is generally thought to result in a more rapid induction of anesthesia. However, the relative rate of induction of anesthesia depends not exclusively on the wash-in but also on the rate of increase of the inspired concentration, the potency (MAC) of the agent, the ventilation, and on the maximal inspired concentration. It is the interplay of these factors that influences the relative rate of induction of anesthesia.

A **right-to-left shunt** refers to a state in which the systemic venous blood bypasses the lungs and reaches the systemic arterial circulation. These shunts can either be intracardiac (cyanotic heart diseases) or intrapulmonary (pneumonia, endobronchial intubation, etc.). Generally, a **left-to-right shunt** does not significantly affect the pharmacokinetics of inhalational anesthetics (unlike IV medications). In contrast, a **right-to-left shunt** can significantly delay the equilibration of F_A/F_I of inhalational anesthetics. The delay will be proportional to the solubility of the anesthetic agent. A less soluble anesthetic will be delayed more significantly as compared to a more soluble anesthetic. The overall **effect of a right-to-left shunt** is to slow induction of anesthesia or even limit the depth of anesthesia that can be achieved with less soluble anesthetics.

KEY FACTS

- Wash-in is the rate of increase of the partial pressures of alveolar to inspired anesthetic (F_A/F_I).

- Six factors affect the wash-in of inhaled anesthetics. Three factors influence the delivery of anesthetic to the lungs: inspired concentration, alveolar ventilation, and functional residual capacity. And three factors influence the uptake of anesthetic from the lungs: cardiac output, the alveolar to venous partial pressure gradient, and the solubility.
- When comparing infant to adult, four factors explain the faster wash-in: the greater fraction of the cardiac output distributed to the vessel-rich group, the greater ratio of alveolar ventilation to functional residual capacity, the reduced tissue/blood solubility, and the reduced blood/gas solubility.
- The overall effect of a right-to-left shunt is to slow induction of anesthesia or even limit the depth of anesthesia that can be achieved with less soluble anesthetics.

REFERENCE

Coté CJ, Lerman J, Anderson B, eds. *A Practice of Anesthesia for Infants and Children*. 5th ed. Philadelphia, PA: Saunders; 2013:100.

14. ANSWER: D

Although **sevoflurane** is the agent of choice for inhaled induction in pediatric anesthesia, when used at concentrations greater than a MAC of 1.5, there is a risk of reducing the heart rate and causing some respiratory depression. In children with congenital heart disease, a decrease in heart rate will lead to a reduced cardiac output. Furthermore, hypoventilation in this subset of patients will cause hypercarbia and hypoxia, which can have severe consequences on the PVR. Sevoflurane remains preferable to halothane, however, since it causes less depression of myocardial contractility during induction of anesthesia. **Sevoflurane** does nonetheless cause a mild decrease in SVR and has caused conduction abnormalities in susceptible patients.

At induction doses, **propofol** can reduce SVR, blood pressure, and cardiac output. Even if it has been used extensively in some children with congenital heart disease, it is typically avoided as an induction agent in situations where a decreased SVR or blood pressure could cause hemodynamic instability. It is especially dangerous in patients with fixed cardiac output (such as severe aortic or mitral stenosis) or in patients with single-ventricle physiology, where a change in Qp:Qs could threaten a stable balanced physiology.

Ketamine increases blood pressure, peripheral vascular resistance, heart rate, and cardiac output through a release of endogenous catecholamines as well as via a direct central increase in sympathetic outflow. Ketamine exerts a direct negative inotropic effect on the denervated heart. This makes the use of ketamine a potential poor choice for children in whom sympathetic stimulation may already be maximal, such as in those with severe cardiomyopathy. It is also a poor choice if tachycardia is undesirable, such as in a child with aortic stenosis. Ketamine is thought to have minimal effect on PVR in children with CHD as long as the airway and ventilation are well preserved.

Etomidate is a short-acting anesthetic with little effect on systemic blood pressure, heart rate, and cardiac output after an induction dose in healthy children. Etomidate maintains its benign hemodynamic profile even when used in patients with hemodynamic instability or with congenital heart disease. However, it has a few clinically important side effects: myoclonus or status epilepticus, pain on intravenous injection, and an increased incidence of nausea and vomiting after use. The major concern about etomidate is the increased mortality rates reported when it is administered as a continuous infusion. This grave side effect has been attributed to adrenal suppression, which occurs due to the inhibition of steroid synthesis typically after a prolonged infusion but can also occur after a single dose of etomidate.

KEY FACTS

- Although sevoflurane is the agent of choice for inhaled induction in pediatric anesthesia, when used at concentrations greater than a MAC of 1.5, there is a risk of reducing the heart rate and causing some respiratory depression.
- At induction doses, propofol can reduce SVR, blood pressure, and cardiac output.
- Ketamine increases blood pressure, heart rate, and cardiac output through a release of endogenous catecholamines.
- Etomidate is a short-acting anesthetic with little effect on systemic blood pressure, heart rate, and cardiac output after an induction dose in healthy children.

REFERENCE

Chapter 6. Nonbarbiturate intravenous anesthetic drugs. In: Stoelting RK, Hillier SC, eds. *Pharmacology and Physiology in Anesthetic Practice*. 4th ed. Philadelphia, PA: Lippincott, Williams & Wilkins; 2005.

15. ANSWER: C

This child is receiving a sodium nitroprusside infusion. **Adverse effects of sodium nitroprusside infusion** include cyanide and thiocyanide toxicities, rebound hypertension, inhibition of platelet function, and increased intrapulmonary shunting.

Cyanide is a by-product of the metabolism of sodium nitroprusside. Because free cyanide radicals may bind

inactive tissue cytochrome oxidase and prevent oxidative phosphorylation, increased cyanide concentrations may precipitate tissue anoxia, anaerobic metabolism, and lactic acidosis. Free cyanide will in effect be conjugated with thiosulfate by rhodanase in the liver to produce thiocyanate. It then will bind to the cytochrome oxidase in the mitochondria, preventing ATP production. Mixed venous PO_2 and cerebral venous PO_2 will be increased, indicating the paralysis of cytochrome oxidase and the inability of tissues to use oxygen. A metabolic acidosis will develop as a reflection of anaerobic metabolism in the tissues. In awake patients, CNS toxicity can include changes in mental status and seizures.

Cyanide toxicity should be suspected in any patients resistant to the hypotensive effects of sodium nitroprusside or in any patient previously responsive who becomes unresponsive. The mechanism explaining this resistance or tachyphylaxis is still poorly understood but could reflect cyanide-induced stimulation of cardiac output. Toxicity is more likely to occur when more than 10 μg/kg per minute is infused, if tachyphylaxis develops within 30 minutes, or if there is immediate resistance to the drug.

Children may have less ability to mobilize thiosulfate stores despite increasing cyanide concentrations, leading to accelerated toxicity. In children who have received sodium nitroprusside for more than 24 hours and those with organ dysfunction, it may be advisable to measure blood cyanide concentrations.

When cyanide toxicity is suspected, sodium nitroprusside infusion should be immediately discontinued and 100% oxygen administered despite normal oxygen saturation. **Sodium bicarbonate** can be administered to correct metabolic acidosis. **Sodium thiosulfate** 150 mg/kg should be administered over 15 minutes. Thiosulfate acts as a sulfur donor to convert cyanide to thiocyanate. **If cyanide toxicity is severe**, with deteriorating hemodynamics and metabolic acidosis, the recommended treatment is a slow IV administration of 5 mg/kg of sodium nitrate. Sodium nitrate converts hemoglobin to methemoglobin, which acts as an antidote by converting cyanide to cyanomethemoglobin.

KEY FACTS

- Adverse effects of sodium nitroprusside infusion include cyanide and thiocyanide toxicities, rebound hypertension, inhibition of platelet function, and increased intrapulmonary shunting.
- Cyanide is a by-product of the metabolism of sodium nitroprusside.
- When cyanide toxicity is suspected, sodium nitroprusside infusion should be immediately discontinued and 100% oxygen administered despite normal oxygen saturation.
- If cyanide toxicity is severe, with deteriorating hemodynamics and metabolic acidosis, the recommended treatment is a slow IV administration of 5 mg/kg of sodium nitrate.

REFERENCE

Chapter 16. Peripheral vasodilators, nitric oxide, and nitrovasodilators. In: Stoelting RK, Hillier SC, eds. *Pharmacology and Physiology in Anesthetic Practice*. 4th ed. Philadelphia, PA: Lippincott, Williams & Wilkins; 2005.

16. ANSWER: B

Ventricular septal defects (VSDs) are communication between the left and right ventricle. They can be classified by their location in the septum. The **most common** is the membranous or perimembranous defects that comprise approximatively 80% of all the VSDs. Other types include subpulmonary, conoventricular, inlet, or muscular VSD.

A VSD is an **example of a simple left-to-right shunt**. The size of the VSD influences the amount of shunting between the two ventricles. A small VSD will restrict the blood flow and create a large pressure gradient across the defect. This limits the amount of blood able to cross the VSD and have limited hemodynamic consequences.

On the other hand, a larger VSD (with an area the size of the aortic valve) will have lower pressure gradient across the defect. This will enable increasingly more blood to cross the VSD as its size increased. As a consequence, the amount and direction of the shunting will become dependent and be limited mainly by the relative resistance between the pulmonary and systemic circulations. Generally, the lower PVR as compared to the SVR will result in a left-to-right shunt. However, with increased PVR, the direction of blood through the defect can be reversed and a right-to-left be created. The Qp:Qs is the ratio of total pulmonary to total systemic blood flow. A ratio of 1 indicates equal blood flow to the pulmonary and systemic circuit. An elevated ratio >1 indicates a net left-to-right shunt. A ratio <1 indicates a net right-to-left shunt.

At birth, the relatively elevated PVR will limit the amount of shunting through a large VSD and the child might have a normal pulmonary blood flow (Qp:Qs = 1). As the PVR decreases over time, the pulmonary blood flow increases and pulmonary overcirculation may become apparent (Qp:Qs > 1). With time, this **elevated pulmonary blood flow will produce** the development of increased PVR (pulmonary vascular occlusive disease) and lead to pulmonary hypertension. As this progresses, the shunt will become bidirectional through the VSD and ultimately right-to-left shunt (Eisenmenger's). For this reason, VSD with Qp:Qs of more than 2 are corrected early.

Clinically, **patients with high Qp:Qs** will have pulmonary congestion from increased left atrial volume and pressure. The systemic blood pressure is maintained as a consequence of large volume load on both the RV and LV. Excessive fluid resuscitation in patients with elevated Qp:Qs will stress the already volume overload ventricles and will have limited impact on systemic blood pressure since the blood will recirculate mainly through the right ventricle. This may exacerbate the pulmonary congestion and decrease pulmonary compliance.

In this example, the increased FiO_2 has diminished the PVR, increasing the Qp:Qs and ultimately diminishing the aortic cardiac output. Strategies to increase the PVR (FiO_2 of 0.21%, permissive hypercapnia, mild acidosis, peep, etc) will help decreasing the Qp:QS and will help support the systemic pressure by increasing aortic cardiac output. Giving vasopressors will increase the SVR and lead to even more left-to-right shunting with little improvement to the blood pressure.

KEY FACTS

- VSDs are communication between the left and right ventricle.
- The most common is the membranous or perimembranous defects that comprise approximatively 80% of all the VSDs. Other types include subpulmonary, conoventricular, inlet, or muscular VSD.
- A VSD is an example of a simple left-to-right shunt.
- Patients with high Qp:Qs will have pulmonary congestion from increased left atrial volume and pressure.
- With time, elevated pulmonary blood flow will produce the development of increased PVR (pulmonary vascular occlusive disease) and lead to pulmonary hypertension.

REFERENCE

Sommer RJ, Hijazi ZM, Rhodes JF Jr. Pathophysiology of congenital heart disease in the adult: part I: shunt lesions. *Circulation*. 2008;117:1090–9.

17. ANSWER: C

Dextro-transposition of the great arteries (d-TGA) is a cyanotic congenital heart defect where the aorta (Ao) is located anatomically following the right ventricle and the pulmonary artery is located following the left ventricle. The relation between the right and left atrium and their respective ventricle is unchanged. The coronaries leave the aortic sinuses posteriorly before dividing to perfuse the myocardium. Common associated anomalies include VSD, subpulmonary stenosis (left ventricular outflow track obstruction), bronchopulmonary collateral vessels, and a patent foramen ovale or ASD. Around 60%–70% of the patients have an intact ventricular septum.

Patients with d-TGA **have two parallel circulations with recirculation of their respective pulmonary and systemic venous blood**. Their survival depends on the amount of inter circulatory mixing created by one or several shunts (PFO, ASD, VSD, PDA, or bronchopulmonary collateral vessels). Anatomic right-to-left shunting typically occurs through the VSD or through the PDA. Anatomic left-to-right shunt occurs through the intra-atrial communication. This provides effective pulmonary and systemic blood flow. Restrictive intra-atrial communication or increased pulmonary vascular resistance will decrease the amount of mixing.

The dynamics of intercirculatory mixing in D-TGA with IVS are complex. The **size of the atrial communication and the cyclic pressure variations between the left and right atria** determine the amount of anatomic shunting. The volume and compliance of the atria, ventricles, and vascular beds in each circuit, as well as heart rate (HR) and phase of respiration, all influence this relationship. Shunting is from the RA to the LA during diastole (reduced ventricular compliance) and from the LA to the RA in systole (large volume of recirculated pulmonary blood flow).

The **size of the intra-atrial communication and the PVR** will dictate the direction of shunting across the PDA. In patients with low PVR and a nonrestrictive intra-atrial communication, shunting is predominantly from the aorta to the PA through the PDA (effective pulmonary blood flow) and from the LA to RA across the atrial septum (effective systemic blood flow). In patients with elevated PVR, shunting across the PDA is likely to be bidirectional. It is usually associated with corresponding bidirectional shunting across the atrial septum. In patients with both elevated PVR and suprasystemic PA pressure, the shunting at the level of the PDA will be from the PA to the aorta. This physiological phenomenon creates a reverse differential cyanosis in which the preductal arterial saturation (right arm) is lower than the postductal arterial saturation (lower extremities). In these patients, the presence of a restrictive atrial communication promotes left atrial hypertension and leads to low effective blood flows (poor mixing) and hypoxemia. A balloon atrial septostomy can be lifesaving in this setting. It will decompress the LA and promote mixing at the atrial level. It will also reduce PVR and PA pressure, increasing mixing at the level of the PDA. Other causes of reverse differential cyanosis to be considered in D-TGA are the presence of an interrupted aortic arch or severe aortic coarctation.

KEY FACTS

- Dextro-transposition of the great arteries (d-TGA) is a cyanotic congenital heart defect where the aorta (Ao)

is located anatomically following the right ventricle and the pulmonary artery is located following the left ventricle.
- Patients with d-TGA have two parallel circulations with recirculation of their respective pulmonary and systemic venous blood.
- The size of the intra-atrial communication and the PVR will dictate the direction of shunting across the PDA.

REFERENCE

DiNardo JA. Transposition of the great vessels. In: Lake CL, Booker PD, eds. *Pediatric Cardiac Anesthesia*. 4th ed. Philadelphia, PA: Lippincott Williams & Wilkins; 2005:357–80.

18. ANSWER: C

Tricuspid atresia is a single-ventricle physiology lesion. There is **agenesis of the tricuspid valve and no communication between the right atrium and the right ventricle**. This leads the right ventricle to become hypoplastic during development. The classification of tricuspid atresia is based on the presence or absence of transposition of the great vessels, the extent of pulmonary stenosis or atresia, and the size of the VSD.

Type I—Normally related great arteries

Type II—D-Transposition of the great arteries

Type III—Great artery positional abnormalities other than D-transposition of the great arteries

All types are subdivided into the following subgroups:

Subgroup a—Pulmonary atresia

Subgroup b—Pulmonary stenosis or hypoplasia

Subgroup c—No pulmonary stenosis (normal pulmonary arteries)

The patient have an **obligatory right-to-left shunt at the atrial level (PFO or ASD) with complete mixing of systemic and pulmonary venous blood in the LA**. When the ASD or foramen ovale is restrictive, there will be a large right atrial to left atrial pressure gradient. This will result in poor decompression of the right atrium and systemic venous congestion. Pulmonary blood flow can be provided by a downstream shunt from either the VSD to PA, VSD to PS, PDA, or multiple aortopulmonary collateral arteries.

The **degree of cyanosis is mainly determined by the Qp:Qs**. Pulmonary blood flow can be restricted, normal, or increased. The majority of neonates with tricuspid atresia have ductal-dependent pulmonary blood flow and will require surgery to provide definitive pulmonary blood flow. The initial palliation includes the creation of a modified Blalock-Taussig (BT) shunt (from the subclavian artery to the pulmonary artery) and the ligation of the PDA. Eventually, with the fall of the pulmonary vascular resistance, the patient will have a bidirectional Glenn (superior cavopulmonary connection) usually around 3–6 months of age. The final stage of palliation is the Fontan (bicavopulmonary connection) around 1–2 years of age.

The physiology of a BT shunt leads to a series of physiologic consequences. First, the continuous blood flow across the BT shunt throughout the cardiac cycle may result in excessive volume load on the single left ventricle. Furthermore, the diastolic flow across the shunt results in lower aortic diastolic pressure (and a wide pulse pressure), resulting in a "steal" of blood flow from the systemic circulation during diastole. This runoff may result in inadequate tissue perfusion to all organ systems, but most important to the coronary circulation, which is predominately perfused in diastole. In summary, **patients with Blalock-Taussig shunt** may not be able to cope with the increased myocardial oxygen consumption of a volume loaded ventricle because of limited coronary perfusion due to the diastolic runoff, making them more prone to ischemia.

KEY FACTS

- Tricuspid atresia is a single-ventricle physiology lesion.
- There is agenesis of the tricuspid valve and no communication between the right atrium and the right ventricle.
- The patient have an obligatory right-to-left shunt at the atrial level (PFO or ASD) with complete mixing of systemic and pulmonary venous blood in the LA.
- The degree of cyanosis is mainly determined by the Qp:Qs.
- Patients with Blalock-Taussig shunt may not be able to cope with the increased myocardial oxygen consumption of a volume-loaded ventricle because of limited coronary perfusion due to the diastolic runoff, making them more prone to ischemia.

REFERENCE

Wyszynski D, Graham T, Correa-Villasenor A, eds. *Congenital Heart Defects: From Origin to Treatment*. New York, NY: Oxford University Press; 2010.

19. ANSWER: B

In healthy neonates, **during the first few minutes after the transition from fetal to extrauterine life**, the pulmonary vascular resistance decreases dramatically, which results in a 50% decrease in the pulmonary artery pressure and a nearly 10-fold increase in pulmonary blood flow. **Persistent pulmonary hypertension of the newborn** (PPHN) is a life-threatening condition where the pulmonary vascular resistance fails to decrease after birth and may even exceed the systemic vascular resistance. In this situation, there will be a right-to-left shunt at the level of the patent foramen ovale

(PFO) or the patent ductus arteriosus (PDA). The affected neonates are unable to establish adequate oxygenation and may develop multiorgan failure. **Most of the cases of PPHN are associated** with parenchymal lung disease such as meconium aspiration syndrome and respiratory distress syndrome. Other causes can include primary PPHN, pneumonia, sepsis, genetic defects, and other congenital abnormalities.

Neonates with PPHN require management tailored to the degree of hypoxemia and physiologic instability. The overall approach should focus on restoring the cardiopulmonary adaptation and decreasing the pulmonary vascular resistance while avoiding lung injury and adverse effects on systemic perfusion. Reversal of right-to-left extrapulmonary shunts requires a reduction in pulmonary artery pressure and maintenance of the systemic blood pressure.

Prolonged exposure to 100% oxygen and aggressive ventilation can be avoided by judicious application of newer therapies, such as inhaled nitric oxide (iNO), surfactant replacement, and inotropic support. The goal should be to achieve a PaO_2 of 70–90 mm Hg. It is important to be mindful that a PaO_2 greater than 100 mm Hg in this population could be potentially harmful to the developing lung and cerebral perfusion.

The introduction of iNO to cause selective pulmonary vasodilation has been the most significant milestone in the treatment of PPHN. Based on the efficacy and safety of iNO from controlled clinical trials, it is now recommended to use iNO before prolonged exposure to a high fraction of inspired oxygen or to maximal ventilator support.

The **ventilator strategy** should target recruitment of the atelectatic segments while avoiding overdistention, which leads to lung injury and increased resistance to pulmonary blood flow. High-frequency oscillation may help to optimize lung expansion in neonates who have PPHN secondary to lung disease. While correction of respiratory and metabolic acidosis facilitates pulmonary vasodilation, it is no longer advocated to use hypocarbia or metabolic alkalosis for long periods since it has been associated with decreased cerebral perfusion and neurologic injury.

Dopamine, dobutamine, and epinephrine have been widely used in the management of PPHN, primarily to optimize cardiac function, stabilize systemic blood pressure, and reduce right-to-left blood shunting. **Milrinone** is also increasingly used to improve oxygenation in neonates with persistent pulmonary hypertension who are unresponsive to therapy with iNO.

Although prostaglandin E1 has been used with varying success to treat pulmonary hypertension, in this situation, it would maintain the PDA, which could potentially exacerbate the right-to-left shunt. Hypothermia can increase PVR.

KEY FACTS

- During the first few minutes after the transition from fetal to extrauterine life, the pulmonary vascular resistance decreases dramatically, which results in a 50% decrease in the pulmonary artery pressure and a nearly 10-fold increase in pulmonary blood flow.
- Persistent pulmonary hypertension of the newborn (PPHN) is a life-threatening condition where the pulmonary vascular resistance fails to decrease after birth, and it may even exceed the systemic vascular resistance.
- Most of the cases of PPHN are associated with parenchymal lung disease such as meconium aspiration syndrome and respiratory distress syndrome.
- In PPHN, prolonged exposure to 100% oxygen and aggressive ventilation can be avoided by judicious application of newer therapies, such as inhaled nitric oxide (iNO), surfactant replacement, and inotropic support.

REFERENCE

Konduri GG, Kim UO. Advances in the diagnosis and management of persistent pulmonary hypertension of the newborn. *Pediatr Clin North Am*. 2009;56:579–600.

20. ANSWER: C

Certain cardiac conditions are predisposed to the development of endocarditis from transient bacteremia. The American Heart Association guidelines recommend antibiotic prophylaxis before dental procedure based mainly on patients at greatest risk for an adverse outcome resulting from endocarditis. **Antibiotics should only be given to patients who have the following conditions**:

a. An artificial heart valve or who have a heart valve repaired with artificial material
b. A history of endocarditis
c. A heart transplant with abnormal heart valve function
d. Certain congenital heart defects including:

- Cyanotic congenital heart disease that has not been fully repaired, including children who have had a surgical shunts and conduits
- A congenital heart defect that has been completely repaired with artificial material or a device for the first 6 months after the repair procedure
- Repaired congenital heart disease with residual defects, such as persisting leaks or abnormal flow at or adjacent to a prosthetic path or prosthetic device (which inhibits endothelialization)

Dental procedures that involve the gingival tissues, the teeth, or perforation of the oral mucosa might produce

transient bacteremia. **Respiratory tract procedures that involve incision or biopsy of the mucosa** may also produce bacteremia, and prophylaxis may be warranted for children at high risk. In contrast to previous guidelines, routine prophylactic administration of antibiotics solely to prevent endocarditis is not recommended for those undergoing genitourinary or gastrointestinal tract procedures.

Antibiotic prophylaxis should be administered 30–60 minutes before the procedure to achieve adequate tissue levels of antibiotics before bacteremia occurs.

KEY FACTS

Antibiotics should only be given to patients who have the following characteristics:

- An artificial heart valve or who have a heart valve repaired with artificial material
- A history of endocarditis
- A heart transplant with abnormal heart valve function
- Certain congenital heart defects (see earlier).

REFERENCE

Wilson W, Taubert KA, Gewitz M, et al. Prevention of infective endocarditis: guidelines from the American Heart Association. A guideline from the American Heart Association Rheumatic Fever, Endocarditis, and Kawasaki Disease Committee, Council on Cardiovascular Disease in the Young, and the Council on Clinical Cardiology, Council on Cardiovascular Surgery and Anesthesia, and the Quality of Care and Outcomes Research Interdisciplinary Working Group. *Circulation*. 2007;116:1736–54.

21. ANSWER: A

Cardiomyopathies are diseases of the myocardium associated with cardiac dysfunction. The **most common types** encountered in the pediatric population are hypertrophic, dilated, and restrictive. Cardiomyopathies can also be found in patients with **Duchenne muscular dystrophy, glycogen storage diseases, mitochondrial disorders, or secondary to chemotherapeutic agents**.

Hypertrophic obstructive cardiomyopathy (HOCM) has a prevalence of approximately 1 in 500 with most of the identified genetic abnormalities exhibiting autosomal dominant inheritance patterns. The hypertrophy initially develops in the septum and extends to the free walls. **Asymmetric septal hypertrophy** leads to a variable pressure gradient between the apical left ventricular chamber and the left ventricular outflow tract (LVOT). The LVOT obstruction leads to increases in left ventricular pressure, which fuels a vicious cycle of further hypertrophy and increased LVOT obstruction. It is the most common cause of sudden cardiac death (SCD) in athletes. Initially, children with HOCM will not necessarily have systemic outflow tract obstruction but will be at risk of worsening obstruction as the disease progresses.

Presenting symptoms often include a heart murmur, syncope, palpitations, or chest pain. The ECG will meet the criteria for left ventricular hypertrophy in most children. Echocardiography is the primary modality for diagnosing and following the evolution of the disease. It will demonstrate a nondilated left ventricle with possible asymmetric hypertrophy.

The **management of children with HOCM** includes maintenance of adequate preload, especially in those with dynamic obstruction. β-Blockers and calcium channel blockers form the basis of medical therapy for HCM. β-Blockade is most useful for preventing sympathetically mediated increases in the subaortic gradient and for the prevention of tachyarrhythmias, which also can exacerbate outflow obstruction. The mechanism of action involves improvement in diastolic relaxation, allowing an increase in LVEDV at a relatively lower LVEDP. The negative inotropy may attenuate the subaortic pressure gradient. Disopyramide, a sodium channel blocker, also has been used to reduce contractility and for its antiarrhythmic properties.

Diuretics are not indicated and often worsen the hemodynamic state by reducing left ventricular volume and increasing the outflow tract obstruction. Digoxin and other inotropic agents and ACE inhibitors are contraindicated in HCM as they worsen the obstruction, though they may have a role in the end-stage dilated thin-walled HCM hearts with impaired LV function.

KEY FACTS

- Cardiomyopathies are diseases of the myocardium associated with cardiac dysfunction.
- The most common types encountered in the pediatric population are hypertrophic, dilated, and restrictive.
- Cardiomyopathies can also be found in patients with Duchenne muscular dystrophy, glycogen storage diseases, mitochondrial disorders, or secondary to chemotherapeutic agents.
- Presenting symptoms often include a heart murmur, syncope, palpitations, or chest pain.
- The management of children with HOCM includes maintenance of adequate preload and preventing sympathetically mediated increases in the subaortic gradient.

REFERENCES

Kaplan JA, Reich DL, Savino JS, eds. *Kaplan's Cardiac Anesthesia: The Echo Era*. 6th ed. Philadelphia, PA: Saunders; 2011.

Maron BJ. Hypertrophic cardiomyopathy in childhood. *Pediatr Clin N Am*. 2004;51:1305–46.

22. ANSWER: C

Cardiac tamponade is an acute type of pericardial effusion that is seen in a variety of clinical situations but most often occurs in malignancies with medical patients or after cardiac surgery in surgical patients. Tamponade exists when fluid in the pericardium accumulates and limits the filling of the heart. The speed at which this fluid accumulates defines the urgency of the situation more than the overall volume contained in the pericardium. Mild tamponade is often asymptomatic. Clinical signs such as hypotension, jugular venous distention and pulsus paradoxus can present as very late findings and may occur shortly before cardiovascular collapse.

Pulsus paradoxus is a decline in systolic blood pressure of more than 12 mm Hg during inspiration caused by a reduced left ventricular stroke volume generated by increased filling of the right heart during inspiration. It is not sensitive or specific for tamponade and may also be found in patients with right ventricular infarction, obstructive pulmonary disease, or chest pain. It may be absent if there is left ventricular dysfunction, positive-pressure breathing, atrial septal defect, or severe aortic regurgitation.

Dyspnea has been found to be the earliest and most sensitive symptom to indicate tamponade. The classical collection of medical signs is called Beck's triad, which includes a decreased arterial pressure, an increased venous pressure, and a small quiet heart. The ECG may show low-voltage QRS complexes, electrical alternans, and T-wave abnormalities. A central line and a pulmonary artery catheter may help in the diagnosis of tamponade by demonstrating a slow "y" descent and eventually the equilibration of the right atrial pressure, the pulmonary artery diastolic pressure, and the pulmonary capillary wedge pressure. Echocardiogram is the gold standard for noninvasive diagnosis of tamponade.

The **hemodynamic consequences** are mainly due to atrial rather than ventricular compression, as increased atrial and pericardial pressures limit diastolic filling. This leads to greatly reduced preload causing lower stroke volume and cardiac output. Sympathetic reflexes will attempt to maintain the cardiac output by increasing contractility and heart rate. The blood pressure now maintained by vasoconstriction will start decreasing as the pericardial fluid continues to accumulate, consequently decreasing the cardiac output. The venous filling pressures will become unable to increase to equal pericardial pressures. This will cause the blood pressure to decline precipitously, decreasing coronary perfusion and creating ischemia. This resembles hypovolemic shock and will initially respond to fluid resuscitation. This vicious circle will continue to progress until it will quickly become fatal if tamponade is not treated.

The **treatment** of cardiac tamponade is the drainage of the pericardial fluid with a pericardiocentesis, insertion of a pericardial drain, or with a pericardiotomy. Hemodynamics will improve immediately after decompression of the pericardium.

Induction of general anesthesia in these patients can cause severe hypotension and even cardiac arrest. This is precipitated by the sympatholysis, decreased venous return, myocardial depression, and the change in heart rate associated with the induction agents and positive pressure ventilation. Spontaneous respiration instead of positive-pressure ventilation can support CO more effectively until tamponade is relieved. Correction of metabolic acidosis and volume expansion is recommended until more definitive treatment is available. Catecholamine infusions or pacing may be used to avoid bradycardia and provide supplemental support to the cardiac output.

KEY FACTS

- Cardiac tamponade is an acute type of pericardial effusion that is seen in a variety of clinical situations, but it most often occurs in malignancies with medical patients or after cardiac surgery in surgical patients.
- Pulsus paradoxus is a decline in systolic blood pressure of more than 12 mm Hg during inspiration caused by a reduced left ventricular stroke volume generated by increased filling of the right heart during inspiration.
- Dyspnea has been found to be the earliest and most sensitive symptom to indicate tamponade.
- The treatment of cardiac tamponade is the drainage of the pericardial fluid with a pericardiocentesis, insertion of a pericardial drain, or with a pericardiotomy.

REFERENCE

Kaplan JA, Reich DL, Savino JS, eds. *Kaplan's Cardiac Anesthesia: The Echo Era*. 6th ed. Philadelphia, PA: Saunders; 2011.

23. ANSWER: B

In children, **primary cardiac tumors are mostly benign** lesions. **Rhabdomyomas and fibromas** are the most common. Malignant tumors constitute only approximately 15% of all primary cardiac tumors, most of which are sarcomas and lymphomas. As opposed to adults who have atrial myxomas as the most common type of intracardiac lesions, children and infants have lesions commonly observed in both atria and ventricles.

Neurocutaneous syndromes can present with intracardiac lesions. The three most common types of neurocutaneous syndromes are neurofibromatosis, tuberous sclerosis complex (TSC), and Sturge-Weber disease. TSC is inherited in an autosomal dominant pattern and formerly characterized by clinical triad of mental retardation, epilepsy, and facial angiofibromas. However, children with TSC may also present with a broad range of clinical symptoms because of variable expressivity. Morbidity of TSC is

related to organ involvement, most commonly involving the brain, skin, eyes, lungs, kidneys, and heart. Overall, the most common cause of death in patients with TSC is status epilepticus or bronchopneumonia.

Rhabdomyomas occur almost exclusively in children and about 80%–90% associated with TSC. These tumors usually present in multiple lesions. They are found more commonly in the ventricles, although up to 30% are found in the atria. These benign tumors develop at about 22–26 weeks gestation, and they may cause fetal death due to non-immune *hydrops fetalis* (abnormal accumulation of fluid in two or more fetal compartments). Like other intracardiac tumors in children, rhabdomyomas may present with one or more of these clinical manifestations:

- Flow obstruction resulting in hypotension, syncope, and heart failure
- Direct invasion of the myocardium leading to impaired contractility, arrhythmias, heart block, or pericardial effusion
- Respiratory manifestation due to compression of the adjacent respiratory pathway
- Acute coronary syndrome due to direct compression of the coronaries
- Embolization

Most cardiac rhabdomyomas regress spontaneously before 6 years of age and therefore conservative clinical observation is the main treatment (about 80% of cases). Symptomatic cases may require surgical intervention, although at times this may not be possible anatomically. Given the findings from prenatal ultrasound, further assessment of intracardiac lesions and/or evaluation from the cardiologist is warranted, as changes under general anesthesia may induce hemodynamic instability or arrhythmias. Intravenous propofol or inhalational mask induction may lead to decreased preload, which may worsen outflow obstruction. Additional stress under general anesthesia releases catecholamines, which may also worsen dynamic outflow tract obstruction and induce arrhythmias. Dexmedetomidine should be used cautiously given the potential cardiac conduction abnormality in patients with intracardiac lesions, as well as the risk of airway obstruction in newborns undergoing sedation without airway protection.

KEY FACTS

- In children, primary cardiac tumors are mostly benign lesions: rhabdomyomas and fibromas are the most common.
- As opposed to adults who have atrial myxomas as the most common type of intracardiac lesions, children and infants have lesions commonly observed in both atria and ventricles.
- Neurocutaneous syndromes can present with intracardiac lesions: the three most common types of neurocutaneous syndromes are neurofibromatosis, tuberous sclerosis complex (TSC), and Sturge-Weber disease.
- Most cardiac rhabdomyomas regress spontaneously before 6 years of age and therefore conservative clinical observation is the main treatment (about 80% of cases).

REFERENCE

Lamba G, Frishman W. Cardiac and pericardial tumors. *Cardiol Rev.* 2012;20:237–52.

24. ANSWER: D

Long QT syndrome (LQTS) can be caused by mutations involving genes encoding critical ion channels of the heart (congenital LQTS) or by metabolic abnormalities or drugs (acquired LQTS). The QT interval represents the duration of activation and recovery of the ventricular myocardium. Dysfunction of cardiac ion channels results in impaired ventricular repolarization and, when amplified by sympathetic activity, can lead to early after-depolarization. Furthermore, transmural dispersion of repolarization creates a functional substrate for reentry circuits. Increased likelihood of early after-depolarization and reentry circuits can trigger ventricular arrhythmia characterized as polymorphic ventricular tachycardia (torsades de pointes) or ventricular fibrillation.

There are at least 12 genes associated with LQTS that have been discovered so far. Within these genes, hundreds of mutations have been identified. Romano-Ward syndrome occurs in people who inherit only a single generic variant from one of their parents. Jervell and Lang-Nielson syndrome is a more severe form where children are born deaf and have multiple LQTS genetic variants from each parent. Multiple medications can lengthen QT interval and they are currently updated on http://www.torsades.org.

There are **medications and treatments** available for LQTS. **Beta-blockers** slow the heart rate and blunt the effects of adrenaline during stress or exertion. An **implantable cardioverter-defibrillator** (ICD) device can monitor arrhythmic rhythms and deliver electrical shocks to restore a normal cardiac rhythm when indicated. **Left cardiac sympathetic denervation** surgery has also helped reduced risk of sudden death in people who are considered at high risk for sudden death, those who do not tolerate medications or are resistant to medications, and those who have frequent interventions from their ICD device. Lastly, **lifestyle changes** by avoiding environmental stimulants and strenuous exercises are also recommended. Recent reviews indicate that the majority of patients can be managed safely and effectively with medical therapies and trigger avoidance.

Torsades may be short-lived and self-terminating, leading to what often is observed as syncope or seizure. Prolonged episodes with hemodynamic instability require emergent asynchronous defibrillation and cardiopulmonary resuscitation (CPR) according to AHA guidelines. Magnesium sulfate is the treatment of choice for prevention of recurrence even in the presence of normal magnesium level.

Propofol has little or no effect on QT interval. Inhalational anesthetics are safe except for halothane because it sensitizes the heart to catecholamines. An ideal muscle relaxant should avoid histamine release, bradycardia, vagal stimulation, and potassium shifts, and be short acting to avoid the need for reversal. Succinylcholine is not a good choice because of its autonomic effects and potassium release. Pancuronium leads to tachycardia due to its vagolytic properties and therefore should also be avoided. Vecuronium and atracurium have been found to be safe. Neuromuscular reversal agents should be avoided if possible due to the effects of tachycardia and bradycardia. Narcotics should be safe except for methadone at very high maintenance doses as it can prolong QT interval. The antiemetic agents droperidol and ondansetron are generally avoided. Regional anesthesia should be safe and beneficial.

During the perioperative setting, sympathetic stimulation should be avoided. Premedication should be provided to blunt the sympathetic system response due to anxiety and stress. However, premedication with ketamine may lead to sympathetic stimulation and it is generally avoided. IV placement for a child while awake may lead to significant stress-induced arrhythmias. The outpatient setting should be avoided due to the complexity of the case and potential CPR management. Temperature should remain approximately 37°C because hypothermia could lengthen the QT interval due to the prolonged recovery of inactivated sodium channel.

KEY FACTS

- LQTS can be caused by mutations involving genes encoding critical ion channels of the heart (congenital LQTS) or by metabolic abnormalities or drugs (acquired LQTS).
- Medications and treatments for LQTS include beta-blockers, implantable cardioverter-defibrillator devices, left cardiac sympathetic denervation, and lifestyle changes.
- Torsades may be short-lived and self-terminating, leading to what often is observed as syncope or seizure.
- Inhalational anesthetics are safe except for halothane because it sensitizes the heart to catecholamines.

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Klies SJ, Pabelick CM, Hurley HA, White RD, Ackerman MJ. Anesthesia for patients with congenital long QT syndrome. *Anesthesiology*. 2005;102(1):204–10.

25. ANSWER: A

This patient shows evidence of right ventricular (RV) dysfunction either related to ischemic injury and/or elevated PVR. Therefore, it is essential to **optimize RV output** by providing inotropic support (e.g., epinephrine, dobutamine, milrinone, dopamine), maintaining appropriate filling pressures, and avoiding high CVP or RV overload. In addition, it is essential to maintain adequate amnesia and analgesia to prevent catecholamine release, effective oxygenation and ventilation (avoiding significant hypocarbia, lung overdistension, or high PEEP), normal pH, and normothermia, as well as pulmonary vasodilator therapy (inhaled nitric oxide). If cardiac output remains inadequate despite maximal drug therapy, mechanical ventricular assist device or extracorporeal membrane oxygenation (ECMO) may be necessary.

The donor heart is subjected to ischemia-reperfusion injury. **Right ventricular dysfunction or failure** is the most common etiology for failure to wean from CPB, especially in the presence of pulmonary hypertension. Patients with end-stage cardiomyopathy present with significant degrees of both systolic and diastolic dysfunction. Increased left ventricular end-diastolic pressure leads to elevated left atrial and pulmonary pressures. Elevated pulmonary vascular resistance (calculated PVR above 5 Wood units during catherization, especially unresponsive to oxygen and nitric oxide) or a high transpulmonary gradient >12 mm Hg (the difference between mean pulmonary arterial pressure and left atrial pressure) remains as one of the few absolute contraindications for cardiac transplantation.

Left ventricular dysfunction may present as diastolic dysfunction. This is characterized by restrictive ventricular filling pressure. Echocardiogram and left atrial pressure monitoring are important for assessment, as well as management of preload, afterload, and inotropy.

The **transplanted heart is functionally denervated** and the donor atrium is the source for the recipient's heart rate. Due to absent vagal tone, resting heart rate averages 90 to 110 bpm. The baroreceptor reflex is also disrupted and therefore heart rate and cardiac output responds less reactively to systemic catecholamines. Agents such as epinephrine and isoproterenol remain effective inotropes and chronotropes due to their direct effects on donor heart alpha- and beta-adrenergic receptors. Epicardial pacing could be attainable for this patient, although stroke volume would likely be the determining factor for low cardiac output in this patient.

KEY FACTS

- Optimize RV output by providing inotropic support (e.g., epinephrine, dobutamine, milrinone, dopamine), appropriate filling pressures, and avoiding high CVP or RV overload.
- Right ventricular dysfunction or failure is the most common etiology for failure to wean from CPB, especially in the presence of pulmonary hypertension.
- Left ventricular dysfunction may present as diastolic dysfunction.
- The transplanted heart is functionally denervated, and the donor atrium is the source for the recipient's heart rate.

REFERENCES

Andropoulos D, Stayer SA, Russell IA, Mossad EB, eds. *Anesthesia for Congenital Heart Disease*. 2nd ed. Chichester, UK: Wiley-Blackwell; 2010:385–403.

Ramakrishma H, Jaroszewski DE, Arabia FA. Adult cardiac transplantation: a review of perioperative management Part-I. *Ann Card Anaesth*. 2009;12(1):71–8.

26. ANSWER: A

Traditional Tetralogy of Fallot (TOF) is more accurately described as TOF with pulmonary stenosis (TOF/PS), which is different than TOF with pulmonary atresia (TOF/PA) or TOF with absent pulmonary valve (TOF/APV). In general, TOF is characterized by pulmonic stenosis (infundibular or subvalvular, valvular, suprvalvular, or a combination), VSD, right ventricle hypertrophy (RVH), and overriding of the aorta. RVH is a result of pressure load on the RV.

In patients with TOF, pulmonary blood flow directly influences arterial oxygen saturation. Traditional TOF/PS patient has a fixed and dynamic RV outflow tract obstruction causing right-to-left shunt and cyanosis. The dynamic component is attributed to the hypertrophied infundibulum and muscle bundle fibers in the RVOT. "Pink" Tets refers to TOF patients who have minimal obstruction to pulmonary blood flow or even left-to-right shunt leading to normal saturation. These patients may present with increased pulmonary blood flow and congestive heart failure.

A **"Tet spell"** is a hypercyanotic episode due to infundibular spasm leading to an acute decrease in pulmonary blood flow (PBF) and right-to-left shunt. It can be initiated spontaneously, but it is usually in response to agitation or increased sympathetic tone that results in increased cardiac contractility leading to infundibular spasm and RVOT obstruction. Spells can also be induced during anesthesia with sudden decrease in SVR or during surgical manipulation prior coming onto CPB. Children classically adopt a squatting posture during a spell to alleviate symptoms. This position increases venous return and RV filling, which reduces RVOT obstruction. Furthermore, squatting increases systemic vascular resistance (SVR), which prevents worsening of right-to-left shunt. Alternatively, deep anesthesia reduces cardiac contractility while volume and direct alpha-agonist (phenylephrine) can be used to treat a spell during perianesthetic setting.

TOF/PA is characterized by hypoplasia of the central and peripheral pulmonary arteries. The main pulmonary artery (MPA) may be absent or the branch PAs may be nonconfluent or stenotic. Pulmonary blood supply is usually via PDA or multiple aortopulmonary collateral arteries (MAPCAs). Duct-dependent TOF/PA requires prostaglandin (PGE1) infusion short after birth. MAPCA-dependent TOF/PA may not show obvious signs or symptoms at birth. However, cyanosis may be present with progression of stenoses within the collateral vessels themselves. Others may show signs of congestive heart failure (CHF) over weeks and months of life due to progressive increase in PBF secondary to decreased PVR. Surgical management is based on clinical and anatomic considerations with determinant factors based on the patient's arterial oxygen saturation, types of collaterals, and anatomy of the pulmonary arteries.

TOF/APV is characterized by either rudimentary ridges or the complete absence of pulmonic valve tissue, which in utero leads to increased pulsatile pulmonary blood flow, producing significantly enlarged main and branch PAs. In addition to compression of the larger bronchi, intrapulmonary bronchi are also involved, as well as reduction of the number of alveoli. This may explain why surgical relief of the larger airway compression alone is not always effective in reversing the severe obstructive respiratory disease. This condition has an extremely wide spectrum of severity. Mild cases with minimal respiratory pathologies present with clinical symptoms and management similar to TOF/PS. At the severe end of the spectrum, patients with TOF/APV often present with features of extensive airway compression and tracheobronchomalacia. Hypoxemia is the result of both intrapulmonary (ventilation-perfusion mismatch) and intracardiac pathology (right-to-left shunt across VSD, although small without the presence of significant RV outflow tract obstruction). Respiratory support with prone position may be indicated, but there are no effective nonsurgical interventions available to treat patients with severe symptoms. As a result, surgery is indicated soon after birth for patients with significant symptoms by using homograft pulmonary valve to replace the central pulmonary arteries, as well as VSD closure with infundibular muscle bundle division as indicated. The main challenge coming off CBP will be management of ventilation due to persistence of tracheobronchomalacia and distal small airway obstruction.

This patient has respiratory failure secondary to significant dilation of the pulmonary arteries and likely associated

tracheobronchomalacia. Respiratory failure will likely persist into the postoperative period, which is often more significant than cardiac complications. Hypoxemia and respiratory failure are due to intrapulmonary and intracardiac pathology, not pulmonary edema.

KEY FACTS

- Traditional Tetralogy of Fallot (TOF) is more accurately described as TOF with pulmonary stenosis (TOF/PS), which is different than TOF with pulmonary atresia (TOF/PA) or TOF with absent pulmonary valve (TOF/APV).
- In patients with TOF, pulmonary blood flow directly influences arterial oxygen saturation.
- A "Tet spell" is a hypercyanotic episode due to infundibular spasm leading to an acute decrease in pulmonary blood flow (PBF) and right-to-left shunt.
- TOF/PA is characterized by hypoplasia of the central and peripheral pulmonary arteries.
- TOF/APV is characterized by either rudimentary ridges or the complete absence of pulmonic valve tissue.

REFERENCE

Jonas R, ed. *Comprehensive Surgical Management of Congenital Heart Disease*. Philadelphia, PA: CRC Press; 2004:293–8, 440–56.

27. ANSWER: C

This patient should remain on room air to avoid increased PBF with oxygen supplement. It is prudent to avoid aggressive fluid administration or blood transfusion prior to bypass due to an already volume-overloaded RV. Goals are to keep PVR relatively elevated by avoiding oxygen supplement, hyperventilation, and hypocapnia. Cardiac output should be maintained to provide adequate systemic and coronary perfusion.

HLHS refers to the underdevelopment of left heart structures. Generally there are four subtypes based on the morphology of the left heart valves: aortic and mitral stenosis, aortic and mitral atresia, aortic atresia and mitral stenosis, and aortic stenosis and mitral atresia. The aorta varies in length, diameter, and degree of hypoplasia depending on subtypes. Aortic atresia tends to be associated with more severe degree of ascending aortic hypoplasia than does aortic stenosis.

In HLHS, systemic and pulmonary blood returns mix in the right atrium through atrial shunting at the level of the foramen ovale or ASD. The right ventricle supports both systemic and pulmonary circulation in a parallel fashion as the main pulmonary artery delivers blood to the pulmonary arteries as well as to the aorta via the ductus arteriosus (PDA). In the presence of limited or no antegrade blood flow to the ascending aorta, the upper body and coronary perfusions unreliably depend on retrograde blood supply through the PDA to the transverse and ascending aorta. This is in addition to the presence of decreased oxygen-carrying capacity due to total mixing of the blood supply and an already volume-overloaded RV. Blood flow to the lower body is antegrade from the PDA via the descending aorta. Thus, PDA narrowing or closure results in inadequate systemic and coronary perfusion, leading to ischemia, acidemia, and ultimately death. PGE1 is vital to keeping the ductus arteriosus patent.

The **key for anesthetic management of HLHS** is to determine and control the balance between pulmonary blood flow (Qp) and systemic blood flow (Qs), otherwise known as the Qp:Qs ratio. Typically a patient with HLHS presents clinically with inadequate systemic output and excessive pulmonary blood flow, as shown in this patient with associated signs of hypotension, relatively high systemic saturation, diminished UOP, and prominent tachypnea.

The **surgical goals** of first-stage reconstruction for HLHS are similar to other palliative procedures in preparation for an ultimate Fontan operation. Ventricular function must be protected by avoiding excessive volume load (i.e., large shunt with high pulmonary blood flow) or pressure load (i.e., RV outflow obstruction due to high aortic arch gradient). In addition, PVR must be minimized by preventing pulmonary venous obstruction (restrictive ASD) or excessive pulmonary blood flow. Lastly, optimal pulmonary artery growth must be achieved by maintaining adequate size and freedom from distortion.

KEY FACTS

- HLHS refers to the underdevelopment of left heart structures.
- In HLHS, systemic and pulmonary blood returns mix in the right atrium through atrial shunting at the level of the foramen ovale or ASD.
- The key for anesthetic management of HLHS is to determine and control the balance between pulmonary blood flow (Qp) and systemic blood flow (Qs), otherwise known as the Qp:Qs ratio.

REFERENCE

Jonas R, ed. *Comprehensive Surgical Management of Congenital Heart Disease*. Philadelphia, PA: CRC Press; 2004:341–56.

28. ANSWER: B

It is **essential to distinguish** systemic hypoxemia in patients with single-ventricle physiology and determine whether it is due to low cardiac output, low mixed venous oxygen saturation, low pulmonary venous saturation, or low Qp:Qs ratio.

The **depressed myocardial performance** needs support in order to provide adequate systemic and pulmonary perfusion. Aortic arch reconstruction, AV valve dysfunction, semilunar valve obstruction, and regurgitation should be evaluated for by echocardiography. It is essential to maintain adequate cardiac output and to prevent the right ventricle volume and pressure overload. It is best to avoid acidosis and electrolyte disturbances, which would worsen cardiac function. With normal HCO_3 and arterial pH, giving sodium bicarbonate is not indicated.

Low mixed venous saturation should benefit from adequate hematocrit and cardiac output. This patient appears to have adequate pulmonary and systemic driving pressures and therefore escalating inotropic support is not recommended. Hct above 40% alleviates excessive demands placed upon the recovering single-ventricle heart to increase systemic output. Thus, the most appropriate intervention is to transfuse to provide adequate oxygen-carrying capacity.

Low pulmonary venous saturation would be difficult to assess intraoperatively, but aggressive ventilatory support to reduce atelectasis and promote O_2 exchange is indicated. This includes ETT suctioning, adequate PEEP, and sufficient minute ventilation. Excessive hyperventilation is not recommended since it may compromise brain perfusion.

Low Qp:Qs can be related to mechanical obstruction or volatile PVR. There are three categories to consider: technical issues, pulmonary vasodilation, and systemic vasoconstriction. Relieve obstruction or replace with larger shunt. Reduce PVR by increasing O_2, moderate hyperventilation, normothermia, alkali, and nitric oxide. These potential causes should be further investigated if hypoxemia does not improve with transfusion.

KEY FACTS

- It is essential to distinguish systemic hypoxemia in patients with single-ventricle physiology and determine whether it is due to low cardiac output, low mixed venous oxygen saturation, low pulmonary venous saturation, or low Qp:Qs ratio.
- Low mixed venous saturation should benefit from adequate hematocrit and cardiac output.
- Low pulmonary venous saturation would be difficult to assess intraoperatively, but aggressive ventilatory support to reduce atelectasis and promote O_2 exchange is indicated.
- Low Qp:Qs can be related to mechanical obstruction or volatile PVR.

REFERENCE

Andropoulos D, Stayer SA, Russell IA, Mossad EB, eds. *Anesthesia for Congenital Heart Disease*. 2nd ed. Chichester, UK: Wiley-Blackwell; 2010:356–72.

29. ANSWER: B

If the patient comes off CPB with evidence of sustained hypotension, ECG changes, high filling pressures, and ventricular distension, **reinstitution of CPB** should begin early enough to prevent worsening subendocardial ischemia and permanent injury to the heart. CPB allows the heart to reperfuse during lower energy consumption state. Once on bypass, causes of poor cardiac function should be investigated. These include heart rate and rhythm, cardiac ischemia, single versus biventricular failure, pulmonary hypertension, residual surgical defects, valvular function, and presence of uncontrolled bleeding.

Williams syndrome (WS) is a congenital elastin disorder involving the vascular system, connective tissue, and central nervous system. **Cardiovascular defects** are the most common cause of death in patients with WS. Patients with WS lack the elasticity of the arterial tree provided by normal elastin leading to arterial stiffness. In addition, occlusion of the arterial lumen also occurs due to abnormal proliferation of vascular smooth muscle cells due to the lack of regulation otherwise provided by normal elastin.

Supravalvular aortic stenosis and pulmonary arterial stenosis are the **most common cardiovascular findings in patients with WS**. Coronary artery abnormalities are also common and may manifest as ostial stenosis, diffuse stenosis, arterial dilatation, or obstruction of coronary blood flow. Mitral and aortic valves may be involved, but this is uncommon. The tricuspid valve is rarely involved. The risk of sudden death in WS patients is estimated to be 25–100 times higher than normal population, with a large number of cardiovascular collapses and deaths occurring in the periprocedural and perioperative settings. The reason for increased risk of sudden death is not completely understood. However, it is believed that patients with both RV and LV outflow tract obstruction and/or coronary artery involvement have higher morbidity and mortality. Recent findings show that long QTc may also be a significant factor since deaths have been reported in WS patients without evidence of other cardiovascular involvement.

Appropriate anesthetic management for patients with WS is essential to avoid devastating complications from compromised coronary perfusion as well as elevated cardiac wall stress. Succinylcholine should be avoided because it may cause a hyperkalemic response. Anesthetic strategies that may lead to negative inotropic effect and decreased SVR should be used cautiously. It is also important to maintain appropriate preload and avoid extreme volume shifts. Heart rate and rhythm should be maintained appropriately. Last but not least, hypotension should be treated aggressively.

Patients with **bilateral supravalvular stenoses** are at high risk for complications after CPB due to thickened ventricles that may not be well protected during CPB. In addition, the potential presence of coronary abnormalities

may lead to cardiac ischemia. Giving epinephrine IV in the presence of escalating inotropic support will not solve the problem. Volume bolus in the presence of failing ventricles may worsen wall tension and ischemia. Nitric oxide may be started if there is pulmonary hypertension and RV failure, but this intervention will take time, which would delay necessary intervention by coming back onto bypass to protect the heart.

KEY FACTS

- Williams syndrome (WS) is a congenital elastin disorder involving the vascular system, connective tissue, and central nervous system.
- Cardiovascular defects are the most common cause of death in patients with WS.
- Supravalvular aortic stenosis and pulmonary arterial stenosis are the most common cardiovascular findings in patients with WS.
- Patients with bilateral supravalvular stenoses are at high risk for complications after CPB due to thicken ventricles that may not be well protected during CPB.

REFERENCE

Collin R. Cardiovascular disease in Williams syndrome. *Circulation*. 2013;127:2125–34.

30. ANSWER: C

Profound, deep, moderate, and mild hypothermia are defined as less than or equal to 14°C, 14.1°C–20°C, 20.1°C–28°C, and 28.1°C–34°C, respectively.

The safe period of DHCA varies depending on multiple factors: infants versus adults, defined primary acceptable outcome, comorbidities (cerebrovascular disease, renal), and DHCA technique (pH and hematocrit management). In children, **DHCA period longer than 60 minutes has shown increased likelihood of adverse neurodevelopmental outcomes**. In adults, DHCA intervals have been kept less than 30–40 minutes.

Hypothermia reduces cerebral metabolic rate of oxygen consumption ($CMRO_2$) and the development of intracellular acidosis. In addition to reducing $CMRO_2$ consumption, hypothermia also reduces release of excitatory neurotransmitters that accompany cerebral ischemia and subsequent reperfusion.

Hemodilution is believed to be essential during DHCA because of increased viscosity through microcirculatory flow related to hypothermia. However, a hematocrit of 30% is more accepted now during DHCA due to improved cardiac output postoperatively and better neurological outcome. In children, **pH stat management is believed to offer several advantages over alpha stat management**: better suppression of cerebral metabolic rate for oxygen, faster and more homogenous cooling due to the effect of decreased cerebral vascular resistance and increased cerebral blood flow, limiting leftward shift of the oxygen-Hb dissociation curve, limiting aortopulmomonary collateral steal, and better cerebral oxygenation. Hyperthermia has a potent negative effect in exacerbating neurological injury after circulatory arrest and should be avoided. Giving calcium above necessity is not a proven approach for brain protection.

KEY FACTS

- Profound, deep, moderate, and mild hypothermia are defined as less than or equal to 14°C, 14.1°C–20°C, 20.1°C–28°C, and 28.1°C–34°C, respectively.
- Hypothermia reduces cerebral metabolic rate of oxygen consumption ($CMRO_2$) and the development of intracellular acidosis.
- In children, a DHCA period longer than 60 minutes has shown increased likelihood of adverse neurodevelopmental outcomes.
- In addition to reducing $CMRO_2$ consumption, hypothermia also reduces release of excitatory neurotransmitters that accompany cerebral ischemia and subsequent reperfusion.
- Hemodilution is believed to be essential during DHCA because of increased viscosity through microcirculatory flow related to hypothermia.

REFERENCES

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Jonas R, ed. *Comprehensive Surgical Management of Congenital Heart Disease*. Philadelphia, PA: CRC Press; 2004:161–74.

31. ANSWER: D

The **first position** refers to the chamber(s) paced, the **second** to the chamber(s) sensed, the **third** to the pacemaker's response to sensing, and the **fourth** to programmability and rate modulation. The **fifth** position is restricted to antitachycardia function and is used infrequently.

Both **single- and double-chamber pacemakers** are available for permanent pacing in children. Single-chamber pacemakers carry electrical impulses from the pulse generator to either the right atrium or right ventricle of the heart. The **modes frequently used in single-chamber** pacemaker are AAI or AAIR, or VVI or VVIR, depending on whether there is presence of atrial or ventricular lead. Dual-chamber pacemakers carry electrical impulses from the pulse generator to both the right ventricle and

Table 5.3 NOMENCLATURE ESTABLISHED BY THE NORTH AMERICAN SOCIETY OF PACING (NASPE) AND ELECTROPHYSIOLOGY AND THE BRITISH PACING AND ELECTROPHYSIOLOGY GROUP (BPEG)

POSITION I	POSITION II	POSITION III	POSITION IV	POSITION V
Chamber(s) paced	Chamber(s) sensed	Response to sensing	Programmability	Multisite pacing
O, none	O, none	O, none	O, none	O, none
A, atrium	A, atrium	I, inhibited	R, rate modulation	A, atrium
V, ventricle	V, ventricle	T, triggered		V, ventricle
D, dual (A+V)	D, dual (A+V)	D, dual (I+T)		D, dual (A+V)

the right atrium, allowing timed contractions between the two chambers. Typical modes are DDD or DDDR. Biventricular pacemakers are a treatment option for people with heart failure. Unlike a regular pacemaker, a **biventricular pacemaker** stimulates both the right and left ventricles, which allows the heart to pump blood more effectively. Because this treatment resets the ventricles' pumping mechanism, it is also referred to as cardiac resynchronization therapy (CRT).

In general, indications for permanent pacemakers are sinus node disease, AV node disease, long QT syndrome, hypertrophic obstructive cardiomyopathy, and dilated cardiomyopathy. For more detailed recommendations, please review **ACC/AHA/HRS 2008 Guidelines for Device-Based Therapy of Cardiac Rhythm Abnormalities (*Circulation*. 2008;117:e350-e408).**

Single-chamber ventricular pacemaker is used when maintenance of AV synchrony during pacing is not necessary or in patients with chronic atrial fibrillation or other atrial tachyarrhythmias.

In situations where the SA node rate is slow and AV node conduction is intact, atrial pacing (AOO/AAI) should be provided since activation of ventricular contraction via the native conduction system provides optimal ventricular synchrony.

With normal SA node function but with a very prolonged AV interval or AV node block, AV universal pacing (DDD) is recommended. VOO is not recommended in the

Table 5.4 ANSWER OF PACEMAKER GENERATOR IN SELECTED INDICATIONS FOR PACING

PACEMAKER GENERATOR	SINUS NODE DYSFUNCTION	ATRIOVENTRICULAR BLOCK	NEURALLY MEDIATED SYNCOPE OR CAROTID SINUS HYPERSENSITIVITY
Single-chamber atrial pacemaker	No suspected abnormality of atrioventricular conduction and not at increased risk for future trioventricular block Maintenance of atrioventricular synchrony during pacing desired	Not appropriate	Not appropriate
Single-chamber ventricular pacemaker	Maintenance of atrioventricular synchrony during packing not necessary Rate response available if desired	Chronic atrial fibrillation or other atrial tachyarrhythmia or maintenance of atrioventricular synchrony during pacing not necessary Rate response available if desired	Chronic atrial fibrillation or other atrial tachyarrhythmia Rate response available if desired
Dual-chamber pacemaker	Atrioventricular synchrony during pacing desired Suspected abnormality of atrioventricular conduction or increased risk for future atrioventricular block Rate response available if desired	Atrioventricular synchrony during pacing desired Atrial pacing desired Rate response available if desired	Sinus mechanism present Rate response available i f desired
Single-lead, atrial-sensing ventricular pacemaker	Not appropriate	Desire to limit the number of pacemaker leads	Not appropriate

SOURCE: From Cote CJ, Lerman J, Todres ID, eds. *A Practice of Anesthesia for Infants and Children*. 4 ed. Philadelphia, PA: Saunders; 2009.

presence of intact SA node because it would not preserve optimal AV synchrony.

When both SA and AV node dysfunction coexist, AV sequential pacing (DDD) will be necessary to allow AV synchrony.

This patient has functional SA node with AV block. Therefore, DDD is the preferred pacing method for a permanent pacemaker.

KEY FACTS

- The first position refers to the chamber(s) paced, the second to the chamber(s) sensed, the third to the pacemaker's response to sensing, and the fourth to programmability and rate modulation. The fifth position is restricted to antitachycardia function and is used infrequently.
- Both single- and double-chamber pacemakers are available for permanent pacing in children.
- Single-chamber pacemakers carry electrical impulses from the pulse generator to either the right atrium or right ventricle of the heart.
- Unlike a regular pacemaker, a biventricular pacemaker stimulates both the right and left ventricles, which allows the heart to pump blood more effectively.
- In general, indications for permanent pacemakers are sinus node disease, AV node disease, long QT syndrome, hypertrophic obstructive cardiomyopathy, and dilated cardiomyopathy.

REFERENCES

Epstein AE, DiMarco JP, Ellenbogen KA, et al. ACC/AHA/HRS 2008 Guidelines for Device-Based Therapy of Cardiac Rhythm Abnormalities. *Circulation*. 2008;117:e350–e408.

Rozner M. The patient with a cardiac pacemaker or implanted defibrillator and management during anaesthesia. *Curr Opin Anaesthesiol*. 2007;20:261–8.

32. ANSWER: D

Critical neonatal aortic valve stenosis is a high-risk CHD. It is **defined as** pressure gradient across the aortic valve of more than 70 mm Hg or aortic valve area of 0.6 cm^2 or less. Patients with this condition have poorly defined leaflets that are almost always associated with some degree of underdevelopment of other left-sided structures.

The **main implication** of critical AS is the increased impedance to LV ejection and produces intraventricular pressure that exceeds aortic systolic pressure. Laplace's law describes the LV wall stress as:

$$\text{LV wall stress} = Pr/2h$$

where P = peak intraventricular pressure, r = ventricular radius, and h = LV wall thickness. LV wall stress is proportional to intraventricular pressure and ventricular radius, and it is inversely related to ventricular wall thickness.

In an effort **to maintain normal LV wall stress and to preserve cardiac output** across the stenotic valve, the ventricular wall thickness will increase in response to the suprasystemic intraventricular pressure. However, there are consequences to this compensation. LV concentric hypertrophy places the subendocardium at risk for ischemia because of elevated LV end-diastolic pressure as well as compression of subendocardial vessels by thicken myocardium.

In the presence of limited antegrade blood flow across the fixed stenotic aortic valve to the ascending aorta, the upper body and coronary perfusions depend on retrograde blood supply through the PDA to the transverse and ascending aorta. **Blood flow to the lower body** is antegrade from the PDA via the descending aorta. Thus, PDA narrowing or closure results in inadequate systemic and coronary perfusion, leading to ischemia, acidemia, and ultimately death. PGE1 is vital to keep the ductus arteriosus patent. Induction with propofol and fentanyl may lead to some degree of cardiac suppression and lower SVR, which can compromise coronary perfusion and cardiac output. Conscious sedation would not be recommended due to the inability of neonates to maintain spontaneous ventilation. Furthermore, considering the high-risk nature of the case, total airway control is essential to provide adequate ventilation during the procedure or while handling potential crises. Finally, inotropic support during the procedure would be beneficial to support cardiac contractility, especially during direct balloon dilation valvuloplasty when there is total obstruction of cardiac output and occlusion of coronary perfusion.

KEY FACTS

- Critical neonatal aortic valve stenosis is a high-risk CHD and is defined as pressure gradient across the aortic valve of more than 70 mm Hg or aortic valve area of 0.6 cm^2 or less.
- The main implication of critical AS is the increased impedance to LV ejection that produces intraventricular pressure that exceeds aortic systolic pressure.
- In an effort to maintain normal LV wall stress and to preserve cardiac output across the stenotic valve, the ventricular wall thickness will increase in response to the suprasystemic intraventricular pressure.
- In the presence of limited antegrade blood flow across the fixed stenotic aortic valve to the ascending aorta, the upper body and coronary perfusions depend on retrograde blood supply through the PDA to the transverse and ascending aorta.

REFERENCE

Jonas R, ed. *Comprehensive Surgical Management of Congenital Heart Disease*. Philadelphia, PA: CRC Press; 2004:320–9.

33. ANSWER: B

Adult patients with CHD, who require noncardiac surgery, can be divided into three groups: those who have had complete anatomic repair of their cardiac defect, those who have undergone previous palliative surgery, and those who have never been operated on. **The main objectives for these patients** can be simplified by optimizing cardiac output, maintaining balanced pulmonary and systemic blood flows, and providing an optimal oxygen delivery with adequate hematocrit level.

The **Fontan procedure** (or total cavopulmonary connection) is generally performed in staged patients at 2–3 years of age. Fontan completion is indicated because patients with hemi-Fontan (bidirectional cavopulmonary shunt or Glenn) are subjected to paradoxical emboli returning via the IVC, worsening hypoxemia due to increased oxygen demand with age, and the development of pulmonary arteriovenous malformation due to the diversion of the IVC blood away from the pulmonary circulation. The **Glenn procedure** (performed around the age of 3–6 months) is an essential staged operation, as it has been shown to reduce morbidity and mortality compared to the acute transition from single ventricle to Fontan physiology. In other words, the Glenn procedure attenuates the volume overload on the single systemic ventricle by diverting SVC blood return directly to the pulmonary artery. Without this staged transition, constant volume overload in a univentricular heart would lead to impaired ventricular function and diastolic compliance. Elevated end-diastolic pressure would lead to poor pulmonary venous return, leading to compromised cardiac output.

Fontan patients require adequate intravascular volume due to passive return of venous systemic blood flow directly to the pulmonary circulation. **Other factors important to maintain cardiac output include** low PVR, normal sinus rhythm for optimal atrial and ventricular filling, adequate cardiac contractility and compliance, normal tricuspid and neoaortic valve, and uncompromised aortic outflow tract. It is important that this patient receive IV fluid prior to induction to maintain adequate cardiac output. Inotropic support is essential for supporting contractility and to decrease venous capacitance. Increased cardiac contractility and sympathetic activation decrease the venous capacitance and promotes venous return indirectly by augmenting cardiac output through the Frank-Starling mechanism, which increases the total blood flow through the circulatory system. Giving esmolol can further decrease cardiac output by limiting heart rate and contractility. It is also important to provide optimal ventilation and oxygen to minimize PVR. A **hematocrit of 35%** is adequate for oxygen-carrying capacity. Higher hematocrits can lead to increased viscosity, which may negatively influence cardiac output.

KEY FACTS

- Adult patients with CHD who require noncardiac surgery can be divided into three groups: those who have had complete anatomic repair of their cardiac defect, those who have undergone previous palliative surgery, and those who have never been operated on.
- The main objectives for these patients can be simplified by optimizing cardiac output, maintaining balanced pulmonary and systemic blood flows, and providing an optimal oxygen delivery with adequate hematocrit level.
- The Fontan procedure (or total cavopulmonary connection) is generally performed in staged patients at 2–3 years of age.
- The Glenn procedure (performed around the age of 3–6 months) is an essential staged operation, as it has been shown to reduce morbidity and mortality compared to the acute transition from single-ventricle to Fontan physiology.

REFERENCES

Cannesson M, Collange V, Lehot JJ. Anesthesia in adult patients with CHD. *Curr Opin Anaesthesiol*. 2009;22:88–94.

DiNardo J, Zvara D, eds. *Anesthesia for Cardiac Surgery*. 3rd ed. Oxford, UK: Blackwell Publishing; 2008:236–9.

34. ANSWER: C

The resuscitation of this child should begin with airway assistance to treat the reversible cause of hypoxia and bradycardia. Chest compressions and IV epinephrine will be needed if his condition worsens due to poor perfusion or full cardiac arrest. AED should be available and may be used as indicated.

The 2010 American Heart Association (AHA) Guidelines for Cardiopulmonary Resuscitation (CPR) and Emergency Cardiovascular Care (ECC) recommend a change of the basic life support (BLS) sequence from "A-B-C" (*A*irway, *B*reathing, *C*hest compressions) to "C-A-B" (*C*hest compressions, *A*irway, *B*reathing) for adults and pediatric patients (children and infants, excluding newborns). This recommendation is based on the following reasons:

- The **vast majority of arrests in adults** are more likely to be of cardiac etiology. Immediate activation of the

emergency response system with chest compressions and early defibrillation is critical for improving survival rates.
- In the A-B-C sequence, chest compressions are often delayed. The C-A-B will allow earlier chest compression and little delay in ventilation, which would soon begin after 30 compressions (compression-ventilation ratio of 30:2).
- Bystander CPR participation is fewer than 50% in cardiac arrests. It is believed that perhaps one of the main impediments for participation is the initiation of airway support with mouth-to-mouth rescue breaths. Bystander involvement early during arrests is important for outcome survival.

The AHA Guidelines also emphasize the importance of health care providers in choosing the sequence of CPR accordingly. **An adult** with witnessed cardiac arrest should receive early chest compressions and defibrillation. In children and infants, **the majority of pediatric cardiac arrests** are asphyxial and CPR should be implemented for five cycles (approximately 2 minutes) before initiating the emergency response system and obtaining an AED. **In newborns**, arrests are more likely caused by respiratory etiology, and resuscitation should begin with A-B-C sequence unless there is a known cardiac etiology.

There is continued **emphasis on high-quality CPR**, with compressions of adequate rate (100 compressions/min) and depth (at least 2 inches or 5 cm in adults and 1.5 inches or 4 cm in infants and newborns), allowing complete chest recoil, minimizing interruptions in chest compressions (taking no more than 5–10 seconds for pulse checks) and avoiding excessive ventilation.

It is also important to recognize and treat reversible causes early during CPR. The 5 H's and T's are as follows: **H**ypovolemia, **H**ypoxia, **H**ydrogen ion (acidosis), **H**ypo/hyperkalemia, **H**ypothermia, **T**ension pneumothorax, cardiac **T**amponade, **T**oxins, pulmonary **T**hrombosis, and coronary **T**hrombosis.

KEY FACTS

- The resuscitation of this child should begin with airway assistance to treat the reversible cause of hypoxia and bradycardia.
- The vast majority of arrests in adults are more likely to be of cardiac etiology.
- An adult with witnessed cardiac arrest should receive early chest compressions and defibrillation.
- In children and infants, the majority of pediatric cardiac arrests are asphyxial and CPR should be implemented for 5 cycles (approximately 2 minutes) before initiating the emergency response system and obtaining an AED.
- In newborns, arrests are more likely caused by respiratory etiology, and resuscitation should begin with A-B-C sequence unless there is a known cardiac etiology.

REFERENCE

Field JM, Hazinski MF, Sayre MR, et al. Part 1: executive summary: 2010 American Heart Association Guidelines for Cardiopulmonary Resuscitation and Emergency Cardiovascular Care. *Circulation*. 2010;122:S640–56.

35. ANSWER: B

Cardiac transplantation in infants and children is performed for both congenital and acquired heart disease. **Neonates with severe congenital abnormalities** such as hypoplastic left heart syndrome or children with severe heart failure following palliative procedures for single-ventricle physiology make up the majority of congenital cases. **Acquired etiologies include** dilated, restrictive, and hypertrophic cardiomyopathies as well as rare diseases such as cardiac tumors or Kawasaki disease. Many of these patients do not survive long enough to reach transplant, as donor organ availability falls well short of demand.

Optimizing anesthetic management for pediatric cardiac transplantation requires keen understanding of a child's underlying disease and physiology. Hemodynamic instability remains an ever-present consideration; therefore, it is important that rapid changes to preload, afterload, heart rate, and contractility are avoided. Meticulous **airway management** following induction is an important factor in preventing hypoxemia and hypercarbia. Both of these disturbances may increase pulmonary vascular resistance and cause depression of cardiac output. Recall that in the denervated heart, **only direct medications** such as epinephrine, isoproterenol, dopamine, and dobutamine will be effective in managing hypotension and/or bradycardia. Indirect agents, including ephedrine, glycopyrrolate, and atropine, will be ineffective. Additionally, epicardial pacing may also be required to maintain an adequate heart rate between 120 to 150 beats per minute. Typically, a balanced anesthetic with opioids, benzodiazepines, isoflurane, and a nondepolarizing muscle relaxant preserves cardiac output and minimizes hemodynamic perturbation.

Transesophageal echocardiography (TEE) remains the gold standard for intraoperative assessment of graft function, mechanical issues, and pulmonary hypertension. In some cases, centers advocate the use of TEE over placement of a pulmonary artery catheter since these invasive catheters carry increased risk when placed in children as compared to adults.

KEY FACTS

- Cardiac transplantation in infants and children is performed for both congenital and acquired heart disease.

- Neonates with severe congenital abnormalities such as hypoplastic left heart syndrome or children with severe heart failure following palliative procedures for single-ventricle physiology make up the majority of congenital cases.
- Acquired etiologies include dilated, restrictive, and hypertrophic cardiomyopathies as well as rare diseases such as cardiac tumors or Kawasaki disease.
- In the denervated heart, only direct medications such as epinephrine, isoproterenol, dopamine, and dobutamine will be effective in managing hypotension and/or bradycardia.
- Transesophageal echocardiography (TEE) remains the gold standard for intraoperative assessment of graft function, mechanical issues, and pulmonary hypertension.

REFERENCE

Cote CJ, Lerman J, Todres ID, eds. *A Practice of Anesthesia for Infants and Children*. 4th ed. Philadelphia, PA: Saunders; 2009:622.

36. ANSWER: A

It is crucial that an adequate preoperative evaluation is performed, as these results ultimately predict the success of cardiac transplant. **Assessment of cardiac function involves** obtaining a detailed medical history with **particular detail focusing on** exercise tolerance, oxygen requirements, and need for diuretics and inotropic support. The pretransplant evaluation ultimately includes cardiac catheterization with angiography. Assessment focuses heavily on determining **the severity of pulmonary hypertension.** The Pulmonary Vascular Resistance Index (PVRI), transpulmonary gradient (TPG), and reactivity of the pulmonary vascular bed to pharmacologic manipulation are essential to this evaluation (see Box 5.2).

A PVRI greater than 6 to 10 Wood units or a TPG greater than 15 mm Hg can lead to acute right ventricular failure. In addition, in elevated PVR, **other contraindications to pediatric heart transplantation** include multiple severe congenital abnormalities, prematurity (<36 weeks), low birth weight (<2 kg), ectopia cordis, diffuse pulmonary artery hypoplasia, pulmonary venous hypoplasia, active malignancy or infection, severe metabolic disease, or irreversible noncardiac end organ damage. Although a Holter monitor, echocardiogram, or chest radiograph may be part of a preoperative workup and provide an assessment of cardiopulmonary function, these are not typically used to determine suitability for transplant.

Box 5.2 CALCULATION OF PVRI AND TPG

$PVRI\ (dynes*sec/cm^5*m^2) = 80 \times [PAP\ (mm\ Hg) - PAWP\ (mm\ Hg)]/CI\ (L/min/m^2)$

$TPG = PAP\ (mm\ Hg) - PAWP\ (mm\ Hg)$

CI, cardiac index; PAP, mean pulmonary artery pressure; PAWP, mean pulmonary artery wedge pressure.

KEY FACTS

- Assessment of cardiac function involves obtaining a detailed medical history with particular detail focusing on exercise tolerance, oxygen requirements, and need for diuretics and inotropic support.
- The pretransplant evaluation ultimately includes cardiac catheterization with angiography, and assessment focuses heavily on determining the severity of pulmonary hypertension.
- In addition in elevated PVR, other contraindications to pediatric heart transplantation include multiple severe congenital abnormalities, prematurity (<36 weeks), low birth weight (<2 kg), ectopia cordis, diffuse pulmonary artery hypoplasia, pulmonary venous hypoplasia, active malignancy or infection, severe metabolic disease, or irreversible noncardiac end organ damage.

REFERENCE

Cote CJ, Lerman J, Todres ID, eds. *A Practice of Anesthesia for Infants and Children*. 4th ed. Philadelphia, PA: Saunders; 2009:619–20.

37. ANSWER: C

Supraventricular tachycardia (SVT) is the most common significant arrhythmia in infants and children. **SVT in children** consists of a regular tachycardia with a narrow QRS morphology. Heart rate is age dependent but usually exceeds 230 beats per minute. A **widening of the QRS** may occur if a concurrent bundle branch block exists. **Management of SVT in children** mimics treatment strategies employed in adults. These steps include the following:

1. Determination of hemodynamic stability (blood pressure, mentation, etc.). If the clinical situation indicates an unstable condition, prompt cardioversion with 0.5–1.0 joules/kg is recommended.
2. If vagal maneuvers are unsuccessful at controlling the heart rate, antiarrhythmic therapy with adenosine is the drug of choice for both diagnosis and treatment of most SVTs. β blockade is often then used for chronic therapy.

3. Treatment of underlying causes of the SVT, including controlling fever, stopping offending medications, or correcting of electrolytes.
4. Consider pacing if all of these steps are ineffective.

Of the remaining arrhythmias, long QT syndrome is associated with congenital syndromes and may lead to torsades de pointes, ventricular fibrillation, bradyarrhythmias, and even cardiac arrest. Ventricular tachycardia is relatively uncommon in children.

KEY FACTS

- SVT is the most common significant arrhythmia in infants and children.
- SVT in children consists of a regular tachycardia with a narrow QRS morphology.
- Heart rate is age dependent but usually exceeds 230 beats per minute.
- A widening of the QRS may occur if a concurrent bundle branch block exists.
- Management of SVT in children mimics treatment strategies employed in adults.
- Long QT syndrome is associated with congenital syndromes and may lead to torsades de pointes, ventricular fibrillation, bradyarrhythmias, and even cardiac arrest.

REFERENCE

Cote CJ, Lerman J, Todres ID, eds. *A Practice of Anesthesia for Infants and Children*. 4th ed. Philadelphia, PA: Saunders; 2009:316–8.

38. ANSWER: D

Management of pacemakers in the operating room remains a high priority for anesthesiologists and surgeons alike. These devices have become incredibly complex with numerous programmable features. **Indications for pacemakers in children** include symptomatic sinus bradycardia, bradycardia-tachycardia syndromes, congenital complete AV block, and advanced second- or third-degree AV block.

It is imperative that all implanted pacemaker devices are **interrogated as part of the preoperative evaluation prior to nonemergent cases**. **Reprogramming** of the device may be needed prior to the operating room to avoid problems related to **electrocautery**; this is the most common source of electromagnetic interference that may affect the functioning of these devices. Table 5.5 summarizes appropriate management strategies.

Of the listed answers, only the use of harmonic scalpel or battery-operated hot wire cautery is a corrected response.

KEY FACTS

- Indications for pacemakers in children include symptomatic sinus bradycardia, bradycardia-tachycardia syndromes, congenital complete AV block, and advanced second- or third-degree AV block.
- It is imperative that all implanted pacemaker devices are interrogated as part of the preoperative evaluation prior to nonemergent cases.
- Reprogramming of the device may be needed prior to the operating room to avoid problems related to electrocautery; this is the most common source of electromagnetic interference that may affect the functioning of these devices.

REFERENCE

Cote CJ, Lerman J, Todres ID, eds. *A Practice of Anesthesia for Infants and Children*. 4th ed. Philadelphia, PA: Saunders; 2009:319–20.

39. ANSWER: C

Cardiac tumors in children are extremely rare. Unlike adults in whom atrial myxomas are by far the most common, most tumors in children are either **rhabdomyomas or cardiac fibromas**. Among these tumors, **rhabdomyomas are the most common pediatric cardiac tumor**. They typically involve the **ventricular septum and left ventricle**. There are multiple tumors in a majority of cases.

Table 5.5 PERIOPERATIVE MANAGEMENT OF PACEMAKERS

SURGEON	ANESTHESIOLOGIST
Use of bipolar cautery	Ensure preoperative interrogation and postoperative reprogramming of the pacemaker completed by cardiology. Rate responsive features should be discontinued for surgery in most cases.
Avoidance of cautery near the generator	Availability of chronotropic drugs and alternate pacing modalities in the event of pacer failure
Positioning of the indifferent plate for electrocautery away from the pacemaker so the device is not between the electrodes	Availability of a magnet to allow for asynchronous pacer if needed
Use of the harmonic scalpel or battery operated hot wire handheld cautery	Close intraoperative monitoring with electrocardiogram; consider invasive arterial blood pressure

Although these tumors are considered to be benign, the decision to surgically excise these neoplasms is dependent on the severity of symptoms. Children with cardiomegaly, congestive heart failure, and arrhythmias are **candidates for surgery**. In the absence of these symptoms, rhabdomyomas tend to regress over time.

As mentioned earlier, atrial myxomas are only common in adults. Although common in children, teratomas are not typical cardiac tumors. Fibromas are common in children, but to a lesser degree as compared with rhabdomyomas.

KEY FACTS

- Cardiac tumors in children are extremely rare.
- Unlike adults in whom atrial myxomas are by far the most common, most tumors in children are either rhabdomyomas or cardiac fibromas.
- Among these tumors, rhabdomyomas are the most common pediatric cardiac tumor.
- They typically involve the ventricular septum and left ventricle.
- There are multiple tumors in a majority of cases.
- Children with cardiomegaly, congestive heart failure, and arrhythmias are candidates for surgery.

REFERENCE

Cote CJ, Lerman J, Todres ID, eds. *A Practice of Anesthesia for Infants and Children*. 4th ed. Philadelphia, PA: Saunders; 2009:302.

40. ANSWER: C

As mentioned previously, **common cardiac tumors in children** are rhabdomyomas and cardiac fibromas with rhabdomyomas being most common. These tumors can occur in **all four chambers of the heart**. This is in contrast to atrial myxomas in adults, which typically only occur in the left atrium. **Surgical excision** of these neoplasms is largely dependent on the symptoms of the child and is not always indicated, particularly in rhabdomyomas since they may regress over time. If **cardiomegaly, congestive heart failure, or arrhythmias** occur, then surgery is warranted. Of particular congenital concern, rhabdomyomas have been associated with children who have tuberous sclerosis.

Recall that **tuberous sclerosis** is a disease characterized primarily by cutaneous and neurologic lesions. **Cardiac and renal manifestations** are less frequent but can be significant. **Presence of cardiac rhabdomyomas** in conjunction with potential conduction defects should be evaIuated prior to surgery. In addition to the cardiac pathology described earlier, children affected by autosomal dominant disease may present with upper airway neoplasms, which may make airway management challenging. Due to neurologic abnormalities, they are also prone to seizure disorders, and therefore all anticonvulsant medications should be continued through the perioperative period.

KEY FACTS

- Surgical excision of these neoplasms is largely dependent on the symptoms of the child and is not always indicated, particularly in rhabdomyomas, since they may regress over time.
- If cardiomegaly, congestive heart failure, or arrhythmias occur, then surgery is warranted.
- Tuberous sclerosis is a disease characterized primarily by cutaneous and neurologic lesions; cardiac and renal manifestations are less frequent but can be significant.
- Presence of cardiac rhabdomyomas in conjunction with potential conduction defects should be evaIuated prior to surgery.

REFERENCE

Cote CJ, Lerman J, Todres ID, eds. *A Practice of Anesthesia for Infants and Children*. 4th ed. Philadelphia, PA: Saunders; 2009:302, 305.

41. ANSWER: A

Hypertrophic cardiomyopathy (HCM) is a congenital form of cardiomyopathy seen frequently in children and follows an autosomal dominant mode of transmission. Approximately **40% of cardiomyopathies** in children are secondary to HCM. It usually occurs as **asymmetric hypertrophy of the interventricular septum** but occasionally may be concentric. The **hallmark pathology** involved with HCM involves basal or dynamic left ventricular outflow obstruction and the potential for systolic dysfunction, putting the child at risk for sudden cardiac death. Children with severe HCM may develop **myocardial ischemia or critically increased outflow obstruction from even modest degrees of hypotension or tachycardia**.

Events or agents that increase outflow obstruction include those that:

- Increase myocardial contractility
- Decrease preload (hypovolemia, hypotension, hemorrhage, vasodilators, tachycardia, excessive positive pressure ventilation)
- Decrease afterload

Events or agents that decrease outflow obstruction include those that:

- Decrease myocardial contractility (β blockers, calcium channel blockers, halothane)

- Increase effective preload (decreased heart rate, volume expansion with crystalloid/colloid)
- Moderately increase afterload

Of the answers listed, heart rate control with calcium channel blockers and β blockers is the best answer since these decrease myocardial contractility. Both diuretics and hypotension on induction would decrease preload, potentially making the obstruction worse. Inotropes increase contractility, also causing a similar end outcome.

KEY FACTS

- HCM is a congenital form of cardiomyopathy seen frequently in children and follows an autosomal dominant mode of transmission.
- Approximately 40% of cardiomyopathies in children are secondary to HCM.
- It usually occurs as asymmetric hypertrophy of the interventricular septum but occasionally may be concentric.
- The hallmark pathology involved with HCM involves basal or dynamic left ventricular outflow obstruction and the potential for systolic dysfunction, putting the child at risk for sudden cardiac death.
- Children with severe HCM may develop myocardial ischemia or critically increased outflow obstruction from even modest degrees of hypotension or tachycardia.

REFERENCE

Cote CJ, Lerman J, Todres ID, eds. *A Practice of Anesthesia for Infants and Children*. 4th ed. Philadelphia, PA: Saunders; 2009:295–8, 389–91.

42. ANSWER: A

Dilated cardiomyopathy (DCM) is characterized by a thin left ventricular wall, dilation of the ventricular cavity, and varying degrees of systolic dysfunction. The causes can be either genetic as well as acquired. **Genetic forms** of DCM follow multiple types of inheritance patterns and are strongly associated with degenerative disorders, namely Duchenne and Becker muscular dystrophy. **Acquired DCM** is typically related to infectious etiologies, mainly viruses. Adenovirus, coxsackievirus, and human immunodeficiency virus are the usual culprits. Other acquired causes include metabolic disorders (thyroid/mitochondrial disorders and carnitine deficiency) and toxic exposures (anthracyclines).

Children affected by DCM typically present with a clinical picture consistent with congestive heart failure. **Tachypnea, dyspnea, diminished pulses, and hepatomegaly** are common exam findings. Cardiomegaly is seen on chest radiograph, and an ECG may reveal rhythm disturbances, including tachyarhythmias. An **echocardiogram** often reveals a dilated, volume-loaded, poorly contractile ventricle. **Treatment** of these patients is aimed at fluid optimization, stabilization of cardiac function, and supportive measures.

Perioperative management of these children includes judicious use of inotropic agents, treating fluid overload with diuretics (in stark contrast to hypertrophic cardiomyopathy where diuretics are relatively contraindicated), and conservative administration of fluids. Remember, DCM is a condition of systolic impairment, with fluid overload being a constant threat; therefore, preload reduction is the cornerstone therapy. Once initial stabilization is achieved, long-term maintenance with β blockade and afterload reduction with angiotensin-converting enzyme inhibitors is initiated.

KEY FACTS

- DCM is characterized by a thin left ventricular wall, dilation of the ventricular cavity, and varying degrees of systolic dysfunction.
- Genetic forms of DCM follow multiple types of inheritance patterns and are strongly associated with degenerative disorders, namely Duchenne and Becker muscular dystrophy.
- Acquired causes of DCM include adenovirus, coxsackievirus, human immunodeficiency virus, metabolic disorders (thyroid/mitochondrial disorders and carnitine deficiency), and toxic exposures (anthracyclines).
- Tachypnea, dyspnea, diminished pulses, and hepatomegaly are common exam findings.
- Perioperative management of these children includes judicious use of inotropic agents, treating fluid overload with diuretics (in stark contrast to hypertrophic cardiomyopathy where diuretics are relatively contraindicated), and conservative administration of fluids.

REFERENCE

Cote CJ, Lerman J, Todres ID, eds. *A Practice of Anesthesia for Infants and Children*. 4th ed. Philadelphia, PA: Saunders; 2009:297.

43. ANSWER: C

The key to understanding this question involves knowing the factors that lead to an increased pulmonary vascular tone.

Pulmonary hypertension is a common sequela of chronic or unoperated congenital heart disease. It may persist or develop after corrective surgery. In children who are

Table 5.6 FACTORS KNOWN TO INCREASE PULMONARY VASCULAR TONE

Hypoxia	Transmitted positive airway pressure
Hypercapnia	Atelectasis
Acidemia	Stress response
Hypothermia	Light anesthesia

SOURCE: Adapted from Cote CJ, Lerman J, Todres ID, eds. *A Practice of Anesthesia for Infants and Children*. 4 ed. Philadelphia, PA: Saunders;2009:475.

susceptible to acute pulmonary hypertensive crises, **symptoms may be manifested by** acute arterial desaturation, bradycardia, and/or systemic hypotension. It is critical that the anesthesiologist recognize potential triggers of pulmonary reactivity, since acute rises in pulmonary pressures can lead to increased right ventricular afterload with subsequent ventricular failure, leftward shifting of the interventricular septum causing compromised left ventricular performance, and overall decreased cardiac output.

If an **acute pulmonary hypertensive crisis** occurs, prompt administration of selective pulmonary vasodilators is indicated. Nitric oxide and other agents are the mainstays of treatment. Simultaneous use of inotropes to support right ventricular function is also key to treatment.

KEY FACTS

- In children who are susceptible to acute pulmonary hypertensive crises, symptoms may be manifested by acute arterial desaturation, bradycardia, and/or systemic hypotension.
- If an acute pulmonary hypertensive crisis occurs, prompt administration of selective pulmonary vasodilators is indicated.

REFERENCE

Cote CJ, Lerman J, Todres ID, eds. *A Practice of Anesthesia for Infants and Children*. 4th ed. Philadelphia, PA: Saunders; 2009:474–5.

44. ANSWER: D

Inhaled nitric oxide (NO) causes pulmonary vasodilation and increases systemic oxygen levels in infants with PPHN. NO is a gas synthesized by NO synthase in endothelial cells from L-arginine. NO freely diffuses into the adjacent vascular smooth muscle cells, stimulating soluble guanylate cyclase to increase levels of cyclic guanosine monophosphate (cGMP). Increased levels of cGMP lead to vascular dilation, decreased right-to-left shunting, and increased systemic oxygenation. NO has gained in popularity, mainly because of its ability to decrease the need of extracorporeal membrane oxygenation (ECMO). Despite being an effective choice for situations of severe PPHN, it is costly, invasive, and not available at many centers.

A physiologic **by-product of NO metabolism is methemoglobin**, although levels typically are not of clinical importance in most cases. Also worth emphasizing is NO's ability to cause pulmonary vasculature dilation, but it is also been shown to be useful in decreasing lung injury associated with prolong pulmonary hypertension. Recent data suggest that **NO decreases pulmonary artery smooth muscle cell proliferation and neomuscularization**. Therefore, it **treats active hypertensive crises as well as prevents lung remodeling** that leads to chronic decline.

KEY FACTS

- Inhaled nitric oxide, by increasing levels of cGMP, causes pulmonary vasodilation, decreased right-to-left shunting, and increased systemic oxygen levels in infants with PPHN.
- A physiologic by-product of NO metabolism is methemoglobin, although levels typically are not of clinical importance in most cases.
- Recent data suggest that NO decreases pulmonary artery smooth muscle cell proliferation and neomuscularization.
- Therefore, it treats active hypertensive crises as well as prevents lung remodeling that leads to chronic decline.

REFERENCE

Cote CJ, Lerman J, Todres ID, eds. *A Practice of Anesthesia for Infants and Children*. 4th ed. Philadelphia, PA: Saunders; 2009:750–1.

45. ANSWER: C

Endocarditis prophylaxis is essential for several broad categories of patients with underlying cardiac disease. Recent guidelines recommend prophylaxis for those with highest risk of an adverse outcome resulting from endocarditis. **Patients at highest risk include those with**:

1. Prosthetic heart valves
2. Prior history of endocarditis
3. Congenital heart disease (CHD): specifically, those with unrepaired cyanotic CHD, including palliative shunts and conduits.
4. Completely repaired CHD with prosthetic material or device with surgery in the *prior 6 months*
5. Repaired CHD with residual defects (prosthetic patch or material that inhibits endothelialization)
6. A cardiac transplant who develops valvulopathy

Procedures requiring prophylaxis include dental procedures that involve gingival tissues, periapical region of teeth, or perforation of mucosa. **High-risk patients** undergoing invasive procedures of the respiratory tract that involve incision of the mucosa should also be considered. Of note, prophylaxis for genitourinary or gastrointestinal procedures is not recommended. Additionally, **transesophageal echocardiography, routine endoscopy, and cardiac catheterization with angiography do not typically require prophylaxis**.

Antibiotics are administered 30 to 60 minutes before the procedure in order to allow for adequate plasma and tissue concentrations. **Amoxicillin is the antibiotic of choice, with cephalexin, clindamycin, azithromycin, or clarithromycin as options for penicillin-allergic patients**.

KEY FACTS

Recent guidelines recommend prophylaxis for those with highest risk of an adverse outcome resulting from endocarditis. Patients at highest risk include those with:

1. Prosthetic heart valves
2. Prior history of endocarditis
3. CHD: specifically, those with unrepaired cyanotic CHD, including palliative shunts and conduits
4. Completely repaired CHD with prosthetic material or device with surgery in the *prior 6 months*
5. Repaired CHD with residual defects (prosthetic patch or material that inhibits endothelialization)
6. A cardiac transplant who develops valvulopathy

REFERENCE

Cote CJ, Lerman J, Todres ID, eds. *A Practice of Anesthesia for Infants and Children*. 4th ed. Philadelphia, PA: Saunders; 2009:300–1.

46. ANSWER: C

Kawasaki disease is a form of systemic vasculitis characterized by a mucocutaneous lymph node syndrome. It is most common in infants and young children, most frequently those of Asian descent. The etiology is not known. Kawasaki disease, although **highly treatable**, **can be fatal** if not recognized, particularly if surgery is required during the acute phase of the disease. **Coronary artery aneurysms** are diagnostic for this form of vasculitis, and a minority of patients may go on to have myocardial ischemia or even infarction. **Children with identified aneurysms** are started on low-dose aspirin and/or anticoagulants or antiplatelet agents. If surgery is mandatory during the acute phase of the disease, it is incumbent on the anesthesiologist to optimize myocardial oxygen demand.

Diagnosis of this disorder is a clinical one, as there are no specific laboratory or radiographic tests for Kawasaki disease. In order to meet criteria, a child must have persisting fevers and at least four of the following:

1. Polymorphous exanthema
2. Peripheral extremity changes: erythema, desquamation, or edema of the hands/feet
3. Bilateral nonexudative conjunctivitis
4. Cervical lymphadenopathy, often unilateral
5. Oral manifestations: red, dry, or cracked lips; strawberry tongue

The treatment of Kawasaki disease involves intravenous gamma globulin during the acute phase of the disease and high-dose aspirin. Once acute symptoms resolve, doses of aspirin are then continued at lower doses for several months.

KEY FACTS

- Kawasaki disease is a form of systemic vasculitis characterized by a mucocutaneous lymph node syndrome.
- Kawasaki disease, although highly treatable, can be fatal if not recognized, particularly if surgery is required during the acute phase of the disease.
- Coronary artery aneurysms are diagnostic for this form of vasculitis, and a minority of patients may go on to have myocardial ischemia or even infarction.
- Children with identified aneurysms are started on low-dose aspirin and/or anticoagulants or antiplatelet agents.

REFERENCE

Cote CJ, Lerman J, Todres ID, eds. *A Practice of Anesthesia for Infants and Children*. 4th ed. Philadelphia, PA: Saunders; 2009:301.

47. ANSWER: D

Myocarditis is a common cause of cardiomyopathy in children. It is defined at **inflammation of the myocardium, often associated with myocyte necrosis and degeneration**. Myocarditis **typically follows a viral infection**, and many children have subclinical or mild disease. The viruses implicated in myocarditis include adenovirus, enterovirus including coxsackievirus B, and parvovirus. A minority of patients will progress to **frank heart failure or have significant arrhythmias**. It is thought that approximately **one third of patient with myocarditis regain ventricular function, one third will recover with residual systolic impairment, and one third will eventually require cardiac transplantation**.

Management of children with myocarditis is largely based on the severity of the symptoms. Previously, aggressive inotropic support was used to maintain cardiac output and perfusion. This management strategy has become less popular as myocardial oxygen demand increases significantly, leading to further complications. Current therapy recommendations include diuresis to decrease preload combined with use of gentle inotropic support. Phosphodiesterase inhibitors (milrinone) are commonly used. The goal is to impove myocardial performance without increasing the demand on a failing heart.

KEY FACTS

- Myocarditis is a common cause of cardiomyopathy in children.
- It is defined as inflammation of the myocardium, often associated with myocyte necrosis and degeneration.
- Myocarditis typically follows a viral infection, and many children have subclinical or mild disease.
- A minority of patients will progress to frank heart failure or have significant arrhythmias.
- It is thought that approximately one third of patient with myocarditis regain ventricular function, one third will recover with residual systolic impairment, and one third will eventually require cardiac transplantation.

REFERENCE

Cote CJ, Lerman J, Todres ID, eds. *A Practice of Anesthesia for Infants and Children*. 4th ed. Philadelphia, PA: Saunders; 2009:298–9.

48. ANSWER: C

Rheumatic heart disease, although not a significant source of acquired heart disease in the United States, continues to be prevalent in the developing world. Early treatment of **streptococcal pharyngitis** with antibiotics is the key to preventing the complications of this disease. **Children between the ages of 5 and 14 years are at highest risk**.

Recall that **rheumatic heart disease** is a complication of rheumatic fever. Rheumatic fever is caused by an infection with group A β-hemolytic *Streptococcus* species, often *Streptococcus pyogenes*. The immune response mounted to these bacterial antigens results in cross reactivity with native issues, resulting in a multisystem inflammatory response. Diagnosis of rheumatic fever is made based on **clinical findings and is based on the modified Jones criteria (see** Box 5.3). Evidence of a prior Streptococcal infection combined with two major or one major and two minor criteria are required to make the diagnosis in children with no prior history of rheumatic fever or echocardiographic evidence of valvulopathy.

Box 5.3 **MODIFED JONES CRITERIA**

Major

- Polyarthritis
- Carditis
- Subcutaneous nodules
- Erythema marginatum
- Chorea

Minor

- Fever
- Arthralgia
- Raised erythrocyte sedimentation rate or C-reactive protein
- Leukocytosis
- Electrocardiogram showing features of heart block
- Previous episode of rheumatic fever

The aortic and mitral valves are most commonly affected by when valvular involvement occurs. Scarring and fibrosis of valve leaflets can lead to both stenotic and regurgitant lesions. Due to its availability, echocardiography has played an increasingly important role in evaluation of suspected rheumatic heart disease. Early treatment of rheumatic fever is crucial because up to 50% of children with their first attack will have some element of cardiac involvement.

KEY FACTS

- Rheumatic heart disease, although not a significant source of acquired heart disease in the United States, continues to be prevalent in the developing world.
- Early treatment of Streptococcal pharyngitis with antibiotics is the key to preventing the complications of this disease.
- Children between the ages of 5 and 14 years are at highest risk.
- Rheumatic heart disease is a complication of rheumatic fever.
- Diagnosis of rheumatic fever is made based on clinical findings and is based on the modified Jones criteria.
- The aortic and mitral valves are most commonly affected by when valvular involvement occurs.

REFERENCE

Cote CJ, Lerman J, Todres ID, eds. *A Practice of Anesthesia for Infants and Children*. 4th ed. Philadelphia, PA: Saunders; 2009:299.

49. ANSWER: C

Cardiac effusion and tamponade are related conditions that involve accumulation of fluid in the pericardial space. **Pericardial effusions are often caused by** system disease processes, including metastatic, immunologic (rheumatoid arthritis, systemic lupus erythematosus), and infectious (viral, fungal, and bacterial) etiologies. Effusions may also accumulate following trauma or prior cardiotomy. It is important to understand the volume of fluid that accumulates in the pericardium as well as the rate of accumulation. Normally, the pericardial space holds 15 to 50 mL of pericardial fluid. Changes in pericardial volume as small as 100 mL may lead to tamponade, resulting in significant cardiac impairment. Interestingly, if an effusion develops gradually, much greater volumes can be tolerated.

The hallmark of **cardiac tamponade is equalization of right atrial pressure and right ventricular end diastolic pressure**. As intrapericardial pressure increases, diastolic filling of the heart is greatly decreased, leading to decreased stroke volume, hypotension, and increased central venous pressure. Intense sympathetic nervous system activation, peripheral vasoconstriction, and tachycardia are compensatory mechanisms that attempt to maintain cardiac output.

Anesthetic goals of patients with symptomatic effusions or tamponade physiology involve maintenance of cardiac output by avoiding anesthesia-induced peripheral vasodilation, direct myocardial depression, or decreased venous return from increased intrathoracic pressure associated with positive pressure ventilation. The mantra for these patients is to run them "fast, full, and tight." Administration of intravenous fluids with continuous infusion of catecholamine is a reasonable strategy to maintain cardiac output until drainage can by achieved in the operating room. Induction and maintenance of anesthesia with ketamine or a benzodiazepine in conjunction with nitrous oxide is a reasonable course of action. Propofol should be avoided due to its detrimental decrease in systemic vascular resistance. Because of the potential for life-threatening hypotension associated with positive pressure ventilation, some advocate prepping and draping the patient for incision prior to induction of anesthesia and intubation in case of cardiovascular collapse.

KEY FACTS

- Cardiac effusion and tamponade are related conditions that involve accumulation of fluid in the pericardial space.
- Pericardial effusions are often caused by system disease processes, including metastatic, immunologic (rheumatoid arthritis, systemic lupus erythematosus), and infectious (viral, fungal, and bacterial) etiologies.
- The hallmark of cardiac tamponade is equalization of right atrial pressure and right ventricular end diastolic pressure.
- Anesthetic goals of patients with symptomatic effusions or tamponade physiology involve maintenance of cardiac output by avoiding anesthesia-induced peripheral vasodilation, direct myocardial depression, or decreased venous return from increased intrathoracic pressure associated with positive pressure ventilation.

REFERENCE

Hines RL, Marschall KE, eds. *Stoelting's Anesthesia and Co-Existing Disease*. 5th ed. Philadelphia, PA: Churchill Livingstone; 2008:128–9.

50. ANSWER: C

Pulsus paradoxus was described by German physician Dr. Adolf Kussmaul in 1873. It is defined as a decrease in systolic blood pressure >10 mm Hg during inspiration. **This finding is reflective of the selective impairment of diastolic filling in the left ventricle seen with cardiac tamponade or restrictive pericarditis**. Pulsus paradoxus is seen in approximately 75% of patient with acute cardiac tamponade compared to only 30% of patients with chronic pericardial effusion. This fact reiterates the important concept that large volumes of pericardial fluid can be tolerated in patients with gradual accumulation. Rapid accumulation of fluid in the pericardial space leads to tamponade physiology.

KEY FACTS

Pulsus paradoxus is defined as a decrease in systolic blood pressure >10 mm Hg during inspiration.

The signs and symptoms of cardiac tamponade include the following:

- Increased central venous pressure
- Pulsus paradoxus
- Equalization of cardiac filling pressures
- Hypotension
- Decreased voltage on the ECG
- Activation of the sympathetic nervous system

REFERENCE

Hines RL, Marschall KE, eds. *Stoelting's Anesthesia and Co-Existing Disease*. 5th ed. Philadelphia, PA: Churchill Livingstone; 2008:126–8.

51. ANSWER: C

The **Fontan palliation** is a staged surgical intervention to treat tricuspid atresia and hypoplastic left heart syndrome.

In this pathology, there is complete arterial and venous admixing of blood in the heart. The atrophic left ventricle is essentially nonfunctioning, leaving the right ventricle to pump both the pulmonary and the systemic circulations. The **ductus arteriosus** keeps the patient alive by providing a shunt for oxygenated blood to mix with deoxygenated blood being pumped into the aorta. PGE1 is infused to maintain patency. The **major complications** of single-ventricle physiology (other than fatal PDA closure) are tissue hypoperfusion and right ventricular failure. The **options for treatment** include heart transplant, comfort measures, and palliative surgery.

Treatment of a normal infant with these vitals would be based on trying to improve oxygenation. Increasing FiO_2 and perhaps using a small amount of PEEP would be helpful to oxygenate. In single-ventricle physiology, however, there are important differences in response to oxygenation, particularly as pertains to the pulmonary vasculature. Ordinarily, **hypocarbia, elevated FiO_2, and increased pH cause pulmonary artery dilation to increase blood flow to the lungs**. However, in single-ventricle physiology, these factors are detrimental because blood shunted to the lungs means blood shunted away from systemic circulation. **Maintenance of anesthesia** for these patients involves doing the exact opposite: allowing for hypoxia and hypercarbia to prevent shunting to the lungs due to an increase in PVR.

KEY FACTS

- The Fontan palliation is a staged surgical intervention to treat tricuspid atresia and hypoplastic left heart syndrome.
- There is complete arterial and venous admixing of blood in the heart.
- The atrophic left ventricle is essentially nonfunctioning, leaving the right ventricle to pump both the pulmonary and the systemic circulations.
- The ductus arteriosus keeps the patient alive by providing a shunt for oxygenated blood to mix with deoxygenated blood being pumped into the aorta.
- PGE1 is infused to maintain patency.
- The major complications of single-ventricle physiology (other than fatal PDA closure) are tissue hypoperfusion and right ventricular failure.
- The options for treatment include heart transplant, comfort measures, and palliative surgery.

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52. ANSWER: B

While the ex utero intrapartum treatment procedure (EXIT) is not frequently performed, the lessons of the procedure have implications for more routine practice. **EXIT procedures are generally indicated for infants with congenital airway abnormalities that would preclude spontaneous breathing** (e.g., a mass obstructing the airway) and for **infants who require immediate extracorporeal membrane oxygenation for survival** (e.g., congenital diaphragmatic hernia). In short, the EXIT procedure involves inducing maternal anesthesia, partially delivering the infant, establishing definitive care (airway or vascular access for ECMO), and separating from uteroplacental circulation. The complicated orchestration required to facilitate multiple providers playing their parts means that planning and dry runs are paramount to success.

The **major anesthetic consideration for the fetus** is that only partial delivery from the uterus must be performed until definitive airway and venous access are established. This has a number of anesthetic implications. First, on the maternal side, it is **important to maintain uterine tone**. Loss of uterine tone can be associated with massive hemorrhage and can endanger the uteroplacental circulation. Second, the **fetus must be only delivered enough that definitive care can be provided**. The mass of the fetus in the uterus helps provide hemostasis. Finally, **umbilical blood supply must be maintained** by promptly addressing maternal hypotension to avoid fetal hypoxia. Specifically, ephedrine and phenylephrine can be used to correct maternal hypotension.

As with a newborn in the operating room, **paralytics and analgesics are administered** to the fetus immediately to facilitate intubation and other surgical maneuvers. Vascular access should be made peripherally and not through the umbilical vein until airway access is attained. In general, it is important to remember that cannulation of the umbilical vein can lead to venous spasticity and loss of access. In a fetus undergoing EXIT procedure, it is important to ensure access to the fetus does not sacrifice uteroplacental exchange until it is time to separate the circulations.

KEY FACTS

- EXIT procedures are generally indicated for infants with congenital airway abnormalities that would preclude spontaneous breathing (e.g., a mass obstructing the airway) and for infants who require immediate extracorporeal membrane oxygenation for survival (e.g., congenital diaphragmatic hernia).
- The EXIT procedure involves inducing maternal anesthesia, partially delivering the infant, establishing definitive care (airway or vascular access for ECMO), and separating from uteroplacental circulation.

- The major anesthetic consideration for the fetus is that only partial delivery from the uterus must be performed until definitive airway and venous access are established.
- Paralytics and analgesics are administered to the fetus immediately to facilitate intubation and other surgical maneuvers.

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53. ANSWER: B

While phenylephrine is ubiquitous in the adult operating room, it has a more limited role in pediatric anesthesia. **Phenylephrine** is an alpha agonist that has its major effect on arterioles, and a lesser effect on venous smooth muscle. It **increases afterload as well as preload**. The increased preload typically causes a **reflex bradycardia** that may be of clinical significance in weak hearts.

Phenylephrine has practical advantages in some pediatric cases due to its ability to increase afterload. Specifically, **increasing afterload** raises the pressures in the left side of the heart and reduces right-to-left shunting. **In patients with shunt physiology** (e.g., PDA, Tetralogy of Fallot, after Norwood and Glenn procedures), the increased afterload can therefore increase the delivery of oxygenated blood.

Tetralogy of Fallot includes by definition right ventricular hypertrophy, overriding aorta, pulmonary valve stenosis, and ventriculoseptal defect. The right-to-left shunt is worsened when the child is under stress (e.g., during exercise or while crying). Increasing SVR lessens the right-to-left shunt and improves the clinical picture. A bolus of 20–100 micrograms phenylephrine per kilogram body weight can be used. **Raising the legs** above the head also increases afterload. Finally, **lowering pulmonary vascular resistance** will decrease the RV pressure and will lessen the shunt. However, children with Tetralogy of Fallot often have a **fixed pulmonary valve stenosis,** and manipulations to lessen pulmonary hypertension may have limited effects.

KEY FACTS

- Phenylephrine is an alpha agonist that has its major effect on arterioles and a lesser effect on venous smooth muscle.
- It increases afterload as well as preload.
- The increased preload typically causes a reflex bradycardia that may be of clinical significance in weak hearts.
- Increasing afterload raises the pressures in the left side of the heart and reduces right-to-left shunting.
- In patients with shunt physiology (e.g., PDA, Tetralogy of Fallot, after Norwood and Glenn procedures), the increased afterload can therefore increase the delivery of oxygenated blood.

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54. ANSWER: D

Classically, **dopamine has been the pressor of choice in pediatric shock**. **It acts on dopamine receptors, as well as on alpha and beta receptors**. It has several attributes that are testable and relevant. First, it increases inotropy both directly via B1 receptors and indirectly via increased catecholamine release. Second, in comparison to epinephrine and ephedrine, dopamine has a lesser effect on rate and is less likely to cause arrhythmia. In infants and small children who already run at high heart rates, chronotropy is less useful than inotropy. Third, there continues to be evidence that there is increased mesenteric and renal blood flow using dopamine in place of other vasoactives.

Dopamine is used in a wide range of doses, owing largely to its fairly wide variation in serum concentration. It can be used at low doses of 0.05 μg/kg per minute to high doses of 10–15 μg/kg per minute or more.

There are some downsides to using dopamine in the pediatric population. **Infants younger than 6 months of age may be refractory to dopamine treatment** due to their immature sympathetic nervous system and low stores of catecholamines. Dopamine can cause **arrythmias** due to its B1 effects. Finally, it may cause an **increase in pulmonary vascular resistance**.

KEY FACTS

- Classically, dopamine has been the pressor of choice in pediatric shock. It acts on dopamine receptors, as well as on alpha and beta receptors.
- It increases inotropy both directly via B1 receptors and indirectly via increased catecholamine release.
- In comparison to epinephrine and ephedrine, dopamine has a lesser effect on rate and is less likely to cause arrhythmia.
- In infants and small children who already have high heart rates, chronotropy is less useful than inotropy.

- There continues to be evidence that there is increased mesenteric and renal blood flow using dopamine in place of other vasoactives.

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55. ANSWER: D

Newborns at birth can fall under three different categories as classified by **gestation age, actual birth weight, and size in relation to gestational age**.

An infant is defined as **premature when gestational age (GA) is less than 37 weeks, term when GA is between 37 and 42 weeks, and postterm when an infant is born after 42 weeks of gestation**. GA can be determined either by determining the infant's mother's last menstrual period (a frequently inaccurate method) or by ultrasonography that is performed during the first trimester of pregnancy (more accurate method). Determination of a fetus's length as measured from crown to rump is frequently used for determination of the GA for fetuses that are less than 20 weeks old. Older fetuses are often measured under ultrasonography from head to toes in order to derive their GA.

Moreover, newborn infants can be classified according to their birth weight. First **classification separates newborns according to their actual birth weight regardless of their GA:** a low birth weight (LBW) infant is considered one who weighs less than 2500 grams; very low birth weight (VLBW) infant, less than 1500 grams; and an extremely low birth weight (ELBW) infant, less than 1000 grams. Newborns weighing less than 750 grams are often categorized as micropreemies.

In addition to the aforementioned category, **infants' weight might be plotted on the age-related weight curve**, and be categorized as appropriate for gestational age (AGA); small for gestational age (SGA), when their weigh falls below 10% of their growth curve for a given gestational age; and large for gestational age (LGA), when their weight is recorded above 90% on the weight curve for their respective age. **Approximate weight-to-gestational age relationship** has been described by Naeye et al. According to this, for an infant born at 28 weeks to be considered as appropriate for gestational age (AGA), he or she should weigh between approximately 1050 and 1275 grams. A 32-week-old AGA infant's weight should be approximately 1600 to 1900 grams; a 36-week AGA infant, 2300 to 2900 grams; and a full-term 40-week AGA neonate, 2900 to 3800 grams. Both, SGA and LGA infants are more likely to experience various complications during the peripartum period. **Small for gestational age (SGA) newborns are more prone to developing** hypothermia and electrolyte and glucose abnormalities, such as hypocalcemia, hypomagnesemia, and hypoglycemia; they also have an increased chance of respiratory distress syndrome and congenital abnormalities. **Large gestation age infants are more prone** than AGA infants to developing hypoglycemia, birth trauma, and hyperbilirubinemia.

KEY FACTS

- Newborns at birth can fall under three different categories as classified by gestation age (GA), actual birth weight, and size in relation to GA.
- An infant is defined as premature when the GA is less than 37 weeks, term when GA is between 37 and 42 weeks, and postterm when an infant is born after 42 weeks of gestation.
- First classification separates newborns according to their actual birth weight regardless of their GA: a low birth weight (LBW) infant is considered one who weighs less than 2500 grams, a very low birth weight (VLBW) infant weighs less than 1500 grams, and an extremely low birth weight (ELBW) infant weighs less than 1000 grams. Newborns weighing less than 750 grams are often categorized as micropreemies.
- Infants' weight might be plotted on the age-related weight curve and be categorized as appropriate for gestational age (AGA); small for gestational age (SGA), when their weigh falls below 10% of their growth curve for a given gestational age; and large for gestational age (LGA), when their weight is recorded above 90% on the weight curve for their respective age.
- SGA newborns are more prone to developing hypothermia and electrolyte and glucose abnormalities, such as hypocalcemia, hypomagnesemia, and hypoglycemia; they also have an increased chance of respiratory distress syndrome and congenital abnormalities.
- Large gestation age infants are more prone than AGA infants to developing hypoglycemia, birth trauma, and hyperbilirubinemia.

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56. ANSWER: C

Fetus heart rate in utero is predominately determined by the parasympathetic nervous system activity. The sympathetic nervous system starts gradually playing a more important role only after birth of an infant. The average heart rate **at birth** is approximately 130 beats per minute. **One month after birth** it tends to increase to about 150 beats per minute, and then slows down to a 110 beats per minute **at age 2 years**, and to 75 beats per minute **at adolescent age**.

KEY FACTS

- The average heart rate at birth is approximately 130 beats per minute.
- One month after birth it tends to increase to about 150 beats per minute.
- It slows down to 110 beats per minute at age 2 years.
- Average heart rate is 75 beats per minute at adolescent age.

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57. ANSWER: A

Transitional physiology of the cardiovascular system is a well-read topic in medicine starting early on in medical school. What may not be clear, however, are the clinical implications of transitional physiology in the very recently born infant up until the fetal circulation completely recedes. For the pediatric anesthesiologist, the following factors are relevant during transitional physiology:

Ductus arteriosus. The ductus arteriosus connects the left pulmonary artery to the aortic arch just distal to the left subclavian artery. In the fetal circulation, it directs 90% of blood away from the lungs. After birth, the drop in pulmonary vascular resistance raises left ventricular pressure over right ventricular pressure, such that oxygenated blood actually flows toward the pulmonary artery until the increased PO_2 causes prostaglandins to be released, which tamponade the ductus and lead to its closure. This occurs in the first few days of life and is relevant because hypoxia is physiologically not likely to be attributable to the PDA.

Ductus venosus. The ductus venosus shunts blood away from the generating liver in the fetal circulation. Following birth, the low-pressure placental sink disappears from the circulation and the ductus venosus closes. Like the ductus arteriosus, this takes up to 4 days and may result in decreased hepatic clearance of medications (e.g., paralytics and opiates).

Foramen ovale. As with the ductus arteriosus, the fall in pulmonary vascular resistance leads to a higher left- than right-sided pressure, which tamponades the foramen ovale closed. However, at least a quarter of the adult population maintains a patent foramen ovale, which can have consequences, especially in conditions where right-to-left flow is possible.

Of key importance to the anesthesiologist, **acidosis and hypoxia can cause a reversal in the transitional circulation changes** mentioned earlier. Specifically, acidosis and hypoxia cause pulmonary arterial dilation, which can revert the circulation to the fetal circulation (as pertains to the ductus arteriosus and foramen ovale). Compounding hypoxia can ensue as more blood shunts to the pulmonary arteries, leading to hypoxemic arrest.

KEY FACTS

- The ductus arteriosus connects the left pulmonary artery to the aortic arch just distal to the left subclavian artery.
- The ductus venosus shunts blood away from the generating liver in the fetal circulation.
- Acidosis and hypoxia can cause a reversal in the transitional circulation changes.

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58. ANSWER: C

SVT is seen on ECG as a narrow-complex tachycardia and is the most common tachyarrhythmia in infants. The **treatment of choice** is adenosine, which usually terminates the arrhythmia. Due to adenosine's extremely short half-life (on the order of seconds), it must be administered rapidly and chased to ensure it reaches the heart as quickly as possible. **Unstable SVT can be treated with** synchronized cardioversion (1 J/kg) and esmolol (100 μg/kg). **Magnesium** is the treatment of choice for torsades de pointes and is a second-line SVT treatment modality. **Defibrillation** is the treatment of pulseless ventricular tachycardia and ventricular fibrillation, which occur infrequently in children but are lethal if untreated.

SVT and atrial fibrillation are also the most common intrauterine tachyarrythmias. These tachyarrythmias are often incidental findings on prenatal fetal ultrasound. Without treatment, there is a risk of fetal hydrops. Treatments include maternal digoxin, amiodarone, and sotalol.

KEY FACTS

- SVT is seen on ECG as a narrow-complex tachycardia and is the most common tachyarrythmia in infants.
- The treatment of choice is adenosine, which usually terminates the arrhythmia.
- Unstable SVT can be treated with synchronized cardioversion (1 J/kg) and esmolol (100 μg/kg).
- Magnesium is the treatment of choice for torsades de pointes and is a second-line SVT treatment modality.
- Defibrillation is the treatment of pulseless ventricular tachycardia and ventricular fibrillation, which occur infrequently in children but are lethal if untreated.

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59. ANSWER: B

There are four major volatile and gas anesthetics available in the United States for anesthetic purposes, each of which has some cardiovascular effects. Importantly, **all the volatiles share their ability to lower SVR**, which may have major implications for induction of unstable children, particularly infants. Cardiovascular collapse can occur with induction. **Sevoflurane**, which has supplanted the others in pediatric practice because it is tolerated for inhalation induction, has mild effects on heart rate or contractility at 1.0 to 1.5 MAC. At higher concentrations, sevoflurane causes myocardial depression, depressed respiratory drive, and decreased SVR. Induction with sevoflurane can raise PVR indirectly if hypercarbia and hypoxia develop. **Desflurane** has a very useful fast onset and offset, but it causes cough and airway irritation. **Isoflurane** has more pronounced cardiovascular effects in infants during induction, lowering ejection fraction and stroke volume in normal infants and in those with CHD (by up to 38%). It also causes laryngospasm in 20% or more infants. **Nitrous oxide** would be contraindicated in a bypass case because it will cause the expansion of gas bubbles; this could cause significant trouble in de-airing the vascular system following separation from bypass and risk of air embolism. Nitrous oxide is more soluble in blood than nitrogen. Thus, nitrogen will diffuse out of gas bubbles more slowly than nitrous oxide will diffuse in, leading to bubble expansion.

KEY FACTS

- All the volatiles share their ability to lower SVR.
- Sevoflurane, which has supplanted the others in pediatric practice because it is tolerated for inhalation induction, has mild effects on heart rate or contractility at 1.0 to 1.5 MAC.
- Desflurane has a very useful fast onset and offset, but it causes cough and airway irritation.
- Isoflurane has more pronounced cardiovascular effects in infants during induction, lowering ejection fraction and stroke volume in normal infants and in those with CHD (by up to 38%).
- Nitrous oxide is more soluble in blood than nitrogen. Thus, nitrogen will diffuse out of gas bubbles more slowly than nitrous oxide will diffuse in, leading to bubble expansion.

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60. ANSWER: C

Ketamine is a powerful analgesic and anesthetic agent used in induction and pain control in pediatrics. It has many well-known **side effects**, such as hypersalivation, dysphoria, and increased cerebral blood flow (and therefore increased intracranial pressure [ICP]). It has regained popularity in recent years due to its ability to minimize opiate requirements and because its dysphoric effects can often be effectively modified with benzodiazepines or minimized by using lower doses. The dose is 2 mg/kg IV, 8–10 mg/kg IM; it can also be given orally. An infusion of 5–10 μg/kg per minute is sometimes used in a balanced technique.

Ketamine has important cardiovascular side effects. It causes central sympathetic activation as well as **catecholamine release,** which can significantly increase heart rate, blood pressure, and cardiac output. **In clinically significant aortic stenosis**, tachycardia is dangerous because of the need for adequate time for ventricular volume offloading. Furthermore, the catecholamine release could precipitate arrhythmias, which could lead to hemodynamic instability or collapse. **Ventricular fibrillation** is a possibility. Finally,

patients with CHF may do poorly with ketamine, since CHF patients already exist in a **catecholamine-depleted state** and may not be able to tolerate further depletion from ketamine.

KEY FACTS

- Ketamine is a powerful analgesic and anesthetic agent used in induction and pain control in pediatrics.
- It has many well-known side effects, such as hypersalivation, dysphoria, and increased cerebral blood flow (and therefore increased ICP).
- Ketamine has important cardiovascular side effects and causes a catecholamine release, which can significantly increase heart rate, blood pressure, and cardiac output.

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61. ANSWER: A

Hypertrophic cardiomyopathy (HCM) is a class of ventricular diseases in which there is myocardial thickening. The incidence is 1 in 500, and patients typically present in late childhood or early adulthood. The disease presents silently, with a **range of cardiac symptoms** (from dyspnea to chest pain and palpitations), and with exercise intolerance. HCM can exist with or without left ventricular outflow tract obstruction. **When LVOT obstruction is present**, the anterior leaflet of the mitral valve can be pulled into the outflow tract and this motion obstructs forward flow (systolic anterior motion [SAM]). **Tachycardia and volume depletion** can further diminish forward flow. **Treatment,** therefore, is based on restoration of intravascular volume, controlling heart rate, and maintaining SVR to maintain preload. In this hemodynamically unstable patient, esmolol would be an appropriate choice to lower heart rate and improve forward flow. Long-term surgical treatment options include surgery (e.g., myotomy, myectomy, cardioverter/defibrillator implantation, and cardiac transplantation).

The **other types of cardiomyopathy seen in children** are dilated cardiomyopathy and restrictive cardiomyopathy. Dilated cardiomyopathy can be caused by a wide range of derangements. Treatment of children with dilated cardiomyopathy involves fluid restriction/diuresis, inotropic support, and ventilatory support. Finally, restrictive cardiomyopathy involves a filling deficit due to abnormally stiffened ventricles. Management is similar to HCM patients; anticoagulation may be indicated.

KEY FACTS

- Hypertrophic cardiomyopathy (HCM) is a class of ventricular diseases in which there is myocardial thickening.
- The disease presents silently, with a range of cardiac symptoms (from dyspnea to chest pain and palpitations), and with exercise intolerance.
- When LVOT obstruction is present, the anterior leaflet of the mitral valve can be pulled into the outflow tract, and this motion obstructs forward flow (SAM).
- Treatment, therefore, is based on restoration of intravascular volume, controlling heart rate, and maintaining SVR to maintain preload.
- The other types of cardiomyopathy seen in children are dilated cardiomyopathy and restrictive cardiomyopathy.

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62. ANSWER: B

There are several important **cardiac lesions associated with Down syndrome**. The most common (50%) is **endocardial cushion defects**. Specifically, this can mean a complete lack of septum and one AV valve (resulting in single-ventricle physiology) or a partial lack of septum, which results in ASD alone or ASD with VSD. The more serious lesions would likely have a corresponding clinical history; **echocardiogram** should be obtained to evaluate murmurs that may represent undiagnosed septal defects. The other common possible defects are **Tetralogy of Fallot (discussed elsewhere) and PDA**.

An **isolated VSD** is likely to be a left-to-right shunt. Over time, the increased load on the right ventricle can cause hypertrophy and the pressures achieved in the right heart can reverse the shunt (**Eisenmenger's syndrome**). However, this usually manifests in the fourth or fifth decade of life. In a young patient, the VSD is not likely to be cyanotic. Left-to-right shunts do not cause clinically meaningful delays in induction, although theoretically they cause a clinically neglible increase in circulating time.

In right-to-left shunts, induction is faster by IV since the pulmonary reservoir is circumvented and more anesthetic can circulate directly to the brain.

KEY FACTS

- There are several important cardiac lesions associated with Down syndrome. The most common (50%) is endocardial cushion defects.
- Echocardiogram should be obtained to evaluate murmurs that may represent undiagnosed septal defects.
- The other common possible defects are Tetralogy of Fallot (discussed earlier) and PDA.
- An isolated VSD is likely to be a left-to-right shunt.
- In right-to-left shunts, induction is faster by IV since the pulmonary reservoir is circumvented and more anesthetic can circulate directly to the brain.

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63. ANSWER: B

Pulmonary vasculature development is not complete at birth, and it takes a few years for many physiologic and anatomic changes to occur for pulmonary vasculature to mature to adult levels. Immediately **at birth newborn lungs contain fewer arterioles, and they have much thicker media smooth muscle** than those of adults. As long as lung oxygenation and ventilation after birth proceed unimpeded, pulmonary vascular resistance continues to diminish.

During the first few years of life, pulmonary arterioles become mature. Over that time the **pulmonary arterioles undergo a rapid proliferation**, and as a consequence of this, the alveoli-to-arterioles ratio decreases from 20:1 at birth to 6:1 in adulthood. In addition to increased proliferation, arterioles undergo **structural changes** as well. **At birth, pulmonary arterioles** contain a thick smooth muscle in their media layer. Over a few years that thick muscle layer thins out. In addition, arteriole smooth muscle at birth extends only up to the respiratory bronchiole level distally. **By the age of 2 years**, smooth muscle in the media layer proliferates down to alveolar duct level, and in adults it finally extends all the way down to alveolar wall level. Thus, **adult pulmonary arterioles** as compared to neonates contain a thinner layer of media muscle that extends much further along the blood vessels toward the alveoli. Lungs that have to face increased volume or pressure load as a result of congenital heart disease, such as unrestricted VSD, undergo specific changes. Namely, their arteriole numbers do not increase as markedly as in unaffected lung (alveoli-to-arterioles ratio remains 25:1). **Arterioles that face an increased blood volume and pressure** retain their thick muscle layer in the media, and the thick arteriolar muscle extends all the way down in the vessels to the alveolar level.

Persistent fetal circulation is a condition where, due to a significant pulmonary hypertension episode, the right ventricle may develop diastolic dysfunction and, as a result of this, a right-to-left shunt might occur. If this condition persists, it can produce a life-threatening hypoxia that might necessitate the use of pulmonary vasodilators, such as inhaled nitric oxide. In most severe cases, extracorporeal membrane oxygenation (ECMO) treatment modality might be a life-saving option.

KEY FACTS

- Pulmonary vasculature development is not complete at birth, and it takes a few years for many physiologic and anatomic changes to occur for pulmonary vasculature to mature to adult levels.
- Immediately at birth newborn lungs contain fewer arterioles and have much thicker media smooth muscle than those of adults.
- Over time, the pulmonary arterioles undergo a rapid proliferation, and as a consequence of this, the alveoli-to-arterioles ratio decreases from 20:1 at birth to 6:1 in adulthood.
- By the age of 2 years, smooth muscle in the media layer proliferates down to alveolar duct level, and in adults it finally extends all the way down to alveolar wall level.
- Thus, adult pulmonary arterioles as compared to neonates contain a thinner layer of media muscle that extends much further along the blood vessels toward the alveoli.
- Arterioles that face an increased blood volume and pressure retain their thick muscle layer in the media, and the thick arteriolar muscle extends all the way down in the vessels to the alveolar level.

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64. ANSWER: D

The neonatal heart has many differences as compared to the developed adult heart. **Neonatal myocardium** exhibits

a paucity of myocytes (30% vs. 60%, in adult heart), and they are less organized and contain fewer mitochondria. **Signaling pathways** in the neonatal myocardium are also immature. A paucity of sarcoplasmic reticulum in concert with immature T tubule network makes neonatal myocardium quite dependent on extracellular ionized calcium concentration. Thus, **calcium-chelating substances**, such as albumin and other blood products, might have a more dramatic depression of neonatal heart contractility as compared to the adult myocardium. **Both right and left ventricles during the neonatal period** demonstrate similar pressure-volume compliance curves, and this ventricular interdependence potentially makes the neonatal heart more likely to develop biventricular failure under stress. Although in neonates **cardiac output is very sensitive to alterations in heart rate**, Doppler echocardiographic studies have revealed that **even fetal hearts can increase stroke volume** in response to metabolic demand under normal physiologic conditions. In addition to differences in the contractile network, there is a marked **misbalance in the effect of both autonomic nervous systems** on neonatal myocardium. Since the **parasympathetic system** matures rapidly within days after birth, its effect is more pronounced on neonatal myocardium than that of the sympathetic system, which completes its maturation during the infancy period. Therefore, neonates' hearts are more prone to exhibit signs of parasympathetic system activity when under stress.

KEY FACTS

- Neonatal myocardium exhibits a paucity of myocytes (30% vs. 60%, in adult heart); they are less organized and contain fewer mitochondria.
- Signaling pathways in the neonatal myocardium are also immature.
- Thus, calcium-chelating substances, such as albumin and other blood products, might have a more dramatic depression of neonatal heart contractility as compared to the adult myocardium.
- Both right and left ventricles during the neonatal period demonstrate similar pressure-volume compliance curves, and this ventricular interdependence potentially makes the neonatal heart more likely to develop biventricular failure under stress.
- Neonates' hearts are more prone to exhibit signs of parasympathetic system activity when under stress.

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65. ANSWER: B

A classic question on the boards relates to the **inability of inotropes to raise cardiac output in neonates and infants**. While there is likely to be a small amount of room to increase inotropy, the **clinical effect of cardioactive medications** is more a result of raising rate than augmenting myocardial inotropy. The reason that heart rate is the main determinant of cardiac output has to do with the architecture of the infant heart. An infant has **stiff, poorly compliant myocardium**. The architecture does not allow for stretch, so the **stroke volume is relatively fixed**. Inotropes are therefore less effective in generating additional squeeze. This **poor compliance** also leads to an inability to handle any additional volume coming into the heart. Since the **input and output are relatively static**, an increase in heart rate has a significantly more pronounced effect on cardiac output than an increase in infant heart contractility. The infant heart can be thought to sit along the **flat part of the Frank-Starling curve**.

KEY FACTS

- While there is likely to be a small amount of room to increase inotropy in neonates and infants, the clinical effect of cardioactive medications is more a result of raising rate than augmenting myocardial inotropy.
- An infant has stiff, poorly compliant myocardium.
- The architecture does not allow for stretch, so the stroke volume is relatively fixed.
- Since the input and output are relatively static, an increase in heart rate has a significantly more pronounced effect on cardiac output than an increase in infant heart contractility.

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Hensley FA, Gravlee GP, Martin DE, eds. *A Practical Approach to Cardiac Anesthesia*. Philadelphia, PA: Lippincott, Williams & Wilkins; 2012:394.

66. ANSWER: C

The ductus arteriosus (DA) is a large vascular channel that connects pulmonary artery and the beginning of

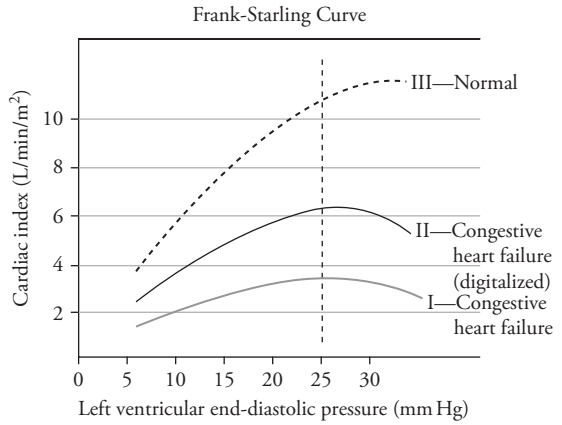

Figure 5.5 Frank-Starling relationship. (From Kliegman RM, Stanton BF, St. Gemell JW, Schor NF, Behrman RE. *Nelson Textbook of Pediatrics*. 19th ed. Philadelphia, PA: Saunders; 2011:436.)

descending aorta. Its media is rich with smooth muscle cells. **DA patency during fetal life** is maintained via effect of prostaglandins (PGE1 and PGI2), which are being produced in placenta as well as intramurally. **12 hours after birth, the DA** starts undergoing functional closure by contracting its smooth muscles in response to increased partial oxygen pressure and decreased concentration of PGE1. At approximately 3 weeks of age, full-term infants undergo **anatomical closure of the DA via fibrosis**. The neonate in this case appears to have Tetralogy of Fallot (TOF). This congenital cardiac defect (CHD) is the most common among cyanotic defects and estimated to comprise up to 11% of all cyanotic CHD. It is not unusual for TOF to be accompanied by other **extracardiac anomalies such as Trisomy 21 and DiGeorge syndrome** (as in the infant described earlier). **Intracardiac defects in TOF** include right ventricular outflow tract (RVOT) obstruction, right ventricular hypertrophy, VSD, and an overriding aorta. If RVOT obstruction is severe, patent DA acts as the main pathway for blood delivery from aorta to pulmonary circulation. **PGE1 is often used to maintain ductal patency in CHD** that depend on it, for example, critical aortic stenosis, interrupted aortic arch, hypoplastic left heart syndrome, and pulmonary or tricuspid atresia, as well as severe TOF. **PGE1 treatment carries some significant side effects**, such as systemic hypotension, CNS irritability, higher risk of developing infection, and significant apnea. It is common to have infants intubated when treated with PGE1. **Inhaled nitric oxide** (NO) is a specific pulmonary vasodilator and is used to treat neonates with persistent pulmonary hypertension as well as in the postoperative period after repair of various CHD. Systemic effects of inhaled NO are very minimal due to its rapid reaction with oxyhemoglobin and, as a result, inactivation. **Serum methemoglobin** levels have to be monitored in patients who are treated with inhaled NO. Intravenous prostacyclin infusion has been used for many years in patients with primary pulmonary hypertension or to treat this condition in children with CHD. It effectively lowers pulmonary arterial pressure, while at the same increasing cardiac output. Due to prostacyclin's brief half-life in blood (1–2 minutes) and relative instability in room temperature, a central line access is required for this therapy. **Epinephrine** due to its agonist effect on alpha, beta-1, and beta-2 adrenergic receptors can significantly increase heart rate and systolic blood pressure, as well as exert inotropic effect. Even at moderate doses, epinephrine has a vasoconstrictive effect, and its use in this case would be undesirable, since the goal for this patient is to maintain a patent DA until surgical correction will be performed.

KEY FACTS

- The ductus arteriosus (DA) is a large vascular channel that connects pulmonary artery and the beginning of descending aorta.
- DA patency during fetal life is maintained via effect of prostaglandins (PGE1 and PGI2), which are being produced in placenta as well as intramurally.
- 12 hours after birth, the DA starts undergoing functional closure by contracting its smooth muscles in response to increased partial oxygen pressure and decreased concentration of PGE1.
- At approximately 3 weeks of age, full-term infants undergo anatomical closure of the DA via fibrosis.
- PGE1 is often used to maintain ductal patency in CHD that depend on it, for example, critical aortic stenosis, interrupted aortic arch, hypoplastic left heart syndrome, and pulmonary or tricuspid atresia, as well as severe TOF.
- PGE1 treatment carries some significant side effects, such as systemic hypotension, CNS irritability, higher risk of developing infection, and significant apnea.

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67. ANSWER: A

Intraoperative echocardiography is employed widely during pediatric cardiac surgery. **CHD occurs in up to 1%** of the population, and TEE can be invaluable in characterizing CHD lesions, planning surgical correction, intraoperative monitoring of contractility, and evaluating intraoperative concerns like residual air. Figure 5.3 shows a prominent atrial septal defect. The view is a

midesophageal four-chamber view. This is often the **starting point in TEE examinations**, and it shows each of the four chambers, as well as the mitral valve, tricuspid valve, and the interatrial and interventricular septae. In the view above, a septal defect is seen between the right and left atrium.

Atrial septal defects make up about 10% of CHD. The majority of ASDs (70%–80%) are **ostium secundum lesions**, which arise in the fossa ovale (in the middle of the interatrial septum). Since ASDs cause left-to-right shunting, they are often asymptomatic. In fact, up to **20% may close spontaneously during the first year of life** if they are small (below 3 mm). However, **persistent ASDs lead to right atrial and ventricular enlargement** and can eventually be complicated by pulmonary hypertension and right heart failure. Patients can also be predisposed to bacterial endocarditis and stroke. **Repair** can be performed either using sternotomy and cardiopulmonary bypass or via catheter through the femoral artery. If a catheter is used, devices such as the Amplatzer device employ a disc on either side of the septum and pull together to close the defect. Over time, the device is endothelialized. **Indications for repair** include RV failure or overload, Qp/Qs > 2, or elective closure.

KEY FACTS

- CHD occurs in up to 1% of the population, and TEE can be invaluable in characterizing CHD lesions, planning surgical correction, intraoperative monitoring of contractility, and evaluating intraoperative concerns like residual air.
- Atrial septal defects make up about 10% of CHD.
- The majority of ASDs (70%–80%) are ostium secundum lesions, which arise in the fossa ovale (in the middle of the interatrial septum).
- Since ASDs cause left-to-right shunting, they are often asymptomatic.
- In fact, up to 20% may close spontaneously during the first year of life if they are small (below 3 mm).
- However, persistent ASDs lead to right atrial and ventricular enlargement and can eventually be complicated by pulmonary hypertension and right heart failure.

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68. ANSWER: D

Children who have undergone cardiac surgery or transcatheter procedures were classically thought to be at risk for infectious endocarditis during dental and other invasive procedures due to transient bacteremia leading to colonization of implants. The **most likely organisms** to cause such colonization are viridans streptococci, *Enterococcus*, or any number of oral and skin organisms. The recent taskforce recommendations from *Circulation* in 2007 take a different tack on the subject of prophylaxis, largely owing to the lack of evidence for previous recommendations (the 1997 guidelines were Level IIb recommendations and LOE C recommendations according to the taskforce). **Evidence linking dental procedures to infective endocarditis** is lacking, and the authors of the new recommendations conclude that transient bacteremia is more likely to develop from everyday activities that cause bacteremia (e.g., tooth brushing) than from dental procedures.

The new guidelines, which were released in 2007, simplify the recommendations. **In summary**, only a small number of children actually require prophylactic antibiotics for dental and other minor procedures. Box 5.1 summarizes the recommendations. **Prophylaxis is indicated for children** with prosthetic valves, history of prior endocarditis, heart transplant patients with known valvulopathy, and specific CHD, which is indicated in the box. The new guidelines are based on the idea that those children at highest risk are those for whom infectious endocarditis would have the worst outcomes.

Indications for prophylaxis in children with CHD (adapted from the Guidelines):

1. Unrepaired cyanotic CHD, including palliative shunts and conduits
2. Completely repaired CHD with prosthetic material or device in the first 6 months after the procedure (after which point endothelialization occurs)
3. Repaired CHD with residual defects at or adjacent to the site or to a prosthetic (the defects inhibit endothelialization)

When prophylaxis is indicated, oral regimens of amoxicillin, cephalexin, clindamycin, or azithromycin can be used. **IV regimens** include ampicillin, cefazolin,

ceftriaxone, and clindamycin. A single dose is indicated 30–60 minutes prior to the procedure.

The child in this question has a graft that has endothelialized by this point. She has no indication for antibiotics.

KEY FACTS

- Children who have undergone cardiac surgery or transcatheter procedures were classically thought to be at risk for infectious endocarditis during dental and other invasive procedures due to transient bacteremia leading to colonization of implants.
- The most likely organisms to cause such colonization are viridans streptococci, *Enterococcus*, or any number of oral and skin organisms.
- Evidence linking dental procedures to infective endocarditis is lacking and the authors of the new recommendations conclude that transient bacteremia is more likely to develop from everyday activities that cause bacteremia (e.g., tooth brushing) than from dental procedures.
- Indications for prophylaxis in children with CHD:

1. Unrepaired cyanotic CHD, including palliative shunts and conduits
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69. ANSWER: B

The **placental circulation** provides a barrier between maternal and fetal circulation. At the lowest cellular level, there are **only two cell layers isolating maternal and fetal blood**. Maternal blood travels through the spiral arteries into the intervillous space, where it is bound by syncitiotrophoblast. On the fetal side, fetal capillaries allow deoxygenated fetal blood from the umbilical artery to interface across the fetal capillary endothelium. **Maternal blood never comes in contact with fetal blood**, but material exchange of gases, nutrients, and waste occurs in the lacunae. (In reality, some translocation of cells, proteins, and other material probably occurs due to imperfections.) Placental transport is complicated and involves mechanisms of **passive and active transport**. The **major clinically significant barriers to movement of anesthetic medications across the placenta** are low lipid solubility, high ionic charge, and large size.

Of the **drugs often given in a rapid sequence induction**, the most clinically significant are probably the opioids, most of which have some lipid solubility and have the ability to cross the membrane and produce fetal cardiac and respiratory depression. **Morphine** is particularly problematic (although not likely to be included in an RSI). **Remifentanil** also travels into fetal circulation readily and could be present following a fast cesarean delivery. **Succinylcholine** is charged and is unlikely to be present in the newborn; even if it is, it is cleared quickly by pseudocholinesterase. The **nondepolarizing neuromuscular blockers** are molecularly large, charged, and do not to cross the placental barrier in significant quantities. **Benzodiazepines** transfer easily and can cause significant apnea. Propofol and ketamine also cross readily. Finally, **inhalational anesthetics** cross freely, so minimizing the MAC of maternal inhalational agents is advisable.

KEY FACTS

- The placental circulation provides a barrier between maternal and fetal circulation.
- At the lowest cellular level, there are only two cell layers isolating maternal and fetal blood.
- Maternal blood never comes in contact with fetal blood, but material exchange of gases, nutrients, and waste occurs in the lacunae.
- The major clinically significant barriers to movement of anesthetic medications across the placenta are low lipid solubility, high ionic charge, and large size.

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70. ANSWER: B

Bupivicaine is a useful local anesthetic commonly used in peripheral nerve block and neuraxial anesthesia. It

is an **amide anesthetic with long duration of action**. Unfortunately, **bupivicaine** is well known for its potential to cause cardiovascular collapse when delivered intravascularly. Because it has **high lipid solubility**, bupivicaine can also have systemic effects via absorption into the bloodstream. The **cardiovascular effects of bupivicaine usually manifest after the central nervous system effects**, but in an anesthetized child, cardiovascular signs are the only ones observable. The **toxicity of bupivicaine** on the cardiovascular system has several mechanisms, but mainly the effect is due to bupivicaine's direct action on myocardial sodium channels.

Just as it has a high affinitiy to peripheral nerve sodium channels, **bupivicaine also has high affinity for myocyte sodium channels**. Bupivicaine has greatest affinity for depolarized sodium channels, so it binds during diastole and stays in the channel. This leaves the **sodium channels trapped in an inactive state**, leading initially to an increased PR interval and QRS complex followed by more harmful arrhythmias. Since the drug is bound strongly to the myocardial sodium channels, resuscitation from bupivicaine-induced cardiovascular collapse is challenging.

Intralipid, a lipid emulsion, is indicated for treatment of LAST (see Box 5.4), along with CPR and hemodynamic support. **Cardiopulmonary bypass** (or ECMO) may be necessary until bupivicaine dissociates enough that cardiac function can be restored.

KEY FACTS

- Bupivicaine is well known for its potential to cause cardiovascular collapse when delivered intravascularly.
- The cardiovascular effects of bupivicaine usually manifest after the central nervous system effects, but in an anesthetized child, cardiovascular signs are the only ones observable.
- The toxicity of bupivicaine on the cardiovascular system has several mechanisms, but mainly the effect is due to bupivicaine's direct action on myocardial sodium channels.
- Intralipid, a lipid emulsion, is indicated for treatment of LAST (see ASRA excerpt, Box 5.4), along with CPR and hemodynamic support.

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Box 5.4 **FOR PATIENTS EXPERIENCING SIGNS OR SYMPTOMS OF LOCAL ANESTHETIC SYSTEMIC TOXICITY (LAST)**

- Get help
- Initial focus
  - o *Airway management*: ventilate with 100% oxygen
  - o Basic and advanced cardiac life support (BLS/ACLS) may require prolonged effort
- Infuse 20% lipid emulsion (values in parentheses are for a 70 kg patient)
  - o *Bolus 1.5 mL/kg* (lean body mass) intravenously over 1 min (~100 mL)
  - o *Continuous infusion at 0.25 mL/kg per minute* (~18 mL/min; adjust by roller clamp)
  - o Repeat bolus once or twice for persistent cardiovascular collapse
  - o Double the infusion rate to 0.5 mL/kg per minute if blood pressure remains low
  - o *Continue infusion* for at least 10 minutes after attaining circulatory stability
  - o Recommended upper limit: approximately 10 mL/kg lipid emulsion over the first 30 minutes
- Avoid vasopressin, calcium channel blockers, β-blockers, or local anesthetic
- Alert the nearest facility having cardiopulmonary bypass capability
- Avoid propofol in patients having signs of cardiovascular instability
- Post LAST events at www.lipidrescue.org and report use of lipid to www.lipidregistry.org

SOURCE: From Neal JM, Bernards CM, Butterworth JF IV, et al. ASRA practice advisory on local anesthetic systemic toxicity. *Reg Anesth Pain Med*. 2010;35:152–61.

71. ANSWER: C

Pediatric heart transplantation occurs at a rate of approximately 400 per year, for a wide variety of indications but mainly for CHD cardiomyopathy. **Survival following heart transplant** is best for infants (19.7 years median survival) and progressively worse as age increases. Survival falls to 16.8 years for children transplanted between 1 and 5 years of age, 14.5 years for those transplanted between 6 and 10 years, and 12.4 years for those 11 years old and older.

During the initial posttransplantation period, the major cause of death is graft failure and surgical technical problems (30%), followed by multiorgan failure (16%), infection (14%), and rejection (12%). **At 10 years**, graft failure continues to be the major cause of death (31%), but coronary artery disease is the second most prominent (26%).

There are **several anesthetic concerns** for a patient who has undergone heart transplantation. The **first** is the potential for cardiovascular disease, necessitating careful induction to preserve coronary perfusion pressure. The **second** is avoidance of using the right internal jugular vein, since this is used for periodic invasive myocyte biopsy. **Third**, the implanted heart is denervated so many of the typical cardiovascular medications will not work (specifically, atropine, glycopyrrolate, and ephedrine are ineffective). **Finally**, one should be mindful of the major morbidities that evolve in these patients, which include hypertension, chronic kidney disease, diabetes, and hyperlipidemia.

KEY FACTS

- Pediatric heart transplantation occurs at a rate of approximately 400 per year, for a wide variety of indications but mainly for CHD cardiomyopathy.
- Survival following heart transplant is best for infants (19.7 years median survival) and progressively worse as age increases.
- During the initial posttransplantation period, the major cause of death is graft failure and surgical technical problems (30%), followed by multiorgan failure (16%), infection (14%), and rejection (12%).
- At 10 years, graft failure continues to be the major cause of death (31%), but coronary artery disease is the second most prominent (26%).

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72. ANSWER: C.

In normal children, **succinylcholine predictably raises the serum potassium concentration** by about 1 mEq/L per dose. Despite its ideal pharmacokinetics for quickly achieving good intubating conditions (i.e., onset of <30 seconds, total paralysis with short duration, etc.), there are a variety of reasons why succinylcholine is often avoided in children. The first is that **clinically significant bradyarrythmias** can develop, sometimes with asystole. Pretreatment with atropine 0.01–0.02 mg/kg is helpful in limiting bradyarrythmias. The second is that **children with neuromuscular diseases** (which may not have yet been diagnosed in a very young child) have an increased number of neuromuscular receptors. Succinylcholine administration to these patients can lead to an **excessive rise in potassium beyond the expected 1 mEq/L**. In the case of **burns**, denervation from injury causes a reflex hyperproliferation of receptors as well, although this would not yet have happened in the patient in this question. This proliferation likely takes at least a few days to weeks, so succinylcholine is not contraindicated in new burn patients but would be contraindicated starting a few days after the injury (and continuing months to perhaps years after the injury). Similarly, **patients who have suffered denervation** (i.e., from spinal injuries) or who have been bedridden also have increased numbers of neuromuscular receptors and can become hyperkalemic.

Rocuronium is a good choice for RSI in a burn patient. A breathe-down induction could be considered, although the airways may be irritable from smoke and a breathe-down could be poorly tolerated. A standard induction with propofol and a neuromuscular blocker with a normal onset of action like cisatracurium is a poor choice, as this child should be considered a full stomach and requires a rapid sequence induction.

Treatment of hyperkalemic arrest in a child relies on stabilizing the myocardium with calcium chloride (10 mg/kg) or gluconate (30 mg/kg), lowering the potassium concentration with insulin, correcting acidosis with bicarbonate and hyperventilation, and CPR with epinephrine until the potassium levels normalize and sinus rhythm returns. Defibrillation without correcting the hyperkalemia is unlikely to be successful.

KEY FACTS

- In normal children, succinylcholine predictably raises the serum potassium concentration by about 1 mEq/L per dose.
- Clinically significant bradyarrythmias can develop, sometimes with asystole, when succinylcholine is used in children.
- Children with neuromuscular diseases (which may not have yet been diagnosed in a very young child) have an increased number of neuromuscular receptors, and succinylcholine administration to these patients can lead to an excessive rise in potassium.
- In patients with burns, denervation from injury causes a reflex hyperproliferation of receptors that can lead to an excessive rise in potassium beyond the expected 1 mEq/L after administration of succinylcholine.

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73. ANSWER: B

There are several distinct **changes in normal ECG pattern that occur with age**. In early infancy, **PR intervals** are slightly shorter (0.1 second) than in adolescence (0.14 second). **QRS complex duration** is also shorter in infancy. As a child reaches adolescence, his or her QRS complex becomes slightly wider than that during infancy; however, under normal development its duration does not exceed the normal QRS span of 0.1 second. Another common physiologic finding during the intrauterine development is a **relative right ventricular hypertrophy, which heralds itself as a right axis deviation** on ECG in newborns. After birth, as the **left ventricle muscle mass rapidly outgrows its right-sided counterpart**, ECG axis shifts and assumes the left-ward direction. That change occurs already within the first month of postnatal period. T waves, on the other hand, undergo a bimodal transformation during childhood. In early newborns they have an upward incline, which during the first hours of life rapidly transitions to an isoelectric pattern. By the end of the first postnatal week, **T waves exhibit an inverted pattern**, mostly notable in the right-sided precordial leads (V1 through V4). If T wave inversion fails to occur during the first week of life, right ventricular hypertrophy should be suspected. **Infants who suffer from significant chronic pulmonary disease** might also demonstrate inverted T waves as a result of right ventricular hypertrophy caused by pulmonary hypertension. This normal inverted T wave pattern lasts into adolescence, when T waves again revert to an upright position in the right-sided ECG leads. In all other aspects, ECG of a normal child at age 3 to 8 years already is identical to that of an adult with the exception of right precordial T waves.

KEY FACTS

- There are several distinct changes in normal ECG pattern that occur with age.
- In early infancy, PR intervals are slightly shorter (0.1 second) than in adolescence (0.14 second).
- QRS complex duration is also shorter in infancy.
- As a child reaches adolescence, his or her QRS complex becomes slightly wider than that during infancy.
- Another common physiologic finding during the intrauterine development is a relative right ventricular hypertrophy, which heralds itself as a right axis deviation on ECG in newborns.
- By the end of first postnatal week, T waves exhibit an inverted pattern, mostly notable in the right-sided precordial leads (V1 through V4).

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74. ANSWER: C

Propofol is a hypnotic agent that is quite hydrophobic and for the purpose of making it more water soluble is formulated as 10% intralipid, containing 1% propofol, 10% soybean oil, 2.25% glycerol, and 1.25% ovolecithin (egg yolk phosphatide). To decrease microbial growth and to maintain its pH in the range of 7.0 to 8.5, **sodium hydroxide and ETDA** have been added. Generic propofol contains **metabisulfite as the antimicrobial** substance. In 1992, five deaths in pediatric patients were reported in children who had been sedated with propofol infusions. All these children developed acute myocardial failure accompanied by **metabolic acidosis**. These and other children reported in later studies were previously healthy and sustained brain injury due to hypoxia. The most common terminal sequence in these patients was identified as development of **lactic acidosis, followed by a heart failure, and ventricular arrhythmias or progressive bradycardias resistant to treatment**. **Hyperkalemia and rhabdomyolysis** were also found.

This collection of symptoms is known as the **propofol infusion syndrome** (PRIS). Based on findings from these studies, it has been suggested that a **propofol infusion dose of more that 4 mg/kg per hour that lasts more than 48 hours** is a predictor to developing PRIS. Other factors found to be associated with PRIS are **male gender, young patient age (less than 18 years), and concomitant catecholamine treatment**. **Progressive elevation of serum lactate** is also a harbinger of developing PRIS. There are also suggestions that PRIS might have a **genetic predisposition**. On PRIS patients' postmortem exam there are a few typical findings; **myocardial and skeletal muscle necrosis** is often evident. Since propofol is known to uncouple oxidative phosphorylation in mitochondria, various muscle tissues that have high oxygen requirements might be especially prone to induced mitochondrial dysfunction and cell death. Moreover, accumulation of fatty acids as a result of mitochondria failure has a proarrhythmic effect on myocardium, which might also be a contributor in developing lethal rhythm disturbances.

KEY FACTS

- Propofol is a hypnotic agent that is quite hydrophobic and for the purpose of making it more water soluble is formulated as 10% intralipid, containing 1% propofol, 10% soybean oil, 2.25% glycerol, and 1.25% ovolecithin (egg yolk phosphatide).
- Propofol infusion syndrome results in the development of lactic acidosis, followed by heart failure, and ventricular arrhythmias or progressive bradycardias resistant to treatment, hyperkalemia, and rhabdomyolysis.
- A propofol infusion dose more that 4 mg/kg per hour that lasts more than 48 hours is a predictor to developing PRIS, as well as male gender, young patient age (less than 18 years), and concomitant catecholamine treatment.

- Progressive elevation of serum lactate is also a harbinger of developing PRIS.

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75. ANSWER: C

Answers A and B are incorrect because **endocarditis prophylaxis is only required for 6 months after repair of noncyanotic heart disease using prosthetic material**. This period allows enough time for endothelialization, which favors **laminar bloodflow and reduces the likelihood that the foreign material will serve as a nidus for bacterial seeding.** Answer D is incorrect because **prophylaxis is only required for unrepaired *cyanotic* heart disease**. Without high right-sided pressures, an ASD is not a cyanotic lesion; with left-to-right flow, this patient would more likely develop heart failure than cyanosis. Answer C is correct because a **defect at the site of a prosthetic patch can lead to turbulent flow and bacterial seeding**.

KEY FACTS

- Endocarditis prophylaxis is indicated for patients with prosthetic valves, those who have valvular disease after heart transplantation, patients with a prior history of infective endocarditis, and those with certain types of congenital heart disease.
- The "congenital" category includes (a) cyanotic heart disease, even if palliated; (b) noncyanotic disease repaired with prosthetic material during the first 6 months after placement; (c) prosthetic material even after 6 months if there is a disruption at the site.

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76. ANSWER: D

There are two approaches to managing arterial blood gas (ABG) information in hypothermic patients: alpha-stat and pH-stat. Either way, the ABG sample is heated to 37°C by the blood gas machine. The difference is whether this warmed ABG data is taken at face value (alpha-stat) or whether an attempt is made to correct for temperature-induced acid-base changes (pH-stat). Alpha-stat management is more often used in adult heart surgery. For **congenital heart surgery**, the current trend favors pH-stat management. **Outcome data are suggestive,** but not conclusive; at least one study suggests better neurodevelopmental outcomes with pH-stat.

The **pH-stat approach attempts to correct for temperature-induced alkalosis**. Low temperatures force gas into solution, thereby reducing the $PaCO_2$ and raising the pH. For example, at 17°C, pH = 7.6 and $PaCO_2$ = 17. When the ABG is warmed by the machine, the sample becomes relatively more acidotic than it would have been when cold, even if the pH "only" falls to 7.4. With **pH-stat management**, the idea is to correct these warmed values so that the hypothermic patient actually experiences a pH of 7.4 (rather than 7.6 in this example). To accomplish this, CO_2 must be added to the bypass circuit, according to a correction based on the original (hypothermic) temperature and the (warmed) pH value. On cardiopulmonary bypass, increasing CO_2 can be done by adding CO_2 to the sweep gas mixture, or by reducing the sweep gas rate (which reduces the efficiency of CO_2 removal).

In **alpha-stat management**, the warmed ABG values are used without adjustment for temperature. Thus, even though the hypothermic child will be alkalotic, he or she will be managed with a goal of achieving a pH of 7.4 at 37°C rather than at 17°C.

Answer A is wrong. If anything, CO_2 will have to be added to the circuit to correct the hypothermic alkalosis, and this may involve lowering (not raising) the sweep gas rate or altering the sweep gas mixture. Answer B is also incorrect. **Low temperatures force gas into solution**, which reduces the $PaCO_2$ and leads to alkalemia, not acidemia. Answer C is not definitively true; although pH-stat is used more commonly in pediatrics, outcome effects are not completely settled in the literature. Answer D is true. ABG samples are always warmed before analysis. The difference between alpha-stat and pH-stat involves how this warmed ABG data are interpreted.

KEY FACTS

- ABG samples are always heated to 37°C before analysis.
- Cold temperature forces gas into solution, reduces $PaCO_2$, raises pH, and produces "hypothermic alkalosis."
- pH-stat management involves correcting the results of the warmed ABG sample by adding CO_2 (i.e., trying to adjust the alkalotic pH downward so that the child experiences a pH of 7.4 when hypothermic).

- Although there is debate about neurodevelopmental outcomes, current practice favors pH-stat for children and alpha-stat for adults.

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77. ANSWER: A

The Boston Circulatory Arrest Trial demonstrated a **direct association between DHCA duration and lower neurodevelopmental outcome**. In that study, a **duration of greater than 41 minutes was linked to significantly worsened developmental quotient**. Even though somewhat longer durations may be tolerable, it is **suggested that DHCA be limited to 20 minutes at a time** (even if multiple "runs" need to be done), with time for reperfusion in between each 20-minute interval.

Uniform cooling is vital for brain preservation during DHCA. Uneven distribution of regional bloodflow may produce nonuniform cooling despite highly controlled temperature of the fluid moving through the bypass machine. Putting ice packs on and around the patient's head during DHCA is a simple, effective way to facilitate even brain cooling. Other interventions thought to improve neurodevelopmental outcomes are also used (e.g., **giving steroids to reduce inflammation, NMDA blockers like ketamine to reduce excitotoxicity, and/or EEG suppressors like thiopental to minimize cellular metabolism**). However, none of these techniques are accepted as definitive, and some may even generate secondary problems (e.g., steroid-related impairment of glucose homeostasis and wound healing).

Answer A is correct; it is standard, accepted practice to facilitate brain cooling by using ice packs around the child's head during DHCA. Answer B, methylprednisolone, is sometimes used but not conclusively proven to improve neurological outcome after DHCA. Answer C is wrong because DHCA intervals should be limited to 20 minutes at a time, not 40 minutes. Finally, Answer D is also incorrect. Although it is arguable that any DHCA may affect neurological development, the Boston Circulatory Arrest Trial suggests a substantial dropoff in neuro-outcomes after approximately 40 minutes, not 12 minutes.

KEY FACTS

- Neurodevelopmental outcome is inversely proportional to DHCA duration, especially beyond 41 minutes.
- If possible, DHCA should be limited to one or more 20-minute intervals.
- Keeping ice packs on the patient's head improves the uniformity of cooling and brain preservation.
- Giving drugs like steroids, NMDA blockers, or barbiturates to patients before DHCA is sometimes done but is not proven to improve neurodevelopmental outcome.

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78. ANSWER: C

Children with Fontan physiology are exquisitely sensitive to decreases in pulmonary blood flow (PBF), which quickly leads to diminished cardiac output. Since the **right side of the heart is bypassed during the Fontan**, PBF occurs by passive drainage from the vena cavae directly into the pulmonary artery. The pressure driving this passive flow can be conceptualized as the difference between central venous pressure (CVP) and pulmonary artery (PA) pressure. Higher CVP and lower PA pressures favor PBF and vice-versa.

Ventilation strategy, via effects on pulmonary vascular resistance (PVR), greatly affects PA pressure. Since positive-pressure ventilation reduces venous return to some degree, **spontaneous ventilation is preferred** for Fontan patients. However, there is a caveat: in the setting of sedation or anesthesia, **spontaneous ventilation may result in significant hypoventilation** (as in this question), with resultant hypoxemia or acidosis increasing PA pressures and impeding PBF. The benefit of spontaneous ventilation on venous return and CVP may be outweighed by the risk of respiratory acidosis-related increases in PVR.

If controlled ventilation is used for a Fontan patient, **ventilation parameters are chosen with the goal of reducing PVR** (i.e., avoiding hypoxia, hypercarbia, and suboptimal tidal volumes) **and allowing adequate venous return**. The inspired oxygen fraction may be set high initially to reduce PVR and then titrated downward to maintain adequate oxygen saturation. Near-normal tidal volumes (e.g., 4–5

mL/kg) also help optimize PA pressure: atelectasis (Vt too low) or pulmonary capillary compression (Vt too high) will both raise PVR. Finally, the **respiratory rate and I:E ratio** are chosen to maximize expiratory time, since this is when most passive PBF occurs. Typically, no more than 1 second of inspiratory time is required, so that low respiratory rates and I:E ratios of 1:3 or 1:4 can be employed.

Answer A is wrong; spontaneous ventilation is good in theory, but not to the point of respiratory acidosis. Answer B is wrong because Vt (11 mL/kg) and PEEP (10 mL/kg) are both high enough to elevate PVR and reduce venous return. Answer D is incorrect because the high respiratory rate and I:E ratio of 1:1 may not allow enough expiratory time, thereby limiting PBF.

KEY FACTS

- PBF is passive in the Fontan physiology, driven by CVP and opposed by PA pressure.
- After a Fontan, preventing pulmonary hypertension is critical to maintaining cardiac output.
- Ventilation strategies have a significant effect on PA pressure.
- Spontaneous ventilation is often the best option; negative-pressure breathing facilitates venous return (and therefore PBF) better than positive-pressure ventilation.
- Controlled ventilation with a high FiO_2, tidal volumes near functional residual capacity, physiological PEEP, and a long expiratory time can facilitate venous return and avoid PVR increases.

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79. ANSWER: A

Adults require higher mean arterial pressures (MAPs) on bypass than children. For adults, the goal is typically 50–80 mm Hg. This range is partly chosen to **maintain cerebral perfusion**, which is autoregulated above 50 mm Hg but starts becoming pressure-dependent below 50 mm Hg. **For neonates, the cerebral autoregulation curve is less well understood**, MAPs as low as 30 mm Hg may be acceptable, and the "lowest tolerable MAP" is not a single value for all ages. To help titrate CPB flow in neonates, other signs of perfusion (e.g., acidosis, mixed-venous oxygen saturation, near-infrared spectroscopy) may be used.

Dilutional effects in neonates may exceed 75%. For example, assuming a pump prime volume of 300–400 mL, a neonate weighing 3 kg with a blood volume of 80 mL/kg or 240 mL would experience a dilution of between 125% (300/240) and 160% (400/240). **Because of this extreme dilution, pediatric bypass circuits are usually primed with blood and other colloids**, while adults' circuits may only need crystalloid priming.

Because of the variable anatomy in complex congenital heart disease, cannulation sites for neonates must be individualized. For example, an isolated persistent left superior vena cava, the ductus arteriosus, or the pulmonary artery may require separate cannulation, and the venous system is often drained via two (rather than one) cannulae.

Ultrafiltration is used more frequently in pediatric than adult heart surgery, with goals of hemoconcentration, reducing inflammatory vasoactive substances, minimizing total body water, and raising hematocrit.

KEY FACTS

- Younger children tolerate lower perfusion pressures on CPB than adults.
- Dilutional effects from the CPB circuit are significant in neonates, often exceeding the baby's blood volume.
- Ultrafiltration is more common in pediatric than adult heart surgery.
- The typical cannulation strategy for adult CPB often must be modified for children with unusual anatomy.

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80. ANSWER: D

The **hybrid procedure**, an alternative approach to the initial palliation of hypoplastic left-heart syndrome (HLHS), involves stenting the patent ductus arteriosus (PDA), banding the pulmonary arteries (PAs), and, often the creation of an unrestricted atrial septum. At 3–6 months of age, the child then undergoes a second-stage procedure involving superior cavopulmonary anastomosis, aortic reconstruction, and removal of PDA stent and PA bands. **Advantages of the hybrid approach** may include less time in the hospital and less exposure to deep hypothermic arrest, cardiopulmonary bypass, and blood products. Definitive long-term

survival data are lacking, but shorter term outcomes are favorable.

Answer A is wrong. Stenting of the ductus arteriosus and PA banding do occur together, but creation of an unrestricted atrial septum can be done at a different time. Indeed, waiting may allow the left atrium to increase in size and thereby facilitate balloon atrial septostomy. Answer B is also incorrect: **The degree of PA band tightening is highly individualized** and depends on patient and pulmonary artery size, hemodynamics, and how saturation responds to the tightening process. Answer C is wrong. It is important to maintain the balance between pulmonary and systemic blood flow throughout and after the hybrid procedure. The patient still has single-ventricle physiology, with right-to-left flow through the stented PDA. **Lowering the pulmonary vascular resistance with 100% oxygen can cause "pulmonary steal"** (i.e., pulmonary overcirculation), resulting in diminished systemic cardiac output, hypotension, and shock. Answer D is true. **Hemodynamic instability is expected during PAB adjustment due to acute changes in oxygenation and blood pressure.** Also, **dysrhythmias may result from manipulation of the left pulmonary artery band**, which is near the left atrial appendage.

KEY FACTS

- The hybrid procedure is an alternative method for first-stage palliation of HLHS.
- The procedure involves placing a stent into the ductus arteriosus, banding the pulmonary arteries, and creating a common atrium.
- Pulmonary banding may be associated with hemodynamic instability, oxygenation changes, and dysrhythmias.
- PA bands are adjusted individually to achieve an acceptable blood pressure and saturation.

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81. ANSWER: B

Wolff-Parkinson-White (WPW) is a syndrome in which the heart contains an anomalous bundle of conducting tissue, called an accessory pathway (AP), which bypasses the normal AV nodal conduction system. **Most accessory pathways are capable of bidirectional conduction** between atrium and ventricle. A tachyarrhythmia resulting from the formation of a circuit between the AV conducting system and the AP is called **an atrioventricular reciprocating tachycardia** (AVRT).

There are **two types of AVRTs: orthodromic and antidromic**. **Orthodromic AVRT** consists of antegrade conduction through the normal AV conducting system and retrogade conduction through the AP. As a consequence, the tachycardia will have a narrow QRS and can be treated with most agents that slow conduction through the AV node (e.g., adenosine, verapamil, esmolol). **Antidromic AVRT**, by contrast, involves antegrade conduction through the AP and retrograde conduction through the AV, and therefore manifests a wide QRS. (Rarely, a wide QRS can also be from orthodromic AVRT with aberrant QRS conduction.) **Administration of AV node blocking agents in the setting of antidromic AVRT** can increase conduction through the AP and potentially lead to **ventricular fibrillation**. Therefore, in the setting of **WPW with wide complex tachycardia**, agents such as procainamide are preferred since they will slow conduction through the accessory pathway.

KEY FACTS

- Wolff-Parkinson-White is a conduction abnormality with an accessory pathway that may result in AVRT.
- Orthodromic AVRT (with a narrow QRS) responds to typical AV nodal blocking agents.
- The use of AV nodal blocking agents in antidromic AVRT (with a wide QRS) may favor the accessory pathway and result in ventricular fibrillation.
- Procainamide is the preferred agent for treatment of stable wide complex tachycardia in WPW.

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82. ANSWER: B

Extracorporeal membrane oxygenation (ECMO), also known as extracorporeal life support (ECLS), is similar in many ways to cardiopulmonary bypass. **ECMO can be used to support both heart and lungs** (veno-arterial ECMO), **or just the lungs** (veno-venous ECMO, in which case the patient's own heart pumps blood through the circuit).

One way to control CO_2 using ECMO is to adjust the "sweep gas" rate. The sweep flows through the oxygenator and is typically a mixture of air, oxygen, and CO_2. Since equilibration of CO_2 across the circuit's membrane occurs more quickly than equilibration of oxygen, raising the sweep gas rate allows more CO_2 to be cleared and will reduce the patient's $PaCO_2$. **Another way to control $PaCO_2$ is to alter the proportion of CO_2** in the sweep gas mixture itself.

Oxygenation on ECMO can be improved in various ways. Since oxygen delivery equals cardiac output (CO) multiplied by arterial oxygen content (CaO_2), raising either of these parameters can improve oxygenation. On full veno-arterial ECMO support, CO is analogous to pump flow, and therefore increasing the pump flow can improve oxygenation. CaO_2 is proportional to hemoglobin, so transfusing red blood cells can also improve oxygenation. In principle, changing ventilator settings can also raise CaO_2 (via effects on oxygen saturation and PaO_2), but the ultimate effect of ventilator-based interventions depends on the relative degree of support provided by ECMO versus the native heart and lungs.

Recirculation occurs during veno-venous ECMO. In recirculation, a fraction of the blood going to the patient from the circuit is immediately returned back to the circuit. Recirculation tends to affect oxygen saturation, not CO_2 exchange. It can be influenced by pump flow, CO, venous cannula positioning, and right atrial geometry.

Answers A and C will affect oxygenation, but not ventilation. Answer D is incorrect because recirculation influences oxygenation, not CO_2, and applies more to veno-venous ECMO.

KEY FACTS

- Increasing the pump flow rate and hematocrit can improve oxygenation on veno-arterial ECMO.
- Increasing the sweep gas rate can reduce CO_2 on veno-arterial ECMO.
- Recirculation of blood on veno-venous ECMO can reduce oxygenation.

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83. ANSWER: C

Acute desaturation after a difficult airway in a patient with Tetralogy of Fallot (TOF) may be due to a "Tet spell." **Tet spells are acute hypercyanotic episodes caused by right-to-left intracardiac shunting through the ventricular septal defect**. TOF patients may have both ***fixed*** **and/or** ***dynamic*** **right ventricular outflow tract obstruction** (RVOTO). Fixed RVOTO may be from pulmonic valve stenosis, while dynamic RVOTO may be caused by infundibular spasm, subvalvular tissue (i.e., conceptually similar to right-sided hypertrophic obstructive cardiomyopathy), or increases in pulmonary vascular resistance (PVR). **Dynamic subvalvular obstruction** becomes more prominent in the setting of a highly contractile but underfilled ventricle. **Pulmonary vascular resistance can be increased** by sympathetic surges (e.g., pain, anxiety), hypercarbia, acidosis, hypoxemia, hypothermia, and large tidal volumes. Since several of these factors occur at the beginning of a case (e.g., hypovolemia, anxiety, crying, hypercarbia, hypoxemia), it is no surprise that anesthetic induction is a high-risk period for Tet spells. This is even more true when a difficult airway is encountered.

Management of a Tet spell has multiple components: (1) **reducing PVR** by delivering 100% oxygen, ensuring adequate or hyperventilation, and reducing sympathetic outflow (e.g., deepening anesthesia or giving opioids or benzodiazepines to reduce pain, anxiety, and bucking on the endotracheal tube). (2) **Reducing dynamic RVOTO** by administering a volume bolus, "squatting" the patient (i.e., putting the patient into knee-chest position to increase venous return), and giving beta-blockade as tolerated. (3) **Increasing systemic vascular resistance** by squatting (kinking of femoral arteries) and direct vasoconstrictors like phenylephrine.

Answer A, **milrinone**, would increase contractility (worsening dynamic RVOTO) and reduce SVR (increasing right-to-left shunt), both of which might worsen the Tet spell. **Dopamine** (Answer B) might also worsen dynamic RVOTO by enhancing contractility. Finally, although the vasoconstrictive effects of **epinephrine** (Answer D) might improve saturation during a Tet spell (i.e., reducing right-to-left shunt), its beta-effects would work against this improvement. Overall, a direct alpha-agonist would be a better option than a mixed alpha-beta agonist.

Answer C, intravascular volume, is correct; in a patient with intravenous access, a volume bolus is often the simplest first-line intervention during a Tet spell. Other reasonable treatments might include hyperventilation with 100% oxygen (to reduce pulmonary vascular resistance), phenlyephrine (to reduce undesirable right-to-left shunting), esmolol (to reduce dynamic RVOTO by slowing heart rate and limiting contractility), and deeper anesthesia (to reduce the effect of increased sympathetic tone on RVOTO).

KEY FACTS

- A Tet spell is an acute hypercyanotic spell in a TOF patient.
- Increased right-to-left shunting through the ventricular septal defect is manifested by hypoxemia.
- The pathophysiology of a Tet spell includes increases in PVR, dynamic RVOTO, and fixed RVOTO.
- There are a variety of standard maneuvers to treat a Tet spell: hyperventilation with 100% oxygen, squatting (or placing an unconscious patient in the knee-chest position), rapid volume expansion, afterload-enhancers like phenylephrine, contractility and heart rate reducers like beta blockers, and sympathetic tone reduction with opioids or other anesthetic agents.

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84. ANSWER: A

Tetralogy of Fallot (TOF), which includes a VSD and right ventricular outflow tract obstruction (RVOTO), may present in many different ways. At one end of the spectrum is a so-called **pink Tet** (i.e., a child who is mostly asymptomatic but may have occasional hypercyanotic "Tet" spells). At the other extreme are so-called **blue Tets** (i.e., children who are cyanotic at baseline). Conceptually, **pink Tets usually have a larger VSD and less RVOTO**, while **blue Tets have relatively more RVOTO,** causing continual right-to-left shunting through the VSD. Not surprisingly, **cyanotic TOF patients** often require surgical correction or palliation at a younger age than pink Tets. **Patients with noncyanotic TOF** develop heart failure from right-sided volume overload, but it may be possible to delay their repair until they are older and better able to tolerate surgery.

Right-to-left intracardiac shunts are thought to slow the speed of inhalational induction, because some of the blood that would normally flow to the lungs to pick up volatile anesthetics is instead passed directly into the systemic circulation, thereby diluting the anesthetic level. Conversely, **right-to-left shunts could in theory speed up an intravenous induction**, since some medication would get to the brain faster without having to traverse the pulmonary circulation. **Left-to-right shunts would therefore potentially speed up an inhalational induction**, but this effect appears to be small and may only be observed in the presence of a coexisting right-to-left shunt.

In this question, the patient's age and oxygen saturation suggest that he or she is a "pink" Tet, with predominantly left-to-right flow through the VSD at baseline. Answers B and C are wrong because these effects would be expected with a right-to-left shunt (i.e., if the patient were having a Tet spell, but not at baseline). Answer D may be true in theory for a left-to-right shunt, but it does not appear to be clinically significant.

KEY FACTS

- Many TOF patients exhibit left-to-right VSD flow and appear normal unless they are having a Tet spell.
- Children with TOF may present with cyanosis from significant RVOTO, with heart failure from left-to-right shunting through a VSD, or a combination of symptoms.
- Left-to-right shunting has little clinical effect on induction speed.
- Right-to-left shunts may slow inhalational induction and speed up intravenous induction.

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85. ANSWER: C

Desaturation during PDA ligation is a common problem. Since lung isolation is not typically used, **compression of the nondependent lung by surgical retractors leads to atelectasis, V/Q mismatch, shunting, and hypoxemia**. Managing this problem requires close communication with the surgeon and a stepwise approach. First, the positioning and integrity of the breathing circuit must be confirmed. Often the patient is completely covered with surgical drapes, making it easy to miss circuit disconnections or kinking of tubes. Next, adjustments to the ventilator are made. With **high-frequency oscillatory ventilation** (HFOV), oxygenation can be increased in two ways: raising the inspired oxygen fraction and increasing the mean airway pressure. If altering the ventilator parameters is not successful, changing from HFOV to a conventional ventilator or hand-ventilation is another option. However, premature babies are often on HFOV precisely because they have failed conventional ventilation. Thus, any rapid change to a different ventilator may lead to a period of instability, even including worsening desaturation. Finally, if other interventions

are unsuccessful or cannot be employed, adequate oxygenation may require a period of **lung re-expansion**. Safe surgery may require several of these "back and forth" periods during which the surgeon removes the lung retractor to facilitate lung re-expansion. After oxygenation reaches an acceptable target level, surgery resumes; this process should be repeated whenever significant desaturation occurs.

Answer A is incorrect; increasing the amplitude during HFOV has the effect of reducing CO_2 rather than increasing oxygenation. Answer B may improve oxygenation, but it is not the first choice because the baby may not tolerate conventional ventilation or may suffer short-term instability during the switch. Answer D is also wrong; Fogarty catheters can be used as bronchial-blockers in children who are too young for a double-lumen endotracheal tube, but the safety and logistical plausibility of placing such a device during surgery into a patient weighing less than 1 kg is questionable.

KEY FACTS

- Desaturation is common during PDA ligation.
- Although PDA ligation is often done via a thoracotomy approach, lung isolation is not used.
- If the ventilator must be changed (e.g., from HFOV to conventional), the change should ideally be made before surgery in order to permit adjustments to achieve optimal ventilation.
- On HFOV, increasing the inspired oxygen level or mean airway pressure will improve oxygenation.
- On HFOV, increasing the oscillation amplitude will reduce CO_2 levels (and vice-versa).
- Alternating periods of surgery with periods of lung recruitment may be necessary.

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86. ANSWER: A

Pulmonary atresia (PA) has a spectrum of different presentations, some of which are named according to the state of the interventricular septum. **PA with ventricular septal defect** (PA/VSD) is often **associated with multiple aortopulmonary collaterals**. These abnormal vessels should be defined by cardiac catheterization prior to surgery and may require unifocalization before or during definitive surgical repair. **Pulmonary atresia with intact ventricular septum** (PA/IVS), on the other hand, is **associated with channels within the right ventricle (RV) known as sinusoids**. When sinusoids fistulize with the coronary arteries, a direct connection between the RV cavity and the coronaries is formed, making it possible to perfuse the coronaries by a combination of normal (oxygenated aorto-coronary) and abnormal (deoxygenated sinusoidal) blood. **Sinusoids are present in about half of those with PA/IVS**. In 20% of patients, there is little aorto-coronary flow and the coronaries are perfused mostly with deoxygenated blood. In a small percentage of patients, there are no anatomical aortocoronary connections; the right coronary is only perfused by sinusoidal blood. This situation is known as "**right-dominant coronary circulation**." For these patients, **maintaining normal RV filling is crucial**; decompression of the RV can reduce or obstruct coronary flow, leading to acute myocardial ischemia.

Answer A is correct; hypotension after induction is common and is often due to hypovolemia exaggerated by the effects of anesthesia on vascular tone. Hypotension from this cause usually improves in the presence of a normally filled (but not overdistended) right ventricle. Reduced ventricular filling is especially problematic in the presence of sinusoids.

Answer B is incorrect; aortopulmonary collaterals are associated with PA/VSD, not PA/IVS. **Pulmonary steal** (i.e., relative overcirculation of blood to the pulmonary tree at the expense of forward systemic flow) could reduce cardiac output and lower the blood pressure, but this would be more likely in the presence of a higher-than-baseline oxygen saturation. Answer C is also wrong. Decompressing the ventricle may worsen ischemia by reducing coronary flow through the sinusoids. Although the extent of coronary sinusoids and right-dominant circulation is not yet known in this patient, caution would suggest at least maintaining normal RV filling pressures rather than trying to reduce preload with nitroglycerin. Finally, Answer D is wrong. PGE1 should already be running; patients with PA/IVS need PGE1 infusions from birth in order to assure adequate pulmonary blood supply through the patent ductus arteriosus.

KEY FACTS

- PA/VSD and PA/IVS have a variety of different presentations.
- PA/VSD is associated with multiple aortopulmonary collaterals.
- PA/IVS is associated with coronary sinusoids and occasionally with right-dominant coronary circulation.
- If coronary arteries are partially or completely supplied by sinusoids, underfilling of the RV can lead to myocardial ischemia.

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87. ANSWER: B

Tetralogy of Fallot (TOF), the most common cyanotic congential heart defect, is characterized by a VSD, an aorta that overrides the right and left ventricles, right ventricular outflow tract (RVOT) obstruction, and right ventricular hypertrophy. **Complete repair of TOF consists of** closure of the VSD and relief of the RVOT obstruction. Sometimes all that is required to improve the right-sided obstruction is a small resection of infundibular muscle. In other cases, the RVOT itself must be augmented (e.g., using a trans-annular patch), which can disrupt the integrity of the pulmonary valve. **Pulmonary regurgitation** is the most common valvular complication following TOF repair. In severe cases, **pulmonary valve replacement** (as an adult) may be required. **Other complications seen among TOF** patients later in life include sudden cardiac death (usually from ventricular tachydysrhythmias), residual RVOT obstruction, progressive aortic regurgitation, and branch pulmonary artery stenosis.

Regarding Answer A, tricuspid regurgitation is possible in an adult who had TOF repair, but it would not be expected until severe pulmonary regurgitation had led to right ventricular dilation with subsequent dilation of the tricuspid annulus. Tricuspid stenosis, on the other hand, would not be expected. Aortic stenosis (Answer C) is not typically reported. Pulmonary stenosis due to residual or restenosis of the RVOT may occur, and aortic dilation leading to aortic regurgitation has also been observed in some patients. Answer D is also not right; TOF involves right-sided, not left-sided, valvular pathology.

KEY FACTS

- TOF includes a VSD, RVOTO, overriding aorta, and right ventricular hypertrophy.
- Pulmonary insufficiency is the most common valvular problem among TOF patients later in life.
- Tricuspid regurgitation, residual RVOT stenosis, and sudden death are other issues for adult TOF patients.

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88. ANSWER: D

Neurological preservation is of prime importance during and after cardiopulmonary bypass (CPB). **Lactate levels and mixed-venous oxygen saturation** have been used to suggest the state of brain oxygenation, but they may reflect global changes more than brain-specific perfusion. More recently, **near-infrared spectroscopy** (NIRS) has been utilized to measure regional tissue perfusion in the brain. In NIRS, one or two (depending upon patient size) monitoring patches are affixed to the skin on the patient's forehead. A **near-infrared beam is transmitted by one area of the patch**; travels through skin, bone, and brain to a depth of 30–35 mm; and is then reflected back. A sensor on a different part of the same monitoring patch picks up the reflected beam. The differential reflectance signal is processed and displayed on a monitor as the **regional oxygen saturation** (rSO_2). A typical NIRS-derived rSO_2 value is 60%–80%. A **NIRS falling more than 20%–30% below baseline suggests the need for intervention**, especially if prolonged.

Standard pulse-oximetry cancels out venous (nonpulsatile) flow in order to estimate arterial oxygen saturation. NIRS, on the other hand, measures saturation of venous, capillary, and arterial blood. Although it is thought that **venous blood accounts for about 70% of the signal, arterial for 20%, and capillary for 5%,** it is important to realize that these proportions have not been rigorously validated in children and may change dynamically according to volume status, medications, and autonomic tone. **In congenital heart disease**, the rSO_2 is correlated to venous saturation obtained from a pulmonary artery catheter or central line, and this correlation extends to neonates and to those with cyanotic disease as well.

Many factors can affect NIRS values. One recent review (Kasman, 2011) organized these factors into a "conceptual" formula, in which brain rSO_2 is proportional to:

$$DO_2 - VO_2$$

and

$$DO_2 = CPP * (Hgb * SaO_2) * \left(radius^4\right)/viscosity$$

where DO_2 is oxygen delivery, VO_2 is oxygen consumption, CPP is the cerebral perfusion pressure (i.e., mean arterial

pressure minus the larger of intracranial pressure or central venous pressure), Hgb is the hemoglobin level, SaO_2 is the arterial oxygen saturation, "radius" is a overall radius of the arterial vessels (raised to the fourth power), and viscosity refers to the blood. The inclusion of VO_2 is necessary because rSO_2 is weighted toward venous rather than arterial saturation. When VO_2 is low, less oxygen is extracted by tissues, more oxygen is returned by the venous system, and rSO_2 increases.

As can be appreciated from this formula, Answers A, B, and C would all lower, not raise, the rSO_2. Specifically, reducing anesthetic depth or warming the patient (Answers A and B) would both increase VO_2. Reducing the pump flow (Answer D) would lower MAP and CPP values, and thereby reduce rSO_2 as well.

Answer D, the correct choice, would raise rSO_2. Reducing the sweep-gas rate on CPB lowers the efficiency of CO_2 clearance. Hypercapnia, with accompanying cerebral vasodilation, raises rSO_2 (and vice-versa for hypocapnia), and may even lead to overestimation of the true cerebral venous saturation.

KEY FACTS

- NIRS-derived rSO_2 correlates with cerebral venous oxygenation among those with congenital heart disease.
- Hyperventilation and alkalosis reduce rSO_2 due to vasoconstriction.
- Increased arterial pressure, CPB flow, hemoglobin level, and arterial saturation all increase rSO_2.
- Increasing blood viscosity, oxygen consumption, and ICP all reduce rSO_2.

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89. ANSWER: B

Pulmonary artery hypertension (PAH), defined as a **mean pulmonary artery (PA) pressure >25 mm Hg at rest or 30 mm Hg with exercise, pulmonary vascular resistance >3 mm Hg/L per square meter, and pulmonary capillary wedge pressure ≤ 15 mm Hg.** There are many causes of PAH. **Eisenmenger physiology**, one category of PAH, is associated with shunt reversal. That is, a left-to-right shunt typically through an atrial septal defect, VSD, atrioventricular septal defect, or patent ductus arteriosus remains uncorrected and pulmonary vascular remodeling over time leads to PAH, right-to-left (or bidirectional) shunting, and oxygen-unresponsive hypoxemia. **Eisenmenger patients often present with** dyspnea and exercise intolerance, although other symptoms, including cyanosis, syncope, hemoptysis, and stroke (from hyperviscosity of blood and sludging in the brain), also occur. On physical examination, a murmur is usually absent because right and left ventricular pressures are similar. Laboratory studies often show polycythemia, hyperuricemia, and low iron levels.

Answer A is wrong. Although **phenylephrine** can cause pulmonary vasoconstriction, its effect is quite limited when pulmonary vascular resistance is fixed. In fact, its systemic vasoconstrictor effect can actually increase left-to-right flow through the VSD and improve oxygenation. Answer C is also incorrect. In a recent review of 124 anesthetics, regional anesthesia was associated with a 5% mortality while general anesthesia was associated with an 18% mortality. However, the authors concluded that this effect was due to the type of surgery, not the choice of anesthetic. At present, no anesthetic technique has clearly been demonstrated to be superior for patients with PAH. Finally, Answer D is wrong. **Pulmonary artery catheters** are not recommended for routine surgery in patients with Eisenmenger physiology: the catheter will be harder to place (sometimes requiring fluroscopy), it will put the patient at a higher risk of pulmonary artery rupture; and, finally, the data provided may be inaccurate (i.e., thermodilution cardiac output with a VSD) or redundant (i.e., pulmonary and systemic vascular resistances can be estimated by simply using oxygen saturation from a pulse oximeter).

The correct answer is B. Although 100% oxygen is indeed a pulmonary vasodilator, its utility in patients with Eisenmenger-associated PAH is debated. This patient's PAH may be oxygen unresponsive. Even if she does have an oxygen-responsive component, outcome data are insufficient to show a definitive benefit of oxygen therapy. While 100% oxygen is certainly a reasonable choice for this patient, avoiding air is not mandatory.

KEY FACTS

- In Eisenmenger physiology, a left-to-right shunt changes over time to one that is right-to-left due to remodeling of the pulmonary vasculature.
- No anesthetic technique is clearly superior for managing patients with PAH.
- Varying degrees of oxygen responsiveness and limited pulmonary vascular reactivity may limit the effectiveness of 100% oxygen in PAH.

- Increasing left-sided pressures with direct vasoconstrictors may reduce shunting and improve oxygenation in Eisenmenger syndrome.

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90. ANSWER: A

Williams syndrome is a genetic disorder related to the deletion of several genes on chromosome 7, including the elastin gene. The syndrome is characterized by a combination of several abnormalities, including an **"elfin" facial appearance, endocrine abnormalities (e.g., hypercalcemia, diabetes), developmental delay, genitourinary abnormalities, and supravalvular aortic stenosis (SVAS)**. In addition to SVAS, many patients with Williams syndrome have mechanical **impairment of coronary blood flow** secondary to abnormal adhesions of the aortic valve to the sinotubular junction, diffuse coronary artery stenosis from elastin arteriopathy, and/or ostial narrowing from the thickened aortic wall. **Pulmonic or branch pulmonary artery stenosis** may also be present. For the anesthesiologist, it is vital to remember that **the degree of coronary blood flow obstruction may not be proportional to the severity of the SVAS**. Thus, an apparently "normal" preoperative echocardiogram is insufficient to rule out significant coronary artery abnormalities.

Answer A is correct; the majority of sudden death in patients with known SVAS has been attributed to myocardial ischemia. Williams syndrome is often associated with aortic obstruction, but not necessarily with dysrhythmias (Answer D). Right-ventricular outflow obstruction (Answer B) is possible although less likely than left-sided obstruction, and it would be unusual for significant pulmonary hypertension to remain undiagnosed. Complete left ventricular outflow obstruction (Answer C) would be unlikely given the apparently mild degree of SVAS noted on the preoperative echocardiogram.

KEY FACTS

- Williams syndrome is associated with SVAS, coronary artery anomalies, and sudden death during anesthesia.
- Echocardiographic grading of SVAS severity may not reflect the degree of coronary obstruction.

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91. ANSWER: C

AV canal defects, sometimes called endocardial cushion defects, **involve some combination of atrioventricular valve abnormalities, an ASD, and a VSD.** These anomalies produce left-to-right shunting at multiple levels and often AV valve regurgitation, especially from the left ventricle to the right atrium. Shunt flow leads to volume overload of the right heart, congestive heart failure, and in some cases, pulmonary hypertension.

There are **three types of AV canal defect**: **partial AV canal** (PAVC) consists of an ASD and a cleft mitral valve; **transitional AV canal** (TAVC) has both an ASD and VSD, along with separate but abnormal AV valves; **complete AV canal** (CAVC) includes an ASD, a VSD, and a single "common" AV valve, which is usually regurgitant. Of the three forms, **CAVC is the most severe** and typically requires repair before 6 months of age. PAVC, on the other hand, tends to be the least severe, and surgical repair may often be delayed well beyond infancy. **Surgical repair** involves patching the ASD, closing the VSD (with patches or sutures), and repairing the atrioventricular valve (e.g., fixing a cleft in the mitral valve).

Anesthetic considerations for patients with AV canal defect include reducing left-to-right shunting (e.g., increasing pulmonary vascular resistance with ventilatory maneuvers like less inspired oxygen and normo- or mild hypercarbia), and avoiding conditions that worsen AV valve regurgitation (e.g., slow heart rates, hypervolemia, high afterload).

About 20% of those with **Down syndrome** also have an AV canal defect. Down syndrome has **many implications for anesthesia**, including atlanto-axial instability, obstructive sleep apnea, large tongue, narrow trachea, and associated diseases like hypothyroidism, dementia, and leukemia. Interestingly, a majority of children with Down syndrome become **bradycardic after a sevoflurane induction**, possibly due to alterations in myocyte number, structure,

or sympatho-excitatory control mechanisms. For many patients, this bradycardia can simply be monitored. For some, however, bradycardia affects cardiac performance. This is especially true for patients at risk for synergistic drug interactions (e.g., cardiac patients getting high-dose opioids or dexemedetomidine) or those with regurgitant lesions (for whom bradycardia can worsen the regurgitant fraction).

Answer A is wrong; intervention is indicated because the blood pressure is low and the patient has an underlying regurgitant lesion. Answer B is also not the best choice. Although phenylephrine may increase blood pressure, it may reduce heart rate even further. Answer D, reducing the inspired oxygen, is incorrect. Balancing pulmonary and systemic vascular resistance is an important aspect of managing AV canal defect. Usually, the goal is to avoid excessive pulmonary flow that would occur with 100% oxygen and alkalosis. However, lowering the inspired oxygen would not be a first-line intervention for bradycardia. Answer C is the best choice; anticholinergic treatment will raise the heart rate and may secondarily increase blood pressure (i.e., less ventricular filling time means less available volume to regurgitate and more forward cardiac output).

KEY FACTS

- AV canal defects are found in about 20% of those with Down syndrome.
- Down syndrome is associated with bradycardia during anesthesia, especially around induction.
- TAVC consists of an ASD, VSD, and abnormal atrioventricular valves.
- PAVC is similar to an ASD; CAVC is like TAVC but with a single AV valve.
- In TAVC, left-to-right shunting and atrioventricular valve regurgitation occur.
- Increased afterload, slower heart rates, and hypervolemia can worsen regurgitant lesions.
- Maintaining pulmonary vascular resistance can reduce left-to-right shunting.

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92. ANSWER: B

Anomalous pulmonary venous connection includes **total anomalous pulmonary venous return** (TAPVR) and **partial anomalous pulmonary venous return** (PAPVR). In these anomalies, some or all of the pulmonary venous connections do not drain into the left atrium, but rather into the right-sided circulation. Both types of anomalous pulmonary venous connection include an **ASD or PFO,** which allows anomalously returned blood to mix with the systemic circulation and permits forward flow through the aorta.

PAPVR, which is often associated with a sinus venosus ASD, **is much better tolerated than TAPVR**. Physiologically, PAPVR behaves in many ways like an ASD. Anesthetically, **the main consideration** involves minimizing excess pulmonary blood flow by maintaining pulmonary vascular resistance (PVR) (e.g., using lower inspired oxygen levels, maintaining normocarbia). Often, children recover quickly and can be extubated soon after PAPVR repair.

TAPVR is more physiologically significant than PAPVR. There are **three types of TAPVR: supracardiac, cardiac, and infracardiac** (also called infra-diaphragmatic). The key issue is whether the abnormal pulmonary venous return pathway is obstructed or not. As the length of the anomalous pathway increases, so does the chance of obstruction. Thus, supracardiac and cardiac TAPVR (in which drainage occurs via an innominate vein into the superior vena cava and direct connection into the right atrium through the coronary sinus, respectively) are less likely to be obstructed than infracardiac TAPVR (which involves drainage into the inferior vena cava via a ductus venosus remnant).

Nonobstructed TAPVR eventually leads to heart failure, but surgery can often be delayed until later in infancy or beyond. Right-sided failure occurs because of increased volume load and pulmonary overcirculation due to left-to-right shunting through the anomalous connection. If the atrial septum is too restrictive, these patients may also be palliated with atrial septostomy to allow surgery to be deferred until the child is older.

Obstructed TAPVR, on the other hand, is one of the few congenital heart lesions requiring urgent surgical intervention. The pathophysiology begins with pulmonary venous hypertension, which causes fluid to back up in the lungs. The pulmonary arteries compensate with vasoconstriction, leading eventually to higher pressure in the right heart. In turn, high right atrial pressures increase right-to-left shunting across the ASD or PFO, worsen the hypoxemia, and trigger a vicious cycle of worsening pulmonary hypertension.

Answer A is the opposite of what would be expected. **Pulmonary hypertension** (not overcirculation) is a problem both pre- and postoperatively for those with obstructed TAPVR. **Management** includes taking steps to avoid pulmonary hypertensive crises (i.e., using 100% oxygen, maintaining alkalosis, preventing sympathetic surges from pain or anxiety), avoiding transesophageal echocardiogram if there is concern about mechanical compression of pulmonary veins, and even using inhaled nitric oxide preemptively

to assist in separation from bypass. Answer C is also wrong. In PAPVR, if the intra-atrial septum is restrictive (i.e., if there is only a PFO and not a true ASD), heart failure will develop sooner. In this case, a balloon atrial septostomy may improve hemodynamics and allow corrective surgery to be delayed until the child is somewhat older. This would typically be done before surgery, not after separating from cardiopulmonary bypass. Answer D is also incorrect; suture lines near the conduction pathway or tissue edema lead to dysrhythmias in about 20% of children with TAPVR, but these are usually tachyarrhythmias, not bradyarrhythmias.

Answer B is correct. After surgical repair, the left heart suddenly experiences an increased volume load. The noncompliant, previously underfilled left atrium and ventricle may take some time to adjust to the higher pressures. Overfilling the ventricle is a common problem, especially in the postbypass period when significant volume (e.g., platelets, fresh-frozen plasma) is often administered. For patients with obstructed TAPVR, a lower left atrial pressure must often be accepted to reduce the risk of failure from an overdistended left ventricle.

KEY FACTS

- Children with PAPVR typically do well and recover quickly, somewhat like patients with an ASD.
- A major factor influencing outcome in TAPVR is whether or not the venous return pathway is obstructed. Obstructed TAPVR is one of the few congenital heart diseases that require urgent surgical intervention.
- Infracardiac TAPVR is more likely to be obstructed than supra- or intracardiac TAPVR.
- Anesthetic issues with TAPVR include pulmonary hypertension (especially when the venous return is obstructed), a highly volume-sensitive noncompliant left ventricle, and tachydysrhythmias.
- TEE is contraindicated if there is concern that mechanical compression may further compromise pulmonary venous flow.

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93. ANSWER: D

Ultrafiltration describes a process where the patient's blood passes through a hemofilter to remove excess interstitial body water and toxins. In heart surgery, **two types of ultrafiltration, conventional and modified ultrafiltration** (CUF and MUF, respectively), are commonly performed. **CUF occurs during CPB, whereas MUF is done after bypass with the aortic and venous cannulae still in place**. MUF is common in current congenital heart surgery practice, but less so for adults. In children, **MUF is associated with** an improvement in cardiac, pulmonary, and immunomodulatory secondary endpoints, but a recent meta-analysis suggests that these benefits occur mostly during the immediate postbypass period.

Technically, MUF occurs at the end of CPB and requires "reversal" of the bypass circuit. Instead of draining the right heart and returning blood to the aorta, the CPB circuit during MUF takes blood from the aortic cannula, filters it, and returns it back to the right atrium. Because the cannulae are still in place, the patient remains heparinized. Continued bleeding may occur; careful attention from the perfusionist and anesthesiologist are important during MUF to avoid hemodynamic instability.

MUF improves both hemodynamics and lung function through several mechanisms: inflammatory markers (e.g., interleukins, bradykinin) are washed away, which raises systemic vascular resistance and blood pressure; interstitial body water and pulmonary edema fluid are reduced, which raises hematocrit, improves pulmonary gas exchange, and (via positive effects on pulmonary blood flow) also improves left ventricular stroke volume and cardiac output.

The duration of MUF is not standardized. **Indications for stopping MUF** may include hemodynamic instability, attainment of a prespecified hematocrit, the passage of a fixed time period (typically 15–20 min at most), or when replacement volume from the CPB circuit is no longer available.

Answer D is true; by removing excess interstitial water, MUF can easily achieve hemoconcentration. This is especially important in cyanotic disease, where the target hematocrit coming off bypass may need to be near 40%.

Answer A is incorrect**; systemic vascular resistance is actually increased** (not decreased) by MUF, likely related to reduced levels of proinflammatory cytokines. Answer B is wrong. While MUF produces a short-term reduction in proinflammatory cytokines, this effect appears to be time limited to the peri-bypass period and may not extend beyond 20 hours. Answer C is also not true. Because heparinization must be prolonged for another 15–20 minutes during MUF, continued intraoperative bleeding, and even hemodynamic instability, is possible.

KEY FACTS

- MUF is employed frequently in pediatric heart surgery.
- MUF is accomplished by reversing the bypass circuit at the end of CPB, and adding a hemofilter.
- Advantages of MUF include reduced body water, higher hematocrit, better blood flow through the lungs (with

lower PVR), reduced proinflammatory substances (e.g., bradykinin, interleukins), and resultant lower pulmonary vascular resistance and higher systemic vascular resistance.
- Since the cannulae and bypass circuit are still in-line during MUF, full protamine reversal of heparin must be delayed, and therefore continued bleeding may occur.

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94. ANSWER: B

Hypertrophic cardiomyopathy (HCM) is an autosomal dominantly inherited disease of the heart muscle that results in left ventricular hypertrophy, either in the free wall or along the septal region. On a cellular level, there is significant disorganization and scarring of the myocytes. **Reduced compliance and LV diastolic dysfunction** are always present. Additionally, a substantial proportion of those with HCM have **dynamic left ventricular outflow tract obstruction**, due to systolic anterior motion of the mitral leaflets and related specifically to the presence of hypertrophy in the anterior ventricular septum.

The clinical spectrum of HCM is extremely variable, **ranging from asymptomatic to heart failure to sudden death from ventricular tachyarrhythmias**. **Treatments for HCM include** medications like beta-blockers, dual-chamber pacing, implantable cardio-defibrillator, and surgery (septal myomectomy). Perioperative management of patients with HCM is directed toward minimizing dynamic subaortic outflow obstruction by maintaining preload and afterload and avoiding increased contractility and tachycardia.

Answer B is correct, because drugs with beta-1-agonist activity such as ephedrine, dobutamine, or dopamine may increase heart rate and contractility and therefore worsen LVOT obstruction.

An **IV fluid bolus** (Answer A) is often helpful because an increased preload minimizes the detrimental effect of an empty hypercontractile ventricle on subaortic outflow obstruction. For these patients, adequate volume resuscitation prior to induction and during the procedure is crucial. **Esmolol** (Answer C) may also help by slowing the heart rate, allowing more time for left ventricular filling, and thereby decreasing outflow obstruction. Finally, **phenylephrine** (Answer D) will increase afterload to help maintain blood pressure and reflexively slow the heart rate as well.

KEY FACTS

- HCM results in left ventricular hypertrophy, diastolic dysfunction, and reduced ventricular compliance.
- Many patients with HCM also have dynamic left ventricular outflow tract obstruction.
- Goals of perioperative management are to maintain or increase preload and afterload while avoiding increases in heart rate and contractility.
- Although beta-1-agonists (e.g., ephedrine, epinephrine, dopamine) are often used to treat hypotension, their inotropic and chronotropic effects may actually worsen hemodynamics in the presence of dynamic outflow obstruction.
- Common techniques to treat hypotension in the face of HCM-associated dynamic outflow obstruction include an IV fluid bolus, alpha-1-agonists like phenylephrine, and beta-blockers.

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95. ANSWER: C

Single-ventricle physiology occurs when there is complete mixing of pulmonary and systemic venous blood, either in the atria, the ventricles, or outside of the heart (e.g., through a patent ductus arteriosus). Because of this mixing, the normal oxygen saturation of these patients is 75%–85%. Many different anatomical abnormalities result in single-ventricle physiology. **Hypoplastic left heart syndrome** (HLHS) is perhaps the archetypal anatomical lesion exhibiting single-ventricle physiology. In HLHS, children are born with a hypoplastic left ventricle and aorta, and therefore require right-to-left flow through a patent ductus arteriosus (PDA) to maintain systemic output.

HLHS may be managed in several different ways, ranging from palliative/hospice care to heart transplantation to staged-surgical palliation. The latter method usually involves three separate surgeries called the **Norwood** (stage 1), the **bidirectional Glenn** (stage 2), and **the Fontan** (stage 3). **The Norwood operation**, done in the neonatal period, consists of the replacement of the PDA with a synthetic systemic-to-pulmonary artery shunt and the creation of a "neoaorta" using native pulmonary artery tissue. Two

types of shunt are currently in use: some surgeons favor a modified Blalock-Taussig shunt (MBTS), a Gore-tex tube graft from the innominate to the right pulmonary artery; others surgeons employ the Sano modification, a tube-graft directly from the right ventricle to the pulmonary artery. Creation of a neoaorta is a complex procedure requiring deep hypothermic circulatory arrest. **During the Glenn** (stage 2), the existing shunt is removed and the superior vena cava is anastomosed directly to the pulmonary artery, thus relieving some of the ventricle's workload. **During the Fontan** (stage 3), the inferior vena cava is also connected to the pulmonary artery, thus allowing systemic venous return to "bypass" the heart completely, restoring series-type circulation, normalizing oxygen saturation, and further reducing the workload of the single ventricle.

Care of patients with HLHS and other types of single-ventricle physiology requires careful attention to oxygen saturation, which reflects the balance between pulmonary and systemic flow (Qp:Qs). For a patient with a normal (two-ventricle) circulation, a decrease in saturation can usually be treated "in isolation" without necessarily considering the blood pressure. In a patient with HLHS, on the other hand, these two parameters are linked and treatment of one affects the other. For example, low blood pressure in the setting of supranormal oxygen saturation (i.e., SpO_2 > 85%) may mean that too much blood is flowing through the pulmonary circulation at the expense of the systemic circulation (Qp:Qs > 1, also known as pulmonary overcirculation or "pulmonary steal"). This problem may be solved simply by increasing pulmonary vascular resistance (e.g., reducing inspired oxygen, increasing $PaCO_2$). On the other hand, low blood pressure in the setting of low oxygen saturation may indicate hypovolemia or poor cardiac performance. In this situation, improving the blood pressure will also increase Qp and secondarily improve the oxygen saturation as well.

Low oxygen saturation in a HLHS patient is not uncommon after bypass, and it may have **several causes**: lung dysfunction (low pulmonary venous saturation), cardiac dysfunction (low mixed-venous saturation), and low Qp:Qs ratio (inadequate pulmonary blood flow). Lung dysfunction is not straightforward to diagnose intraoperatively, but it can be treated preemptively by optimizing tidal volumes, PEEP, and other ventilation parameters. Cardiac dysfunction is suggested by hypotension, narrow pulse pressures, lactic acidosis, and low mixed-venous oxygen saturation. Hypoxemia from a low cardiac output state may respond to improvement in volume status and vasoactive drugs. Finally, inadequate PBF (i.e., Qp:Qs < 1) may respond to ventilation strategies that reduce pulmonary vascular resistance like raising the inspired oxygen fraction or lowering end-tidal CO_2, or to resizing or repositioning of the MBTS.

In this patient, hypoxemia is accompanied by signs of poor cardiac performance (i.e., hypotension, low mixed-venous oxygen saturation, and reduced pulse-pressure). This suggests that improving cardiac function will improve saturation. Answer C, dopamine, is a reasonable option. Other steps might include administering volume, treating hypocalcemia, and ensuring adequate heart rate and rhythm.

Answers A, B, and D are not correct. Any of these interventions would lower pulmonary vascular resistance, increase pulmonary blood flow, and therefore improve saturation. However, the improved saturation comes at the expense of forward cardiac output ("pulmonary steal") and will eventually lead to worsening hypotension, lactic acidosis, and shock. While higher inspired oxygen fraction may indeed be required in some patients with HLHS, its use should be part of a titrated, cautious intervention in the setting of low saturations and adequate cardiac performance (i.e., when hypoxemia is due to lung dysfunction or low Qp:Qs ratio).

KEY FACTS

- Single-ventricle physiology involves complete mixing of systemic and pulmonary venous blood.
- HLHS is one of many anatomical cardiac abnormalities that produce single-ventricle physiology.
- HLHS can be surgically palliated in stages, the first of which (Norwood procedure) involves creation of a neoaorta and placement of a systemic-to-pulmonary shunt (i.e., a MBTS or a Sano modification).
- In an otherwise stable patient with single-ventricle physiology, a saturation of 75%–85% is often interpreted to mean that Qp:Qs = 1 (i.e., PVR and SVR are balanced).
- Balancing Qp:Qs ratio is critical in managing patients with single-ventricle physiology
- Prolonged periods of Qp:Qs > 1 may lead to "pulmonary steal," in which excessive pulmonary blood flow occurs at the expense of forward systemic cardiac output. In this case, oxygen saturations will be higher than expected (i.e., above 85%) and systemic blood pressure will be low. Pulmonary steal may often be reversed by reducing the inspired oxygen content, ventilating to normo- or a mild hypercarbia, or adding CO_2 to the inspired gas mixture.
- Another common problem after HLHS repair is hypoxemia, which may be due to inadequate PBF (i.e., Qp:Qs < 1), lung problems (i.e., low pulmonary venous saturation), or low cardiac output (i.e., low mixed-venous oxygen saturation).

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96. ANSWER: B

Ventricular septal defect (VSD) accounts for about half of all congenital heart disease, making it the most common congenital cardiac anomaly. Most VSDs (70%–80%) are located in the **membranous portion of the interventricular septum** ("perimembranous"). The remainder are located in the muscular portion of the septum ("muscular"), within the outlet septum ("subarterial"), or near the tricuspid valve ("inlet"). Besides anatomical location, VSDs are **also characterized by their size and the direction of shunting**. **Restrictive** VSDs are small enough that left-to-right flow is limited by the actual defect size, and they are associated with a significant pressure gradient. **Nonrestrictive** VSDs, on the other hand, are big enough that the shunt flow depends on the relative magnitudes of the pulmonary vascular and systemic vascular resistance (PVR and SVR).

VSD is typically repaired operatively by placement of a patch, but **transcatheter closure** is also possible in certain cases. Small, restrictive VSDs may remain asymptomatic and will frequently close spontaneously (especially muscular or perimembranous types). Larger nonrestrictive VSDs, by contrast, are more hemodynamically significant. Flow is typically left to right, especially as PVR declines after birth. If untreated, children with nonrestrictive VSD can develop heart failure. If pulmonary flow remains chronically elevated, the child may develop fixed pulmonary hypertension and Eisenmenger syndrome.

In this clinical scenario the patient has a large, nonrestrictive VSD with left-to-right shunting. During a difficult intubation, the patient becomes hypercarbic and hypoxemic, either of which could acutely increase PVR. Higher PVR coupled with lower SVR from sevoflurane results in acute shunt reversal through the VSD. As a result of right-to-left shunting, the saturation remains lower than normal despite adequate ventilation with 100% oxygen. Methods to reduce right-to-left shunt focus on either increasing SVR or decreasing PVR.

Administering a bolus of **phenylephrine** (Answer B) will increase SVR and thereby decrease the right-to-left shunt. Increasing PEEP (Answer A) is incorrect; excessive PEEP may even further increase PVR. **Decreasing the minute ventilation** (Answer C) will be detrimental because hypercarbia will further increase PVR. **Administering a blood transfusion** (Answer D) will increase the oxygen carrying capacity, but at the expense of increased viscosity. Although SVR and PVR will both increase with a higher hematocrit, PVR increases proportionally more than SVR, with the net result being a worsening of the right-to-left shunt.

KEY FACTS

- VSDs are characterized by location, size, and direction of shunt flow.
- Flow through small, restrictive VSDs is limited by the size of the defect; these lesions often close spontaneously.
- Blood flow across larger (nonrestrictive) VSDs depends on the ratio of PVR to SVR. Acute increases in PVR or decreases in SVR may lead to shunt reversal with associated desaturation.
- Methods to reduce right-to-left shunt include increasing SVR (e.g., alpha-1-agonists like phenylephrine) or decreasing PVR (e.g., avoiding hypoxia, hypercarbia, excessive PEEP, hyperviscosity).

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97. ANSWER: B

Transposition of the great arteries (TGA) is a form of cyanotic congenital heart disease characterized by ventriculoarterial discordance and atrioventricular concordance. That is, the aorta arises from the right ventricle and the pulmonary artery arises from the left ventricle, but the relationship between atria and ventricles is normal. As a consequence, there is separation of the pulmonary and systemic circulations rather than the normal series pathway. **Mixing of blood between these two parallel circulations is essential for life**, and it may occur at various levels (i.e., a patent ductus arteriosus, patent foramen ovale, atrial septal defect, and/or VSD).

The **operation of choice for TGA is the arterial switch operation** (ASO), in which the aorta and the pulmonary artery are transected distal to their respective valves and switched to restore normal ventriculoarterial concordance. Critical to the success of this operation is the proper reimplantation of the coronary arteries onto the "neoaorta." Other operations for TGA exist as well. The Mustard and Senning procedures use intra-atrial baffles to redirect blood from the left atrium into the right ventricle (and vice-versa), but they leave the failure-prone right ventricle as the systemic ventricle and predispose to atrial tachy-arrhythmias.

The Rastelli procedure makes use of an existing VSD to channel blood from the left ventricle into the aorta; pulmonary flow is established by a valved conduit from right ventricle to pulmonary artery.

Prior to repair, the left ventricle (LV) of a child with TGA only needs to support the low-pressure pulmonary circulation. As a consequence, LV deconditioning occurs, and inotropic support is usually needed after bypass. (For this reason, a period of pulmonary artery banding is sometimes used to "retrain" the LV prior to ASO.) LV deconditioning is especially pronounced when TGA occurs with an intact ventricular septum, since the presence of a VSD allows the LV to be exposed to a higher (systemic) pressure. LV overdistension is poorly tolerated, so left atrial pressure (LAP) must be monitored carefully when coming off bypass after an ASO. Air within the coronaries or kinking and stretching of these vessels may also reduce LV function.

In this scenario, it appears that **rapid administration of volume** (i.e., blood products) has overdistended the LV and worsened myocardial performance. Answer B, active removal of circulating volume titrated to a reduction of LAP, is the best treatment given the severity and rapidity of hemodynamic deterioration. **Left atrial dilation**, in addition to serving as a marker of LV dysfunction, can actually itself worsen coronary ischemia. This occurs when (secondary) pulmonary artery dilation anatomically compresses the newly reimplanted coronary arteries.

Answer C, **furosemide**, will decrease filling pressures and LAP, but it may not work rapidly enough for an acutely worsening patient. **Nitroglycerin** acts to dilate the coronary arteries and decrease preload; decreasing nitroglycerine (Answer A) will not improve volume overload and could potentially worsen myocardial ischemia. **Atropine** (Answer D) is also unlikely to be helpful in this patient, as the resulting increase in heart rate will increase the oxygen demand of an already ischemic left ventricle.

KEY FACTS

- In TGA, the aorta arises from the right ventricle and the pulmonary artery arises from the left ventricle.
- Mixing between the two parallel circulations is essential; mixing can be enhanced by a prostaglandin E1 infusion to maintain ductal patency and, in cases of severe cyanosis, a balloon atrial septostomy.
- The preferred method of surgical repair is the ASO, in which the aorta and pulmonary artery are transected, switched, and the coronary arteries are reimplanted.
- After ASO, the LV is very sensitive to overdistension. Fluid overload may cause left atrial dilation, increased LAP, pulmonary artery dilation, compression of the coronary arteries, and acute myocardial ischemia. Close monitoring of LAP helps avoid acute hypervolemia.
- Postbypass LV dysfunction may also occur due to coronary artery air or malpositioning.
- In an acutely decompensating patient with an overdistended LV and high LAP, removal of blood from the central line can rapidly improve hemodynamics.

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98. ANSWER: A

Coarctation of the aorta is a narrowing of the aortic lumen. When described by the relationship of the coarcted segment to the ductus arteriosus, it may be classified into **preductal, juxta-ductal, and postductal coarctation**. **Preductal** coarctation is a classic "ductal-dependent" lesion, in which a seemingly healthy baby goes home and returns a few days later in heart failure after closure of the ductus arteriosus. In preductal coarctation, all distal aortic blood flow is supplied by the ductus, and its closure produces rapid hemodynamic compromise. **Signs and symptoms** may include difficulty feeding; short, frequent feedings; cyanosis or sweating while feeding; acidosis; and weak or absent femoral pulses. Once diagnosed, supportive measures include infusion of prostaglandin E1 to maintain or reopen the ductus arteriosus. **Postductal** coarctation presents later in life, because there is time (beginning in utero) for the development of coarctation-spanning collateral vessels. Presenting **signs and symptoms** include differential blood pressures or pulse delay in the upper versus lower extremities, notching of ribs on chest X-ray from collateral arteries, and (in undiagnosed adults) hypertension.

Types of surgical repair include resection of the narrowed segment with end-to-end anastomosis, bypass graft across the area of coarctation, and aortoplasty with either a subclavian flap or prosthetic patch. For neonates, surgical correction is favored; for older infants, balloon angioplasty may also be considered. Balloon angioplasty is usually successful but is associated with a significant restenosis rate (about 25%), which may necessitate further procedures. Balloon angioplasty is, however, a first-line treatment for restenosis after surgery. Endovascular stenting may also be employed, but the large access sheaths required may limit this therapy to somewhat older patients.

Anesthetic considerations during surgical repair of coarctation include the necessity of a right-arm arterial line (due the concern about losing a left-sided pressure signal during cross-clamping), need for inotropic support in a failing

heart, inadequate ventilation (from retraction of the nondependent lung if the surgery is done via a thoracotomy), spinal cord preservation, and postrepair hypertension (related to temporarily abnormal autonomic reflexes and/or endocrine signals). Concerns related to a high aortic cross clamp include heart failure, aortic dissection, and cerebrovascular accident.

Paraplegia is a rare but devastating complication of coarctation repair, occurring about 1% of the time. Blood flow to the anterior spinal artery may be compromised during cross-clamping of the aorta, leading to hypotension distal to the cross-clamp and spinal cord injury. Babies with preductal coarctation may be at even higher risk for paraplegia, because they lack the collateral vessels that typically supply the spinal cord during cross-clamping.

Low-grade hypothermia to 34°C–35°C (Answer A) is thought to be protective against spinal cord injury by reducing cellular metabolic demands. Maintenance of perfusion to the distal cord is also vital, but a mean arterial pressure of only 30 mm Hg (Answer C) may not be adequate. Hypocarbia (Answer D) should be avoided since it reduces spinal cord blood flow by causing spinal and cerebral vasoconstriction. The administration of furosemide (Answer B) or osmotic diuretics may facilitate brain preservation in cases of high intracranial pressure, but they have not been demonstrated to reduce the incidence of paraplegia after coarctation surgery. Moreover, hypovolemia-associated hypotension may even be detrimental to spinal cord perfusion.

KEY FACTS

- Preductal coarctation often presents in the neonate as congestive heart failure after PDA closure.
- Postductal coarctation may present later and less precipitously, since collateral vessel formation allows some distal aortic blood flow.
- In a neonate, treatment of coarctation is usually surgical; in older patients or those with restenosis, balloon angioplasty or stenting is also effective.
- Paraplegia is a rare but devastating consequence of coarctation repair with high aortic cross-clamping.
- Spinal preservation measures include mild hypothermia, avoiding hyperventilation, and maintaining adequate mean arterial pressure distal to the clamp.

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6.

CENTRAL NERVOUS SYSTEM

Ryan Palacio, Megan Clinton, Albert Yeung, Meredith Brooks, and Herodotos Ellinas

1. A 7-year-old child with epilepsy is undergoing resection of seizure foci under general anesthesia. Which of the following interventions is most likely to produce seizure activity on electroencephalography (EEG)?

A. Methohexital
B. Hypoventilation
C. Isoflurane
D. Midazolam

2. A 4-year-old girl with intractable epilepsy is scheduled to undergo a temporal lobectomy. She is on several anticonvulsant drugs, including valproic acid. Which of the following is most likely to be a result of valproic acid therapy?

A. Weight loss
B. Coagulopathy
C. Gingival hyperplasia
D. Hyperkalemia

3. A 10-year-old girl who presented with headaches and visual impairment undergoes resection of a craniopharyngioma. Postoperatively, she has a high output of dilute urine. Which serum laboratory finding is *most* likely?

A. Hypoosmolality
B. Hypernatremia
C. Hypoglycemia
D. Hyperkalemia

4. An obese 5-year-old boy is found to have a 3 cm by 2 cm lesion in the posterior fossa and will undergo surgical resection in the sitting position. Which clinical situation is most frequently associated with the sitting position?

A. Decreased risk of venous air embolism
B. Increased blood loss
C. Increased airway pressures
D. Increased ability to hyperventilate

5. A 12-year-old girl is undergoing surgical resection of an intracranial tumor. Which of the following is the most sensitive detector of intraoperative venous air embolism?

A. Precordial Doppler
B. Decrease in $ETCO_2$
C. Hypotension
D. Oxygen desaturation

6. Most arteriovenous malformations (AVMs) produce symptoms and are discovered in what time period of life?

A. Infancy
B. <10 years old
C. 20–40 years old
D. 40–50 years old

7. What is the best ventilation strategy for a patient with moyamoya disease?

A. Mild hyperventilation to $PaCO_2$ of 35
B. Normocarbic ventilation
C. Hypoventilation
D. Hyperventilation to $PaCO_2$ of 30

8. A 6-month-old child with craniosynostosis is undergoing cranial vault reconstruction. Suddenly, the patient becomes hypotensive and there is a decrease in end-tidal CO_2. Which of the following should *not* be done in response?

A. Flood the surgical field with saline.
B. Aspirate from central venous catheter.
C. Place patient in reverse Trendelenburg position.
D. Begin fluid resuscitation.

9. Which of the following is an indication for cranial vault reconstruction in a patient with craniosynostosis?

A. Normal intracranial pressure
B. Patent foramen ovale
C. Seizures
D. Prevention of developmental delay

10. Which of the following syndromes is associated with craniosynostosis?

A. Pierre Robin syndrome
B. Williams syndrome
C. Apert syndrome
D. Marfan syndrome

11. A 16-year-old girl presents for posterior spinal fusion for idiopathic scoliosis. Her angle of curvature is 70 degrees. Which of the following is most likely to be true about her clinical status?

A. Pulmonary artery pressure is elevated.
B. Restrictive lung disease is absent.
C. Vital capacity is increased.
D. Prognosis is worse than in neuromuscular scoliosis.

12. During scoliosis surgery, intraoperative neurophysiologic monitoring using somatosensory evoked potentials (SSEPs) is performed. SSEP readings are most affected by which of the following?

A. Neuromuscular blockade
B. Dexmedetomedine infusion
C. Volatile agent at 0.5 MAC
D. Hypotension (MAP < 55 mm Hg)

13. You are performing intraoperative neurophysiologic monitoring with SSEPs. You are using a volatile anesthetic technique and your current end-tidal isoflurane concentration reads 1.2 MAC (minimum alveolar concentration). What would be the changes you would expect in SSEP amplitude and latency?

	Amplitude	*Latency*
A.	Increased	Decreased
B.	Increased	Increased
C.	Decreased	Increased
D.	Decreased	Decreased

14. You are beginning the anesthetic for a scoliosis surgery case for which you plan to monitor SSEPs. Which medication will cause an increase in SSEP amplitude?

A. Ketamine
B. Propofol
C. Isoflurane
D. Dexmedetomidine

15. A 14-year-old girl was placed prone for scoliosis spinal surgery lasting 10 hours. Intraoperatively, she remained hemodynamically stable, requiring no vasopressors or blood product transfusions. Estimated blood loss was noted to be 300 mL. An hour into her postanesthesia care unit (PACU) stay she notes "blurry" vision in both eyes, with left worse than right. Fundoscopic exam reveals a normal optic disk without edema. What is the most likely mechanism of her injury?

A. Ischemic optic neuropathy
B. Compression of the globe
C. Central retinal artery occlusion
D. Corneal abrasion

16. Most children with meningocele have what associated malformation?

A. Arnold Chiari
B. Congenital heart disease
C. Urologic complications
D. Orthopedic complications

17. Which of the following is most likely to be a consideration in the anesthetic management of patients undergoing myelomeningocele repair?

A. Massive blood loss
B. Positioning difficulties
C. Increased risk of allergic reaction to antibiotics
D. Decreased risk of latex sensitivity

18. A 10-year-old previously healthy boy underwent resection of a medulloblastoma 1 year ago. He remains anxious in the medical setting and requests sedation for his follow-up brain magnetic resonance imaging (MRI). Which of the following items is the most likely to be a consideration during his imaging study?

A. Increased heart rate caused by the magnet
B. Auditory protection during the scan
C. Development of severe hypothermia
D. Low risk of focal heating

19. A 5-year-old boy is scheduled to undergo a brain and spine MRI with contrast to evaluate for neurofibromas. Which of the following is true about the gadolinium contrast agent that is to be used for this patient?

A. Gadolinium is not approved for use in children.
B. Gadolinium is associated with the development of nephrogenic systemic fibrosis.

C. Gadolinium is more likely to cause anaphylactic reactions than iodine-based contrast media.
D. Gadolinium should never be used in patients with chronic renal disease.

20. A 3-year-old girl with epilepsy is admitted to the hospital because of frequent seizures. She is scheduled for a single-photon emission computed tomography (SPECT) scan. Which of the following is true regarding this scan?

A. The scan may be used to localize seizure foci.
B. The radionuclide must *not* be injected during a seizure.
C. The radionuclide may cause hemodynamic instability.
D. Patient should undergo scan within 12 hours of the seizure.

21. A 5-year-old boy with myotonic dystrophy type 1 is scheduled for laparoscopic gastrostomy tube placement. Which of the following medications is most likely to cause myotonic contraction?

A. Lidocaine
B. Desflurane
C. Rocuronium
D. Succinylcholine

22. A 13-year-old boy with a history of myelomeningocele repair and lower-extremity paralysis is undergoing revision of a ventriculoperitoneal shunt. Shortly after skin incision, the patient has a sudden drop in his blood pressure. What is the most likely cause of his hypotension?

A. Autonomic hyperreflexia
B. Increased intracranial pressure
C. Venous air embolism
D. Anaphylaxis

23. A 13-year-old girl with cerebral palsy underwent scoliosis surgery 2 days ago. She has a fever and is complaining of hallucinations and pruritis. Discontinuation of which of her preoperative medications is most likely the cause of her symptoms?

A. Dantrolene
B. Phenytoin
C. Baclofen
D. Cimetidine

24. A 13-year-old girl is undergoing posterior spinal fusion for idiopathic scoliosis with SSEP monitoring. Which of the following changes is concerning for ischemia?

A. Increased amplitude, increased latency
B. Increased amplitude, decreased latency
C. Decreased amplitude, increased latency
D. Decreased amplitude, decreased latency

25. A 7-year-old boy with a closed head injury shows signs of impending herniation. Which intervention will decrease his intracranial pressure the fastest?

A. Furosemide 0.5 mg/kg IV
B. Hyperventilation to $PaCO_2$ of 30 mm Hg
C. Dexamethasone 0.5 mg/kg IV
D. Mannitol 1 g/kg IV

26. A 4-year-old boy with familial dysautonomia presents for Nissen fundoplication for severe gastroesophageal reflux. Which of the following would be expected in this patient?

A. Increased lacrimation
B. Increased baseline norepinephrine serum concentrations
C. Increased respiratory response to hypoxia
D. Increased incidence of central sleep apnea

27. A 9-year-old girl is in the intensive care unit after a traumatic brain injury. Her serum sodium on admission was 139 mEq/L. It is now 125 mEq/L. Which of the following is most consistent with a diagnosis of syndrome of inappropriate antidiuretic hormone secretion?

A. Low urine osmolarity
B. Low central venous pressure
C. High plasma osmolarity
D. High urine sodium concentration

28. Which of the following conditions is most likely present in a 1-day-old neonate presenting for closure of a myelomeningocele?

A. Arnold-Chiari malformation
B. Intracranial hypertension
C. Tetralogy of Fallot
D. Obstructive sleep apnea

29. An 8-year-old girl is admitted to the intensive care unit after a closed brain injury. Intracranial pressure (ICP) monitoring is placed. Over the course of the next hour, the ICP increases from 15 mm Hg to 22 mm Hg. Other vital signs remain unchanged. Which of the following should be avoided in the initial management of the increased ICP?

A. Hyperventilation to $PaCO_2$ of 30 mm Hg
B. Administration of 3% saline, 0.1 to 1.0 mL/kg per hour
C. Administration of mannitol 0.25 to 1.0 g/kg
D. Administration of rocuronium 1.2 mg/kg

30. A 3-year-old boy is scheduled for a ventriculoperitoneal shunt placement for hydrocephalus. Over the past 24 hours, he has started vomiting and is increasingly lethargic. A rapid sequence induction and tracheal intubation is planned. Which of the following induction agents should be avoided?

A. Etomidate
B. Ketamine
C. Propofol
D. Thiopental

31. A 12-year-old girl with cerebral palsy is scheduled for placement of a baclofen pump for treatment of spasticity. Baclofen mediates its effects through which of the following receptors?

A. Voltage-gated calcium channel
B. Alpha-2 adrenergic receptor
C. Gamma-aminobutyric acid (GABA) A receptor
D. Gamma-aminobutyric acid (GABA) B receptor

32. A 3-year-old boy presents for elective tonsillectomy and adenoidectomy. During your preoperative evaluation you notice that he only speaks single words at a time (no two- or three-word sentences), he repeats words, he jumps up and down while looking out the window, and does not respond when his father calls him. He walked at about 12 months of age. You are not sure how he will handle preoperative sedative medications.

The most likely diagnosis associated with your preoperative evaluation is:

A. Cerebral palsy
B. Seizure disorder
C. Autism
D. Attention-deficit/hyperactivity disorder (ADHD)

33. A 5-year-old boy was an unrestrained backseat passenger in a motor vehicle collision. Upon arrival to the emergency department (ED), he is obtunded and there is concern for brain herniation. The attending physician orders mannitol in an attempt to decrease intracranial pressure (ICP).
Effects of mannitol administration include the following:

A. Pharmacologic osmotic duration >12 hours
B. Transient increase in cerebral blood flow (CBF)
C. Prolongation of rocuronium effect
D. Increase in cerebrospinal fluid (CSF) production

34. A 3-year-old boy was recently diagnosed with a posterior fossa tumor and is undergoing resection. The neurosurgeon requests dexamethasone during the procedure.
Dexamethasone's pharmacologic effects and/or therapeutic uses include the following:

A. High mineralocorticoid activity and use for adrenal insufficiency
B. Superior central nervous system penetration and use to decrease cerebral edema
C. Glucocorticoid effect equivalent to hydrocortisone
D. Clinical effect similar with both low- and high-dose administration

35. A 5-year-old boy with epilepsy on anticonvulsants is being operated for leg fracture status post fall.
Perioperative considerations include the following:

A. He will have an increase requirement of nondepolarizing muscle relaxants.
B. Antiepileptic medications should be held for day of surgery.
C. He will need fewer opioids postoperatively for pain management.
D. His induction may include methohexital.

36. Correct statements about brain tumors in children include the following:

A. They are the most common pediatric malignancy.
B. Posterior fossa tumors present with ataxia and vomiting.
C. With prone positioning, risk of venous air embolus is minimal.
D. With chronic anticonvulsant therapy, fewer perioperative opioids are required.

37. A 10-year-old girl presents to the operating room for resection of a craniopharyngioma.
What are perioperative concerns regarding her diagnosis?

A. Decreased urinary output is a presenting symptom.
B. Hyperthyroidism with anxiety and palpitations is associated with this diagnosis.
C. Stress dose steroids are recommended for surgical procedures.
D. Transphenoidal approach is a common technique in children.

38. The major excitatory neurotransmitter in the central nervous system is:

A. GABA
B. Glycine
C. Calcium
D. Glutamate

39. Benzodiazepines, volatile anesthetics, and barbiturates act primarily at which receptor?

A. AMPA
B. $GABA_A$
C. $GABA_B$
D. NMDA

40. The global cerebral blood flow of children is approximately what rate?

A. 40 mL/100 g per minute
B. 50 mL/100 g per minute
C. 60 mL/100 g per minute
D. 70 mL/100 g per minute

41. Cerebral glucose utilization in the child reaches its highest level at which age?

A. 5 weeks
B. 2 years
C. 8 years
D. 20 years

42. Cerebrospinal fluid circulation begins at what time during development?

A. Early during intrauterine development
B. Just before birth
C. Just after birth
D. 3 months

43. The lower limit of cerebral autoregulation in nonanesthetized preterm infants is approximately what value?

A. 15 mm Hg
B. 20 mm Hg
C. 25 mm Hg
D. 30 mm Hg

44. Cerebral blood flow increases with:

A. Alkalosis
B. Hyperoxia
C. Hypercapnia
D. Hypocapnia

45. Failure of neural tube closure occurs during what week of development?

A. Fourth week
B. Fifth week
C. Sixth week
D. Seventh week

46. Peripheral cutaneous sensory receptors start developing at what gestational age in the fetus?

A. Second week
B. Seventh week
C. Tenth week
D. Fifteenth week

47. Inflammation may impact neonatal pain in what way?

A. It may cause weakening of the immune system, causing increased vulnerability to pain.
B. It may cause certain spinal neurons to "die," thereby creating a hypersensitized area in the body.
C. It may cause expansion of receptor fields of myelinated nociceptors, thereby causing hypersensitivity to pain.
D. It may cause reorganization of myelinated and unmyelinated nociceptors within the dorsal lamina of the spinal cord, which causes hypersensitivity to pain.

48. Closure of the anterior fontanelle occurs by what age?

A. 6 months
B. 9 months
C. 13 months
D. 20 months

49. The spinal cord is formed by what process?

A. Neural mesoderm thickens to form folds that later develop into the neural tube, which becomes the spinal cord.
B. Neural endoderm fuses initially at the caudal end of the neural tube and then fuses at the cranial end forming the central nervous system.
C. Neural ectoderm fuses to close the anterior end of the neural tube and then closes throughout its length before fusing the caudal end of the neural tube.
D. Neural endoderm forms the neural tube, where fusion begins in the cervical region and proceeds in both the cephalad and caudal direction.

CHAPTER 6 ANSWERS

1. ANSWER: A

Patients with epilepsy and intractable seizures are often candidates for surgical intervention. Surgical techniques that have been used to treat patients with epilepsy include **resection of seizure foci, lobectomy, corpus callosotomy, and hemispherectomy**. An alternative surgical intervention is placement of a **vagal nerve stimulator**. If good outcomes can be achieved with either resection of seizure foci or placement of a vagal nerve stimulator, these techniques would be chosen because they are often the least fraught with complication.

Resection of seizure foci in older, cooperative children may be performed via an **awake craniotomy** or by using very little sedation. Younger children are less likely to be cooperative for an awake craniotomy, and for these children, general anesthesia is used. During general anesthesia, intraoperative electrophysiologic studies may be employed to minimize damage to brain tissue that controls important functions and maximize the chances of resecting all of the tissue involved in seizure generation. These studies include somatosensory evoked potentials (SSEPs), motor evoked potentials (MEPs), and electroencephalogram (EEG), as mentioned in this question.

When intraoperative EEG is used to identify seizure foci, agents that depress cerebral electrical activity should be discontinued. These agents include volatile anesthetics and midazolam. Some recommend that a **nitrous oxide/opioid anesthetic technique** be used for these procedures because these anesthetics have **little effect on the seizure threshold**. **Hyperventilation is a technique that may be used to lower the seizure threshold** and produce seizure activity on EEG. Injection of methohexital (0.25–0.5 mg/kg) has also been shown to activate EEG seizure discharges when used in patients with epilepsy. Both of these techniques are sometimes used when it is difficult to identify a seizure focus. Interestingly, methohexitol has not been shown to provoke EEG seizure activity in nonepileptic patients, although it can cause excitatory side effects such as abnormal muscle movements, hiccoughing, or tremor.

Vagal nerve stimulators can be helpful in patients with intractable epilepsy. These stimulators are implanted subcutaneously, with electrodes implanted around the left vagus nerve. By frequent stimulation of the vagus nerve, these devices seem to inhibit seizure activity at the brainstem and cortical levels. For many patients with epilepsy, vagal nerve stimulators dramatically improve seizure control. Reported side effects of vagal nerve stimulators are rare and include bradycardia and vocal cord impairment.

KEY FACTS

- Patients with epilepsy and intractable seizures can be treated surgically with resection of seizure foci, lobectomy, corpus callosotomy, and hemispherectomy and insertion of a vagal nerve stimulator.
- Volatile anesthetics and midazolam can depress cerebral electrical activity.
- Nitrous oxide and opioid anesthetics have little effect on the seizure threshold.

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2. ANSWER: B

Patients who present for seizure surgery can be on a variety of anticonvulsant drugs. These medications have various side effects, some of which are important to consider for anesthetic planning. **Abnormalities of hematologic function** are seen with several anticonvulsant medications, and they can manifest as a **decreased platelet count**, **decreased red or white blood cell production, or abnormalities in coagulation**. **Hepatotoxicity** is another frequent effect of anticonvulsants.

Valproic acid is a commonly used anticonvulsant medication in the pediatric population. A side effect of this medication that is particularly concerning in the setting of a craniotomy is **valproate-induced coagulopathy**. **Thrombocytopenia** is the typical coagulopathic abnormality of valproate therapy, but increased bleeding with a normal platelet count can also be seen with this drug. The thrombocytopenia caused by valproate therapy is thought to be a result of **peripheral antibody-mediated platelet destruction and bone marrow suppression**. Elevated plasma valproic acid levels seem to correlate with the incidence of thrombocytopenia, and platelet counts tend to normalize after reduction in valproic acid dosing. In patients on valproic acid with normal platelet counts and platelet dysfunction, there is frequently a platelet aggregation defect that also tends to normalize as the dose of valproate is decreased. To reduce the likelihood of coagulopathy on valproate, drug levels should be followed by the patient's neurologist. **Preoperatively, platelet count and coagulation studies** should be assessed.

Other severe side effects of valproic acid include **hemorrhagic pancreatitis, bone marrow suppression, hepatotoxicity, and encephalopathy**. Weight gain can also be seen. It is not common to see gingival hyperplasia with valproate therapy; rather, this is a well-known side effect of phenytoin therapy. Finally, electrolyte abnormalities are usually not associated with valproic acid therapy.

When a patient is taking anticonvulsant medication, it is important to recognize that the **metabolism** of anesthetic medications may be affected. This is particularly true for **muscle relaxants and opioids**. Patients on anticonvulsants may require an increased dose of these medications.

KEY FACTS

- Anticonvulsant medications can cause abnormalities of hematologic function, including decreased platelet count, decreased red or white blood cell production, or abnormalities in coagulation.
- Hepatotoxicity is another frequent effect of anticonvulsants.
- Side effects of valproic acid include coagulopathy, thrombocytopenia, hemorrhagic pancreatitis, bone marrow suppression, hepatotoxicity, and encephalopathy.
- Metabolism of anesthetic medications may be affected by anticonvulsants.

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3. ANSWER: B

Craniopharyngioma tumors arise in the suprasellar region and have a peak incidence between 5 and 15 years of age. Accounting for 1%–3% of all pediatric brain tumors, these tumors are also frequently associated with hypothalamic and pituitary dysfunction. The question describes a patient who develops **diabetes insipidus postoperatively**, a common problem in patients with craniopharyngioma tumors.

Diabetes insipidus (DI) is a result of a **deficiency of the antidiuretic hormone arginine vasopressin (ADH)**, and central DI may be caused by **surgical trauma to vasopressin neurons, damage to the hypothalamic-pituitary stalk, or by neoplasms themselves**. DI may be seen in the postoperative period in patients who did not have the condition preoperatively, and it may develop hours after surgery when residual ADH in the posterior pituitary is depleted. A sudden **increase in dilute urine output accompanied by hypernatremia and hyperosmolality** is a sign of postoperative DI. One would not expect to see an associated hypoglycemia in these patients. **Hypokalemia**, rather than hyperkalemia, would be expected because of urine potassium losses. The correct answer is hypernatremia, an expected finding in DI.

Treatment of acute postoperative DI with large urinary losses includes an **infusion of aqueous vasopressin (1 to 10 mU/kg per hour),** in addition to **replacement of urinary losses** with **crystalloid** and close monitoring of fluid input and output as well as electrolytes. Patients should be cared for in an intensive care unit. These patients should be transitioned to oral fluid intake as soon as possible because thirst sensation will be a better regulator of blood osmolality. Desmopressin can then be started in a patient with new-onset DI.

KEY FACTS

- DI is a common postoperative complication in patients with craniopharyngioma tumors.
- DI results from a deficiency of the antidiuretic hormone ADH.
- Central DI may be caused by surgical trauma to vasopressin neurons, damage to the hypothalamic-pituitary stalk, or by neoplasms themselves.
- A sudden increase in dilute urine output, accompanied by hypernatremia and hyperosmolality, is a sign of postoperative DI.

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4. ANSWER: D

Variations in positioning during neurosurgical procedures are associated with different anesthetic considerations. Patients with **signs and symptoms of increased intracranial pressure** should be maintained with **head elevation to maximize cerebral venous drainage**. Head position should maximize surgical exposure while minimizing other possible problems. For example, **extreme neck flexion** can cause brainstem compression in patients with a posterior fossa mass, and it could also lead to endotracheal tube kinking. Pinning is often used to secure head position in older children. Neonates and infants have thin calvaria,

Table 6.1 ADVANTAGES AND DISADVANTAGES OF THE SITTING POSITION

ADVANTAGES OF SITTING POSITION	DISADVANTAGES OF SITTING POSITION
Increased diaphragmatic excursion	Increased risk of venous air emboli
Increased ease of hyperventilation	Cervical cord stretching from excessive neck flexion
Decreased airway pressure	Obstruction of venous drainage from face/tongue
Access to the face and endotracheal tube	Abdominal compression from excessive knee flexion
Increased surgical exposure	Sciatic nerve injury
Decreased blood loss	

Table 6.2 ADVANTAGES AND DISADVANTAGES OF THE PRONE POSITION

ADVANTAGES OF PRONE POSITION	DISADVANTAGES OF PRONE POSITION
Decreased risk of venous air emboli	Endotracheal tube dislodgement, especially with excessive neck flexion
Head elevation decreases venous bleeding	Postoperative blindness
May be optimal position for posterior fossa surgery	Facial, conjunctival, or airway edema
	Risk of facial erosion or damage from oral/nasal tubing pressure

precluding the use of pins. Various headrests can be used to best position these small patients. Surgery of the posterior fossa generally involves the prone position for children, which has advantages and disadvantages. With larger children, the sitting position may be preferred. The lateral/beach chair position is infrequently used in pediatrics.

The sitting position provides ideal exposure for surgical procedures involving the posterior fossa, but it is uncommonly used for children under the age of 3. This position may be used for obese children who would not otherwise tolerate excessive intrathoracic and abdominal pressures inflicted by the prone position. Advantages and disadvantages of the sitting position are listed in Table 6.1.

Posterior fossa and spinal surgery is often performed with patients in the **prone position**. One important consideration for this position is ensuring that there is free abdominal wall motion, because increased intra-abdominal pressure may impair ventilation. Care should be taken to avoid compression of both the femoral nerve and the genitalia when patients are in the prone position. Endotracheal tube dislodgement is a concern with this position, and airway edema may develop in prolonged procedures in the prone position. Advantages and disadvantages of the prone position are listed in Table 6.2.

KEY FACTS

- Patients with signs and symptoms of increased intracranial pressure should be maintained with head elevation to maximize cerebral venous drainage.
- Advantages and disadvantages of various positions for neurosurgical positions are listed earlier.

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5. ANSWER: A

Venous air embolism (VAE) can occur during neurosurgical procedures in infants and children. Entrainment of air is more likely to occur when there is **a larger pressure gradient** between the **operative site and the heart**. Because of this, a VAE would be more likely to occur in the **sitting** position versus the supine or prone position. It should be noted that children undergoing suboccipital craniotomy in the sitting position have a similar incidence of VAE as adults.

In children who experience VAE, there appears to be a higher incidence of **hypotension** and a lower likelihood of successful aspiration of air via central line. If air enters the venous circulation, its presence can impede right ventricular outflow. **Pulmonary changes, including edema, bronchoconstriction, and right heart failure,** can ensue. A **ventilation/perfusion mismatch may lead to an acute drop in end-tidal CO_2**. Hypoxia secondary to increased dead space ventilation may not become evident until cardiovascular collapse is imminent. If invasive monitoring is being used, increases in right atrial and pulmonary artery pressures can be an indication of embolism size. These changes are often delayed, making the use of these monitors less reliable in the intraoperative setting.

Precordial Doppler ultrasonography, an inexpensive and noninvasive technique, has been demonstrated to be the **earliest and most sensitive** indicator of venous air

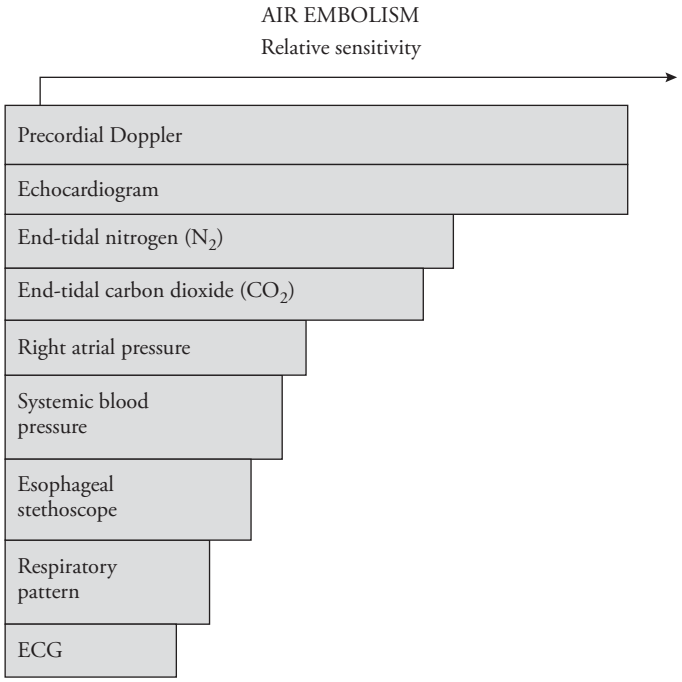

Figure 6.1 Relative sensitivity of air-embolism monitoring devices. (Reprinted with permission from Cote CJ, Lerman J, Todres ID, eds. *A Practice of Anesthesia for Infants and Children*. 4 ed. Philadelphia, PA: Saunders; 2009.)

embolism. Doppler can often diagnose VAE prior to catastrophic complications. Ideal **positioning of the Doppler is over the fourth intercostal space at the right sternal border**. For infants in the prone position, an alternative placement location is between the scapulae. Proper placement of the Doppler can be confirmed by injecting 5 mL of saline and listening for the characteristic change in sound. Figure 6.1 illustrates the relative sensitivity of air-embolism monitoring devices.

While precordial Doppler is the most sensitive monitor of VAE, other methods of detecting VAE exist. **Echocardiography** is the most **specific** method for **detecting venous air embolism**. The use of echocardiography during pediatric neurosurgery is limited because of patient size and positioning. End-tidal CO_2 concentration should be measured, as acute decreases may signify the presence of VAE, as described earlier. End-tidal nitrogen increases in the setting of VAE; however, this monitor is not readily available in most operating rooms. Increases in right atrial pressure and decreases in systemic blood pressure are also associated with VAE. Most clinicians employ several of these monitoring techniques during pediatric neurosurgical procedures.

KEY FACTS

- VAE is more likely to occur when there is a larger pressure gradient between the operative site and the heart.
- Echocardiography is the most specific method for detecting venous air embolism.
- Signs of VAE include hypotension and pulmonary changes, including edema, bronchoconstriction, and right heart failure. Ventilation/perfusion mismatch may lead to an acute drop in end-tidal CO_2.

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6. ANSWER: D

Hereditary and congenital vascular lesions range from the common and benign (nevus flammeus) to the rare and serious (neurocutaneous). Broadly, vascular lesions are classified as either **hemangiomas or vascular malformations**. Hemangiomas are the most common vascular lesions and present in infancy and childhood, and result from a **dense, abnormal, dilated collection of blood vessels**. Most occur sporadically and are small, causing cosmetic issues only. They are of concern if they **ulcerate or interfere with vision, airway, or organ function**. Hemangiomas are

present at birth in about 30% of those affected but sometimes are not obvious until 1 month of age. Typically hemangiomas will grow during the first year before involuting over the next decade. Forty percent resolve completely; the remainder do not and may require treatment.

Vascular malformations are classified as **arteriovenous malformations (AVMs), venous anomalies, and capillary telangiectasias**. AVMs are shunts between the arterial and venous systems. Venous anomalies result from abnormal venous drainage. **Capillary telangectasias** are capillary malformations that may form **extensive vascular networks through an organ**. Hereditary hemorrhagic telangiectasia (**HHT; Osler-Weber-Rendu syndrome**) is an autosomal dominant vascular disorder with an incidence of 1 per 3000 and is associated with mutations in endoglin on chromosome 9 and activin receptor-like kinase-1 on chromosome 12. The vascular lesion may be associated with **Klippel-Trenaunay syndrome or Sturge-Weber syndrome**.

Pediatric vascular lesions, including those involving the posterior cerebral artery and the great **vein of Galen**, present during the neonatal period with signs and symptoms of **congestive heart failure**. However, the majority of vascular lesions are discovered in the fourth to fifth decade of life. Only **18% present before age 15**. Older children will present with **signs of subarachnoid hemorrhage or intraventricular hemorrhage**.

KEY FACT

- Vascular malformations are classified as AVMs, venous anomalies, and capillary telangiectasias.

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7. ANSWER: B

Moyamoya disease is a condition that involves **abnormal vascular networks** in the brain, which can lead to **occlusion of intracranial vessels**. There is both a congenital and an acquired form of this condition, which is often diagnosed after patients **experience transient ischemic attacks or strokes**. One common trigger of these events is hyperventilation.

Treatment of moyamoya disease may be medical or surgical. Medical treatment involves antiplatelet therapy. Surgical treatment is pial syangiosis, in which the superficial temporal artery is inserted into the pial surface of the brain to cause revascularization.

The anesthetic management of patients with moyamoya disease involves careful attention to ventilation, as addressed by this question. Even mild hyperventilation may result in reduction in regional blood flow in these patients who already have compromised cerebral blood flow. **Hyperventilation and the associated hypocarbia can also result in profound vasoconstriction, resulting in vasospasm**. The ventilation goal for these patients should be to achieve normocarbia, in contrast to other pediatric neurosurgical procedures in which mild hyperventilation is desired. Maintenance of **adequate hydration** and **normothermia** are also important in patients with moyamoya disease.

KEY FACTS

- Moyamoya disease is a condition that involves abnormal vasculature of the brain, leading to occlusion of intracranial vessels.
- Key anesthetic goals include avoidance of hyperventilation and the associated hypocarbia that can also result in profound vasoconstriction, resulting in vasospasm. Furthermore, maintenance of adequate hydration and normothermia are also important.

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8. ANSWER: C

Venous air embolism (VAE) is a complication that has been reported to occur frequently in patients undergoing craniectomy for craniosynostosis repair. While the incidence of VAE may be as high as 83% in this procedure, it is usually not a hemodynamically significant event. VAE occurs when the noncollapsible veins of the cranium are exposed to atmospheric pressure, and air is entrained. This complication occurs more readily in surgical procedures in

which the head is positioned above the heart (i.e., the sitting position), but it can be seen in craniosynostosis because **significant blood loss can decrease central venous pressure** and lead to a gradient between the surgical site and the right atrium. If a large volume of air is entrained, hemodynamic consequences can be severe. Right ventricular outflow obstruction can occur secondary to the air, which may lead to **right-sided heart failure**, which in turn may lead to cardiovascular collapse.

An important sign of a VAE is a **decrease in end-tidal CO_2**. This occurs because air blocks the passage of blood from **the right ventricle into the pulmonary artery, reducing pulmonary blood flow and causing ventilation/perfusion mismatching**. There are other tools that are more sensitive in monitoring for VAE. **Precordial Doppler** is the most sensitive modality to detect intravascular air. Echocardiography is the most specific tool for detecting intravascular air, but it is of limited use in craniosynostosis repair because of patient positioning and the small size of the patients undergoing this procedure. **Monitoring end-tidal nitrogen concentration** is another mechanism to detect air embolism; however, the clinical utility of this is questionable as the increase in end-tidal nitrogen that results from VAE is very small and may be difficult to detect. Other symptoms of VAE are less sensitive. These **include hypotension, bradycardia, electrocardiogram changes, and increased right atrial pressures.**

Practitioners need to take several important steps in the setting of suspected VAE. When VAE is suspected, the surgeon should be immediately notified so that the surgical field can be flooded with saline. This prevents further air entrainment. If nitrous oxide is being used, it should immediately be discontinued because of the risk of enlarging the volume of air that has been introduced into the circulation. The child should be placed in the Trendelenburg position, which will help to decrease entrainment of air and increase the patient's central venous pressure. Aspiration of air via central venous catheter may also be performed. In the case of a hemodynamically significant VAE, fluid resuscitation and vasopressors may be warranted.

VAE in the pediatric population has several important considerations. **The ability to aspirate intravascular air is less likely to be successful in a pediatric patient**. Additionally, children tend to **respond to VAE with hypotension** more frequently than the adult population. Finally, children have a **high potential for intracardiac shunts, such as patent foramen ovale, atrial or ventricular septal defects, or other sequelae of congenital cardiac disease**. When these shunts exist in the setting of VAE, it is possible for air to pass to the systemic circulation with disastrous consequences.

KEY FACTS

- Right ventricular outflow obstruction can occur secondary to the VAE, which may lead to right-sided heart failure, which in turn may lead to cardiovascular collapse.
- Precordial Doppler is the most sensitive modality to detect intravascular air. Echocardiography is the most specific tool.

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9. ANSWER: D

Craniosynostosis occurs when one or more of the **cranial sutures fuse prematurely**, resulting in **abnormal bone growth** that leads to an **abnormal head shape**. This disorder may be isolated or may occur in association with a syndrome. Its incidence is approximately 5 per 10,000 births. Males are affected more than females. Skull growth continues for the **first 2 years of life, by which time the skull is more than 90% of its adult size**. If the sagittal suture fuses, **sagittal synostosis**, the head appears boat-shaped. This is known as **scaphocephaly**. Unilateral **coronal synostosis** causes **ipsilateral flattening of the forehead** and orbit deviation outward. This is known as **plagiocephaly**. A broad, flattened forehead, **brachycephaly, results from bilateral coronal synostosis**. Flattening of the occiput may result from unilateral/bilateral lambdoid synostosis or physical remolding from supine sleeping. The major concern with this disorder is **compromised intracranial volume** and impaired brain growth leading to neurologic dysfunction.

Craniosynostoses syndromes result from **FGFR gene mutation**. **Crouzon syndrome** is the most common disorder and presents with **multiple suture fusions**. Other craniosynostoses syndromes often have limb and/or cardiac anomalies as well. These syndromes include **Pfeiffer, Apert, Jackson-Weiss, and Saethre-Chotzen**. Occasionally, craniosynostosis is associated with metabolic disorders, including **hyperthyroidism and hypophosphatasia**.

There are several indications for cranial vault reconstruction in patients with craniosynostosis, including **elevated intracranial pressure**, **psychosocial reasons, and prevention of adverse neurologic consequences** (developmental delay, visual loss, and evolving hydrocephalus). While seizures can occur in patients with craniosynostosis (and may, in fact, be a result of hydrocephalus), this is rarely an indication for surgery. Cranial vault reconstruction is typically an elective procedure, but there are several indications for an urgent repair. These include the need to protect the eyes in

patients with **severe proptosis** resulting from craniosynostosis and to manage acute or chronically raised ICP.

KEY FACTS

- Craniosynostosis occurs when one or more of the cranial sutures fuses prematurely, resulting in abnormal bone growth that leads to an abnormal head shape.
- Indications for cranial vault reconstruction in patients with craniosynostosis include elevated intracranial pressure, psychosocial reasons, and prevention of adverse neurologic consequences (developmental delay, visual loss, and evolving hydrocephalus).

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10. ANSWER: C

In 20% of cases of craniosynostosis, the condition is associated with a syndrome. More than 150 syndromes have a known association with craniosynostosis. Of the syndromes listed, Apert syndrome is the one commonly associated with the condition.

Pierre Robin syndrome: While this is a craniofacial syndrome, it is not typically associated with craniosynostosis. Rather, the hallmarks of the Pierre Robin syndrome include **micrognathia, glossoptosis, and cleft palate**. These patients may present as newborn emergencies because of airway occlusion, which can result from the small mandible and sucking action of the infant. If cases are mild, the infants are placed prone during care and feeding. In severe cases, a **tracheostomy** may be necessary to **prevent airway occlusion**. The tongue may be sutured anteriorly to the mandible, to keep the airway open. Eventually, the mandible grows enough to accommodate the tongue and patients learn to keep the tongue forward, preventing airway occlusion. Direct laryngoscopy can be very difficult in these patients, and airway obstruction is common. A nasal trumpet can be helpful to prevent airway occlusion. **Distraction osteogenesis can be used to prevent tracheostomy**. Feeding issues may necessitate a nasogastric or gastrostomy tube. There is an increased incidence of congenital heart disease in patients with cleft lip or cleft palate.

Williams syndrome: This syndrome is not associated with craniosynostosis. The most notable features of Williams syndrome are the **cardiac manifestations**, most commonly **supravalvular aortic stenosis**. These patients may exhibit other congenital cardiac malformations and are known for having "elfin" facies and **neonatal hypercalcemia**. Distinctive characteristics of the Williams facies include **wide mouth, almond-shaped eyes, upturned nose, and small pointed ears**. Williams syndrome is also characterized by mild developmental delay often with increased musical aptitude and social affability. Patients with this syndrome may be sensitive to noise with delayed communicative speech and visual, spatial, and motor skill defects, making them seem more delayed than they actually are. In 90% of cases this syndrome is a result of a microdeletion on chromosome 7 on or near the gene encoding elastin.

Apert syndrome: This syndrome, also known as **acrocephalosyndactyly**, is an **autosomal dominant disorder** associated with synostoses of the cranium, vertebral bodies, hands, and feet. This syndrome results from a **mutation of the FGFR-2 gene**. The skull may be irregular in shape and manifest as "cloverleaf skull." These patients also exhibit **hypertelorism, proptosis**, and **mid-face hypoplasia**. Apert syndrome also includes the presence of **syndactyly**, which is not associated with the phenotypically similar Crouzon syndrome. Anomalous nasopharyngeal passage may be present. Diffuse acneiform lesions may involve arms, buttocks, and thighs and is treatment resistant. These patients may also have severe seborrhea, nail dystrophy, and cutaneous and ocular hypopigmentation.

Marfan syndrome: An **autosomal dominant** disease of skeletal and connective tissue, this syndrome is not associated with craniosynostosis. Common manifestations of Marfan syndrome include **aortic aneurysm s**econdary to weakness of the aortic media leading **to ascending aorta dilation, mitral valve prolapse and regurgitation, spontaneous pneumothorax, ectopia lentis (optic lens dislocation), myopia, scoliosis, joint laxity, arachnodactyly (long digits), pectus excavatum, and tall stature**. Diagnosis in patients with no family history requires skeletal features, two other affected systems, and one of the following major criteria: ectopia lentis, aortic root dilation, and aortic dissection. If a family history is present, diagnosis necessitates only two affected systems. The most concerning feature of this disease is aortic aneurysm formation, which usually starts as dilation of the aortic root. Mutations in the fibrillin-1 gene account for most cases, resulting in abnormal or decreased levels of fibrillin deposited in the extracellular matrix. Shprintzen-Goldberg syndrome is a very rare phenotypically similar syndrome, which does include craniosynostosis.

KEY FACTS

- Hallmarks of the Pierre Robin syndrome include micrognathia, glossoptosis, and cleft palate.
- Williams syndrome is associated with supravalvular aortic stenosis and neonatal hypercalcemia.
- Apert syndrome, also known as acrocephalosyndactyly, is an autosomal dominant disorder associated with synostoses of the cranium, vertebral bodies, hands, and feet.
- Marfan syndrome is an autosomal dominant disease of skeletal and connective tissue, including aortic aneurysm secondary to weakness of the aortic media, leading to ascending aorta dilation, mitral valve prolapse and regurgitation, spontaneous pneumothorax, ectopia lentis (optic lens dislocation), myopia, scoliosis, joint laxity, arachnodactyly (long digits), pectus excavatum, and tall stature.

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11. ANSWER: A

Patients presenting for **scoliosis surgery** have some degree of **pulmonary impairment**, which tends to be more severe with a more severe thoracic curvature. Other factors that contribute to pulmonary morbidity include the morphology of the curve, the number of involved vertebrae, and the rigidity of the curve. Curvature in scoliosis surgery is usually measured by the **Cobb angle**, which is depicted in Figure 6.2. In this method, the vertebrae that tilt most severely toward the convex side of the curve are used to determine the angle.

An **angle of less than 10 degrees is normal**. Surgical intervention is typically recommended for patients with a **curvature of greater than 40 to 50 degrees**. Patients with curvature as minor as 25 degrees have been found to have an increase in pulmonary artery pressures on echocardiography. This increased pulmonary

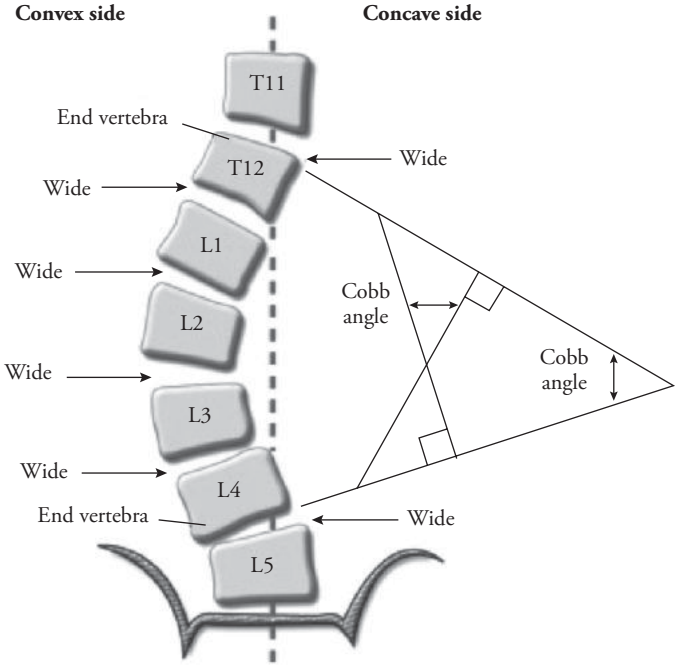

Figure 6.2 Cobb angle. (Reprinted with permission from Cote CJ, Lerman J, Todres ID, eds. *A Practice of Anesthesia for Infants and Children*. 4 ed. Philadelphia, PA: Saunders; 2009:634.)

vascular resistance is due to thoracic cage lung compression, impaired development of the pulmonary vascular bed in the setting of scoliosis, and hypoxic pulmonary vasoconstriction. The **severity of pulmonary complications increases as the curvature increases**. **Vital capacity decreases with curves greater than 60 degrees**, and **symptomatic lung disease manifests in patients with curves greater than 100 degrees**. Moderate or severe pulmonary impairment is defined as having **pulmonary function tests that are less than 65% predicted**. This level of pulmonary impairment is present in 20% of patients with a thoracic curve of 50–70 degrees. Table 6.3 summarizes the effects of increasing scoliosis curvature, with the caveat that respiratory symptoms can be seen with lesser curves in some patients.

Patients with idiopathic scoliosis tend to have fewer complications than patients with neuromuscular scoliosis. In patients with neuromuscular scoliosis there is an increased risk of hyperkalemia after succinylcholine administration, a potentially life-threatening complication. Patients with neuromuscular scoliosis have higher blood loss during scoliosis surgery and have a higher incidence of respiratory complications and ventilatory support postoperatively.

KEY FACTS

- Patients presenting for scoliosis surgery have some degree of pulmonary impairment, which tends to be more severe with a more severe thoracic curvature.
- Severity of pulmonary complications increases as the curvature increases.
- Vital capacity decreases with curves greater than 60 degrees, and symptomatic lung disease manifests in patients with curves greater than 100 degrees.

Table 6.3 EFFECTS OF INCREASING SCOLIOSIS CURVATURE

ANGLE OF CURVE	CLINICAL SIGNIFICANCE
<10	Normal
>25	Echocardiographic evidence of increased pulmonary artery pressures
>40–50	Surgical intervention (less for neuromuscular scoliosis)
>65	Restrictive lung disease
>100	Symptomatic lung disease, dyspnea on exertion
>120	Alveolar hypoventilation

SOURCE: Adapted from lecture "Orthopedics, Trauma, Burns" from Society for Pediatric Anesthesia Intensive Review of Pediatric Anesthesiology course 2013.

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12. ANSWER: D

The incidence of neurologic injury associated with scoliosis surgery is less than 0.5% and has decreased in recent years. Neurologic injury is more common in children with greater curvatures (100 degrees or greater), congenital scoliosis, and kyphosis. Intraoperative monitoring of spinal cord function can help prevent neurologic injury. There are several methods of monitoring spinal cord function, including the **wake-up test, somatosensory-evoked potentials (SSEPs), and motor-evoked potentials (MEPs).** Intraoperative monitoring with these techniques can result in immediate removal of surgical instruments and may improve prognosis should spinal cord injury result. Because of the devastating nature of neurologic injury, one or more of these techniques should be used for every patient undergoing major scoliosis surgery.

The **wake-up test** involves **decreasing the patient's depth of anesthesia** and asking the patient to **perform motor tasks**. If a patient is able to squeeze a hand but is unable to move her feet, a problem with the integrity of the spinal cord may exist. In the case of a positive test, removal of the spinal instrumentation immediately may prevent permanent neurologic injury. The limitation of the wake-up test is that it can only be used on children who can follow instruction appropriately. With the development of SSEP and MEP monitoring, the wake-up test is performed less frequently. Intraoperative recall and accidental extubation during the wake-up test are some of the risks.

SSEPs work by stimulating a peripheral nerve and then measuring the response to that stimulation via scalp electrodes. The pathway involves the electrical signal traveling from the dorsal root ganglia up the dorsal columns to the dorsal column nuclei at the cervical medullary junction. Secondary fibers then cross the midline and travel to the thalamus through the medial lemniscus, and third-order fibers then continue from the thalamus to the frontoparietal sensorimotor cortex. These cortical signals are picked up by the scalp electrodes.

SSEPs reflect the integrity of the dorsal columns, responsible for **proprioception and vibration**. The dorsal columns are **supplied by the posterior spinal artery**. The limitation of this technique is that it is a measurement of

the sensory nervous system only, and it does not specifically reflect the integrity of the motor pathways. Because these sensory tracts are close in proximity to the motor tracts, however, changes in SSEP signals may reflect compromise of the motor pathways. In fact, SSEP has been shown to decrease the incidence of neurologic deficits by approximately 50%. When there is a decrease in amplitude and an increase in latency of SSEP data, spinal cord function may be compromised.

Several clinical alterations have an important effect on SSEP data. **Hypotension affects SSEP amplitude more than latency**. The largest changes in SSEP slowing are noted with mean arterial pressures less than 60 mm Hg. Intentional hypotension aimed at decreasing blood loss can make SSEP monitoring less reliable as a clinical tool. Hyperventilation causes vasoconstriction, decreasing spinal cord blood flow, causing ischemia (CO_2<20 mm Hg) and increasing SSEP amplitude. Most volatile anesthetics cause a dose-dependent depression in amplitude and a dose-dependent increase in latency. In general, SSEP recording can be performed with 0.5 to 0.75 minimum alveolar concentration of volatile anesthetic without complication. Neuromuscular blockade does not have an effect on SSEP monitoring. Additionally, dexmedetomidine does not seem to have an effect on SSEP monitoring.

MEPs reflect the integrity of **motor pathways** in the **anterior spinal cord**, which is supplied by the **anterior spinal artery**. Measuring MEPs involves electrical stimulation of the motor cortex applied via the scalp. Motor responses are then measured distal to the area of interest. These pathways are affected by neuromuscular blockade.

KEY FACTS

- There are several methods of monitoring spinal cord function, including the wake-up test, SSEPs, and MEPs.
- SSEPs reflect the integrity of the dorsal columns, responsible for proprioception and vibration.
- MEPs reflect the integrity of motor pathways in the anterior spinal cord, which is supplied by the anterior spinal artery.

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13. ANSWER: C

Neurophysiologic monitoring, including both SSEPs and MEPs, is an important aspect of caring for patients undergoing scoliosis surgery. These evoked potentials are measured in terms of amplitude and latency. Amplitude signifies the evoked potential wave's peak-to-peak voltage difference. Latency represents the time from the stimulus to peak of response. **Anesthetic drugs** have various effects on SSEPs, with the majority of anesthetic agents causing **decreased amplitude and increased latency**.

Inhalational anesthetics cause a **dose-dependent** change in evoked responses. As inhalational concentration increases, SSEP waveforms will have a **depression of amplitude and an increase in latency**. These dose-dependent changes can lead to limitations when using intraoperative neurophysiologic monitoring to prevent neurologic injury. In general, SSEP recording can be performed with 0.5 MAC of the volatile anesthetic without changes in either amplitude or latency.

Table 6.4 summarizes the effects of common anesthetic agents on SSEPs. While most volatile and intravenous anesthetics depress both SSEPs and MEPs, ketamine and etomidate are the exceptions. Both **ketamine and etomidate enhance amplitudes** on both monitoring modalities.

KEY FACTS

- Anesthetic drugs have various effects on SSEPs, with the majority of anesthetic agents causing decreased amplitude and increased latency.
- Both ketamine and etomidate enhance amplitudes on both monitoring modalities.

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14. ANSWER: A

See Table 6.4 for a summary of the effects of common anesthetic agents on SSEPs. While most volatile and intravenous anesthetics depress both SSEPs and MEPs, ketamine and etomidate are the exception. Both ketamine and etomidate enhance amplitudes on both monitoring modalities.

Table 6.4 EFFECTS OF ANESTHETICS ON SSEP DATA

AGENT	AMPLITUDE	LATENCY	COMMENTS
Volatile anesthetics	↓	↑	Dose-dependent depression of SSEPs and MEPs; may use in subanesthetic doses
Nitrous oxide	↓	0	Mostly negative effects on SSEPs and MEPs
Propofol	↓	↑	Better preserves amplitude than volatile agents
Dexmedetomidine	0	0	Minimal effect on SSEPs; more studies needed
Opioids	↓	↑	Minimal effects on SSEPs and MEPs; dose-dependent depression in large doses
Ketamine	↑	0	
Etomidate	↑	↑	
Midazolam	↓	0	
Neuromuscular blockade	0	0	No effect on SSEPs; limit recording during MEPs

MEPs, motor-evoked potentials; SSEPs, somatosensory-evoked potentials.

Propofol causes a less than 10% reduction in SSEP amplitude. Dexmedetomidine does not seem to affect SSEP data.

KEY FACTS

- Anesthetic drugs have various effects on SSEPs, with the majority of anesthetic agents causing decreased amplitude and increased latency.
- Both ketamine and etomidate enhance amplitudes on both monitoring modalities.

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15. ANSWER: A

Postoperative visual loss is a devastating complication associated with spinal surgery. With an incidence as great as **0.2%**, this complication is unpredictable and not well understood.

Ischemic optic neuropathy (ION) is the most common cause of postoperative blindness in nonophthalmic surgery. ION accounts for 90% of cases, with the remaining 10% resulting from central retinal artery occlusion (CROA).

The mechanism of ION is **infarction of the optic nerve**, and it is a complication that has been reported after **spinal surgery, cardiopulmonary bypass**, and other types of operations. Most reports of ION involve adult patients, but older children have also been affected. ION can be classified as anterior or posterior, depending on the location of damage to the optic nerve. Posterior ION is the most common type of injury following prone positioning. Patients may experience a **momentary blurring of vision** that seems to be predominantly in the left eye. On initial fundoscopic examination, the optic nerve and disk appear to be normal. In contrast, anterior ION is often associated with optic disk edema.

The ASA Task Force on Perioperative Blindness sites many possible factors as contributing to development of ION. These include hypotension, blood loss, anemia, hypovolemia, hypoxia, hemodilution, edema of the face, use of vasopressors, infusion of large amounts of fluid, pressure on the eye, prone and head-down positions, increased venous pressure, and extended duration of surgery. ION does not appear to be related to pressure on the globes.

CROA, however, does seem to be related to **pressure on the globes**. It is usually secondary to decreased **retinal perfusion pressure** due to **arterial hypotension** or **intraocular hypertension**. CROA is usually unilateral and can be complicated by poor positioning.

The most common ophthalmic complication after general anesthesia is **corneal abrasion**. This complication usually occurs because of inadvertent **direct trauma** to the cornea while the patient is under anesthesia. The symptoms of corneal abrasion include pain, foreign body sensation in the eye, and photophobia. Fluorescein staining of the cornea confirms the diagnosis. Corneal abrasions usually heal within several days, and the treatment includes eye patching and antibiotic ointment. While the patient in this question

would be more likely to experience a corneal abrasion than ION, the absence of pain and photophobia make this the incorrect answer.

KEY FACTS

- ION is the most common cause of postoperative blindness in nonophthalmic surgery.
- Mechanism of ION is infarction of the optic nerve.
- CROA does seem to be related to pressure on the globes. It is usually secondary to decreased retinal perfusion pressure due to arterial hypotension or intraocular hypertension.

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16. ANSWER: A

Neural tube closure defects are one of the most common congenital disorders of the nervous system with an incidence of one per 1000 live births. **Spina bifida malformations are categorized as spina bifida occulta, spina bifida cystic with meningocele, and spina bifida cystic with myelomeningocele**.The malformations most commonly occur in the lumbar and sacral areas. Myelomeningocele is the most common form and most likely to lead to disability.

Spina bifida occulta results from **incomplete closure of vertebrae,** but the abnormality is usually small. The cord remains in the spinal canal and there is no external sac. The overlying skin may be normal or have hair growing from the area or be marked by a dimple, birthmark, or lipoma.

Spina bifida cystic with meningocele is the least common form of spina bifida and has abnormal vertebrae along with protrusion of meninges, dura, and arachnoid, through vertebral laminae defect. A cystic swelling occurs, usually in the lumbosacral area. The spinal cord remains in the spinal canal and the nervous system is usually normal. There are unlikely to be long-term effects.

Spina bifida cystic with myelomeningocele has abnormal vertebrae along with protrusion of meninges and a portion of the spinal cord. The incidence is 10 times that of meningocele.

Meningocele generally **lacks an association with cardiac, urologic, and orthopedic abnormalities**. However, Arnold-Chiari malformations are quite common in patients with this condition. Alternatively, patients with **myelomeningocele (involving herniation not only of meninges but also neural elements)** commonly present with cardiac defects and urologic and orthopedic complications. Many children with myelomeningocele will develop **hydrocephalus** and require a cerebrospinal fluid shunt. Specifically, a type II Arnold-Chiari lesion is the most common in patients with both meningocele and myelomeningocele.

KEY FACTS

- Spina bifida malformations are categorized as spina bifida occulta, spina bifida cystic with meningocele, and spina bifida cystic with myelomeningocele.
- Meningocele generally lacks an association with cardiac, urologic, and orthopedic abnormalities.

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17. ANSWER: B

Blood loss is generally **low during myelomeningocele** repair, usually consisting of **less than 10% of the patient's blood volume**. Rarely, anatomic variants can complicate surgical correction. This is more likely to occur if the sac is large or if a large amount of skin repair is necessary. **Temperature regulation** is always a concern in the neonate. Positioning and intubation can be problematic specifically with occipital encephalocele patients. If a difficult airway is suspected, awake intubation should be considered. Lastly, for unknown reasons, children with **myelodysplasia** have an **increased prevalence of allergy to latex**. They do not have an increased risk of allergic reaction to antibiotics when compared to the general population.

Positioning neonates with myelomeningocele (MMC) for induction of general anesthesia and intubation may be problematic as no direct pressure should be applied to the protruding spinal cord. Children with MMC have an increased incidence of intestinal, renal, cardiac, and

tracheoesophageal malformations. Hydrocephalus and Chiari malformation are commonly found in patients presenting for MMC and VP shunt placement may occur simultaneously with repair of MMC. Scoliosis, clubfoot (talipes equinovarus), and flat or high-arched foot are common orthopedic abnormalities present in patients with MMC. Electrolyte abnormalities may also be present. Hydrocephalus, CSF leak, wound infection, and/or wound dehiscence can occur postoperatively and result in re-presentation to the operating room.

Given that most of these patients are young, usually less than 1 year of age and often only days old, common intraoperative problems associated with the infant population should be considered. Hypoxemia, bradycardia, laryngospasm, and bronchospasm may occur.

KEY FACTS

- Blood loss is generally low during myelomeningocele repair, usually consisting of less than 10% of the patient's blood volume.
- Children with myelodysplasia have an increased prevalence of allergy to latex.

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18. ANSWER: B

Magnetic resonance imaging (MRI) is frequently used to evaluate intracranial neoplasms, as well as many other disorders. MRI studies require patient immobility to achieve the best image quality, and the studies themselves tend to be long (frequently longer than 1 hour). Therefore, anesthesiologists are commonly needed to provide either sedation or general anesthesia for patients having MRI scans.

Because MRI uses a superconducting magnet to generate a strong magnetic field (usually 0.5 to 3 Tesla), there are many safety considerations when anesthetizing a patient for an MRI scan. **Ferrous objects** that are mistakenly brought into the scanner room can become **projectiles**, attracted by the strong magnetic field. Projectile disasters can cause injury to patients, and there have even been reports of death from projectile objects brought into the MRI scanner. Only trained providers should be allowed in the MRI suite, and they should be vigilant regarding ferromagnetic objects. The US Food and Drug administration has created a nomenclature system for MRI compatibility:

- **MRI-safe**—object is not known to be hazardous in the MRI environment
- **MRI-conditional**—object may or may not be safe in the MRI environment
- **MRI-unsafe**—object poses a real hazard or risk in the MRI environment and should never be placed in the MRI environment

Many objects or devices that patients have implanted may pose risks in the MRI suite, and providers should investigate the MRI safety of these implants before a patient is allowed to enter the MRI scanner area. These objects may include **intracranial aneurysm clips, cochlear implants, vascular stents, prosthetic limbs, cardiac pacemakers, and tracheostomy tubes**. Specifically, Bivona tracheostomy tubes should be replaced with an endotracheal tube or an MRI-safe tracheostomy tube (such as a Shiley tracheostomy tube) prior to scanning. The hazards that Bivona tracheostomy tubes may produce in the MRI environment include tracheostomy tube motion or rotation, risk of thermal injury, and creation of artifact on images.

The MRI environment poses monitoring considerations for providers. MRI-safe monitors are available to be used for patients undergoing MRI imaging. These monitors do not contain ferromagnetic components. Even MRI-safe monitors are prone to **artifact** during scanning. Artifact is frequently seen on electrocardiogram tracing. Additionally, elevation of the T-wave may be seen during MRI scan, because of superimposed induced voltages. MRI does not affect heart rate, blood pressure, or contractility.

Monitoring in MRI may be hazardous when **focal heating** occurs. This can happen when there are exposed wires or when a conductive loop of wire causes thermal injury. Therefore, Answer D is incorrect, because focal heating is always a risk. Unconnected imaging coils should never be left on the patient during the scan, as this would predispose the patient to this type of problem.

Providers should insure that patients undergoing MRI imaging have adequate **auditory protection**, as the MRI scanner produces a loud banging sound during scanning. Ranging from 65 to 95 dB, this level of noise is not generally hazardous if the exposure is for a short period of time. However, all patients undergoing MRI should have earplugs or headphones. Choice B is correct because auditory protection during the scan is an important consideration.

Severe hypothermia is unlikely to develop in this patient during his MRI scan. It is more common for patients to have an increase in body temperature during MRI imaging, as the exposure to magnetic fields tends to increase body temperature. Small children and infants may be more susceptible to cooling during longer scans, but this is unlikely to result in severe hypothermia.

KEY FACTS

- **Ferrous objects** that are mistakenly brought into the scanner room can become **projectiles**, attracted by the strong magnetic field.
- Patients undergoing MRI imaging should have adequate **auditory protection.**

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http://www.MRIsafety.com

19. ANSWER: B

Gadolinium is a contrast agent used for MRI enhancement. It is approved by the FDA for use in adults and children. Gadolinium is biodistributed to the extracellular compartments because it forms a complex with chelating agents. It undergoes **renal elimination, with a half-life between 1.3 and 1.6 hours**. It has a **lower incidence of severe anaphylactic reactions** than conventional contrast material, with an incidence of less than 0.01%.

Gadolinium has been associated with the development of **nephrogenic systemic fibrosis (NSF)** in both adult and pediatric patients. NSF is seen in patients with renal impairment, and it manifests as a multisystem fibrosing disease. It is most common in dialysis patients given high doses of gadolinium. It is a rare disorder, with approximately 500 reported cases, but its effects are debilitating. **Skin fibrosis and joint contractures** are the most common manifestations, but it has been implicated in fibrosis of other organ systems as well. Of the patients who develop NSF, 5% have a rapidly progressive course. Patients who continue to have poor renal function after developing NSF typically do not have an improvement in symptoms. There have been cases of improvement in NSF symptoms in patients who have subsequently undergone renal transplant or who have regained renal function after their diagnosis.

NSF has been reported in 10 children, but little is known about this condition in the pediatric population. Because neonates have immature renal function, the current guidelines recommend that gadolinium not be given to neonates and that it is used with extreme caution in infants. Interestingly, there has not been a reported diagnosis of NSF in a neonate or infant. The youngest reported case of NSF is in an 8-year-old child. In children with renal impairment who require gadolinium contrast, the smallest dose should be used.

Gadolinium is sometimes necessary for diagnostic purposes in patients undergoing MRI, including patients with renal failure. In these patients, the lowest possible dose of gadolinium should be used. Additionally, if the patient regularly receives hemodialysis, there may be benefit in scheduling a dialysis treatment immediately after gadolinium has been given. **Hemodialysis reduces serum gadolinium concentrations rapidly**.

KEY FACTS

- Gadolinium is a contrast agent used for MRI enhancement. It undergoes renal elimination, with a half-life between 1.3 and 1.6 hours. It has a lower incidence of severe anaphylactic reactions than conventional contrast material, with an incidence of less than 0.01%.
- Gadolinium has been associated with the development of nephrogenic systemic fibrosis (NSF) in both adult and pediatric patients, resulting in skin fibrosis and joint contractures.

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20. ANSWER: A

Epilepsy is a disease that involves **recurrent spontaneous seizures** that can be from either congenital or acquired factors. It is a disease that frequently presents in childhood and is present in approximately 0.6% of the population. Epileptic seizures can manifest in a variety of ways: simple, complex, partial, or generalized. Evaluation of a patient with epilepsy usually consists of **MRI and electroencephalography (EEG), frequently with video**. If further localization of seizure foci is warranted, nuclear medicine tests may be performed. Medical treatment of epilepsy with anticonvulsant drugs may be effective; however, surgical treatment is used for patients who do not respond to these drugs. Surgical options may include **resection** of the **pathologic area of the brain**, **corpus callosotomy, or in severe cases, hemispherectomy**.

The nuclear medicine studies that most frequently require **sedation or general anesthesia** are **SPECT and positron emission tomography (PET)**. Both of these scans are useful for determining seizure foci and are commonly performed on inpatients who are admitted awaiting both

a seizure and subsequent scan. Other uses for these scans include evaluation of cerebrovascular disease and cognitive and behavioral disorders. Patients undergoing these scans must be motionless for approximately 1 hour, so anesthesiologists are frequently called on to care for these patients.

SPECT scans involve the use of **radiolabeled technetium-99m**, which has a **half-life of 6 hours**. This radionuclide is injected during a seizure and tags areas of increased cerebral blood flow, which correspond to the seizure foci. Patients should be scanned 1 to 6 hours after the seizure for optimal results. **Technetium-99m** is **nonallergenic** and **does not have physiologic consequences**. There is no alteration in the patient's hemodynamic status as a result of this radionuclide.

PET scan is another nuclear medicine study that may be used to evaluate seizure foci and can also be used to monitor for tumor recurrence. This scan uses radionuclide tracers of metabolic activity (oxygen or glucose metabolism). These **scans are most effective when performed during the seizure or shortly thereafter (within an hour)**. Because they may occur on short notice, the anesthesia team must be immediately available and should be involved in planning the care of these children. It is helpful if IV access is achieved while the patient is NPO and awaiting a seizure, to reduce the likelihood of hypovolemia.

KEY FACTS

- Epilepsy is a disease that involves recurrent spontaneous seizures that can be from either congenital or acquired factors.
- Surgical options may include resection of the pathologic area of the brain, corpus callosotomy, or in severe cases, hemispherectomy.

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Mason KP, Koka BV. Chapter 46: Anesthesia Outside the Operating Room. In: Coté C, Lerman J, Todres D, eds. *Practice of Anesthesia in Infants and Children*. 4th ed. Philadelphia, PA: Saunders Elsevier; 2009:998.

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21. ANSWER: D

The **myotonias** are hereditary neurodegenerative diseases **marked by involuntary contraction of muscle fibers caused by transient hyperexcitability of the surface membrane**. The contracture can occur after voluntary contraction or electrical stimulation. The myotonias are a family of **channelopathies** that can be divided into **two groups: dystrophic and nondystrophic**. The dystrophic group, of which **myotonic dystrophy** is the most common, **shows progressive muscle wasting; the nondystrophic group does not exhibit wasting**.

Myotonic dystrophy type 1, also known as **Steinert muscular dystrophy**, is an autosomal dominant disease that results from expansion of unstable trinucleotide repeats in the dystrophia myotonica-protein kinase (DMPK) gene. Changes in DMPK expression lead to abnormal splicing of a transmembrane calcium channel in skeletal and smooth muscle. Expansion of trinucleotide repeats leads to earlier onset in life and **increased severity of symptoms** in subsequent generations. In children and adults, myotonic dystrophy can present as **facial weakness**, **muscular wasting of the forearms and calves**, and **inability to relax the handgrip**. In **infants**, it may present with **severe weakness, poor sucking and swallowing, and motor and developmental del**ay. It is a systemic disease, and patients may have developmental delay, cardiac conduction abnormalities, central sleep apnea, respiratory insufficiency, endocrinopathies, delayed gastric emptying, and intestinal pseudo-obstruction. Treatment is symptomatic and includes medications that depress sodium influx into muscle cells, such as mexiletine and phenytoin.

Perioperative morbidity and mortality is due principally to **cardiopulmonary complications**. In addition to preoperative evaluation for cardiomyopathy and respiratory insufficiency, the anesthesiologist should anticipate **abnormal responses to anesthetic medications**. **Succinylcholine** results in exaggerated contracture that can be so severe that ventilation and tracheal intubation can be impossible. Another medication that may induce myotonic reactions is **neostigmine**. The response to nondepolarizing neuromuscular blockers appears to be normal. However, short-acting nondepolarizing neuromuscular blockers or avoidance of relaxation may be prudent to avoid the need for neostigmine. Patients have **increased sensitivity** to the respiratory depressant effects of **opioids, barbiturates, benzodiazepines, and inhaled anesthetics**. Neuraxial and regional techniques have been used successfully. It is likely that myotonic dystrophy is not associated with malignant hyperthermia.

Other triggering factors include **hypothermia**, **shivering**, **mechanical stimulation, or electrical stimulation such as with a twitch monitor**. Phenytoin and procainamide may help stabilize skeletal muscle membranes intraoperatively if contractions occur. Volatile anesthetics can also abolish myotonic contractions but may cause myocardial depression.

KEY FACTS

- Myotonias are hereditary neurodegenerative diseases marked by involuntary contraction of muscle fibers caused by transient hyperexcitability of the surface membrane.

- Two groups: dystrophic and nondystrophic
- Nondystrophic does not exhibit wasting.
- The dystrophic group, of which myotonic dystrophy is the most common, shows progressive muscle wasting.

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22. ANSWER: D

Myelodyplasia refers to **abnormal fusion of the embryologic groove** that normally closes during the first month of gestation. Failure of the end of the neural tube to close results in **defects of the vertebral arches, known as spina bifida**. A sac-like herniation through the defect that contains CSF is known as a **meningocele**. If the herniation contains both **CSF and neural tissue**, it is called a **myelomeningocele**. Myelomeningocele is associated with hydrocephalus and Arnold-Chiari malformation, and it can result in paralysis below the level of the lesion. Most patients born with myelomeningocele undergo **primary closure** within the **first 48 hours** of life to prevent infection. Many surgeons also place a ventriculoperitoneal shunt. Myelomeningoceles may also be repaired before birth, with some evidence of improved neurological outcomes.

Historically, children with myelodysplasia have shown an **increased risk of latex allergy**. Patients with myelomeningoceles undergo multiple surgical procedures and often are dependent on bladder catheterizations and thus may have repeated exposures of latex to mucosal surfaces. With clinician and parental awareness of the risk of latex sensitization in this population, these children are now routinely managed in latex-free environments from birth, and it is likely that the incidence of latex allergy has decreased. Children with latex allergy also show cross-reactivity with some antibiotics and foods. Anaphylaxis should be considered in any patient with a history of myelomeningocele with sudden hypotension.

Autonomic hyperreflexia may develop in patients with a chronic spinal cord lesion **above the level of T7**. It is characterized by severe **paroxysmal hypertension with bradycardia**, typically in response to **noxious stimuli** such as bladder or rectal distension. Increased ICP may be present in patients with hydrocephalus requiring shunt. Hemodynamic responses to increased ICP include **hypertension and bradycardia**.

Venous air embolism (VAE) is a concern during neurosurgical procedures, especially in the sitting position and in infants and small children undergoing craniotomies, because the head is large in relation to the rest of the body. VAE is also a possibility during the distal placement of a ventriculoatrial shunt. VAE can present with **hypotension**. In this situation, where the patient is a teenager and skin incision has just occurred, it is unlikely that VAE is the cause of hypotension.

KEY FACTS

- Myelodyplasia refers to abnormal fusion of the embryologic groove that normally closes during the first month of gestation.
- Spina bifida is a failure of the end of the neural tube to close, resulting in defects of the vertebral arches.
- Autonomic hyperreflexia develops in patients with a chronic spinal cord lesion above the level of T7 and is characterized by severe paroxysmal hypertension with bradycardia in response to noxious stimuli such as bladder or rectal distension.

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23. ANSWER: C

Cerebral palsy (CP) is a **static encephalopathy** characterized by nonprogressive motor and postural impairment. It comprises of a group of disorders manifesting with **poor muscle control**, **weakness**, and **increased muscle tone**. CP is the most common childhood disease of motor function, occurring in 2 in 1000 live births. It is caused by **cerebral injury** occurring antenatally, perinatally, or postnatally. CP can be classified by characteristics of the motor abnormality (spastic, hypotonic, dystonic, athetotic), the distribution involved (monoplegia, hemiplegia, diplegia, quadriplegia), and the severity of the deficit.

Skeletal muscle spasticity is the most common manifestation of CP. Some patients have normal intelligence,

while others may have developmental delay and speech defects. Approximately one third of CP patients have a coexisting seizure disorder. **Obstructive sleep apnea, recurrent respiratory infections, feeding dysfunction, and gastroesophageal reflux** are common. CP patients often undergo orthopedic procedures to improve function of the extremities and to correct spinal deformities.

Medications used to relieve skeletal muscle spasticity include **baclofen**, **dantrolene**, and **botulinum toxin A (Botox)** injections. The mechanism for muscle spasticity is thought to be from **inadequate release of γ-aminobenzoic acid (GABA)** in the dorsal horn of the spinal cord, leading to excessive motor neuron stimulation by excitatory glutamate. **Baclofen** is a GABA(B) receptor agonist that binds to receptors located in the dorsal horn of the spinal cord. Baclofen can be administered orally or intrathecally via a continuous pump. Baclofen should not be discontinued abruptly in the perioperative period due to **acute withdrawal**, which includes **seizures, hallucinations, delirium, hyperthermia, and pruritis**. Withdrawal symptoms can occur for up to **72 hours** after cessation.

Dantrolene is a hydantoin derivative that **reduces efflux of calcium** from the **sarcoplasmic reticulum**. In addition to its role in management of malignant hyperthermia, dantrolene is used to treat spasticity. Cessation of dantrolene is not associated with the described symptoms. **Phenytoin** is an **antiepileptic medication** that blocks voltage-gated sodium channels. Its half-life is variable, averaging 20 to 30 hours. Most anticonvulsants have a long elimination half-life. A missed dose over 24 hours is unlikely to result in seizures. **Cimetidine** is a histamine H2-receptor blocker used in the treatment of **gastroesophageal reflux**. It is an inhibitor of the cytochrome P450 system and can **prolong the half-life of many drugs**.

KEY FACTS

- CP is a static encephalopathy characterized by nonprogressive motor and postural impairment.
- Skeletal muscle spasticity is the most common manifestation of CP. Patients may also have obstructive sleep apnea, recurrent respiratory infections, feeding dysfunction, and gastroesophageal reflux.
- Baclofen should not be discontinued abruptly in the perioperative period due to **acute withdrawal**, which includes **seizures, hallucinations, delirium, hyperthermia, and pruritis**. Withdrawal symptoms can occur for up to **72 hours** after cessation.

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24. ANSWER: C

Somatosensory evoked potentials (SEPs or SSEPs) can be used to monitor for spinal cord injury during scoliosis surgery. It provides real-time, continuous assessment of spinal cord function. An **SEP is a signal in the sensory pathway** that is generated in response to **stimulation** of a **sensory nerve**. Typically in scoliosis surgery, a peripheral nerve (such as the median, peroneal, or posterior tibial nerve) is stimulated at a fixed interval during a procedure. The resulting SEP can be recorded over the scalp or spine. An intact neural pathway is required for an SEP to be generated. Intraoperative changes in the SEP during scoliosis surgery may indicate that this pathway has been jeopardized, either from ischemia or mechanical disruption of the pathway.

SEPs are described in terms of **polarity** (direction of the wave signal), **amplitude** (voltage difference between two peaks of opposite polarity), and **latency** (time measured from the application of the stimulus to the point of maximum amplitude of the evoked potential). SEPs are continuously repeated during surgery, with the amplitude and latency compared to baseline values. SEP monitoring and interpretation require special equipment and training. With ischemia, SEP amplitude decreases and latency increases. In general, **a reduction in amplitude of greater than 50% and an increase of latency of 10% are regarded as clinically significant**. SEPs are more reliable in patients with idiopathic scoliosis compared to those with neuromuscular scoliosis. SEPs only monitor the sensory pathway and provide no direct information for motor function or the anterior spinal cord. If SEP monitoring is equivocal, some advocate an intraoperative wake-up test to access motor function.

SEPs are affected by both pharmacologic and physiologic variables. For intraoperative monitoring, the most important variables are **anesthetic agents, blood pressure, oxygenation, and body temperature**. Volatile inhaled anesthetics produce dose-dependent decreases in amplitude and increases in latency. Nitrous oxide alone decreases amplitude but has no effect on latency. In general, intravenous anesthetic agents have less effect on SEPs. Propofol, opioids, and dexmedetomidine appear to have minimal effect on SEPs. Hypotension results in progressive decrease in amplitude with no change in latency. Hypoxia produces a decrease in amplitude similar to the change seen

in ischemia. Both hypothermia and hyperthermia can cause perturbations in amplitude and latency.

KEY FACTS

- An SEP is a signal in the sensory pathway that is generated in response to stimulation of a sensory nerve.
- SEPs are described in terms of polarity (direction of the wave signal), amplitude (voltage difference between two peaks of opposite polarity), and latency (time measured from the application of the stimulus to the point of maximum amplitude of the evoked potential).
- In general, a reduction in amplitude of greater than 50% and an increase of latency of 10% are regarded as clinically significant.

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25. ANSWER: B

Traumatic brain injury is the leading cause of mortality and morbidity in children over the age of 1. At initial presentation, a child may present with minimal symptoms of increased ICP. After the primary insult, the **ICP can progressively increase from intracranial bleeding and cerebral edema**. Symptoms include **headache, nausea, vomiting, and papilledema**. With abrupt increases in ICP, cerebral tissue from one compartment of the intracranial vault can herniate into a different compartment. Herniation resulting in brainstem compression results in **altered consciousness, defects in gaze, hemodynamic and respiratory instability**, and eventually death.

Methods for decreasing ICP include **head elevation, hyperventilation, hyperosmotic therapy, diuretics, and corticosteroids**. **Hyperventilation** is controversial in the setting of traumatic brain injury. Guidelines recommend maintaining normocapnia except in the presence of impending herniation, which will result in neurological devastation. If there is evidence of herniation, the ICP can be rapidly reduced with hyperventilation to a $PaCO_2$ of 30–35 mm Hg. Cerebral circulation is very sensitive to changes in $PaCO_2$. The fast response of the cerebral vasculature to $PaCO_2$ results from rapid diffusion of arterial CO_2 across the blood–brain barrier. Hyperventilation causes cerebral vasoconstriction, rapidly reducing cerebral blood volume and therefore the ICP. However, the decrease in cerebral blood volume results from decreased cerebral blood flow, which may exacerbate cerebral ischemia. In the setting of impending herniation, hyperventilation is useful in controlling ICP until more definitive measures are taken. The **effect of hyperventilation on decreasing ICP ceases after 6 to 12 hours**.

Hyperosmotic drugs, such as **mannitol,** cause transient increases in plasma osmolarity, which draws water away from tissues, including the brain, thus decreasing ICP. Decreases in ICP can be seen within 30 minutes, with the maximum effect reached within 1 to 2 hours. **Furosemide** promotes a decrease in ICP by promoting diuresis and systemic dehydration. The effect is not seen until diuresis commences. Dexamethasone is useful in lowering increased ICP in the setting of localized vasogenic cerebral edema associated with brain tumors. **Corticosteroids** have not been shown to decrease ICP in closed head injuries. The resulting increase in blood glucose concentration may have a detrimental effect in the setting of ongoing brain ischemia with a traumatic brain injury.

KEY FACTS

- Traumatic brain injury is the leading cause of mortality and morbidity in children over the age of 1.
- Methods for decreasing ICP include head elevation, hyperventilation, hyperosmotic therapy, diuretics, and corticosteroids.

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26. ANSWER: D

Familial dysautonomia (FD), or Riley-Day syndrome, is a neurodegenerative disorder resulting from the **loss of unmyelinated nerve fibers**. FD is an autosomal recessive disease that has been mainly reported in the Ashkenazi Jewish population. The loss of unmyelinated nerve fibers affects **central autonomic nervous system control** and the

perception of pain and temperature. Children affected with FD present early in infancy with **feeding difficulties, failure to thrive**, **generalized hypotonia, gastroesophageal reflux, chronic aspiration, developmental delay, seizures, diminished response to nociceptive stimuli, and emotional lability**. Prior to DNA testing, the diagnosis of FD was based on five clinical features: (1) Ashkenazi Jewish origin and a decrease or absence of (2) lacrimation, (3) deep tendon reflexes, (4) lingual fungiform papillae, and (5) axon flare after intradermal histamine injection. Currently, diagnosis is confirmed by DNA analysis by genetic linkage testing.

Patients with FD suffer from recurrent episodes of **dysautonomic crises** that are triggered by stress. Episodes are characterized by a rapidly changing pattern of **hypertension** and **hypotension** with **tachycardia and bradycardia**, **abdominal pain, diaphoresis, skin mottling, and vomiting**. The lack of autonomic nerve terminals on peripheral blood vessels seems to be responsible for the **labile blood pressure**. The autonomic dysfunction worsens with age. Baseline serum concentrations of norepinephrine are decreased, and patients with FD may have extreme responses to adrenergic medications. **Dysfunctional chemoreceptors may be responsible for a decreased ventilatory response to hypoxia and hypercarbia, with an increased incidence in central sleep apnea.** Almost 40% of patients with FD have prolonged **QT syndrome**.

Management of anesthesia includes appropriate **premedication** and pain control as **dysautonomic crises** can be triggered by **stress or pain**. FD patients are chronically **hypovolemic** from sweating and decreased fluid intake due to dysphagia. Correction of hypovolemia prior to surgery can reduce hemodynamic instability. Hypotension should be treated first with **volume replacement**, as these patients can have an exaggerated response to adrenergic medications. During induction, decreased doses of medications should be considered to avoid hypotension and bradycardia. A **rapid sequence induction** may be indicated for patients with severe gastroesophageal reflux. FD patients have decreased lacrimation and their eyes should be lubricated and protected. Postoperatively, analgesia should be optimized. If a dysautonomic episode occurs, **diazepam** is the drug of choice.

KEY FACTS

- **Familial dysautonomia** (FD), or Riley-Day syndrome, is a neurodegenerative disorder resulting from the loss of unmyelinated nerve fibers.
- The loss of unmyelinated nerve fibers affects central autonomic nervous system control and the perception of pain and temperature.
- Dysautonomic crises are triggered by stress and are characterized by a rapidly changing pattern of hypertension and hypotension with tachycardia and bradycardia, abdominal pain, diaphoresis, skin mottling, and vomiting.
- **Dysfunctional chemoreceptors may be responsible for a decreased ventilatory response to hypoxia and hypercarbia, with an increased incidence in central sleep apnea.**

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27. ANSWER: D

The **syndrome of inappropriate antidiuretic hormone secretion (SIADH**) is characterized by **euvolemic hypotonic hyponatremia**. The **dilutional hyponatremia** results from persistent or increased levels of antidiuretic hormone (ADH), which is also known as arginine vasopressin (AVP). ADH affects the distal tubules in the kidneys by **promoting water reabsorption and excretion of concentrated urine**. Factors that can stimulate the release of ADH include **hypovolemia, pain, surgical stress, critical illness, sepsis, pulmonary disease, central nervous system injury, and a variety of drugs**. SIADH can occur after neurosurgery and traumatic brain injury. In **awake** patients, clinical manifestations of SIADH include **headaches, nausea, vomiting, muscle cramps, lethargy, restlessness, disorientation, and depressed reflexes**. The severity of the symptoms depends on the absolute serum sodium concentration and the rate of decrease. Hyponatremia to the point of seizures is only occasionally observed.

SIADH should be suspected in any child who has had **asphyxia, meningitis, a brain tumor, trauma, surgery, or pulmonary disease**. Patients with SIADH demonstrate **hyponatremia, decreased plasma osmolarity, high urine sodium and osmolarity in the absence of volume depletion, cardiac failure, nephropathy, adrenal insufficiency, or cirrhosis**. Treatment of SIADH includes free water restriction, repletion of sodium deficits, and countering ADH effects with judicious use of diuretics.

Cerebral salt wasting is also common after traumatic brain injury and neurosurgical procedures. Cerebral salt wasting results from excessively high levels of atrial or brain

Table 6.5 CHARACTERISTICS OF SIADH, CEREBRAL SALT WASTING, AND DIABETES INSIPIDUS

	SIADH	CEREBRAL SALT WASTING	DIABETES INSIPIDUS
Central venous pressure	High (>5 mm Hg)	Low (<5 mm Hg)	Low
Urine output	Decreased	Increased	Increased
Urine sodium	High (>20 mmol/L)	High (>20 mmol/L)	<20 mmol/L
Urine osmolarity	High	Low or normal	Low
Serum osmolarity	Low	Low or normal	High
Antiduretic hormone	High	Normal	—

natriuretic peptides. Cerebral salt wasting is characterized by hyponatremia, hypovolemia, and excessive urinary loss of sodium. See Table 6.5.

Diabetes insipidus is a frequent complication of surgery involving or adjacent to the pituitary gland and hypothalamus. A **deficiency in ADH** leads to **hypernatremia**, **high output of dilute urine, dehydration, and hypovolemia**.

KEY FACTS

- Syndrome of inappropriate antidiuretic hormone secretion (SIADH) is characterized by euvolemic hypotonic hyponatremia.
- ADH affects the distal tubules in the kidneys by promoting water reabsorption and excretion of concentrated urine.
- Patients with SIADH demonstrate hyponatremia, decreased plasma osmolarity, high urine sodium and osmolarity in the absence of volume depletion, cardiac failure, nephropathy, adrenal insufficiency, or cirrhosis.
- Treatment of SIADH includes free water restriction, repletion of sodium deficits, and countering ADH effects with judicious use of diuretics.

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28. ANSWER: A

Myelodysplasia, or spina bifida, is a congenital anomaly of the spine. **Myelodysplasia results from abnormal fusion of the embryologic groove that normally closes during the first month of gestation**. Failure of the end of the neural tube to close results in defects in the vertebrae. Tissue can herniate through the defect. A sac-like herniation through the defect containing CSF but no spinal tissue is known as a meningocele. If neural tissue is present in the lesion, it is called a myelomeningocele. Both genetic and environmental factors likely play a role in the development of myelodysplasia. Maternal and environmental factors that have been implicated include **folate deficiency, hyperthermia, and exposure to alcohol, valproic acid, carbamazepine, or isotretinoin**.

Myelomeningocele is one of the most complex congenital lesions compatible with life. Patients with **myelomeningoceles will likely have motor and sensory deficits**. In addition to the initial surgical closure of the meningomyelocele, these patients will require additional procedures later in life, such as orthopedic and urologic surgery. Primary closure of the myelomeningocele usually occurs within the first day of life to minimize the risk of infection. Some surgeons also place a ventriculoperitoneal shunt at the time of initial surgery, as most will have associated hydrocephalus.

Patients with myelomeningocele can have associated congenital conditions. **The Arnold-Chiari Type II malformation almost always coexists**, and hydrocephalus is frequently found at birth. However, neonates presenting for repair of meningomyelocele rarely present with increased ICP. Other congenital conditions that may be present include **clubfoot, dislocation of the hips, exstrophy of the bladder**, **prolapsed uterus, Klippel-Feil syndrome, and congenital cardiac defects**. Tetralogy of Fallot is not specifically associated with meningomyelocele.

Arnold-Chiari malformations are anatomic abnormalities consisting of cephalad displacement of the cerebellum. In a Chiari Type II malformation, there is an abnormality of the posterior fossa with caudal displacement of the cerebellar vermis and lower brainstem below the foramen magnum. Cervical cord compression can occur. Patients may present with vocal cord paralysis, respiratory distress, central apnea, abnormal swallowing, and pulmonary aspiration.

KEY FACTS

- Myelodysplasia results from abnormal fusion of the embryologic groove that normally closes during the first month of gestation.

- Both genetic and environmental factors likely play a role in the development of myelodysplasia. Maternal and environmental factors that have been implicated include folate deficiency, hyperthermia, and exposure to alcohol, valproic acid, carbamazepine, or isotretinoin.

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29. ANSWER: A

Head trauma is a major cause of mortality and morbidity in children and is the leading cause of death and disability in children over the age of 1 year. **Head injuries include subdural and epidural hematomas, subarachnoid hemorrhage, skull fractures, and brain edema**. Children with head trauma may initially present with minimal symptoms, but neurological deficits may develop progressively from intracranial hypertension or brain edema. Children suffer from **diffuse cerebral edema** more than adults, while adults have hematomas more frequently. Injuries to other body parts and organs must also be taken into consideration in patients presenting with head trauma. Initial management of a patient with a head injury includes **assessment of airway, ventilation, adequacy of oxygenation, and circulation**.

Management of traumatic brain injury includes ongoing assessment of the severity of injury to detect dynamic changes in the patient's neurological status. Adequate cerebral perfusion should be maintained, as cerebral hypoperfusion is associated with cerebral ischemia and poor outcome. **Cerebral perfusion pressure (CPP) is the difference between the mean arterial pressure (MAP) and either the central venous pressure (CVP) or the ICP,** depending on whichever is higher. Commonly used methods of monitoring ICP include intraventricular catheters and intraparenchymal catheters. ICP monitoring may be indicated in infants and children presenting with traumatic brain injury and a Glasgow Coma Scale of 8 or less.

Initial management of **increased ICP (>20 mm Hg) includes elevation of the head, neuromuscular blockade, and hyperosmolar therapy**. **Mannitol** at 0.25 to 1.0 g/kg can be administered. The mechanism of mannitol in decreasing ICP may be related to shifting fluid from the brain compartment into the intravascular compartment. **Hypertonic saline** decreases ICP in a similar manner by facilitating the movement of water in the brain into the intravascular compartment. Current guidelines recommend maintaining normocapnia ($PaCO_2$ of 35 to 40 mm Hg) except in the setting of impending brain herniation. **Hyperventilation** is an effective and rapid way to produce cerebral vasoconstriction, therefore decreasing cerebral blood volume and ICP. However, the decrease in ICP is achieved at the expense of cerebral blood flow.

KEY FACTS

- CPP is the difference between the MAP and either the CVP or the ICP, depending on whichever is higher.
- Initial management of increased ICP (>20 mm Hg) includes elevation of the head, neuromuscular blockade, and hyperosmolar therapy.

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30. ANSWER: B

Hydrocephalus is the most common neurosurgical condition in pediatric patients. Hydrocephalus occurs when there is a mismatch in the production and absorption of CSF. Hydrocephalus can be **congenital or acquired**. It is caused by **congenital abnormalities (e.g., aqueductal stenosis), neoplasms, inflammatory conditions (e.g., meningitis), and overproduction of CSF (choroid plexus papillomas)**. Hydrocephalus can be described as nonobstructive/communicating or obstructive/noncommunicating. Treatment of hydrocephalus includes placement of a ventricular drain or ventriculoperitoneal (VP) shunt unless the underlying cause can be treated. VP shunts are placed in the lateral ventricles and allow drainage of CSF into the peritoneal cavity. If there is a problem with placing the shunt in the peritoneal cavity, the distal end of the shunt can be placed in the right atrium or pleural cavity.

Untreated hydrocephalus in children leads to an **increase in ICP or a decrease in intracranial compliance**. The signs and symptoms of hydrocephalus depend on intracranial compliance and how rapidly the CSF volume

increases. In young infants with open cranial sutures and open fontanelles, the clinical manifestations of increased ICP may not be present as the skull may expand insidiously, resulting in **craniomegaly**. In older children with fused cranial bones, the cranial cavity is unable to expand to accommodate the developing hydrocephalus, and as a result the patient may develop signs and symptoms of **increased ICP such as lethargy, vomiting, cranial nerve dysfunction, bradycardia, and ultimately death**.

Management of a symptomatic patient presenting for VP shunt placement for hydrocephalus should be directed to controlling ICP. The patient should be evaluated for signs and symptoms of increased ICP. Patients with vomiting are at risk of aspiration and the airway should be secured with a rapid sequence induction and endotracheal intubation. During induction, patients with increased ICP should be placed in a head-up position. Stimulation from laryngoscopy can acutely increase ICP, and trachea should be intubated as smoothly as possible with adequate anesthesia. **Ketamine**, unlike other intravenous anesthetic medications, causes sudden intracranial hypertension and is **contraindicated in a patient with hydrocephalus** presenting with signs and symptoms of increased ICP. Mild hyperventilation can decrease ICP until the VP shunt is placed.

KEY FACTS

- Hydrocephalus can be congenital or acquired and is caused by congenital abnormalities (e.g., aqueductal stenosis), neoplasms, inflammatory conditions (e.g., meningitis), and overproduction of CSF (choroid plexus papillomas).
- Ketamine, unlike other intravenous anesthetic medications, causes sudden intracranial hypertension and is contraindicated in a patient with hydrocephalus presenting with signs and symptoms of increased ICP.

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31. ANSWER: D

Skeletal muscle spasticity is common in children with **cerebral palsy**. The mechanism of muscle spasticity is thought to be related to **inadequate release of gamma-aminobutyric acid (GABA)** in the dorsal horn of the spinal cord. Without the inhibitory effects of GABA in the central nervous system, the relative **excess of excitatory glutamate on the alpha motor neurons** produces simultaneous contractions of agonist and antagonist muscle groups. Surgical treatment of spasticity includes **selective dorsal rhizotomy**. Medical management includes **botulinum neurotoxin** (Botox) injections, **dantrolene, and baclofen**.

Baclofen is a centrally acting muscle relaxant used for medical management of spasticity in patients with cerebral palsy and spinal cord injury. It is an **agonist to the GABA**(B) receptor in the dorsal horn of the spinal cord. It produces **presynaptic inhibition** of monosynaptic and polysynaptic reflexes. It is used to reduce pain associated with muscle spasms and to delay development of muscle contractures. Baclofen can improve range of motion and independent function in patients with spasticity. Baclofen can be administered orally or intrathecally via a continuous infusion from an implanted pump.

Side effects from baclofen include **hypotension, drowsiness, dizziness, gastrointestinal distress, and urinary retention**. Side effects can be managed by decreasing the dose. Baclofen use has been implicated in delayed awakening, bradycardia, and hypotension during general anesthesia. Baclofen should be continued perioperatively, as abrupt withdrawal can result in **seizures, hallucinations, delirium, hyperthermia, and pruritis**.

KEY FACTS

- Skeletal muscle spasticity is a common symptom in children with cerebral palsy.
- The mechanism of muscle spasticity is believed to be related to inadequate release of GABA in the dorsal horn of the spinal cord.
- Medical management includes Botox injections, dantrolene, and baclofen.
- **Baclofen** is a centrally acting muscle relaxant used for medical management of spasticity in patients with cerebral palsy and spinal cord injury. It is an **agonist to the GABA**(B) receptor in the dorsal horn of the spinal cord.

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32. ANSWER: C

The diagnostic criteria for **autism spectrum disorder (ASD)** include **social communication impairment** and **repetitive/restrictive behaviors,** both of which this child exhibits (*Diagnostic and Statistical Manual of Mental Disorders*, fourth and fifth editions). Autistic children tend to have **poor eye contact**, tend to be **unaware of other people,** and **may be aloof**. Their **language development** may be delayed and they may have **repetitive patterns, echolalia, or simply unusual intonation**. They may show little imagination with their activities but rather be involved in repetitive play. Perioperatively these children feel at loss, out of place, and may have higher anxiety levels. They may struggle with the physical exam (sensitivity to touch); they may have a hard time with multiple persons in the room and overall may need an IM sedative such as ketamine for cooperation. These children may require parental presence for induction along with a sedative in order to allow for a smooth anesthetic process. Depending on the severity of the disorder, they may benefit from early introduction to the operating room environment in order to prevent anxiety-provoking incidences on the day of surgery.

Children with **attention-deficit/hyperactivity disorder (ADHD) exhibit short attention span and hyperactivity** (most commonly seen in boys). Although they may have a learning disability, their developmental delay is related to **inattention** and not due to **social reciprocity (ASD feature)**.

Epilepsy occurs in 20%–30% of ASD persons, but based on what we know in this vignette this child does not display clinical seizure activity.

With normal motor development and normal age of walking, cerebral palsy would not be supported as a diagnosis.

KEY FACTS

- Autism spectrum disorder (ASD) includes social communication impairment and repetitive/restrictive behaviors.
- These children have poor eye contact, tend to be unaware of other people, and may be aloof.
- Language development may be delayed and they may have repetitive patterns, echolalia, or simply unusual intonation.

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33. ANSWER: B.

An initial transient increase in cerebral blood flow (CBF) may be noted due to **mannitol's direct smooth muscle vasodilatory effects** while reducing systemic blood pressure.

Mannitol is a **nonreabsorbable carbohydrate** that filters freely through the renal apparatus. It does not cross the blood–brain barrier and while holds water within the extracellular space, it allows for **diuresis and natriuresis**. It acts like an osmotic diuretic agent, reducing extracellular fluid volume and thus cerebral edema, especially in conjunction with a loop diuretic such as furosemide. If the blood–brain barrier has been disrupted as in traumatic brain injury, it should be used with caution since it may cause rebound cerebral edema by entering the central nervous system and drawing fluid with it.

The recommended initial dose of 0.25–0.5 g/kg (larger initial doses may predispose patients to rebound ICP increase) administered over 15–30 minutes will **decrease ICP within 30 minutes** and will have a **peak effect in about 1–2 hours**. Eighty percent of a 100 g dose appears in the urine in 3 hours with pharmacologic effect lasting no longer than 4–6 hours. The potentiation of natriuresis depends on renal blood flow and intravascular volume. In patients who are intravascularly depleted (prolonged fasting) and who are vasodilated (under anesthesia) administration should be extremely cautious. Hemodynamic instability may ensue with extreme hypotension.

Mannitol does not alter glomerular filtration rate and therefore it does not change the elimination rate of nondepolarizing neuromuscular blockers such as rocuronium.

Mannitol may ameliorate ICP increase by decreasing CSF production and thus decreasing cerebrospinal fluid volume.

KEY FACTS

- Mannitol is a nonreabsorbable carbohydrate, does not cross the blood–brain barrier, and allows for diuresis and natriuresis.
- Mannitol administered over 15–30 minutes will decrease ICP within 30 minutes and will have a peak effect in about 1–2 hours.

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34. ANSWER: B

Dexamethasone has a **superior central nervous system penetration** and, with **minimal mineralocorticoid activity,** is frequently used to **decrease cerebral edema** and associated increase in ICP in both oncologic and trauma situations. In neurosurgical cases, it is also used for its antinausea properties, and although the exact mechanism is unclear, in animal models its effect is on the **nucleus solitarius**.

Dexamethasone is about **30** times more potent than hydrocortisone with anti-inflammatory and analgesic properties. When the integrity of the hypothalamic-pituitary-adrenal axis is in question, it is administered empirically (especially with craniopharyngiomas). Due to its minimal mineralocorticoid activity it is not used alone in adrenal insufficiency, but it is rather used in conjunction with other corticosteroids with **higher mineralocorticoid potency** such as **fludrocortisone**.

Dexamethasone is frequently used in otolaryngologic procedures for postoperative nausea and vomiting (PONV) prevention as well as for amelioration of pain and airway swelling. Effective doses have ranged from 0.4 to 1 mg/kg (with higher doses having a better anti-inflammatory effect).

One of its side effects is perineal burning and itching; therefore, dexamethasone should not be given to awake patients.

KEY FACTS

- Dexamethasone has a superior central nervous system penetration with minimal mineralocorticoid activity to decrease cerebral edema.
- Dexamethasone is about 30 times more potent than hydrocortisone with anti-inflammatory and analgesic properties.

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35. ANSWER: A

Chronic anticonvulsant use causes **induction of hepatic microsomal enzymes** (cytochrome P450), enhancing the metabolism of medications such as **nondepolarizing muscle relaxants** and **opioids**. Therefore, the perioperative requirement of medications such as vecuronium and fentanyl may be increased in patients on chronic antiepileptic medications.

Epilepsy is prevalent in childhood (0.5%–1% of school age children) with the diagnosis made based on clinical presentation and supporting imaging and electroencephalographic (EEG) findings. Epilepsy syndromes can be subsequently determined based on seizure type, age of presentation, associated EEG findings, associated characteristics, and response to medications. **Perioperatively**, children with epilepsy can have an **unprovoked seizure** or **increased seizure frequency** for many reasons, including antiepileptic medication missed dose, anesthetic administration, hypoxia, cerebrovascular instability, coincidental exacerbation of their disease process, electrolyte imbalance, and direct effect from neurosurgical procedure.

Anesthetic administration of a potent volatile such as the epileptogenic enflurane or a short-acting barbiturate with lowering seizure threshold abilities such as methohexital can be detrimental. **Methohexital** causes increase in excitatory phenomena such as myoclonus and with continuous infusion can trigger postoperative seizures in one third of patients.

Perioperative preparation of a child with epilepsy should include the following:

1. Consultation with child's pediatrician or neurologist if time permits
2. Clarification of seizure type and triggering factors
3. Careful surgery scheduling to avoid prolonged fasting and omission of medications
4. Blood levels of antiepileptic medications to evaluate subtherapeutic or toxic effects
5. Blood work to evaluate any hematologic dysfunction
6. Careful review of drug–drug interactions

KEY FACT

- Chronic anticonvulsant use causes induction of hepatic microsomal enzymes (cytochrome P450), enhancing the metabolism of medications such as of nondepolarizing muscle relaxants and opioids.

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36. ANSWER: B

Posterior fossa tumors obstruct CSF flow and can cause increased ICP early; **morning nausea and vomiting** as well as **ataxia** are early presenting signs. Other symptoms include **cranial nerve V, VII, and X palsies** with **hypertension** or **hypotension**, **bradycardia,** and **facial muscle movements**. In young children symptoms may be confused with gastrointestinal manifestations and therefore the diagnosis may be delayed.

The most common **pediatric malignancy** is **leukemia**. **Brain tumors** are the most common **solid tumors** in children and have the highest morbidity of all children with malignancies. Two thirds are located in the infra-tentorium and one third in the supra-tentorium. Presentation depends on location of the tumor. Diagnostic imaging includes MRI, and treatment entails surgery with radiation and chemotherapy.

Although awake craniotomies are infrequently performed, in children any positioning for a craniotomy may place the head above the heart and therefore increase the risk of VAE. The head is frequently placed 10–20 degrees up to improve venous drainage. In infants and toddlers, the head is also large relative to body size and therefore accentuates this head-up position.

Anticonvulsants are frequently used in children with brain tumors both to prevent and treat seizures. Chronic use causes induction of hepatic microsomal enzymes (cytochrome P450), enhancing medication metabolism such as of nondepolarizing muscle relaxants and opioids. Therefore, the perioperative requirement of medications such as vecuronium and fentanyl may be increased in patients on chronic antiepileptic medications.

KEY FACTS

- Posterior fossa tumors obstruct CSF flow and can cause increased ICP early.
- Morning nausea and vomiting as well as ataxia are early presenting signs; other symptoms include cranial nerve V, VII, and X palsies with hypertension or hypotension, bradycardia, and facial muscle movements.

REFERENCES

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37. ANSWER: C

This question addresses pediatric **craniopharyngiomas,** the most common pediatric brain tumors of nonglial origin. Children with craniopharyngiomas should be considered **ACTH deficient** and treated empirically with **stress dose corticosteroids perioperatively**. Hypothalamic and pituitary tumor involvement necessitates preoperative hormonal evaluation (thyroid, cortisol, gonadotropins, prolactin, and growth hormone) for any evidence of dysfunction. **Thyroid deficiency** is associated with craniopharyngiomas due to tumor compression, displacement, and sometimes involvement of the pituitary gland. Severe deficiency is mostly seen with previously partially resected patients, and preoperative adherence to thyroid supplement is paramount.

Pediatric craniopharyngiomas have an incidence of about 6%–9% of pediatric brain tumors. There is an equal sex ratio and the distribution by age is bimodal with peak incidence in children of 5–14 years old and in adults of 65–74 years old. Because they are slow-growing extra-axial brain tumors, symptoms frequently do not occur until the tumor is very large. Common presenting symptoms include **headaches, vomiting, and somnolence,** all related to increased ICP due to either the size of the tumor or obstruction of CSF flow with hydrocephalus. Visual impairment is also common in children as a presenting finding but sometimes large tumors may cause minimal to no visual defects. Endocrine dysfunction can occur in 60%–90% of children with craniopharyngiomas, but it is rare to bring a child for medical attention due to an endocrine related issue. Findings may include **short stature, morbid obesity, diabetes insipidus, hypothyroidism, and elevated prolactin levels**. Questioning increased thirst and enuresis may reveal the diagnosis of DI preoperatively (17% incidence).

MRI with contrast is important for surgical approach and delineation of vessel and other important structure proximity. Computerized tomography (CT) is useful to identify intrasellar calcifications present in 50%–90% of pediatric craniopharyngiomas and is valuable for postoperative evaluation of a complete resection.

Although transphenoidal approach is the most common technique in adults, in children due to extension of the tumor into the suprasellar region, a transcranial approach is recommended.

Anesthetic considerations in a craniopharyngioma resection include but are not limited to the following:

1. Focused history to ascertain endocrine dysfunction as outlined herein.
2. Baseline focused exam entailing visual fields and neurological status for signs of increased intracranial pressure
3. Intraoperative and postoperative monitoring for evidence of DI
4. Intraoperative monitoring for VAE

KEY FACTS

- Children with craniopharyngiomas should be considered ACTH deficient and treated empirically with stress dose corticosteroids perioperatively.
- Hypothalamic and pituitary tumor involvement necessitates preoperative hormonal evaluation (thyroid, cortisol, gonadotropins, prolactin, and growth hormone) for any evidence of dysfunction.
- Common presenting symptoms include headaches, vomiting, and somnolence—all related to increased ICP due to either the size of the tumor or obstruction of CSF flow with hydrocephalus.

REFERENCES

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Winn HR, ed. *Youmans Neurological Surgery*. 6th ed. Chapter 198, Pediatric Craniopharyngioma. Philadelphia, PA: Saunders Elsevier; 2011:2069, 2073, 2075.

38. ANSWER: D

Glutamate is the major excitatory neurotransmitter in the central nervous system. Its activation depolarizes neurons, increasing the number of action potentials generated. GABA and glycine are major inhibitory neurotransmitters in the central nervous system. Their activation hyperpolarizes neurons, decreasing the number of action potentials generated. Glutamate binds inotropic (AMPA, kainate, and NMDA) and metabotropic receptors. **AMPA and kainate** receptors are attached to ion channels that allow sodium and potassium to pass through them; a small number of kainate receptors are also permeable to calcium. Activated NMDA channels are permeable to Na, K, and Ca. Overactivation of glutamate receptors has been associated with neuronal injury from epilepsy, trauma, and ischemia.

KEY FACTS

- Glutamate is the major excitatory neurotransmitter in the central nervous system.
- GABA and glycine are major inhibitory neurotransmitters in the central nervous system.

REFERENCES

Krass I. Physiology and metabolism of the brain and spinal cord. In: Newfield P, Cottrell JE, eds. *Handbook of Neuroanesthesia*. 4th ed. Philadelphia, PA: Lippincott, Williams & Wilkins; 2007:1–20.

39. ANSWER: B

The **$GABA_A$ receptor** contains a chloride channel that is opened when GABA binds. This activity is augmented by benzodiazepines, volatile anesthetics, and barbiturates. The **$GABA_B$ receptor** acts via a second messenger to open potassium channels. **AMPA, NMDA, and kainate** are the three major inotropic glutamate receptors that are activated by glutamate, the major excitatory neurotransmitter in the central nervous system.

KEY FACTS

- The $GABA_A$ receptor contains a chloride channel that is opened when GABA binds.
- This activity is augmented by benzodiazepines, volatile anesthetics, and barbiturates.

REFERENCES

Krass I. Physiology and metabolism of the brain and spinal cord. In: Newfield, P, Cottrell JE, eds. *Handbook of Neuroanesthesia*. 4th ed. Philadelphia, PA: Lippincott, Williams & Wilkins; 2007:1–20.

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40. ANSWER: D

Cerebral blood flow rates are greatly determined by the cerebral metabolic rate for oxygen consumption. There is coupling of blood flow and metabolism on a regional basis. **The global cerebral blood flow of children is approximately 70 mL/100 g per minute, reaching this maximum rate at approximately 5 years of age**. Cerebral blood flow decreases to reach adult levels after 19 years. The global cerebral blood flow of adults is approximately 50 mL/100 g per minute. This global measure is composed of flow from the gray matter, where neuronal cell bodies and synapses are located and has a blood flow of 75 mL/100 g per minute, and the white matter, which consists of mainly fiber tracts and has a blood flow of 20 mL/100 g per minute. In contrast, infants have a slightly lower global cerebral blood flow than adults (40 mL/100 g per minute). Spinal cord blood flow gray matter in adults has a rate of 60 mL/100 g per minute and the white matter a rate of 20 mL/100 g per minute.

KEY FACTS

- The global cerebral blood flow of children is approximately 70 mL/100 g per minute, reaching this maximum rate at approximately 5 years of age.
- The global cerebral blood flow of adults is approximately 50 mL/100 g per minute.

REFERENCES

Krass I. Physiology and metabolism of the brain and spinal cord. In: Newfield P, Cottrell JE, eds. *Handbook of Neuroanesthesia*. 4th ed. Philadelphia, PA: Lippincott, Williams & Wilkins; 2007:1–20.

Tasker R. Brain vascular and hydrodynamic physiology. *Semin Pediatr Surg*. 2013;22:168–73.

41. ANSWER: C

Cerebral glucose utilization in a 5-week-old infant is three-quarters that of an adult brain. The developing brain also metabolizes lactate, ketone bodies, amino acids, and free fatty acids. Adult rates of glucose utilization are first achieved by the age of 2 years. **After 2 years of age there is a further increase through the age of 8 years, followed by a decline in metabolic rate through the age of 20 years.** The crescendo-decrescendo pattern of change likely represents the consequence of brain development and subsequent "pruning" of neurons, synapses, and pathways that occurs with maturation.

KEY FACT

- Cerebral glucose utilization is three quarters that of an adult brain at 5 weeks of age, increases to adult rates at 2 years of age, and further increases to the age of 8 years, followed by a decline in metabolic rate through the age of 20 years.

REFERENCE

Tasker R. Brain vascular and hydrodynamic physiology. *Semin Pediatr Surg*. 2013;22:168–73.

42. ANSWER: A

Eighty percent of CSF is produced in the choroid plexus of the lateral and fourth ventricles. The remainder is produced in the interstitial space and ependymal lining. The need for CSF circulation begins early during intrauterine development because the choroid plexus is formed during the first trimester. There is a minor, infantile pathway for CSF circulation with cerebrospinal fluid drainage through the ventricular ependymal, interstitial and perivascular space, and perineural lymphatics. CSF is drained through arachnoid villi into the venous sinuses with the major, adult CSF circulation pathway. It is likely the main pathway used during infancy and during childhood is the minor pathway because arachnoid granulations do not appear until just before birth. There is evidence that arachnoid granulations continue to develop until adulthood.

KEY FACTS

- CSF circulation begins early during intrauterine development.
- Arachnoid granulations continue to develop until adulthood.

REFERENCE

Tasker, R. Brain vascular and hydrodynamic physiology. *Semin Pediatr Surg*. 2013;22:168–73.

43. ANSWER: D

The **lower limit of cerebral autoregulation** for non-anesthetized preterm infants is approximately **30 mm Hg**. There are no available data to determine whether the cerebral autoregulation curve for ex-premature infants mimics that of term infants. Intrinsic cerebral vasoreactivity and autoregulatory mechanisms are poorly developed in the immature brain. In normal term infants, several days are required for the maturation of vascular

responses. Cerebral autoregulation is poorly developed at birth. Studies in preterm infants have shown that **cerebral blood flow increases over the first 3 postnatal days of life**. Autoregulation may be disturbed in ill preterm and full-term infants suffering from cerebral hypoxia-ischemia. There is evidence to suggest that the **autoregulatory reserve is less in older infants than in children and adults** and that the physical state of the patient matters. Autoregulation pressure ranges are narrower and lower with decreasing gestational age. Given the lack of clear parameters, the most conservative approach would be to assume a very narrow autoregulatory range around the patient's baseline blood pressure.

KEY FACTS

- The lower limit of cerebral autoregulation for nonanesthetized preterm infants is approximately 30 mm Hg.
- Cerebral autoregulation is poorly developed at birth and may be disturbed in ill preterm and full-term infants suffering from cerebral hypoxia-ischemia.

REFERENCE

Tasker, R. Brain vascular and hydrodynamic physiology. *Semin Pediatr Surg*. 2013;22:168–73.

44. ANSWER: C

In all age groups, cerebral blood flow increases with increasing $PaCO_2$. It has been demonstrated that the change in cerebral blood flow per mm Hg change in $PaCO_2$ is higher in newborns than in fetuses, which may relate to the differences in cerebral metabolic rate of oxygen in newborns versus fetuses. **Hypocapnia leads to cerebrovascular vasoconstriction and lower cerebral blood flow.** Hypoxia not hyperoxia elevates cerebral blood flow. When PaO_2 falls to approximately 50 mm Hg, cerebral blood flow increases. Cerebrovasodilation is additive with that produced by metabolic acidosis and hypercapnia. See Figure 6.3.

KEY FACTS

- Cerebral blood flow increases with increasing $PaCO_2$.
- Hypocapnia leads to cerebrovascular vasoconstriction and lower cerebral blood flow.
- Hypoxia increases cerebral blood flow.
- When PaO_2 falls to approximately 50 mm Hg, cerebral blood flow increases.

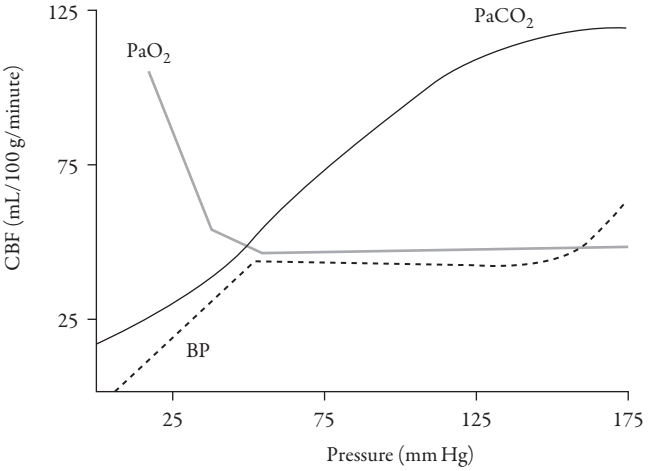

Figure 6.3 Cerebral blood flow changes with PaO_2 and $PaCO_2$.

- Cerebrovasodilation is additive with that produced by metabolic acidosis and hypercapnia.

REFERENCE

Tasker R. Brain vascular and hydrodynamic physiology. *Semin Pediatr Surg*. 2013;22:168–73.

45. ANSWER: A

The central nervous system is developed from the **neural tube**. The neural tube is initially open cranially and caudally. The openings close during the fourth gestational week. Neural tube defects, such as **anencephaly and spina bifida**, are caused by **failure of neural tube closure**. The alar plate comprises the dorsal part of the neural tube, which is primarily associated with sensation. The basal plate comprises the ventral part of the neural tube, which is associated with motor control.

KEY FACTS

- Neural tube defects, such as anencephaly and spina bifida, are caused by failure of neural tube closure.
- This occurs during the fourth week of neural development.

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Noia G, Cesari E, Visconti D, et al. Pain in the fetus. In: Buonocore G, Bellieni C, eds. *Neonatal Pain: Suffering, Pain and Risk of Brain Damage in the Fetus and Newborn*. Milan, Italy: Springer; 2008:45–8.

46. ANSWER: B

Peripheral cutaneous sensory receptors develop early in gestation. At approximately 7–8 weeks they appear in the perioral cutaneous area and then later in the palmar regions (10–10.5 weeks), abdominal wall (15 weeks), and then all over the body (15 weeks). These peripheral cutaneous sensory receptors form the basis for the peripheral nervous system. The peripheral sensory neuron synapses in the dorsal horn, which then stimulates the ventral horn motor neuron, creating a motor reflex—the withdrawal of a limb in a response to noxious stimuli.

KEY FACTS

- Peripheral cutaneous sensory receptors start developing in the seventh week of neural development.
- These peripheral cutaneous sensory receptors form the basis for the peripheral nervous system.

REFERENCE

Noia G, Cesari E, Visconti D, et al. Pain in the fetus. In: Buonocore G, Bellieni C, eds. *Neonatal Pain: Suffering, Pain and Risk of Brain Damage in the Fetus and Newborn*. Milan, Italy: Springer; 2008:45–8.

47. ANSWER: C

Cutaneous afferents of peripheral axons range in size from small, **thinly myelinated (Aδ)** and **unmyelinated (C) fibers** to **large-diameter, thickly myelinated (Aβ) fibers**. Small, thin fibers have historically been equated with nociceptive afferents and large fibers with low-threshold mechanoreceptors. Studies suggest that large-diameter fibers are the first to penetrate into the spinal gray matter of embryos, followed by the small-diameter fibers a few days later. It is thought that the early arrival of large-diameter fibers invades "pain-specific" laminae within the dorsal horn and this invasion extends into the third week of postnatal life in the rodent model. Traditionally, the **invasion of pain circuits** and **activation of low-threshold mechanoreceptors** has been thought to **underlie the hypersensitivity to tactile stimuli** seen in neonates. Recently, it has been found in rodent models that tactile afferents in neonates are small versions of their adult counterparts and do not activate pain circuitry as traditionally thought. Myelinated nociceptors are well developed early and display thresholds to mechanical and noxious heat stimuli that are indistinguishable from their adult counterparts. These nociceptive afferents extend throughout pain-specific laminae and can account for bulk-labeling patterns that were previously credited to tactile afferents. **The low mechanical threshold of these myelinated nociceptors can explain the marked hypersensitivity seen among neonates**. Answer A is incorrect because a weakening of the immune system does not cause an increased sensitivity to pain. Answer B is incorrect because inflammation does not cause neurons to die but instead causes an expansion in their receptor fields. Injury may cause neurons to die. Answer D is incorrect because it is thought that expansion of fields of myelinated nociceptors within the dorsal horn and not unmyelinated receptors is what causes hypersensitivity to pain.

KEY FACT

- The low mechanical threshold of myelinated nociceptors can explain the marked hypersensitivity seen among neonates.

REFERENCE

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48. ANSWER: D

During the first 2 years of life, the brain increases in size to approximately 75% of its adult size. The remaining 25% of growth occurs over the next 18 years. Closure of fontanelles and sutures occurs in a particular pattern. Fusion of sutures leads to closure of the posterior fontanelle at approximately 2 months and anterior fontanelle at 20 months. The metopic suture closes at approximately 2 years of age, and the remaining sutures close once craniofacial growth is completed, which is typically adulthood.

KEY FACTS

- Closure of fontanelles and sutures occurs in a particular pattern.
- Fusion of sutures leads to closure of the posterior fontanelle at approximately 2 months and anterior fontanelle at 20 months of age.

REFERENCE

Kimonis V, Gold J, Hoffman T, et al. Genetics of craniosynostosis. *Semin Pediatr Neurol*. 2007;14:150–61.

49. ANSWER: C

The **neural ectoderm** fuses to close the anterior end of the neural tube and then closes throughout its length before

fusing the caudal end of the neural tube. At approximately the third week of life, the central nervous system appears as an area of thickened ectoderm, called the neural plate. The lateral edges of the neural plate elevate to form neural folds. The folds fuse to form the neural tube. Fusion starts in the cervical region and continues in both the cephalad and caudal directions. The anterior neuropore closes approximately 25 days after conception. After closure of the anterior neuropore, the neurocele, which is the embryonic canal of the spinal cord, closes throughout its length. This process is called occlusion, which isolates the cranial vesicles, prevents drainage of fluid from the vesicles, and maintains them in distended state. The caudal end of the neural tube forms an open communication between the neurocele, which is the lumen of the neural tube, and amniotic fluid. The caudal neuropore closes approximately 2 days later, typically by 28 days after conception. Approximately 48 hours later, after closure of the caudal neuropore, the neurocele reopens without loss of fluid from the cranial vesicles.

KEY FACTS

- Neural ectoderm fuses to close the anterior end of the neural tube and then closes throughout its length before fusing the caudal end of the neural tube.
- The anterior neuropore closes approximately 25 days after conception. After closure of the anterior neuropore, the neurocele, which is the embryonic canal of the spinal cord, closes throughout its length.
- The caudal neuropore closes approximately 2 days later, typically by 28 days after conception.

REFERENCE

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7.

GASTROINTESTINAL SYSTEM

Luke S. Janik, Somaletha T. Bhattacharya, and Laura A. Downey

1. A neonate with necrotizing enterocolitis is brought to the operating room for exploratory laparotomy. The surgeon resects a portion of necrotic ascending colon. What segment of the gastrointestinal tract is the ascending colon derived from, and what is its primary blood supply?

A. Foregut; superior mesenteric artery
B. Midgut; superior mesenteric artery
C. Hindgut; inferior mesenteric artery
D. Midgut; celiac artery

2. A 2-year-old boy presents with abdominal pain and nausea. An abdominal computed tomography (CT) scan reveals an obstruction related to a Meckel's diverticulum. The most likely location of this finding is the:

A. Duodenum
B. Jejunum
C. Ileum
D. Ascending colon

3. Auerbach's (myenteric) plexus is the component of the enteric nervous system responsible for peristalsis. Within which layer of the gastrointestinal (GI) tract is Auerbach's plexus found?

A. Mucosa
B. Submucosa
C. Muscularis externa (propria)
D. Serosa

4. The *primary* mechanism of gastroesophageal reflux (GER) in the neonate is:

A. Increased gastric acidity of the neonate
B. Delayed gastric emptying time of the neonate
C. Elevated intra-abdominal pressure
D. Transient lower esophageal sphincter relaxation unrelated to swallowing

5. Which of the following is a characteristic of an omphalocele?

A. Exposed bowel is not covered by a sac
B. Defect is located to the right of midline
C. Common association with cardiac anomalies
D. Common association with bowel atresia

6. A neonate with an omphalocele is noted to be persistently hypoglycemic shortly after delivery. The anesthesiologist should have a high index of suspicion for which syndrome?

A. Beckwith-Wiedemann syndrome
B. Alagille syndrome
C. Down syndrome
D. Pierre Robin syndrome

7. During embryo development, which describes the midgut rotation (as viewed from anterior to posterior)?

A. 180 degrees counterclockwise around the superior mesenteric artery
B. 180 degrees clockwise around the superior mesenteric artery
C. 270 degrees counterclockwise around the superior mesenteric artery
D. 90 degrees counterclockwise around the superior mesenteric artery

8. A toddler with midgut malrotation is brought to the operating room for an intestinal obstruction related to a Ladd's band. A Ladd's band is:

A. A fibrous band of peritoneal tissue attaching the cecum to the abdominal wall, creating an obstruction of the duodenum
B. A fibrous band of peritoneal tissue attaching the sigmoid colon to the abdominal wall, creating an obstruction of the duodenum

C. A fibrous band of peritoneal tissue attaching the jejunum to the abdominal wall, creating an obstruction of the transverse colon
D. A fibrous band of peritoneal tissue attaching the stomach to the abdominal wall, creating an obstruction of the transverse colon

9. A 1-week-old infant presents with acute onset vomiting and signs of peritonitis. Which of the following findings is most consistent with diagnosis of acute midgut volvulus?

A. A double-bubble sign on abdominal radiograph
B. Upper GI contrast study showing normal duodenum-jejunum flexure position
C. Projectile nonbilious vomiting
D. Bilious emesis

10. The most common type of tracheoesophageal fistula is:

A. Gross Type A/Vogt II
B. Gross Type B/Vogt III
C. Gross Type C/Vogt IIIb
D. Gross Type D/Vogt IIIa

11. Which of the following is most consistent with a diagnosis of esophageal atresia?

A. Abdominal distention with feeding
B. Inability to pass an orogastric tube beyond 9 cm
C. Prenatal ultrasound demonstrating oligohydramnios
D. Chest radiograph demonstrating a double-bubble sign

12. An infant with a Type C tracheoesophageal fistula develops laryngospasm during inhalation induction. An intravenous propofol bolus is given and successfully relieves the laryngospasm, but the patient becomes apenic as a result. Gentle bag-mask ventilation is attempted, but ventilation becomes increasingly difficult as the abdomen becomes progressively distended. The patient begins to desaturate. The next *most* appropriate intervention is:

A. Administer atropine
B. Begin cardiopulmonary resuscitation
C. Percutaneous needle decompression of the stomach
D. Endotracheal intubation with direct laryngoscopy

13. The classic metabolic derangements described in patients presenting with pyloric stenosis include:

A. Hyperkalemic, hypochloremic metabolic alkalosis
B. Hypokalemic, hypochloremic metabolic alkalosis
C. Hypokalemic, hyperchloremic metabolic acidosis
D. Hypokalemic, hypochloremic metabolic acidosis

14. A surgical intern calls the operating room to schedule a pyloromyotomy for a 3-week-old male with pyloric stenosis. Which of the following set of lab values is most consistent with a patient who has been adequately resuscitated and medically optimized in the setting of pyloric stenosis?

A. Na 149 mEq/L; K 2.8 mEq/L; Cl 110 mEq/L; HCO_3 26 mEq/L
B. Na 137 mEq/L; K 3.7 mEq/L; Cl 95 mEq/L; HCO_3 26 mEq/L
C. Na 128 mEq/L; K 2.6 mEq/L; Cl 76 mEq/L; HCO_3 34 mEq/L
D. Na 145 mEq/L; K 4.4 mEq/L; Cl 110 mEq/L; HCO_3 17 mEq/L

15. Which of the following statements regarding infants with pyloric stenosis is true?

A. The total gastric fluid volume is 5.0 cc/kg on average, which is 10 times the average amount in an otherwise healthy, fasted infant.
B. Fasting intervals significantly affect the average gastric fluid volume.
C. Barium from a radiographic evaluation increases the gastric fluid volume.
D. The presence of a preoperative nasogastric tube (≤10 French) significantly reduces gastric fluid volume.

16. A 3-month-old is admitted to the emergency room with right-sided nontender groin swelling. A diagnosis of inguinal hernia is made. The surgeon successfully reduces the swelling. The next step would be:

A. Emergency repair of the inguinal hernia after reduction
B. Reduction should not be attempted.
C. No further intervention
D. Surgery should be delayed for 4–6 hours or scheduled electively after reduction.

17. Spinal anesthesia is a common regional technique used for inguinal hernia repair. Which of the statements describes the best anesthetic technique?

A. A spinal anesthetic in order to reduce the risk of postoperative apnea in a 3-week-old, full-term male neonate
B. Use of isobaric lidocaine with epinephrine and clonidine for an awake spinal anesthesic in a 35-week postconceptual age preterm infant

C. Use of hyperbaric tetracaine for an awake spinal anesthesic in a 25-week postconceptual age preterm infant
D. Use of ketamine with spinal anesthesia as it will provide adequate sedation while decreasing the risk of postoperative apnea in a preterm 45-week postconceptual age preterm infant

18. A diagnosis of prune belly syndrome has been made during an ultrasonographic examination of a pregnant female in the second trimester. The finding that points toward the diagnosis is:

A. Flat abdomen
B. Polyhydraminios
C. Hydroureter
D. Single kidney

19. A 5-year-old child admitted with vomiting is diagnosed by CT scan as having a duplication cyst of the gastrointestinal tract. Which is the most common site of a duplication cyst?

A. Gastro-duodenal junction
B. Ileum
C. Ascending colon
D. Jejunum

20. A 1-month-old baby is admitted with a history of chronic constipation. The gastroenterologist suspects Hirschsprung disease. Which one of the investigation is consistent with the diagnosis of Hirschsprung disease?

A. Anorectal manometry revealing that the internal anal sphincter is relaxing
B. Contrast enema revealing a dilated proximal colon that transitions to a normal or narrow caliber rectum
C. Incomplete evacuation of barium from the rectum hours after a contrast enema
D. Suction biopsy below dentate line showing absence of ganglionic cells on histology

21. Ulcerative colitis and Crohn's disease are two of the most common inflammatory bowel diseases with many similarities and some distinguishing features. Which colonoscopic finding would suggest Crohn's disease?

A. Presence of inflammation of colonic mucosa with rectal sparing and skip lesions
B. Presence of polyps
C. Presence of inflammation of colonic mucosa especially the rectum
D. Presence of ulcers in the colonic mucosa

22. A 5-year-old boy swallowed a lithium battery accidentally. He had his dinner prior to the incident. The patient is asymptomatic. Radiographic images reveal the presence of circular battery in the midesophageal area. The next step would be:

A. Advise the parents to take patient home and come back if he is symptomatic.
B. Since patient is asymptomatic but has a full stomach, wait at least 8 hours before scheduling removal.
C. Wait and take an X-ray after 3 hours and then proceed for removal if it has not moved.
D. Immediate removal of the battery endoscopically and observe the patient for complications.

23. A 4-week-old premature baby (28 weeks at birth) develops feeding intolerance and is found to be lethargic with temperature instability and tachypnea. The physician suspects necrotizing enterocolitis. Which of the following investigation confirms his diagnosis?

A. Metabolic acidosis
B. Plain abdominal film showing pneumatosis intestinalis and portal venous gas
C. Thrombocytosis
D. Coagulopathy

24. Which of the following conditions is an absolute indication for surgery in necrotizing enterocolitis?

A. Pneumoperitoneum
B. Portal venous gas
C. Abdominal tenderness and distention
D. Abdominal mass with intermittent intestinal obstruction

25. A 3-year-old admitted with abdominal pain, vomiting, and fever is diagnosed as having acute appendicitis. If the child has a perforated appendix, the first line of treatment should be:

A. Urgent appendectomy
B. Broad spectrum antibiotics and pain control
C. Intravenous fluid, antibiotics, and pain control
D. Immediate percutaneous drainage

26. A 4-year-old undergoes colonoscopy for episodic bouts of rectal bleed. He is not anemic. A single polyp is found in the rectosigmoid area. This child will require:

A. Colonoscopy annually
B. Repeat colonoscopy only if bleeding recurs
C. An upper endoscopy
D. Resection of the rectosigmoid colon due to increase chance of malignancy

27. Which one of the following is true of juvenile polyposis syndrome?

A. Colorectal screening should occur every 3–5 years.
B. Affected individuals do not need to have the polyps removed.
C. It is diagnosed by the presence of any polyps in the stomach and intestine.
D. It has an autosomal recessive inheritance pattern.

28. Celiac disease is associated with:

A. Patients of Asian and African heritage
B. Psoriasis
C. Type 2 diabetes
D. Hashimoto thyroiditis

29. A 6-month-old ex-premature infant is diagnosed with short bowel syndrome following bowel resection for necrotizing enterocolitis. If the portion of bowel resected was the ileum, which of the following function will be affected?

A. Absorption of bile salts/acids
B. Absorption of fat-soluble vitamins
C. Absorption of iron
D. Absorption of folate

30. An 8-year-old child with cerebral palsy is diagnosed with gastroesophageal reflux and a hiatal hernia. He has failed medical management of gastroesophageal reflux and is scheduled to undergo laparoscopic Nissen fundoplication. This surgery involves:

A. Insufflation of air via a gastric tube at the end of surgery
B. Large fluid shifts
C. Moderate blood loss
D. Moderate to severe postoperative pain

31. A 6-month-old girl is brought by an anxious mother to the surgeon's office with an umbilical swelling that becomes prominent when the child cries. The surgeon diagnosed the swelling as an umbilical hernia. What should he tell the mother?

A. Schedule patient for surgery to repair the umbilical hernia.
B. Inform her that 90% of umbilical hernias close spontaneously by 2–3 years of age.
C. Umbilical hernia is prone for incarceration.
D. Apply a tight abdominal binder.

32. In patients who have underlying liver dysfunction, such as cirrhosis, the metabolism of which medication is *most* likely to be prolonged?

A. Propofol
B. Ketamine
C. Remifentanil
D. Midazolam

33. The Centers for Disease Control and Prevention (CDC) recommends which of the following methods as the most appropriate and easiest screening tool for childhood obesity?

A. Body mass index (BMI)
B. Absolute weight
C. Weight-for-height percentiles
D. Percentiles of ideal body weight

34. Which of the following is a common complication from the hepatic portoenterostomy (Kasai procedure) for biliary atresia:

A. End-stage liver disease
B. Water-soluble vitamin deficiency
C. Fat-soluble vitamin deficiency
D. Hepatocellular carcinoma

35. Which of the following is true regarding morbidly obese patients undergoing general anesthesia for bariatric laparoscopic gastric banding surgery?

A. Patients have a higher risk of aspiration during induction.
B. Drug and fluid administration should be based on actual weight.
C. Postoperative ventilation is required after laparoscopic gastric banding.
D. Patients are at lower risk of thromboembolism in the postoperative period.

36. Patients with gastroesophageal reflux are at increased risk for the following complication under general anesthesia when compared to healthy patients:

A. Bronchospasm
B. Laryngospasm
C. Delayed emergence
D. Prolonged neuromuscular blockade

CHAPTER 7 ANSWERS

1. ANSWER: B

Formation of the gastrointestinal tract begins around week three of gestation, when the primitive gut tube develops from the endoderm lining the yolk sac. During gestation, this tube undergoes a series of complex folds, rotations, tissue differentiation, and elongation driven by molecular patterning signals and anatomical constraints. The key events of prenatal gastrointestinal tract development are highlighted in Table 7.1.

The gastrointestinal tract is divided **into three functional segments based on the blood supply**. The ***foregut*** is supplied by the celiac artery and includes the esophagus, stomach, liver, gallbladder, pancreas, and proximal duodenum. The ***midgut*** is supplied by the superior mesenteric artery and includes the distal duodenum, jejunum, ileum, cecum, appendix, and the proximal two thirds of the colon. The ***hindgut*** is supplied by the inferior mesenteric artery and includes the distal one third of the colon, sigmoid colon, rectum, and superior part of the anal canal.

KEY FACTS

- Formation of the gastrointestinal tract begins around week three of gestation, when the primitive gut tube develops from the endoderm lining the yolk sac.
- The gastrointestinal tract is divided into three functional segments based on the blood supply.
- The foregut is supplied by the celiac artery and includes the esophagus, stomach, liver, gallbladder, pancreas, and proximal duodenum.
- The midgut is supplied by the superior mesenteric artery and includes the distal duodenum, jejunum, ileum, cecum, appendix, and the proximal two thirds of the colon.
- The hindgut is supplied by the inferior mesenteric artery and includes the distal one third of the colon, sigmoid colon, rectum, and superior part of the anal canal.

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Carlson BM. Digestive and respiratory systems and body cavities. In: *Human Embryology and Developmental Biology*. 5th ed. Philadelphia, PA: Saunders Elsevier; 2014:344–6.

2. ANSWER: C

A **Meckel's diverticulum** is a true diverticulum typically located on the antimesenteric side of the distal ileum and results from incomplete obliteration of the vitelline (omphalomesenteric) duct. In the embryo, this duct connects the primitive gut tube to the yolk sac for nutrition and is usually obliterated around the 6th—8th week of gestation after midgut rotation takes place. Meckel's diverticula have been described by the **"rule of two's**," because they are found in 2% of the population, are twice as common in males as in females, typically present before the age of 2 years, and are found on the ileum within 2 feet of the ileocecal valve in adults.

Meckel's diverticula are the **most prevalent congenital abnormality of the gastrointestinal (GI) tract**. The **most**

Table 7.1 **TIMETABLE OF KEY EVENTS OF PRENATAL GASTROINTESTINAL TRACT DEVELOPMENT**

GESTATIONAL AGE	PRENATAL DEVELOPMENT EVENTS
3rd week	• The primitive gut tube forms from the endoderm liming of the yolk sac
4th week	• Liver bud, tracheal bud, dorsal, and ventral pancreatic buds appear • Oropharyngeal membrane ruptures
5th week	• Intestinal elongation • Stomach begins to rotate 90 degrees about its craniocaudal aspect
6th week	• Intestinal elongation continues • Stomach rotation complete (previously dorsal convex border now faces left, and previously ventral concave border now faces right)
7th week	• Intestinal loop herniates outward through the yolk sac with the superior mesenteric artery as its axis • Dorsal and ventral pancreatic buds fuse
8th week	• Herniated intestinal loop rotates 270 degrees counterclockwise around the superior mesenteric artery • Migration of parasympathetic neurons from the neural crest to the gut begins
9th week	• Herniated intestinal loop returns into abdominal cavity • Epithelial differentiation of GI tract mucosa begins
11th week	• Intestinal villi and goblet cells begin to form
16th week	• Intestinal villi completely line the intestine
20th week	• Peyer's patches (intestinal lymphatic tissue) develop

common presentation in children is a GI bleed. This is thought to be due to the presence of ectopic gastric and pancreatic tissue, which causes ulcerations from the acidic and alkaline secretions, respectively. It is unclear why Meckel's diverticula contain ectopic tissue, but **gastric mucosal tissue was found in roughly 60% of cases and pancreatic tissue in 5%.** The second most common presentation is intestinal obstruction. In children, obstruction is usually due to intussusception of the diverticulum. However, obstruction may also be due to entrapment of the diverticulum in a hernia, formation of obstructing stones in the diverticulum (Meckel's diverticulum lithiasis), or volvulus of the diverticulum.

Diagnosis of a Meckel's diverticulum can be challenging, and the presentation is often misdiagnosed as appendicitis. Abdominal X-ray is an unreliable diagnostic tool as the findings are often nonspecific. **Ultrasound and abdominal CT scan are the preferred diagnostic modalities.**

Treatment of symptomatic Meckel's diverticula is surgical excision. Management of asymptomatic Meckel's diverticula is more controversial. The general consensus is that asymptomatic Meckel's diverticula should not be resected given the low likelihood that it will become symptomatic over a lifetime. However, some surgeons favor elective resection of the diverticulum, especially if it is large.

KEY FACTS

- A Meckel's diverticulum is a true diverticulum typically located on the antimesenteric side of the distal ileum and results from incomplete obliteration of the vitelline (omphalomesenteric) duct.
- Rule of Two's: Meckel's diverticuli are found in 2% of the population, are twice as common in males as in females, typically present before the age of 2 years, and are found on the ileum within 2 feet of the ileocecal valve in adults.
- Meckel's diverticula are the most prevalent congenital abnormality of the GI tract.
- The most common presentation in children is a GI bleed.
- Gastric mucosal tissue was found in roughly 60% of cases and pancreatic tissue in 5%.

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3. ANSWER: C

The gastrointestinal tract is comprised of four distinct functional layers, listed here from innermost to outermost: mucosa, submucosa, muscularis externa (propria), and serosa.

The mucosa is the innermost layer of the GI tract and has three distinct components: the epithelium, the lamina propria, and the muscularis mucosae. The histologic characteristics of the mucosa vary depending on the function. The four basic mucosal types are protective, secretory, absorptive, and absorptive/protective. Protective mucosa is typically found in the oral cavity, pharynx, esophagus, and anal canal, and is composed of stratified squamous epithelium, which protects against frictional trauma. Secretory mucosa is found in the stomach and consists of tubular glands that secrete acid and digestive enzymes. Absorptive mucosa lines the small bowel and contains villi, which increase the surface area of the mucosa to improve nutrient absorption. Absorptive/protective mucosa lines the large intestine and is characterized by packed tubular glands specialized for water absorption and mucus secretion.

The submucosa is a layer of loose connective tissue surrounding the mucosa that contains blood vessels, lymphatics, and nerves. Within the submucosal layer lies the Meissner (submucosal) plexus, composed primarily of postganglionic parasympathetic fibers supplying the mucosal glands and smooth muscle of muscularis mucosae.

The muscularis externa (propria) surrounds the submucosa and is comprised of two distinct smooth muscle layers: an inner circular layer and outer longitudinal layer. Between these muscle layers lies Auerbach's (myenteric) plexus, a collection of primarily postganglionic parasympathetic fibers supplying the inner and outer longitudinal layers of smooth muscle. Auerbach's plexus is responsible for the peristaltic activity of the GI tract under input from the Interstitial Cells of Cajal, which function as the "pacemaker" of the gut. Failure of neural crest cells to migrate from the neural plate to the GI tract during development results in dysmotility. The most well-known example of this is Hirschprung disease, also known as congenital aganglionic megacolon. Hirschprung disease usually presents in the neonatal period as failure to pass meconium. Imaging is notable for spasm in the denervated colon, with significantly dilated colon proximal to the affected area, which may develop into toxic megacolon.

The serosa (adventitia) is a thin, loose connective tissue supporting the tubular GI tract.

KEY FACTS

- The GI tract is comprised of four distinct functional layers, listed here from innermost to outermost: mucosa, submucosa, muscularis externa (propria), and serosa.

- The mucosa is the innermost layer of the GI tract and has three distinct components: the epithelium, the lamina propria, and the muscularis mucosae.
- The four basic mucosal types are protective, secretory, absorptive, and absorptive/protective.
- The submucosa is a layer of loose connective tissue surrounding the mucosa that contains blood vessels, lymphatics, and nerves.
- The muscularis externa (propria) surrounds the submucosa and is comprised of two distinct smooth muscle layers: an inner circular layer and outer longitudinal layer.
- The serosa (adventitia) is a thin, loose connective tissue supporting the tubular GI tract.

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4. ANSWER: D

As defined by the North American Society of Pediatric Gastroenterology, **gastroesophageal reflux (GER) is the retrograde passage of gastric contents into the esophagus with or without regurgitation and vomiting.** When GER causes complications or morbidity, it is defined as gastroesophageal reflux disease (GERD). The **primary mechanism of GER** is transient lower esophageal sphincter relaxation, unrelated to swallowing. While **elevated intra-abdominal pressure and delayed gastric emptying** contribute to GER, they are not the primary cause. Neonates have a lower basal acid output than adults, with preterm infants producing less acid than term infants.

Signs and symptoms of GER in the infant are often nonspecific and include poor weight gain, irritability, wheezing, stridor, cough, apnea spells, and apparent life-threatening events. In addition to history and physical exam, **diagnostic studies** include esophageal pH monitoring, intraluminal impedance monitoring, motility studies, endoscopy and biopsy, barium contrast radiography, and nuclear scintigraphy. Often crying and vomiting are confused with GERD and may be related to a milk protein sensitivity. A trial of extensively hydrolyzed protein formula is recommended in these cases. **Thickened formula may reduce the amount of visible regurgitation and is often recommended in term infants, but it has not been shown to decrease the frequency of GERD.** Furthermore, commercial thickeners are not recommended for preterm infants as their effectiveness remains unclear, and concern exists for a possible link to necrotizing enterocolitis. Other treatment options in infants include medical management with histamine-2 receptor antagonists, proton pump inhibitors, prokinetic therapy, and ultimately surgical treatment. The anesthesiologist must pay particular attention to the **risk of aspiration** during induction of infants with GERD and may consider emptying the stomach prior to induction and avoiding or minimizing mask ventilation.

KEY FACTS

- GER is the retrograde passage of gastric contents into the esophagus with or without regurgitation and vomiting.
- The primary mechanism of GER is transient lower esophageal sphincter relaxation, unrelated to swallowing.
- While elevated intra-abdominal pressure and delayed gastric emptying contribute to GER, they are not the primary cause.
- Signs and symptoms of GER in the infant are often nonspecific and include poor weight gain, irritability, wheezing, stridor, cough, apnea spells, and apparent life-threatening events.
- Diagnostic studies include esophageal pH monitoring, intraluminal impedance monitoring, motility studies, endoscopy and biopsy, barium contrast radiography, and nuclear scintigraphy.

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5. ANSWER: C

Omphalocele and gastroschisis are the two most common abdominal wall defects in the neonate, resulting in herniation of the bowel outside of the abdominal cavity. Both defects are typically discovered during prenatal workup by fetal ultrasound and elevated maternal serum alpha-fetoprotein.

Omphaloceles result as a failure of the bowel to return into the abdominal cavity during the 6th–10th week

of gestation. Omphaloceles are **located in the midline and are covered by a sac** consisting of peritoneum and the covering layers of the umbilical cord. In addition to bowel, the **sac may also contain** liver, stomach, bladder, and reproductive structures. The viscera tend to be functionally normal. Omphaloceles are often associated with additional anomalies. Specifically, 18%–24% of infants with omphalocele have associated **cardiac defects**, so an echocardiogram is warranted. **Pulmonary hypoplasia** is also common, often necessitating intubation and mechanical ventilation. **Syndromes** such as Beckwith-Weidemann, Donnai-Barrow, cloacal exstrophy, and to a lesser extent VACTERL defects and holoprosencephaly/anencephaly are also associated with omphaloceles.

The **underlying etiology of gastroschisis is unclear**, though retrospective data linking gastroschisis to maternal use of vasoactive substances and smoking suggest an in-utero vascular accident as the cause. Gastroschisis is located to the right of the umbilicus and is not covered by a sac, leaving the bowel exposed to the surrounding environment. While gastroschisis is not usually associated with additional anomalies, the exposed bowel can suffer substantial damage, resulting in impaired motility, impaired absorptive capacity, systemic inflammatory response, and ischemic bowel.

Treatment for both omphalocele and gastroschisis involve ample IV fluid resuscitation, gastric decompression, and application of warm saline-soaked gauze sponges to the exposed bowel. Temperature and fluid losses from the exposed bowel are significant in both defects, but more so with gastroschisis. In addition, plastic wrap is typically applied to the bowel to minimize evaporative loses. Surgical management is the definitive treatment and may be done as a primary closure or a staged closure. The surgical approach and timing of the operation vary by institution.

KEY FACTS

- Omphalocele and gastroschisis are the two most common abdominal wall defects in the neonate, resulting in herniation of the bowel outside of the abdominal cavity.
- Omphaloceles result as a failure of the bowel to return into the abdominal cavity during the 6th–10th week of gestation, are located in the midline, are covered by a sac consisting of peritoneum and the covering layers of the umbilical cord, and may also contain liver, stomach, bladder, and reproductive structures.
- Omphaloceles are associated with cardiac defects, pulmonary hypoplasia, syndromes such as Beckwith-Weidemann, Donnai-Barrow, cloacal exstrophy, and to a lesser extent VACTERL defects and holoprosencephaly/anencephaly.
- The underlying etiology of gastroschisis is unclear, though retrospective data linking gastroschisis to maternal use of vasoactive substances and smoking suggest an in-utero vascular accident as the cause.
- Treatment for both omphalocele and gastroschisis involve ample IV fluid resuscitation, gastric decompression, and application of warm saline-soaked gauze sponges to the exposed bowel.

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6. ANSWER: A

Beckwith-Wiedemann syndrome is a congenital disorder characterized by macroglossia, omphalocele, hemihyperplasia, and coarse facies (prominent eyes, infraorbital creases, prominent mandible, and anterior earlobe creases). Neonates with Beckwith-Weidemann syndrome may also have refractory hypoglycemia related to islet cell hyperplasia and hyperinsulinemia. In addition to the perioperative concerns related to the omphalocele, the anesthesiologists must also pay particular attention to the blood glucose levels intraoperatively and must be prepared for a difficult airway given the often encountered macroglossia.

Alagille syndrome is characterized by chronic cholestasis due to an underdeveloped biliary system, peripheral pulmonary artery stenosis, dysplastic kidneys, and abnormal facies. Omphalocele and hypoglycemia are not part of this syndrome.

Down syndrome (Trisomy 21) is not associated with omphalocele. Rather, the most common gastrointestinal problem in patients with Down syndrome is duodenal atresia. In utero, this may be suspected by polyhydramnios on ultrasound. Postnatally, the classic finding on abdominal radiograph is the "double-bubble sign," which is the result of a distended stomach and duodenum separated by the pyloric valve. Patients with duodenal atresia should be treated with full-stomach precautions, as they are high risk for aspiration during induction of anesthesia. In addition to duodenal atresia, patients with Down syndrome often present a host of challenges to the anesthesiologist such as (1) difficult airway due to small mouth opening, large tongue, and atlantoaxial instability; (2) subglottic stenosis; (3) propensity for bradycardia in response to sevoflurane inhalation induction; (4) cardiac anomalies; and (5) upper airway obstruction/sleep apnea, just to name a few.

Pierre Robin syndrome is characterized by a high-arching or cleft palate, micrognathia, and glossoptosis. Patients with Pierre Robin syndrome are notoriously difficult to intubate. Omphalocele is not associated with Pierre Robin syndrome.

KEY FACTS

- Beckwith-Wiedemann syndrome is a congenital disorder characterized by macroglossia, omphalocele, hemihyperplasia, and coarse facies.
- Alagille syndrome is characterized by chronic cholestasis due to an underdeveloped biliary system, peripheral pulmonary artery stenosis, dysplastic kidneys, and abnormal facies.
- The most common gastrointestinal problem in patients with Down syndrome is duodenal atresia.
- Pierre Robin syndrome is characterized by a high-arching or cleft palate, micrognathia, and glossoptosis.

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7. ANSWER: C

Around the sixth week of gestation, the midgut elongates rapidly, exceeding the anatomical constraints of the embryonic abdominal cavity. This results in a hairpin loop of small bowel that herniates outward through the yolk sac, with the superior mesenteric artery serving as its axis. Over the next several weeks, the bowel rotates a total of 270 degrees counterclockwise around the SMA axis (fig. 7.1). **The initial 180 degrees of rotation** occurs while the hairpin loop is still herniated, and the **last 90 degrees of rotation** occurs as the proximal small bowel is returning to the abdominal cavity. This rotation accounts for the normal anatomical position of the large bowel in relation to the small bowel. During rotation, the **duodenojejunal junction passes behind the superior mesenteric artery and becomes fixed in the left upper quadrant by the Ligament of Treitz**. The cecum passes anterior to the SMA and moves from the left side of the abdomen to the right side. **Defects in abdominal rotation**, such as malrotation and reverse rotation, can result in obstruction, volvulus, abdominal pain, and other symptoms. Intestinal malrotation occurs in 1:500 live births and affects males and females equally. **The majority (60%) present in the first month of life, while 20% present in the first year of life, and 20% present beyond the first year of life.**

KEY FACTS

- During rotation, the duodenojejunal junction passes behind the superior mesenteric artery and becomes fixed in the left upper quadrant by the Ligament of Treitz.
- Defects in abdominal rotation, such as malrotation and reverse rotation, can result in obstruction, volvulus, abdominal pain, and other symptoms.

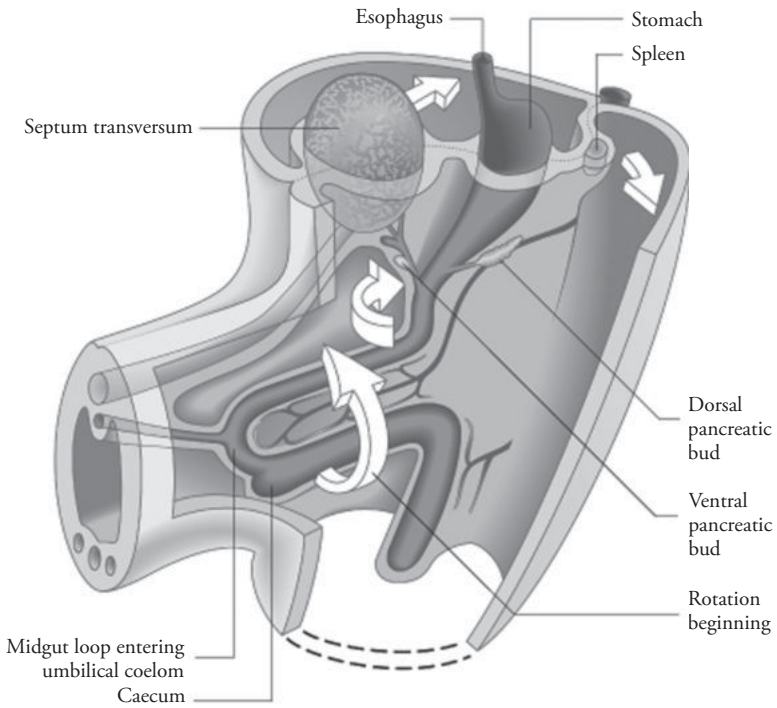

Figure 7.1 Development and Rotation of the Midgut

(From Standring S. *Gray's Anatomy: The Anatomical Basis of Clinical Practice*. 39th ed. Philadelphia, PA: Elsevier; 2005.)

- The majority (60%) of patients with intestinal malrotation present in the first month of life, while 20% present in the first year of life, and 20% present beyond the first year of life.

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Standring S. *Gray's Anatomy*. 39th ed. Philadelphia, PA: Churchill Livingstone; 2005.

8. ANSWER: A

Ladd's bands are fibrous bands of peritoneal tissue attaching the cecum to the abdominal wall. **They result from** malrotation and can cause duodenal obstruction as they course over the duodenum. The **definitive treatment** is surgical correction by the "Ladd's procedure," which involves de-rotation of twisted bowel, lysis of Ladd's bands, mobilization and straightening of the duodenum, mobilization of the cecum and appendectomy, and placement of the colon in the left abdomen. These patients **often present with** abdominal pain and bilious or nonbilious vomiting, depending on the location of the obstruction relative to the ampulla of Vater.

Patients with duodenal obstruction from a Ladd's band are likely to be **hypovolemic from persistent vomiting and poor PO intake, and they often will have electrolyte abnormalities related to the persistent vomiting**. In addition, they are at **high risk for aspiration,** given the small-bowel obstruction. Anesthetic management of these patients should focus on preoperative medical optimization with fluid and electrolyte repletion, and intraoperative rapid-sequence or modified-rapid sequence induction to minimize the risk of aspiration. Emptying the stomach prior to induction, as is commonly done for patients with pyloric stenosis, is a reasonable measure to minimize the aspiration risk.

KEY FACTS

- Ladd's bands (fig. 7.2) are fibrous bands of peritoneal tissue attaching the cecum to the abdominal wall that result from malrotation and can cause duodenal obstruction as they course over the duodenum.
- The definitive treatment is surgical correction by the "Ladd's procedure," which involves de-rotation of twisted bowel, lysis of Ladd's bands, mobilization and straightening of the duodenum, mobilization of the cecum and appendectomy, and placement of the colon in the left abdomen.
- These patients often present with abdominal pain and bilious or nonbilious vomiting, depending on the location of the obstruction relative to the ampulla of Vater.
- They are at high risk for aspiration, given the small-bowel obstruction.

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9. ANSWER: D

During normal embryonic development, the primitive gut tube elongates beyond the anatomical constraints of the abdominal cavity, resulting in a physiologic herniation of the primitive gut into the yolk stalk around the

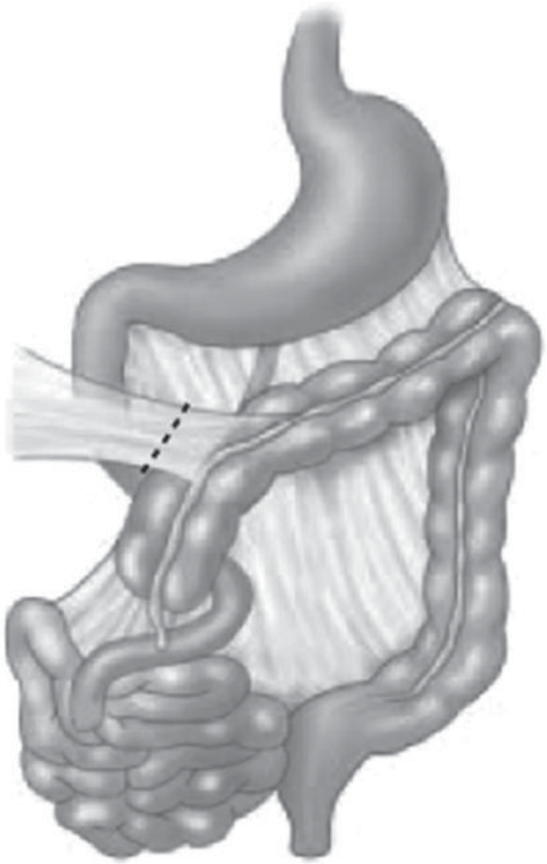

Figure 7.2 Ladd's Bands
(From Chung DH. Pediatric surgery. In: *Sabiston Textbook of Surgery*. 19th ed. Philadelphia, PA: Saunders Elsevier; 2001:1843–4.)

sixth week of gestation. Over the course of the next several weeks, this hairpin loop of bowel rotates 270 degrees counterclockwise (viewed anterior to posterior) around its functional axis—the superior mesenteric artery—and then retracts back into the abdominal cavity. This intestinal rotation is responsible for the normal orientation of the small and large bowel in the abdominal cavity, and it results in stabilization of the small bowel with a broad mesentery, extending from the ligament of Treitz in the left upper quadrant to the ileocecal valve in the right lower quadrant. This broad mesentery, which contains the superior mesenteric artery, anchors the small bowel and prevents volvulus.

In patients with intestinal malrotation, the mesenteric attachment of the small bowel is short and narrow, predisposing the small bowel to twist around its axis, resulting in a midgut volvulus. **Midgut volvulus typically presents** in the first month of life as acute-onset bilious vomiting, because the obstruction is located distal to the ampulla of Vater, where bile drains into the gut. It is a **surgical emergency** because the superior mesenteric artery becomes occluded, resulting in ischemic bowel. These infants may also present with hematochezia from intraluminal bleeding secondary to intestinal mucosal ischemia, and their clinical condition can rapidly deteriorate, leading to acidosis, shock, and even death. **Definitive treatment** is emergent surgical de-rotation of the volvulus and resection of nonviable ischemic bowel, as well as lysis of obstructing fibrous bands, division of the ligament of Treitz, straightening of the duodenum, and relocation of the bowel into a "nonrotated" position. This is known as the "Ladd's procedure." Patients requiring resection of significant portions of small bowel are at risk for short gut syndrome.

A quick diagnosis of midgut volvulus is critical. Plain radiographs are usually unhelpful in the diagnosis, as they often demonstrate a normal bowel gas pattern. The **diagnosis of midgut volvulus** is best made with an upper GI contrast study demonstrating an abnormal duodenum-jejunum flexure position, the proximal jejunum in the right abdomen, and a spiral "corkscrew" pattern of the distal duodenum and proximal jejunum. However, in infants who are unstable and clinically deteriorating, an exploratory laparotomy for suspicion of midgut volvulus may be warranted.

KEY FACTS

- In patients with intestinal malrotation, the mesenteric attachment of the small bowel is short and narrow, predisposing the small bowel to twist around its axis, resulting in a midgut volvulus.
- Midgut volvulus typically presents in the first month of life as acute-onset bilious vomiting, because the obstruction is located distal to the ampulla of Vater.
- It is a surgical emergency because the superior mesenteric artery becomes occluded, resulting in ischemic bowel.
- Definitive treatment is emergent surgical de-rotation of the volvulus and resection of nonviable ischemic bowel, as well as lysis of obstructing fibrous bands, division of the ligament of Treitz, straightening of the duodenum, and relocation of the bowel into a "nonrotated" position.
- The diagnosis of midgut volvulus is best made with an upper GI contrast study demonstrating an abnormal duodenum-jejunum flexure position, the proximal jejunum in the right abdomen, and a spiral "corkscrew" pattern of the distal duodenum and proximal jejunum.

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10. ANSWER: C

The Gross and Vogt classification systems are commonly used to describe the anatomy of tracheoesophageal fistulas (TEFs). Figure 7.3 provides illustrations of the various types of TEFs and their incidence.

The overall incidence of TEF is 1:2500–3000 live births. **Type C** TEF is the most common type, accounting for approximately 86%, while **Type A** accounts for 7%, **Type E** for 4%, **Type B** for 2%, and **Type D** for <1%. Type A is defined as isolated esophageal atresia, with no communication between the esophagus and the airway. Type B is esophageal atresia with a proximal TEF. Type C is esophageal atresia with a proximal blind pouch and a distal TEF. Type D is esophageal atresia with a TEF of both the proximal and distal segments. Type E is a TEF without esophageal atresia.

TEFs are often associated with other congenital anomalies. A review by Broemling and Campbell found the following **rates of associated anomalies**: cardiac 29%, gastrointestinal 14%, genitourinary 14%, musculoskeletal 10%, VACTERL 10%, respiratory 6%, and genetic 4%. Risk factors for increased perioperative morbidity/mortality include congenital heart disease, weight <2 kg, poor lung compliance, and a large pericarinal fistula.

Given the risk of gastric insufflation with positive pressure mask ventilation (making ventilation more difficult), many anesthesiologists favor **maintaining spontaneous ventilation** until the airway is secured distal to the fistula. Usually, patients undergo an inhalation induction with spontaneous ventilation. Prior to operative repair, surgeons often perform a rigid bronchoscopy to further characterize

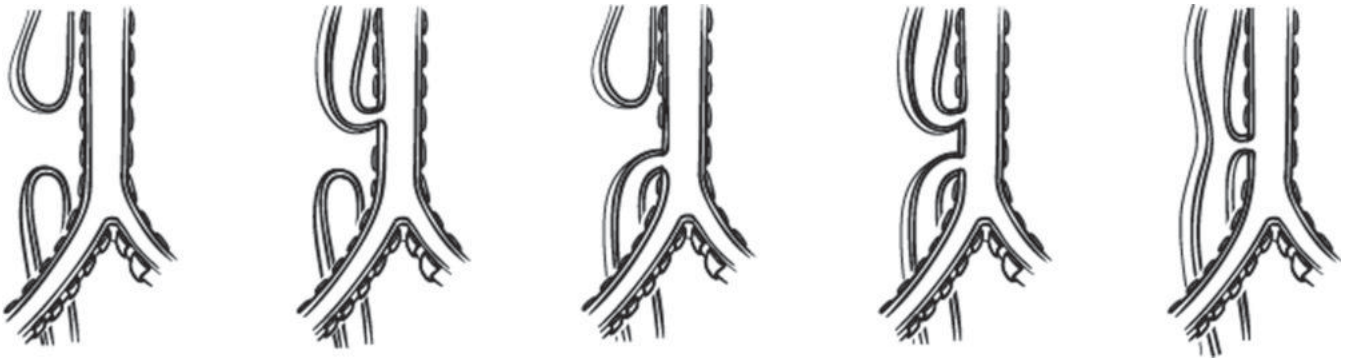

Figure 7.3 Classifications of tracheoesophageal fistula
(From Broemling N, Campbell F. Anesthetic management of congenital tracheoesophageal fistula. *Pediatr Anesth*. 2011;21:1092–9. Reprinted with permission.)

the size and location of the fistula. A propofol infusion is commonly used during this portion of the case to maintain spontaneous ventilation. Fistulas greater than 3 mm in diameter are associated with increased difficulty ventilating. The **most common method of definitive airway control** is placement of an endotracheal tube without a side-hole beyond the fistula. Confirmation of correct position via fiberoptic bronchoscopy is useful. Other strategies, such as occluding the fistula with a Fogarty balloon catheter, or one-lung ventilation have also been described.

KEY FACTS

- Type C TEF is the most common type, accounting for approximately 86%.
- TEFs are often associated with other congenital anomalies.
- Rates of associated anomalies: cardiac 29%, gastrointestinal 14%, genitourinary 14%, musculoskeletal 10%, VACTERL 10%, respiratory 6%, and genetic 4%.
- Many anesthesiologists favor maintaining spontaneous ventilation until the airway is secured distal to the fistula.
- The most common method of definitive airway control is placement of an endotracheal tube without a side-hole beyond the fistula.

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11. ANSWER: B

Esophageal atreasia (EA) is suspected in the antenatal period when fetal ultrasound demonstrates polyhydramnios and the absence of a gastric bubble. However, fetal ultrasound alone is unreliable to definitively make a prenatal diagnosis. **EA is usually diagnosed** within the first 24 hours of life, with symptoms including increased salivation and secretions from the mouth and nose, choking and cyanosis noted with early feeding, and the inability to pass an orogastric or nasogastric tube beyond 9–10 cm (the normal distance to the gastric cardia if the infant is 17 cm). A **chest radiograph** demonstrates air in the proximal esophageal pouch and will show the oro/naso-gastric tube to be coiled in the proximal pouch. The presence of air in the stomach raises suspicion for a coexisting tracheoesophageal fistula (TEF).

EA and TEF are frequently associated with other anomalies, including cardiovascular, musculoskeletal, genitourinary, mediastinal, and head/neck defects. EA/TEF are also seen in VACTERL syndrome (Vertebral, Anal, Cardiac, Tracheoesophageal fistula, Renal, and Limb anomalies) and CHARGE syndrome (Coloboma, Heart, Atresia of the choanae, Retarded growth, Genital Hypoplasia, Ear deformities).

Several prognostic classification systems exist, including the Waterson system, Spitz system, and Okamoto system. **Waterson** initially determined that weight, associated congenital anomalies, and presence of pneumonia were the biggest prognostic factors of perioperative mortality. The **Spitz** system removed pneumonia as a risk factor, given the overall low incidence of pneumonia. **Okamoto** further refined the prognostic system, noting that a weight of less than 2 kg and associated congenital heart disease were the two biggest risk factors of perioperative mortality.

KEY FACTS

- EA is suspected in the antenatal period when fetal ultrasound demonstrates polyhydramnios and the absence of a gastric bubble.

- EA is usually diagnosed within the first 24 hours of life, with symptoms including increased salivation and secretions from the mouth and nose, choking and cyanosis noted with early feeding, and the inability to pass an orogastric or nasogastric tube beyond 9–10 cm.
- EA and TEF are frequently associated with other anomalies, including cardiovascular, musculoskeletal, genitourinary, mediastinal, head/neck defects, VACTERL syndrome, and CHARGE syndrome.

REFERENCE

Broemling N, Campbell F. Anesthetic management of congenital tracheoesophageal fistula. *Pediatr Anesth*. 2011;21:1092–9.

12. ANSWER: C

This patient is facing an impending respiratory arrest in the setting of progressive abdominal distention. In the case described, positive-pressure ventilation via bag mask resulted in progressive gastric insufflation through the existing fistula. In turn, this leads to poor pulmonary compliance, making ventilation difficult. Additionally, the increase intra-abdominal pressure leads to decreased venous return and poor cardiac filling. Continual gastric insufflation also places the patient at risk for gastric rupture and tension pneumoperitoneum.

The most appropriate next step is emergent needle decompression of the stomach to relieve the elevated intragastric pressure. Endotracheal intubation with the cuff of the endotracheal tube beyond the tracheoesophageal fistula is indicated, but even if achieved in an expedient manner, ventilation may still prove difficult without decompression of the stomach. In anticipation of bradycardia secondary to oxygen desaturation, many pediatric anesthesiologists would have a low threshold to administer atropine early in this setting as a temporizing measure. However, because atropine does not address the underlying cause of inadequate ventilation, it is not the *most* appropriate next step. Beginning cardiopulmonary resuscitation should never be delayed in cardiac arrest; however, the question stem does not indicate the patient is in cardiac arrest.

Traditionally, anesthetic **management in TEF** has focused on avoiding or minimizing positive pressure ventilation until the airway is secured distal to the fistula. Toward this end, most pediatric anesthesiologists utilize an **inhalation induction**. Prior to surgical intervention, **rigid bronchoscopy** is commonly performed to evaluate the airway anatomy. In a study of 113 neonates, 67% had TEF >1 cm above the carina, 22% <1 cm above the carina, and 11% below the carina. Studies suggest that **fistulas <3 mm in diameter** do not present ventilation challenges. A **propofol infusion** is often used to maintain spontaneous ventilation during rigid bronchoscopy. Once the location and size of the tracheoesophageal fistula is characterized by rigid bronchoscopy, the airway is secured by endotracheal intubation. Usually, a cuffed endotracheal tube without a Murphy's eye (side hole) is used, and it is positioned with the tip above the carina and the cuff below the fistula. Correct endotracheal tube position is critical, and it is often confirmed by auscultation and clinical exam. The endotracheal tube may be intentionally advanced into the right mainstem bronchus and slowly withdrawn until breath sounds are heard in the left chest, without evidence of gastric distention. However, the use of a flexible fiberoptic bronchoscope to guide and confirm the position of the endotracheal tube is recommended, as the risk of an incorrectly positioned endotracheal tube can be catastrophic.

KEY FACTS

- Traditionally, anesthetic management in TEF has focused on avoiding or minimizing positive pressure ventilation until the airway is secured distal to the fistula.
- Most pediatric anesthesiologists utilize an inhalation induction in patients with a TEF.
- Prior to surgical intervention, rigid bronchoscopy is commonly performed to evaluate the airway anatomy.
- Studies suggest that fistulas <3 mm in diameter do not present ventilation challenges.
- A propofol infusion is often used to maintain spontaneous ventilation during rigid bronchoscopy.
- The endotracheal tube may be intentionally advanced into the right mainstem bronchus, and slowly withdrawn until breath sounds are heard in the left chest, without evidence of gastric distention.

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13. ANSWER: B

Pyloric stenosis is a condition in which hypertrophy of the muscularis layer of the pylorus results in obstruction of gastric emptying. Pyloric stenosis **typically presents** in the second to sixth week of life as nonbilious, projectile vomiting. Pyloric stenosis affects **males more than females**, and for unclear reasons commonly affects the **first-born male**. Exam may be notable for a **palpable olive-shaped mass** in the epigastrium and visible peristalsis. Infants are typically

hungry shortly after vomiting ("hungry vomiter"). In addition to history and physical exam, ultrasound is a low cost, noninvasive, reliable method of diagnosis.

Pyloric stenosis is a medical (*not surgical*) emergency. The **classic metabolic derangement** described in pyloric stenosis is a hypokalemic, hypochloremic, metabolic alkalosis due to the loss of gastric juices containing sodium, potassium, chloride, and hydrochloric acid. The initial renal response to the metabolic alkalosis is urinary excretion of bicarbonate, resulting in alkaline urine. However, as dehydration sets in, the primary renal response shifts away from maintenance of pH and toward maintenance of intravascular volume status by resorption of water and sodium. This occurs by three main mechanisms: (1) aldosterone levels rise, which increases sodium resorption in the distal tubule via a Na-K exchange channel (consequently worsening the hypokalemia); (2) sodium exchange channels in the distal tube cause reabsorption of sodium in exchange for hydrogen ions, resulting in paradoxical aciduria (consequently worsening the metabolic alkalosis); and (3) antidiuretic hormone increases, causing water absorption from the collecting ducts. While **metabolic alkalosis is the classic acid-base abnormality in the early stages of pyloric stenosis**, profound dehydration from ongoing vomiting and poor oral intake can lead to hypovolemic shock resulting in poor tissue perfusion and lactic acidosis. **Thus, the presence of acidosis in a patient with pyloric stenosis is an indication that the patient is severely underresuscitated.**

KEY FACTS

- Pyloric stenosis is a condition in which hypertrophy of the muscularis layer of the pylorus results in obstruction of gastric emptying.
- Pyloric stenosis typically presents in the second to sixth week of life as nonbilious, projectile vomiting.
- Pyloric stenosis affects males more than females, and for unclear reasons commonly affects the first-born male.
- Exam may be notable for a palpable olive-shaped mass in the epigastrium and visible peristalsis.
- Pyloric stenosis is a medical (*not surgical*) emergency.
- The classic metabolic derangement described in pyloric stenosis is a hypokalemic, hypochloremic, metabolic alkalosis due to the loss of gastric juices containing sodium, potassium, chloride, and hydrochloric acid.
- Thus, the presence of acidosis in a patient with pyloric stenosis is an indication that the patient is severely underresuscitated.

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14. ANSWER: B

Infants with **pyloric stenosis** should be adequately resuscitated prior to surgical management, paying particular attention to their intravascular volume status and electrolyte abnormalities. **Clinical findings suggestive of hypovolemia** in this population include dry mucous membranes, decreased skin turgor, poor capillary refill, sunken fontanelles and eyes, poor urine output, irritability and lethargy, tachycardia, and hypotension. An intravenous catheter should be placed upon admission, and fluid resuscitation with crystalloid should be initiated. Each institution has its own practice patterns, but usually infants will be **resuscitated with** a bolus of 15–20 cc/kg normal saline followed by an infusion of D_5 ½ normal saline at 1.5–2 times the maintenance infusion rate. A glucose bolus may be required if the infant is hypoglycemic. Once the patient has adequate urine output, potassium chloride (10–20 mEq/L) is often added to the infusion fluids. Electrolytes should be followed closely throughout the resuscitation.

Classically, **patients with pyloric stenosis have a hypokalemic, hypochloremic metabolic alkalosis.** However, **they may present with a lactic acidosis if they are in hypovolemic shock.** Patients are deemed optimized for surgery when they are hemodynamically stable, euvolemic on examination, and their electrolyte derangements have been corrected. While there are no universally accepted guidelines for electrolyte values reflective of adequate resuscitation, **it is generally accepted that a K >3 mEq/L, Cl > 90 mEq/L, and HCO_3 < 30 mEq/L are necessary before proceeding to the operating room.** Answer A is reflective of a patient with hyperaldosteronism leading to hypernatremia and hypokalemia. Regardless, a patient with a K < 3 mEq/L is not optimized for this procedure. Answer C shows typical lab values that may be encountered on admission, reflecting a hypochloremic, hypokalemic metabolic alkalosis. Answer D is consistent with a metabolic acidosis with elevated anion gap, as would be seen in severely underresuscitated pyloric stenosis with hypovlemic shock.

Pediatric anesthesiologists should be aware that **postoperative apnea has been reported in patients with pyloric stenosis and is believed to be caused by elevated cerebrospinal fluid pH**. Despite the correction of serum electrolyte abnormalities, the cerebrospinal fluid may remain alkalotic in the postoperative period, decreasing the drive to breathe through central CO_2 chemoreceptors. For this reason, it is also important to avoid hyperventilation intraoperatively.

KEY FACTS

- Infants with pyloric stenosis should be adequately resuscitated prior to surgical management, paying particular attention to their intravascular volume status and electrolyte abnormalities.
- Clinical findings suggestive of hypovolemia in this population include dry mucous membranes, decreased skin turgor, poor capillary refill, sunken fontanelles and eyes, poor urine output, irritability and lethargy, tachycardia, and hypotension.
- Usually infants will be resuscitated with a bolus of 15–20 cc/kg normal saline followed by an infusion of D5 ½ normal saline at 1.5–2 times the maintenance infusion rate.
- Patients with pyloric stenosis have a hypokalemic, hypochloremic metabolic alkalosis. It is recommended to correct electrolytes to K >3 mEq/L, Cl >90 mEq/L, and HCO_3 <30 mEq/L before proceeding to the operating room.
- They may present with a lactic acidosis if they are in hypovolemic shock.
- Postoperative apnea has been reported in patients with pyloric stenosis and is believed to be caused by elevated cerebrospinal fluid pH.

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15. ANSWER: A

Infants with **pyloric stenosis have impaired gastric emptying and large gastric fluid volumes**, putting them at risk for vomiting and aspiration during induction of anesthesia. In a prospective study evaluating the gastric fluid volume of 75 infants undergoing pyloromyotomy for pyloric stenosis, Cook-Sather et al. demonstrated that the **average total gastric fluid volume was 5.0 cc/kg**, which is 10 times more than otherwise healthy, fasted infants for elective surgery. In 15 of those patients, they used upper gastrointestinal endoscopy after suctioning to measure the residual volume of gastric contents. They found that after two to three passes of a large-bore multiorifice gastric tube (14 French) in the supine position awake, the average residual gastric volume was 0.8 cc/kg. In other words, **emptying the stomach in this manner prior to induction resulted in recovery of 96% of the gastric contents**. In addition, they also found that the presence of a preoperative nasogastric tube (≤10 French) does not reliably reduce gastric fluid volume. Due to this finding, some institutions no longer advocate placing nasogastric tubes routinely in patients admitted for pyloric stenosis. It is recommended **that in situ nasogastric tubes be aspirated and removed prior to induction**, and the stomach suctioned awake two to three times with a large-bore multiorifice catheter. Proper suction catheter placement should be verified by insertion to a measured topographic distance, observation of tenting the epigastrium, and aspiration of gastric contents with wall suction. Some pediatric anesthesiologists advocate for **suctioning the stomach in supine, right lateral decubitus, and left lateral decubitus position** to maximize gastric emptying. Contrary to what one might expect, this study found that fasting intervals and evaluation with a barium swallow study did not affect the gastric fluid volumes.

KEY FACTS

- Infants with pyloric stenosis have impaired gastric emptying and large gastric fluid volumes, putting them at risk for vomiting and aspiration during induction of anesthesia.
- The average total gastric fluid volume was 5.0 cc/kg, which is 10 times more than otherwise healthy.
- Emptying the stomach in this manner prior to induction results in recovery of 96% of the gastric contents.
- In situ nasogastric tubes should be aspirated and removed prior to induction.
- Some pediatric anesthesiologists advocate for suctioning the stomach in supine, right lateral decubitus, and left lateral decubitus position to maximize gastric emptying.

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16. ANSWER: D

Inguinal hernias occur due to the congenital failure of processus vaginalis/Canal of Nuck to obliterate. They **are more common in males**. **Right-sided (60%) hernias are more common** than left (30%), with bilateral hernias present in 10% of cases.

Risk factors are prematurity, family history (siblings), connective tissue disorders (Ehler-Danlos syndrome), cystic fibrosis, increased intra-abdominal pressure (ventriculo-peritoneal shunt, ascites), abdominal wall

defects (omphalocele, gastroschisis), and urological conditions (exstrophy of bladder, cryptorchidism).

Premature babies with inguinal hernias are more prone to incarceration; therefore, inguinal hernias should be repaired as soon as they are medically stable. Irreducible inguinal hernias typically present as a groin lump that can be tender and firm, an irritable or fussy baby, a history of vomiting, and erythema of the affected area. If irreducible, a diagnosis of incarcerated or obstructed hernia is made. **Emergency surgery** is required in this case, **given the risk of bowel ischemia or gonadal infarction**. If it is reducible, surgery may be delayed for a few hours until the bowel and tissue edema subsides, or it can be scheduled electively.

KEY FACTS

- Inguinal hernias occur due to the congenital failure of processus vaginalis/Canal of Nuck to obliterate.
- They are more common in males. Right-sided (60%) hernias are more common than left (30%), with bilateral hernias present in 10% of cases.
- Risk factors are prematurity, family history, connective tissue disorders, cystic fibrosis, increased intra-abdominal pressure, abdominal wall defects, and urological conditions.
- Premature babies with inguinal hernias are more prone to incarceration; therefore, inguinal hernias should be repaired as soon as they are medically stable.
- Emergency surgery is required for irreducible inguinal hernias, given the risk of bowel ischemia or gonadal infarction.

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17. ANSWER: C

Premature infants less than 50–60 weeks postconceptual age are at risk of obstructive and central apnea for up to 24 hours postoperatively. Term infants can experience apneic spells following general anesthesia, but much more rarely. The **greatest risks for postoperative, postanesthesia apnea** include a low gestational age at birth, anemia (<30%), hypothermia, sepsis, and neurological abnormalities. **Intravenous caffeine (10 mg/kg) or aminophylline** may decrease the risk of postanesthetic apnea.

For **spinal anesthesia** involving inguinal hernia repair, an intrathecal injection of hyperbaric tetracaine (equal volumes of 1% tetracaine and 10% dextrose) in a dose 1 mg/kg or isobaric bupivacaine (1 mg/kg) with 0.01 mL/kg epinephrine (1:100,000) through a 22-gauge spinal needle provides surgical anesthesia for 1–2 hours. Smaller doses can be used for surgery on lower extremities. The addition of **clonidine** also **prolongs the duration but may cause hypotension and apnea in larger doses**. Epidural anesthesia via the lumbar or caudal route has the advantage of ease and placement of a catheter to prolong the duration of block.

Total spinal anesthesia is manifested by apnea and no change in systemic blood pressure. It typically occurs when the lower part of the body is elevated above the head; for example, while placing the electrocautery pad on the back. Ideally, the entire body should be elevated horizontally to place the pad. Other factors increasing the risk of total spinal anesthesia include the rate and force of injection or unintended barbotage. Management of a total spinal anesthetic consists of assisted or controlled ventilation until the return of spontaneous respiration.

One of the **advantages cited for spinal anesthesia is the decrease in incidence of postoperative apnea compared to general anesthesia**. Welborn and colleagues compared the incidence of postoperative apnea after general anesthesia compared to spinal anesthesia and spinal anesthesia with ketamine supplementation. No apnea was reported in the spinal group, but the incidence of apnea was 89% in the spinal group receiving supplemental ketamine and 31% in the general anesthesia group.

KEY FACTS

- Premature infants less than 50–60 weeks postconceptual age are at risk of obstructive and central apnea for up to 24 hours postoperatively.
- Term infants can experience apneic spells following general anesthesia, but much more rarely.
- The greatest risks for postoperative, postanesthesia apnea include a low gestational age at birth, anemia (<30%), hypothermia, sepsis, and neurological abnormalities.
- Intravenous caffeine (10 mg/kg) or aminophylline may decrease the risk of postanesthetic apnea.
- One of the advantages cited for spinal anesthesia is the decrease in incidence of postoperative apnea compared to general anesthesia.

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18. ANSWER: C

Prune belly syndrome, or Eagle–Barrett syndrome, is more common in males (>90%) than females. The **syndrome is characterized** by deficient abdominal wall, hypotonia, pathophysiological dilatation of the urinary system, and bilateral cryptorchidism. It can also be **associated with pulmonary hypoplasia, cardiovascular involvement (ventricular septal defect, patent ductus arteriosus, tetralogy of Fallot), gastrointestinal involvement (malrotation, cloacal anomaly), musculoskeletal involvement (scoliosis, club feet, congenital dislocation of hip), Trisomy 18, and Trisomy 21**. The postnatal course is dictated by comorbidities like prematurity. Severe renal dysfunction with pulmonary hypoplasia results in 100% mortality soon after birth.

Pathogenesis theories include an obstructed urethra and mesodermal developmental defect. Sonographic features include bilateral hydroureter and hydronephrosis, a distended thin-walled bladder, and oligohydramnios. Oligohydramnios implies poor urine output and renal dysfunction.

Management aims to preserve renal function and prevent urinary infection. The abdominal distension in utero results in weak rectus muscles contributing to limited expiration, limited ability to cough (prone for aspiration, pneumonia), and inability to increase intra-abdominal pressure during defecation, resulting in constipation.

These children require **orchidopexy at an early age to preserve testicular function, various urological surgeries to preserve renal function, and abdominal reconstruction to increase tone**.

KEY FACTS

- Prune belly syndrome, or Eagle–Barrett syndrome, is more common in males (>90%) than females.
- The syndrome is characterized by deficient abdominal wall, hypotonia, pathophysiological dilatation of the urinary system and bilateral cryptorchidism.
- It can also be associated with pulmonary hypoplasia, cardiovascular involvement, gastrointestinal involvement, musculoskeletal involvement, Trisomy 18, and Trisomy 21.
- Management aims to preserve renal function and prevent urinary infection.

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19. ANSWER: B

Duplication cysts of the gastrointestinal tract are uncommon congenital lesions with an incidence of 1:4500. They can occur anywhere from mouth to anus. The **most common affected site is the ileum.** The cysts are located on the mesenteric border and may or may not have communication with the bowel. The cysts are spherical in most cases, but also occur in tubular form. They have a mucosal lining and are usually filled with fluid. Gastric mucosa is found in almost 50% of the cysts.

Presentation depends on the age of the patient, size, and location of cysts. **Neonates and infants usually present with abdominal distension and vomiting (volvulus, intussusception). Older children present with pain in the abdomen and vomiting.** Esophageal cysts may cause dysphagia or respiratory issues. Prenatal ultrasound helps in diagnosis of the cyst and early treatment before symptoms appear. Ultrasound, CT scan, and MRI are used in diagnosis. Management involves resection of the cyst and occasionally the bowel.

KEY FACTS

- Duplication cysts of the gastrointestinal tract are uncommon congenital lesions with an incidence of 1:4500.
- They can occur anywhere from mouth to anus, and the most common affected site is the ileum.
- The cysts are located on the mesenteric border and may or may not have communication with the bowel.
- Neonates and infants usually present with abdominal distension and vomiting (volvulus, intussusception), while older children present with pain in the abdomen and vomiting.

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20. ANSWER: C

Hirschsprung disease is an idiopathic congenital disorder of colorectal motility, characterized by the absence

of ganglion cells in the myenteric plexus and Auerbach's plexus of the rectum and part of the colon. **Hirschsprung disease is more common in males and typically presents as failure to pass meconium at birth and constipation in infants and toddlers.**

The **diagnosis is usually made by a contrast enema, rectal biopsy, and in some centers by anorectal manometric study. Anorectal manometry** is done in children older than 2 weeks. An inflated balloon in the rectum normally causes a reflex relaxation of the internal anal sphincter. In Hirschsprung disease, the sphincter does not relax and the measured pressure at the sphincter may actually increase in response to the balloon inflation of the rectum.

Contrast enema is performed with barium or water-soluble contrast agent. The classic picture is dilated proximal colon that transitions rapidly to a normal or narrow-caliber rectum. The transition zone may not always be appreciated. Radiograph taken 24 hours after contrast enema strongly suggests Hirschsprung disease if there is incomplete evacuation of barium from the rectum. In a normal individual, the diameter of the rectum is larger than the sigmoid and descending colon.

Rectal biopsy is performed in most cases as a suction biopsy and in some cases ass open rectal biopsy. Suction rectal biopsy has to be performed about 2–3 cm above the dentate line because the most distal part of rectum (anal canal) is normally aganglionic. The biopsy should include the submucosal tissue. **Hirschsprung disease is confirmed if there are no ganglionic cells in the submucosal plexus**. Presence of hypertrophied nerve trunks with aganglionic cells increases the accuracy. Increased amount of acetylcholinesterase shown by staining also confirms the diagnosis.

The definitive treatment is surgical resection of the aganglionic segment of bowel and replacement with the normally innervated proximal bowel.

KEY FACTS

- Hirschsprung disease is an idiopathic congenital disorder of colorectal motility, characterized by the absence of ganglion cells in the myenteric plexus and Auerbach's plexus of the rectum and part of the colon.
- Hirschsprung disease is more common in males and typically presents as failure to pass meconium at birth and constipation in infants and toddlers.
- The diagnosis is usually made by a contrast enema, rectal biopsy, and in some centers by anorectal manometric study, and anorectal manometry is done in children older than 2 weeks.
- Hirschsprung disease is confirmed if there are no ganglionic cells in the submucosal plexus.
- The definitive treatment is surgical resection of the ganglionic segment of bowel and replacement with the normally innervated proximal bowel.

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21. ANSWER: A

Ulcerative colitis is characterized by mucosal inflammation limited to the colon. The rectum is involved in 95% of patients. **The most common presentation is rectal bleeding associated with abdominal pain and diarrhea.** The **inflammation is continuous,** starting in the rectum and extending variably in the colon.

Crohn's disease is characterized by transmural inflammation and is not limited to the colon. The inflammation can extend from mouth to anus, and the lesions are patchy. The terminal ileum is the most common site of involvement. **Patients usually present with abdominal pain, poor appetite, weight loss, and diarrhea.** Perianal disease is much more common and can present as abscesses, fistulas, and fissures.

Extraintestinal manifestations are common in both ulcerative colitis and Crohn's disease. The cutaneous manifestations include erythema nodosum (more in Crohn's disease) and pyoderma gangrenosum. Joint manifestation includes arthralgia or arthritis. Ocular manifestations include episcleritis and anterior uveitis. Oral aphthous stomatitis is more common in Crohn's disease than ulcerative colitis. Other manifestations include osteoporosis, pancreatitis, primary sclerosing cholangitis, nephrolithiasis, and thrombosis.

Diagnosis is made by upper endoscopy, colonoscopy, and tissue histology. The main goals of treatment are induction and maintenance of remission. Treatment prior to 2000 was mainly with steroids. Today, treatment includes medications like aminosalicylates (sulfasalazine), immunomodulators (methotrexate), and biologics (infliximab). Other treatment modalities are nutrition therapy, antibiotics, and surgery.

KEY FACTS

- Ulcerative colitis is characterized by mucosal inflammation limited to the colon, and the rectum is involved in 95% of patients.
- The most common presentation is rectal bleeding associated with abdominal pain and diarrhea.
- The inflammation is continuous, starting in the rectum and extending variably in the colon.
- Crohn disease is characterized by transmural inflammation and is not limited to the colon.
- The inflammation can extend from mouth to anus, and the lesions are patchy.

- The terminal ileum is the most common site of involvement.
- Patients usually present with abdominal pain, poor appetite, weight loss, and diarrhea.
- Perianal disease is much more common and can present as abscesses, fistulas, and fissures.

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22. ANSWER: D

According to the National Poison System Data, the percentage of **ingestion of button batteries resulting in major or fatal outcome has increased 6.7-fold** from 1985 to 2009. There is an increase in ingestion of 20 mm and 25 mm lithium batteries due to the increased use and availability. **Ingestion of a lithium battery results in the following**:

1. **Electrical discharge**: electric current flows from the negative pole of the battery through surrounding tissue, causing local hydrolysis of tissues, production of hydroxide at the negative pole, and corrosive tissue injury.
2. **Leakage of battery contents**: seal of the battery may be compromised by stomach acid, leading to leakage of alkaline hydroxides.
3. **Pressure necrosis**: compression of the mucosa by the battery causes tissue injury over time.

It is **not necessary** to obtain mercury levels in blood or urine after battery ingestion because batteries with mercuric oxide have not been produced since 1996. Cylindrical batteries usually pass easily along the gastrointestinal tract. They should be removed endoscopically if lodged in the esophagus or for more than 48 hours in the stomach.

Button batteries cause more tissue injury. The 20 mm size battery has higher capacitance and voltage. Even a **dead battery** can still generate electricity. Anterior-posterior and lateral radiograph of neck, chest, and abdomen should be taken if history is unreliable. **Endoscopic removal** is advised for battery lodged in the esophagus as soon as possible. If the button battery is beyond the esophagus and patient is asymptomatic, the patient can be observed at home. Stools can be checked to verify that the battery has passed; repeat radiographs can be obtained in 10 to 14 days if the battery has not yet passed. **The battery should be removed** from the stomach or beyond if a magnet was also ingested, the patient develops GI symptoms, the patient is less than 6 years and ingests a battery 15 mm or larger, or the battery remains in the stomach for 4 days or more. **Necrosis of gastric mucosa** may be seen within 4 hours of battery ingestion and hence early removal is indicated. After removal, patient should be observed for **complications** like tracheoesophageal fistula, aortoesophageal fistula, bleeding, mediastinitis, perforations, and respiratory problems.

KEY FACTS

- The percentage of ingestion of button batteries resulting in major or fatal outcome has increased 6.7-fold from 1985 to 2009.
- Ingestion of a lithium battery can result in pressure necrosis and injury from electrical discharge and leakage of battery contents.
- Button batteries cause more tissue injury.
- Even a dead battery can still generate electricity.
- Endoscopic removal is advised for battery lodged in the esophagus as soon as possible.
- Complications that may occur include tracheoesophageal fistula, aortoesophageal fistula, bleeding, mediastinitis, perforations, and respiratory problems.

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23. ANSWER: B

Necrotizing enterocolitis (NEC) is usually seen in premature infants and results from bowel necrosis. Clinical suspicion of **necrotizing enterocolitis (NEC)** warrants both radiological and laboratory investigations to confirm diagnosis and aid in management. Clinical signs and symptoms may be nonspecific.

Plain abdominal supine anterior-posterior films may show nonspecific signs like diffuse distension and asymmetrical bowel pattern. Pneumatosis intestinalis and portal venous gas are pathognomonic signs of NEC. A left lateral decubitus or lateral film in the supine position is indicated for detection of free air from bowel perforation. Serial films are indicated to assess progress of the condition.

Laboratory findings such as thrombocytopenia, neutropenia, coagulopathy, and persistent metabolic acidosis are found with impending or severe NEC. Serial hematological and metabolic investigations are conducted to assess progression and aid in management. A sudden increase in the C-reactive protein points to severe inflammatory condition/NEC.

Abdominal wall erythema with abdominal distension is an ominous sign of severe inflammation.

KEY FACTS

- NEC is usually seen in premature infants and results from bowel necrosis.
- In a patient with NEC, plain abdominal supine anterior-posterior films may show nonspecific signs like diffuse distension and asymmetrical bowel pattern.
- Pneumatosis intestinalis and portal venous gas are pathognomonic signs of NEC.
- Laboratory findings such as thrombocytopenia, neutropenia, coagulopathy, and persistent metabolic acidosis are found with impending or severe NEC.

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24. ANSWER: A

The **absolute indications for surgery** in a patient with NEC are pneumoperitoneum, clinical deterioration in spite of maximal medical management, and abdominal mass with persistent intestinal obstruction (persistent dilated bowel loops that looks dilated and remains unchanged on sequential films).

The **relative indications for surgery** in a patient with NEC are portal venous gas and increased abdominal tenderness, distension, and/or discoloration.

The **principle of surgery** in a patient with necrotizing enterocolitis is to remove necrotic intestine, control intra-abdominal sepsis, and preserve as much intestine as possible.

Surgical options depend on the condition of the patient and surgical preferences. The traditional approach is to excise nonviable bowel and exteriorize until healing occurs. The continuity of the bowel is achieved at a later stage. Some surgeons do the anastomosis at the same setting depending on the condition. If the disease is multifocal, multiple resection and anastomosis are performed or a "clip and drop" approach is done followed by a second look laparotomy. Care may be withdrawn if the involvement is extensive on laparotomy.

KEY FACTS

- The absolute indications for surgery are pneumoperitoneum, clinical deterioration in spite of maximal medical management, and abdominal mass with persistent intestinal obstruction.
- The relative indications for surgery are portal venous gas and increased abdominal tenderness, distension, and/or discoloration.
- The principle of surgery in a patient with necrotizing enterocolitis is to remove necrotic intestine, control intra-abdominal sepsis, and preserve as much intestine as possible.

REFERENCES

Hall NJ, Eaton S, Pierro A. Necrotizing enterocolitis: prevention, treatment and outcome. *J Ped Surg*. 2013;48:2359–67.

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25. ANSWER: C

Acute appendicitis has a peak incidence between the ages of 12–18 years. It is rare in children <5 years of age and is slightly more common in males and whites in the United States. A seasonal peak incidence is seen in autumn and spring.

Perforation is more common in the younger age group with an incidence of 82% in children <5 years and nearly 100% in infants.

Symptoms vary depending on position of appendix, time of presentation, age of patient, and progression of disease. **Abdominal pain is consistent and is usually the primary symptom**. The other symptoms consist of malaise, anorexia, vomiting, diarrhea, and urinary symptoms. Retrocecal appendicitis may mimic a septic hip.

Surgery is indicated in acute appendicitis. Prior to surgery patient should receive hydration, pain control, and antibiotics. If perforation is identified at the time of diagnosis, surgery is less urgent. In these cases proper preoperative management is more critical than urgent surgery.

Stabilization of patient with hydration and antibiotics should be a priority. If indicated, percutaneous placement of drainage catheters is performed for fluid collection/abscess.

KEY FACTS

- Acute appendicitis has a peak incidence between the ages of 12–18 years, with a seasonal peak incidence in the autumn and spring.
- Perforation is more common in the younger age group with an incidence of 82% in children <5 years and nearly 100% in infants.
- Abdominal pain is consistent and is usually the primary symptom. The other symptoms consist of malaise,

anorexia, vomiting, diarrhea, and urinary symptoms; retrocecal appendicitis may mimic a septic hip.

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26. ANSWER: B

Juvenile polyp is the most common intestinal polyp found in childhood. It usually occurs during the first decade of life with a peak incidence between the ages of 2 and 5 years. It is rare in the first 12 months of life.

The typical presentation is episodic bouts of rectal bleed not associated with any abdominal discomfort or significant anemia.

No polyps are discovered in the upper gastrointestinal tract during endoscopy. During colonoscopy almost **53% of the polyps are located in the rectosigmoid area** with the remainder equally distributed in the rest of the colon. The polyps are removed by using a snare and eletrocautery. Removed polyps are sent for histology. Repeat colonoscopy is indicated if rectal bleeding recurs.

Juvenile polyp is a benign nonneoplastic tissue growth. There is no association with any genetic disorder or with a family history of polyps.

KEY FACTS

- Juvenile polyp is the most common intestinal polyp found in childhood.
- The typical presentation is episodic bouts of rectal bleed not associated with any abdominal discomfort or significant anemia.
- 53% of the polyps are located in the rectosigmoid area with the remainder equally distributed in the rest of the colon.
- Juvenile polyp is a benign nonneoplastic tissue growth.

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27. ANSWER: A

Juvenile polyposis syndrome is a rare syndrome associated with multiple polyps throughout the intestinal tract with majority in the colon. It is transmitted as an **autosomal dominant** trait. Approximately 85% of patients with juvenile polyposis report a family history of polyps.

The age at presentation is the first and second decade of life. The presenting symptoms are more severe than juvenile polyps. **The presentation includes rectal bleeding, abdominal pain, anemia, mucus in stools, diarrhea, prolapse of polyp or rectum, and also hypokalemia and hypoalbuminemia due to protein-losing enteropathy.**

Histological features of juvenile polyposis are not distinguishable from juvenile polyps.

Patient with juvenile polyposis are at risk of developing **gastrointestinal tumors with a lifetime risk near 55%**.

Endoscopy and colonoscopy are conducted initially to identify and remove all polyps. **Screening colonoscopy is indicated every 1 to 3 years,** depending on the number of polyps found. Upper endoscopy is conducted every 3 years. Family members should be screened also. **In severe cases with numerous polyps**, total colectomy or gastrectomy may be needed. Polyps should be removed during frequent upper endoscopies and colonoscopies in affected patients.

Peutz-Jeghers syndrome is the presence of gastrointestinal polyps with abnormal pigmentation of skin and oral mucosa.

KEY FACTS

- Juvenile polyposis syndrome is a rare syndrome associated with multiple polyps throughout the intestinal tract with the majority in the colon.
- Juvenile polyposis syndrome is transmitted as an autosomal dominant trait, and approximately 85% of patients with juvenile polyposis report a family history of polyps.
- The presentation includes rectal bleeding, abdominal pain, anemia, mucus in stools, diarrhea, prolapse of polyp or rectum, and also hypokalemia and hypoalbuminemia due to protein-losing enteropathy.
- Patients with juvenile polyposis are at risk of developing gastrointestinal tumors with a lifetime risk near 55%.

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28. ANSWER: D

Celiac disease (CD) is an enteropathy due to ingestion of gluten. Clinical presentation includes both intestinal and extraintestinal manifestations. The **typical presentation of pediatric celiac disease** includes failure to thrive, diarrhea, constipation, vomiting, distension of abdomen, and irritability. The **extraintestinal manifestations** are dermatitis herpetiformis, anemia, aphthous stomatitis, delayed growth/puberty, dental enamel defects, osteopenia, osteoporosis, and abnormal liver function tests.

Celiac crisis is a rare medical emergency, typically seen in toddlers. It presents as explosive, watery diarrhea with marked abdominal distension leading to dehydration, hypotension, electrolyte imbalance, and lethargy. Celiac crisis typically responds to corticosteroids in a few days.

Dermatitis herpetiformis is the most common skin lesion in CD, but it is not as common in children. It presents as chronic, pruritic, papular/vesicular rash.

CD is **commonly associated with type 1 diabetes, Hashimoto thyroiditis, Down syndrome, Turner syndrome, Williams syndrome, and a positive family history of CD**. The less common associations are with juvenile arthritis, alopecia areata, vitiligo, hepatitis, cholangitis, Sjögren syndrome, Addison disease, peripheral neuropathy, psoriasis, and autoimmune cardiomyopathy. It occurs in up to 1% of Caucasians of European heritage and is rare in those of Asian and African heritage.

Diagnosis of CD is based on clinical presentation, screening using IgA antitissue transglutaminase (TTG) antibody test, and confirmation with small-bowel biopsy (atrophic villi).

Treatment is lifelong avoidance of gluten in the diet.

KEY FACTS

- CD is an enteropathy due to ingestion of gluten.
- The typical presentation of pediatric celiac disease includes failure to thrive, diarrhea, constipation, vomiting, distension of abdomen, and irritability.
- The extraintestinal manifestations are dermatitis herpetiformis, anemia, aphthous stomatitis, delayed growth/puberty, dental enamel defects, osteopenia, osteoporosis, and abnormal liver function tests.
- Celiac crisis is a rare medical emergency, typically seen in toddlers, which presents as explosive, watery diarrhea with marked abdominal distension leading to dehydration, hypotension, electrolyte imbalance, and lethargy; it typically responds to corticosteroids in a few days.
- CD is commonly associated with type 1 diabetes, Hashimoto thyroiditis, Down syndrome, Turner syndrome, Williams syndrome, and a positive family history of CD.

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29. ANSWER: A

A **term neonate** has 250 cm of small bowel and 40 cm of colon. The jejunum, ileum, and colon double in length during the last trimester. In an **adult**, the small bowel is 400–700 cm.

The small bowel is involved in **digestion and absorption of nutrients and fluid balance**.

The **duodenum** is responsible for absorption of iron, carbohydrates, and electrolytes (calcium, magnesium, zinc). It neutralizes the gastric acidic contents. Gastric secretions are mixed with intestinal, hepatic, and pancreatic secretions to aid digestion. Chylomicrons are also formed in duodenum to aid fat absorption further downstream.

The jejunum has a larger absorptive area and higher enzyme and carrier protein concentration. Folate, trace elements, electrolytes (calcium and other minerals), fat-soluble vitamins, carbohydrates, free fatty acids, and water are absorbed in the **jejunum**. Although the ileum can compensate for some of the jejunal function, it cannot replace it. Loss of jejunum results in loss of production of cholecystokinin and motilin, thus affecting motility and digestion. Biliary and pancreatic secretions are decreased when the jejunum is lost, but gastrin levels are increased, resulting in gastric hypersecretion.

The **ileum** has less absorptive area but more lymphoid tissue (immune regulation) compared to jejunum. Ileal resections can result in decreased **absorption of** bile acids, bile salts, complex of intrinsic factor with vitamin B12, fluid, and electrolytes. The jejunum cannot compensate for the loss of ileum. Ileum is also the site of **production of** the enzymes peptide YY and enteroglucagon. Peptide YY controls the rate of gastric emptying and is also known as the "ileal brake." Ileal resection can also lead to gallstones and renal stones.

The **ileocaecal valve** plays an important role in slowing the intestinal transit and prevents colonization of the

small bowel by colonic bacteria. So excision or loss of the ileocecal valve results in increased loss of fluids and electrolytes and small-bowel bacterial overgrowth. Preservation of the ileocaecal valve during resection improves prognosis for short-bowel syndrome.

KEY FACTS

- A term neonate has 250 cm of small bowel and 40 cm of colon, while in an adult, the small bowel is 400–700 cm.
- The small bowel is involved in digestion and absorption of nutrients and fluid balance.
- The duodenum is responsible for absorption of iron, carbohydrates, and electrolytes (calcium, magnesium, zinc), and it neutralizes the gastric acidic contents.
- Folate, trace elements, electrolytes (calcium and other minerals), fat-soluble vitamins, carbohydrates, free fatty acids, and water are absorbed in the jejunum.
- In the ileum, bile acids, bile salts, complex of intrinsic factor with vitamin B12, fluid, and electrolytes are absorbed, and the enzymes peptide YY and enteroglucagon are produced.

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30. ANSWER: A

Hiatal hernia and gastroesophageal reflux (GER) can present as frequent emesis, regurgitation, refusal of feeds (especially in presence of esophagitis), and chronic respiratory issues.

Diagnostic methods for hiatal hernia and GER are upper gastrointestinal series, nuclear scintigraphy, endoscopy with biopsies, pH probe or wireless pH monitoring, multichannel intraluminal impedance monitoring, and empirical pharmacological therapy (only in GER).

Surgical treatment is indicated in hiatal hernia and failed medical management of GER. Nissen fundoplication involves wrapping the gastric fundus around the gastroesophageal junction. In recent years, a laparoscopic approach has become the preferred method. The patient has to be intubated and is usually extubated at the end of surgery. The surgery is not associated with significant postoperative pain, large fluid shifts, or blood loss. The anesthesiologist usually inserts a bougie catheter to assist the surgeon in gauging how tight to tie the stomach around the esophagus. At the end of surgery, it is common to inject air through a gastric tube to assess that there is no leak in the gastric mucosa following the procedure.

Some of the **complications following a Nissen fundoplication are dysphagia, gas bloat syndrome, dumping syndrome, paraesophageal hernia, and small-bowel obstruction.**

KEY FACTS

- Hiatal hernia and gastroesophageal reflux (GER) can present as frequent emesis, regurgitation, refusal of feeds (especially in presence of esophagitis), and chronic respiratory issues.
- Diagnostic methods for hiatal hernia and GER are upper gastrointestinal series, nuclear scintigraphy, endoscopy with biopsies, pH probe or wireless pH monitoring, multichannel intraluminal impedance monitoring, and empirical pharmacological therapy (only in GER).
- Surgical treatment is indicated in hiatal hernia and failed medical management of GER.
- Some of the complications following a Nissen fundoplication are dysphagia, gas bloat syndrome, dumping syndrome, paraesophageal hernia, and small-bowel obstruction.

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31. ANSWER: B

Umbilical hernia is an outpouching of abdominal contents through a defect in the area of the umbilicus. This abdominal defect is usually covered with skin. Umbilical hernias are **common in** premature babies and babies of African descent, and they occur equally in both sexes. They **present as** a prominent protuberance at the umbilical area when the baby cries, coughs, or strains. Umbilical hernias are typically **nontender and easily reducible**.

Umbilical hernias tend to **shrink spontaneously** as the child grows. In almost 90% of cases it closes spontaneously by the age of 3 and no surgery is indicated. Most parents just have to be reassured. Complications are rare.

Surgery is indicated if the swelling is tender, irreducible, still present by 4 years of age, or if the swelling is large. General anesthesia is required. If the swelling is

small and muscle relaxation is not required by the surgeon, the case can be done with an LMA. A rectus sheath block can be performed for postoperative pain relief.

KEY FACTS

- Umbilical hernia is an outpouching of abdominal contents through a defect in the area of the umbilicus.
- Umbilical hernias are common in premature babies and babies of African descent, and they occur equally in both sexes.
- An ubilical hernia presents as a prominent protuberance at the umbilical area when the baby cries, coughs, or strains; it is typically nontender and easily reducible.
- Surgery is indicated if the swelling is tender, irreducible, still present by 4 years of age, or if the swelling is large.

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32. ANSWER: D

Almost all intravenous anesthetics undergo some degree of **hepatic metabolism through oxidation and conjugation**. In **patients with underlying liver disease**, many of these medications may have altered metabolism due to (1) decreased ability to carry out phase I and II reactions and (2) decreased circulating albumin and therefore increased free drug concentration. For medications that have a large percentage bound to albumin, diseases that decrease the concentration of albumin increase the free fraction of the active medication, resulting in a much greater effect of the medication. **Propofol** is primarily eliminated via renal excretion (88%), and therefore hepatic injury minimally affects metabolism. **Ketamine**, while metabolized in the liver, is not usually affected by liver disease. Therefore, the metabolism of ketamine is minimally affected by liver disease. **Serum opiate concentration** is a balance of hepatic clearance and protein binding that determines the overall effect of the opiate. Most opiates are oxidized in the liver, except remifentanil. **Remifentanil** is metabolized by plasma and tissue esterases. The enzymes are mature in term neonates and are minimally affected in patients with liver disease. **Midazolam's** has a high hepatic extraction ratio and therefore the drug's clearance rate is dependent on hepatic blood flow. In patients with cirrhosis, the **clearance of midazolam** is half of healthy controls. As a result, the half-life of the drug is doubled and has a prolonged effect in patients with liver disease. Additionally, midazolam is 95%–97% bound to albumin in healthy children. In patients with liver disease, the decreased concentration of albumin increases the active fraction of the drug. With decreased metabolism and increased free active drug available, the effect of midazolam is dramatically prolonged in patients with liver disease.

KEY FACTS

- Almost all intravenous anesthetics undergo some degree of hepatic metabolism through oxidation and conjugation.
- In patients with underlying liver disease, many of these medications may have altered metabolism due to (1) decreased ability to carry out phase I and II reactions and (2) decreased circulating albumin and therefore increased free drug concentration.
- Propofol is primarily eliminated via renal excretion (88%), and therefore hepatic injury minimally affects metabolism.
- Ketamine metabolism is not usually affected by liver disease.
- Serum opiate concentration is a balance of hepatic clearance and protein binding that determines the overall effect of the opiate.
- In patients with cirrhosis, the clearance of midazolam is half of healthy controls.

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33. ANSWER: A

Obesity is the most common health problem for pediatric patients in the United States, and the prevalence is rapidly increasing. As of May 2013, the CDC estimated that **16.9% of children aged 2 to 19 years are obese**. The most recent recommendations from the CDC suggest using body mass index (BMI) as the most appropriate and easiest available method to determine obesity. **BMI is calculated by** taking a child's weight in kilograms divided by the height in meters squared. The CDC defines obesity as a child whose BMI (kg/m^2) was equal to or greater than the 95th percentile on the sex- and age-specific 2000 CDC

growth charts. Children with a BMI greater than 30 are considered **obese**, while patients with a BMI great than 40 are considered **morbidly obese**. Children with morbid obesity are at increased risk for problems similar to their adult counterparts. These include **psychological problems, hypertension, hypercholesterolemia, diabetes mellitus, obstructive sleep apnea, coronary artery disease, and hepatitis**. Obese children are more likely to be admitted to the hospital and are often associated with a need for surgery. Examples of surgeries that bariatric patients may require include slipped epiphysis repair, cholecystectomy for gallstones, bariatric surgery, and tonsillectomy for obstructive sleep apnea.

KEY FACTS

- Obesity is the most common health problem for pediatric patients in the United States and the prevalence is rapidly increasing.
- As of May 2013, the CDC estimated that 16.9% of children aged 2 to 19 years are obese.
- BMI is calculated by taking a child's weight in kilograms divided by the height in meters squared.
- Children with a BMI greater than 30 are considered obese, while patients with a BMI great than 40 are considered morbidly obese.
- Children with morbid obesity are more likely to have psychological problems, hypertension, hypercholesterolemia, diabetes mellitus, obstructive sleep apnea, coronary artery disease, and hepatitis.

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Zhang X, Onufrak S, Holt JB, Croft JB. A multilevel approach to estimating small area childhood obesity prevalence at the census block-group level. *Prev Chronic Dis*. 2013;10:120252.

34. ANSWER: C

Biliary atresia is characterized by an **obstruction to the extrahepatic bile duct**, resulting in obstructed bile flow. The post-natal form of biliary atresia accounts for 65%–90% of cases, while the remaining cases are associated with other **congenital anomalies**, most commonly **situs inversus** with **polysplenia/asplenia**. The incidence is 1:10,000–15,000 per live births in the United States. The palliative procedure is a **hepatic portoenterostomy (Kasai procedure)** that has demonstrated a survival rate at 2-, 5-,10-, and 15-year survival at 57.1%, 32.9%, 32.4%, and 28.5% in a study on 695 patients. However, patients who were operated on before 60 days of life, 10-year survival was 70%. Complications of the surgical repair include **cholangitis** (50%), **portal hypertension** (60%), and **fat-soluble vitamin deficiency**. If the Kasai fails, **secondary cirrhosis** may develop and later **hepatocellular carcinoma (HCC)**. Many of these patients eventually develop complete liver failure and must undergo liver transplantation for survival. However, HCC and end-stage liver disease are not direct complications from the procedure. Patients who have undergone the Kasai procedure are at increased risk for **fat-soluble vitamin deficiency**, *not* water-soluble vitamin deficiency.

KEY FACTS

- Hepatic portoenterostomy (Kasai procedure) is a palliative procedure for biliary atresia, characterized by obstruction to the extrahepatic bile duct.
- Complications of the surgical repair include cholangitis, portal hypertension, and fat-soluble vitamin deficiency.
- If the Kasai fails, patients may develop secondary cirrhosis, HCC, and end-stage liver disease.

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35. ANSWER: A

Gastric bypass and laparoscopic adjustable gastric banding have been performed in adult patients for several decades. However, there is increasing demand for these procedures on **morbidly obese teenagers** in hopes of preventing the long-term obesity-related morbidities, which were mentioned earlier. **Pediatric patients undergoing bariatric banding should undergo thorough psychologic and medical evaluation, as well as behavior modification, prior to surgery**. Several small studies in the past decade have demonstrated that the laparoscopic gastric banding is relatively safe and many of the obesity-related morbidities can be reversed. One study of 11 adolescents (2003) aged 11–17 years old who underwent lap-banding demonstrated a decrease in BMI from 46.6 to 32.1 kg/m^2. For children undergoing bariatric surgery, many have very similar risks to morbidly obese patients and adult patients undergoing bariatric surgery. As with all morbidly obese patients, the **risk for aspiration** is very high due to **large gastric volumes and low pH**. Morbidly obese patients also have a **high incidence of GER**. Anesthesiologists may consider treating the patients with an H_2-receptor antagonist, a nonparticulate antacid, or metoclopramide 60–90 minutes

prior to induction. Obese patients are often at increased risk for **hypoxemia after induction**, **intraoperatively** or **postoperatively**. After induction, many obese patients become hypoxemic in the supine position despite adequate pre-oxygenation due to **upper airway obstruction** and a **diminished FRC**. **Tracheal intubation** should be considered for most obese patients undergoing general anesthesia due to the increased risk of aspiration, difficult mask ventilation/intubation, and **obstructive sleep apnea**. Many anesthesiologists will choose **a rapid sequence induction**, an **awake fiberoptic intubation,** or at least the availability of a difficult airway cart. Most obese patients undergoing laparoscopic gastric banding do not require postoperative ventilation if the patient does not have other significant morbidities such as cardiac disease or respiratory disease. Patients are sometimes extubated to CPAP or biPAP if necessary. The anesthesiologist must choose an **anesthetic that will not cause hypoventilation or airway obstruction postoperatively**. Some anesthesiologist will choose to use an insoluble inhalational agent, minimal narcotics, and maximize local anesthetic for pain management, including infiltration or regional techniques. As many medications are fat soluble and patients with morbid obesity have **increased volumes of distributions**, medication doses and fluid administration should be based on **ideal body weight**. Obese surgical patients are at high risk for the development of **thromboembolism**. One study estimated a 5% incidence of pulmonary emboli after laparotomy in obese patients. The risk can be reduced with the use of pneumatic compression boots and/or lovenox or heparin postoperatively.

KEY FACTS

- Morbidly obese patients have a high risk for aspiration due to large gastric volumes and low pH.
- Morbidly obese patients have a high incidence of GER.
- Morbidly obese patients have an increased risk for hypoxemia after induction, intraoperatively or postoperatively due to upper airway obstruction and a diminished FRC.
- Medications doses and fluid administration should be based on ideal body weight.
- Obese surgical patients are at higher risk for the development of thromboembolism.

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36. ANSWER: A

Gastroesophageal reflux (GER) involves a dysfunction of the sphincter that prevents gastric contents from returning to the esophagus. GER may be secondary to (1) **an immature lower esophageal mechanism**, (2) patients who are **neurologically compromised**, and (3) patients with **prior history of GI surgery of dysfunction,** including **diaphragmatic hernia, tracheoesophageal fistula, or esophageal atresia repair**. Symptoms in pediatric patients may range from asymptomatic to **severe esophagitis**, **malnutrition,** or **respiratory complications**. Respiratory complications occur from long-standing gastric contents and food entering the lung. As a result, these patients often have underlying **reactive airway disease, chronic aspiration pneumonitis,** and problems with **bronchospasm** under anesthesia. These patients are not at increased risk for developing laryngospasm when compared with healthy patients. While many patients that have GER are neurodevelopmentally delayed and therefore may take antiepileptic medications that prolong neuromuscular blockade, this is not due to GER. While patients with GER may have neurologic or respiratory problems that delay emergence, this is not directly related to GER.

KEY FACTS

- GER may be secondary to (1) an immature lower esophageal mechanism, (2) patients who are neurologically compromised, (3) patients with prior history of GI surgery of dysfunction, including diaphragmatic hernia, tracheoesophageal fistula, or esophageal atresia repair.
- Symptoms in pediatric patients may range from asymptomatic to severe esophagitis, malnutrition or respiratory complications.
- Patients with GER often have underlying reactive airway disease or chronic aspiration pneumonitis, which places them at increased risk for developing bronchospasm under anesthesia.

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8.

RENAL AND URINARY SYSTEM

Amy E. Vinson

1. You are caring for a 3-day-old neonate who was born at 29 weeks gestational age by cesarean section for severe oligohydramnios not caused by an amniotic fluid leak. The infant is noted to have large, low-set, floppy ears as well as a very small mouth. Which of the following imaging tests is most likely to be normal?

A. Echocardiogram
B. Renal ultrasound
C. Skeletal survey
D. Hip ultrasound

2. In the embryologic development of the urogenital system, which of the following structures is separated by the urorectal septum into the urogenital sinus and the rectum?

A. Urachus
B. Cloaca
C. Allantois
D. Bladder

3. A full-term newborn infant is found to have lost 6% of its birth weight on day of life 2. Compared to adult values, this normal physiologic finding is best explained by the neonate's:

A. Increased ability to excrete potassium
B. Decreased renal concentrating ability
C. Increased fractional excretion of sodium
D. Increased glomerular filtration rate

4. Which of the following medications or classes of medications, when taken by the mother, is *most likely* to impact renal development in the fetus?

A. Selective seretonin reuptake inhibitors (SSRIs)
B. Angiotensin-converting enzyme inhibitors (ACE inhibitors)
C. Beta-adrenergic antagonists (beta blockers)
D. Tetracycline

5. Which of the following is the most likely etiology of acute kidney injury in a previously healthy 15-year-old girl?

A. Rapidly progressive glomerulonephritis (RPGN)
B. Renal vein thrombosis
C. Vesicoureteral reflux
D. Hemolytic uremic syndrome

6. You are caring for a neonate in the operating room for placement of a dialysis catheter. The infant was diagnosed in utero with polyhydramnios, developed renal failure shortly after birth, and is now requiring dialysis for severe volume overload and electrolyte instability. Which of the following causes is most likely the cause of renal failure in this patient?

A. Prune belly syndrome
B. Posterior urethral valves
C. Sacrococcygeal teratoma
D. Sepsis

7. You are caring for a 4-month-old male infant who presents for correction of his hypospadias. Which of the following is most commonly associated with hypospadias?

A. An abnormal opening of the urethra on the dorsal side of the penis
B. A chordee, or abnormal curvature of the penis
C. Other congenital anomalies
D. An abnormal cleft extending from the glans to the perineum

8. Which of the following conditions is *most commonly* associated with cryptorchidism?

A. Prune belly syndrome
B. Umbilical hernia
C. Volvulus with malrotation
D. Phimosis

9. Which of the following best characterizes uretopelvic junction (UPJ) obstruction?

A. Most cases are bilateral.
B. UPJ obstruction is far more common on the left.
C. UPJ obstruction leads to dilated ureters.
D. UPJ obstruction cannot be discovered in utero.

10. A 16-year-old, previously healthy male presents to the emergency department with the sudden onset of severe lower abdominal pain, left scrotal pain, and emesis. He describes a history of brief intermittent scrotal pain in the past, but this is the first time the pain has not abated in minutes. This episode began 1 hour prior while having dinner at a fast food restaurant. He is afebrile and color Doppler ultrasound in the emergency department demonstrates severely decreased blood flow in the left testicle. The most appropriate next step is to:

A. Obtain an emergent computed tomography (CT) scan of the pelvis.
B. Proceed immediately to the operating room with planned rapid sequence induction.
C. Obtain a blood culture prior to antibiotic dosing.
D. Proceed to the operating room once the patient is appropriately fasted.

11. You are caring for a 3-year-old girl with grade 3 vesicoureteral reflux (VUR). Which of the following best characterizes VUR?

A. VUR is caused by a stricture in one or both of the ureters.
B. VUR is present in 30%–40% of children with febrile urinary tract infections.
C. Most cases of VUR occur in males.
D. Primary VUR is caused by a valve at the origin of the urethra.

12. Ureteral reimplantation improves vesicoureteral reflux by:

A. Relieving the obstruction to flow located at the junction of the ureter and bladder
B. Resecting the area of stricture within the distal portion of the ureter
C. Creating a functional antireflux valve at the origin of the ureter just past the renal pelvis
D. Creating a functional antireflux valve at the junction of the ureter and bladder

13. A 4-week-old male infant presents for a single staged repair of a classic bladder extrophy. Which of the following is the *most* appropriate for use throughout the intraoperative course?

A. Tunneled caudal epidural catheter
B. Femoral vein central venous line
C. Saphenous peripheral intravenous catheter
D. Foley catheter

14. A 3-year-old boy is undergoing a staged repair for classic bladder extrophy. Which of the following is a component of the staged repair?

A. Stenting of the reconstructed urethra utilizing a red rubber catheter
B. Delayed bladder closure at approximately 6 months of age
C. Pelvis osteotomy to create a pubic symphysis
D. Initial bladder neck reconstruction during neonatal period

15. Which of the following represents the *most common* cause of end-stage renal disease in pediatric patients undergoing renal transplantation?

A. Renal aplasia/dysplasia
B. Focal segmental glomerulosclerosis
C. Prune belly syndrome
D. Polycystic kidney disease

16. You are caring for a 14-year-old, 67 kg female undergoing a living-related donor renal transplant for focal segmental glomerulosclerosis, prior to her needing dialysis for her condition. Which of the following is *most essential* for her anesthetic?

A. Central venous access utilizing the subclavian approach
B. Large-bore intravenous access
C. Placement of an arterial catheter
D. Avoidance of nondepolarizing muscle relaxants that require renal metabolism

17. What is the most common presentation of a Wilms tumor?

A. Painful pelvic mass in a 13-year-old girl at menses
B. Unrelenting abdominal pain in a 3-year-old child
C. Unexplained renal failure in a 9-year-old boy presenting with diarrhea
D. Painless abdominal mass noted in a 2-year-old boy at bath time

CHAPTER 8 ANSWERS

1. ANSWER: A

This infant likely has **Potter's sequence** (also known as oligohydramnios sequence), which is a consequence of **prolonged oligohydramnios** and **the resultant cramped fetal environment**. Oligohydramnios, or an abnormally low level of amniotic fluid, can be caused by either losses (e.g., chronic amniotic fluid leak) or decreased production. By **mid gestation the great majority (~90%) of amniotic fluid is produced by the fetal kidneys**; thus, in situations where there is oligohydramnios and no amniotic fluid leak, one must logically suspect either structural or functional renal abnormalities. It can occur in conditions such as **bilateral renal agenesis (BRA), obstruction of the urinary tract, autosomal recessive polycystic kidney disease (ARPKD), autosomal dominant polycystic kidney disease (ADPKD) (in rare cases), and renal hypoplasia**. Many clinicians feel that Potter's sequence rather than Potter's syndrome is a more appropriate terminology since Potter's sequence is not technically a syndrome, as it does not collectively present with the same characteristics and symptoms in every case. It is more accurately described as a "sequence" or chain of events that may have different beginnings (absent kidneys, cystic kidneys, obstructed ureters, or other causes) but which all end with a similar conclusion.

The **Potter's sequence** is characterized by various developmental anomalies caused by external compression during fetal growth. They demonstrate the typical facies of an infant whose developing face has been compressed by the uterine wall: **micrognathia, low-set ears that are floppy from a lack of cartilaginous development, a flat nasal bridge, and eyes that are widely set (orbital hypertelorism)**. These infants also have other typical musculoskeletal features caused by external compression: **scoliosis, hip dysplasia, torticollis, and clubfeet**. Due to the **pulmonary hypoplasia** that can occur in this condition, infants are also at **risk for pneumothorax** in the first few hours of life.

In this situation, one must **highly suspect a renal anomaly**, which would be elucidated via renal ultrasound. A skeletal survey may show scoliosis, and a hip ultrasound may show hip dysplasia. There is no indication that there are any intracardiac abnormalities, and oligohydramnios alone does not lead to developmental abnormalities of internal organs. Therefore, of the studies listed, an echocardiogram is the one most likely to be normal.

KEY FACTS

- Potter's sequence (also known as oligohydramnios sequence) is a consequence of prolonged oligohydramnios and therefore cramped fetal environment.
- It is characterized by micrognathia, low-set floppy ears, flat nasal bridge, widely set eyes, scoliosis, hip dysplasia, torticollis, clubfeet, and pulmonary hypoplasia.

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2. ANSWER: B

During the **5th week of fetal development**, the structures that are to become the **mature kidneys and collecting systems begin to form**. The mesonephric ducts give rise to paired ureteric buds, which are diverticula that will ultimately become the renal collecting tubules and ureters. The calices and collecting tubules emerge from the ureteric buds as they elongate in their development; as development continues, the collecting system continues to branch into its eventual adult organization. One end of the bud pierces the metanephric mass, which will eventually become the mass of the kidney itself.

Early in fetal development, at the base of the hindgut, the **cloaca forms as the common opening of the urogenital system and the caudal end of the gut**. Cloaca is Latin for "sewer." The urorectal septum further divides the cloaca into the urogenital sinus and the rectum. The bladder then arises from the urogenital sinus. The caudal ends of the **mesonephric ducts, which will eventually become the ureters**, join the bladder to form the trigone. Very rarely, an infant will be born without the division of the cloaca having occurred. They are logically diagnosed with a "cloaca" and will require multiple complex reconstructive operations in order to attain more normal functioning.

Early in bladder development, it is contiguous with a structure called the allantois, which empties into the cloaca. The **allantois** eventually constricts to become the **urachus** and ultimately closes off and can be found vestigially in adults as the **median umbilical ligament**.

There are many points at which this development can be interrupted, and these perturbations lead to some of the more common congenital renal abnormalities. In the case of renal agenesis, the ureteric bud either does not reach the metanephric mass or a dysplastic kidney involutes. If the ureteric bud divides, a duplicated collecting system forms. If the end of the ureteric bud that pierces the metanephric mass fails to induce nephrogenesis, severely dysplastic kidneys arise.

KEY FACTS

- The structures destined to become the kidneys and collecting systems begin to form in the 5th week of fetal development.
- The cloaca forms as the common opening of the urogenital system and the caudal end of the gut.

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3. ANSWER: C

Renal development begins early in fetal life, but it does not attain **full maturation until roughly 2 years** of age. **Glomerular filtration is initially low in newborn** full-term infants and, while it rises rapidly within the first few weeks of postnatal life, it does not reach **full adult levels until 18–24 months of age**.

In addition to the global function of glomerular filtration, solute loads are handled differently in the neonatal kidney. **Fractional excretion of sodium is initially quite high**, especially in **preterm neonates** who are susceptible to **significant salt wasting**. In fact, this loss of sodium and subsequent free water can lead to an initial weight loss over the first few days of life when oral intake (and therefore sodium intake) is reduced. Generally a **weight loss of up to 10%** is acceptable for otherwise healthy term newborns, but it is expected that this weight will be regained by a week to 10 days as the infant begins to take a larger solute load by mouth.

Neonates have a **decreased ability to excrete potassium**, which places them at **increased risk for hyperkalemia** from exogenous sources (TPN, formula, and blood transfusions).

Infants are born with the ability to excrete the same minimum concentration of urine as their adult counterparts, but they have a decreased concentrating ability that is not fully developed until early childhood. Although Answer B is true, it does not explain the initial weight loss seen in healthy term newborns.

KEY FACTS

- Glomerular filtration is initially low in newborns; it reaches full adult levels by 18–24 months of age.
- Fractional excretion of sodium in preterm neonates is initially quite high, making them susceptible to significant salt wasting.
- Neonates have a decreased ability to excrete potassium, which places them at increased risk for hyperkalemia from exogenous sources.

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4. ANSWER: B

The **fetus can be exposed to a wide array of toxins** and teratogens during development, many of which have predictable and often profound consequences.

SSRIs are one of the more commonly prescribed medications being taken by parturients. As such, much attention has been given to the potential adverse outcomes associated with the use of such agents during fetal development. Several outcomes have been postulated, including withdrawal states after birth, autism, poor weight gain, congenital anomalies, and pulmonary hypertension. In 2006, a population-based study found **that fetal exposure to SSRIs increased the infant's chances of low birth weight (<10th percentile) and increased the infant's chances of neonatal respiratory distress**. This study used women with depression not being treated pharmacologically as its control group.

The fetus, infant, and young child have higher levels of renin that peak in the early neonatal period. These high levels lead, in turn, to high levels of angiotensin II, which has a strong impact on the development of the renal system. If the **production of angiotensin II is blocked** (by ACE inhibitor medications) in the second and third trimesters, the fetus can experience **dysgenesis of the kidneys, oligohydramnios, and even subsequent pulmonary hypoplasia**.

While **beta-adrenergic blockade has been associated with mild intrauterine growth restriction**, there is no indication that it increases the risk of fetal malformation or dysgenesis. Beta blockers are one of the more commonly used agents for treating maternal hypertension during pregnancy, but many advocate for the use of nifedipine instead due to the decrease in intrauterine growth restriction and apparent safety profile.

Tetracycline is one of the more **notorious teratogens** and, in fact, most prescribers require women taking tetracycline to also be on a reliable form of birth control. While the teratogenic effects are wide, the most commonly cited effects are **defects in skeletal and dental growth, limb malformations, and cataracts**.

KEY FACTS

- Intrauterine SSRI exposure outcomes have been postulated, including withdrawal states after birth, autism, poor weight gain, congenital anomalies, and pulmonary hypertension.
- Exposure to ACE inhibitors in the second and third trimester can lead to dysgenesis of the kidneys, oligohydramnios, and pulmonary hypoplasia.
- Tetracycline is one of the more notorious teratogens; the most commonly cited effects are defects in skeletal and dental growth, limb malformations, and cataracts.

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5. ANSWER: A

As with any incident of acute kidney injury (AKI), an organized approach to prerenal, intrinsic renal, and postrenal causes should be used. However, in the **pediatric population, the age at onset** can also **help delineate the cause of AKI**.

Rapidly progressive glomerulonephritis (RPGN), as its name indicates, is a severe and rapidly progressive form of glomerular injury by definition destroying at least half of the glomeruli within weeks to months via an inflammatory process. The pathophysiology in the **pediatric age group is most likely lupus glomerulonephritis or IgA nephropathy,** and this illness tends to occur in **older children and adolescents**. It is not uncommon for these children to ultimately develop chronic renal insufficiency with the **requirement of dialysis and renal transplantation**.

Renal vein thrombosis is a cause of AKI, and it is most commonly seen in **the neonatal population**. It would be unusual for an otherwise healthy teenager to have renal vein thrombosis severe enough to cause AKI.

Vesicoureteral reflux is the flow of urine in a retrograde manner across the uretovesicular junction. Its severity is classified by the degree of reflux, which is determined radiographically. These children will generally be on low-dose antibiotic prophylaxis until the condition spontaneously resolves or until it is surgically corrected. The main reason for prophylaxis is to prevent renal scarring that can occur with repeated infections.

Hemolytic uremic syndrome is an often severe **early childhood illness**, which is classically initiated by a **systemic reaction to the toxin found in *E. coli* H:0157 gastroenteritis**. It is characterized by **hematuria, microangiopathic hemolytic anemia, thrombocytopenia, and ultimately renal failure**. This illness is one of the main reasons why antibiotics are not recommended in pediatric cases of gastroenteritis. If antibiotics are given to children infected with *E. coli* H:0157, the bacterial death leads to a sudden and profound release of toxins, which can dramatically increase the severity of illness. These children often require monitoring in an intensive care unit. They frequently require dialysis as a result of uremia causing altered mental status.

KEY FACTS

- In the pediatric population, the age at onset can help delineate the cause of AKI.
- RPGN is a severe and rapidly progressive form of glomerular injury, destroying at least half of the glomeruli within weeks to months in older children and adolescents.
- Renal vein thrombosis is a cause of AKI most commonly seen in the neonatal population.
- Hemolytic uremic syndrome is an often severe early childhood illness, classically a systemic reaction to the toxin found in *E. coli* H:0157. It is characterized by **hematuria, microangiopathic hemolytic anemia, thrombocytopenia, and renal failure.**

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6. ANSWER: D

There are many etiologies for renal failure in neonates, and they can be organized into prerenal, renal, and postrenal or obstructive causes. In the **neonate, prerenal causes include hypovolemia from any cause, cardiac failure, or any other hypoperfusion state and rarely hepatorenal syndrome**. **Intrinsic renal causes** are varied and include **developmental abnormalities of the renal parenchyma** as well as **drug toxicity and abnormalities of blood supply**. **Obstructive causes** tend to be anatomical abnormalities

of the collecting system and include **uteropelvic junction obstruction, posterior urethral valves, prune belly syndrome, ureteroceles, and rarely tumors**.

This patient's clinical picture of renal failure is unlikely a postrenal cause since the prenatal ultrasound showed **polyhydramnios**, which is a medical condition describing an **excess of amniotic fluid** in the amniotic sac. It is seen in about **1% of pregnancies**. One cause is **maternal diabetes mellitus,** resulting in fetal hyperglycemia and polyuria. **Fetal anomalies** that impair the ability of the fetus to swallow include gastrointestinal abnormalities such as **esophageal atresia, duodenal atresia, facial cleft, neck masses, tracheoesophageal fistula**, **diaphragmatic hernias**, **annular pancreas,** and **Bochdalek's hernia**. **Fetal renal disorders** that result in increased urine production during pregnancy include **antenatal Bartter syndrome**. **Neurological abnormalities** may also lead to polyhydramnios and include anencephaly, which impairs the swallowing reflex, chromosomal abnormalities (such as **Down syndrome** and **Edwards syndrome**), **skeletal dysplasia, and dwarfism**.

A **common etiology for acute renal failure in newborns** is an acute insult such as **sepsis or perinatal hypoxic ischemic injury**. The acute renal failure is usually reversible and the need for acute dialysis is uncommon, but it may be required for a short period to support renal function in expectation of recovery. This is usually started after appropriate discussion between the neonatologist and the nephrologist.

Prune belly syndrome is also referred to as "triad syndrome" or "Eagle-Barrett syndrome" and consists of **absent or decreased abdominal musculature**, **undescended testicles**, and **abnormalities of the urinary tract**. The etiology is not fully understood, but it is thought that **severe urethral obstruction occurs** early in fetal life, leading to the subsequent abnormalities. These patients present with varying degrees and locations of urinary tract dilations. As these abnormalities can lead to dysgenesis of both the kidneys and the lungs, the prognosis depends on the degree of these perturbations. On fetal ultrasound, patients frequently display **vesicoureteral reflux and hydronephrosis with oligohydramnios**.

While rare, **sacrococcygeal teratomas** are one of the more common tumors found in newborn infants. They are usually benign, but they can certainly exert mass effects that can significantly impact the neonate's clinical presentation, including **hydronephrosis** and **obstructive uropathy** caused by compression at the level of the ureters or urethra, and **oligohydramnios**.

Posterior urethral valves cause varying degrees of obstruction and can be found between the prostatic urethra and the external urinary sphincter. Many of these cases are **detected by fetal ultrasound**, due to the enlarged and thickened bladder, **hydronephrosis,** and **oligohydramnios**. In severe cases, **pulmonary hypoplasia** can ensue. The treatment is either surgical or with balloon dilation, and the timing of this is predicated on the degree of obstruction and overall health of the infant.

KEY FACTS

- Prerenal causes of renal failure in the neonate include hypovolemia, cardiac failure, sepsis, or any other hypoperfusion state.
- Intrinsic renal causes in the neonate are varied and include developmental abnormalities of the renal parenchyma as well as drug toxicity and abnormalities of blood supply.
- Obstructive causes in the neonate tend to be anatomical abnormalities of the collecting system and include uretopelvic junction obstruction, posterior urethral valves, prune belly syndrome, ureteroceles, and rarely tumors.
- Polyhydramnios can be caused by fetal anomalies, resulting in an impairment of the fetus to swallow the amniotic fluid or an increased production of amniontic fluid by the fetal kidneys.
- Oligihydramnios can be caused by a postrenal obstruction from sacrococcygeal teratomas, posterior urethral valves, or prune belly syndrome.

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7. ANSWER: B

Hypospadias repair is one of the more common procedures for a pediatric urologist and therefore one of the more common cases for a pediatric anesthesiologist. By definition, **hypospadias** occurs when the urethra has an **abnormal opening on the ventral side of the penis** and it can occur **anywhere from the glans of the penis all the way to the perineum**. As one can imagine, repairs done for hypospadias at the level of the perineum are far more rare and complex than those done at the level of the glans. Such repairs often are done in stages instead of a single repair and require tissue grafts. Fortunately, a great majority of the cases occur either on the glans or at the distal end of the penis.

Hypospadias involves the ventral opening of the urethral meatus as well as the **ventral curvature of the penis (chordee)**, which is corrected during the surgical repair.

This congenital abnormality does not seem to have any strong associations with other major congenital abnormalities, but infants with hypospadias do tend to have **higher rates of inguinal hernia and cryptorchordism**, so a careful examination should be performed. There is also an association with **low birth weight**. These are generally well infants with no significant comorbidities.

Repair is recommended at an early age while still in infancy for several reasons. Tissue healing seems to be faster with fewer complications at an early age. Additionally, early repair can often prevent the issues of psychosexual development occurring with penile congenital anomalies.

The anesthetic for a hypospadias repair can vary widely with regional practices. General anesthesia with a laryngeal mask airway or endotracheal tube is common practice, and pain control can be accomplished with a regional technique (caudal or penile block).

KEY FACTS

- Hypospadias involves both a chordee (ventral curvature of the penis) as well as the ventral opening of the meatus.
- The definition of hypospadias involves an abnormal ventral opening of the urethra—it can occur anywhere from the glans to the perineum.
- Infants with hypospadias tend to have higher rates of inguinal hernia and cryptorchordism.

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8. ANSWER: A

Cryptorchidism is the state of having undescended testicles (UDTs) either on one side or both. It is often diagnosed in the newborn nursery, as palpation of the scrotal sacs for presence of testicles is a standard component of a thorough newborn examination. This is a very common condition affecting up to **2% of full-term newborn males**. It is important to **diagnose early** because failure to repair can lead to **testicular degeneration**, **infertility, testicular torsion,** and even unrecognized **germ cell tumors**.

There are several conditions associated with cryptorchidism, including **gastroschisis, posterior urethral valves, and the prune belly syndrome**. In fact, the prune belly syndrome is also known as the "triad syndrome" due to the combination of urologic abnormalities, cryptorchidism, and malformed abdominal musculature.

Cyrptorchidism is **usually unilateral** (and usually on the right), but in about **one third of cases it occurs on both sides**. The treatment is orchidopexy, or the fixation of the testicle into the scrotum. This can be accomplished through an inguinal incision or laparoscopically, depending on the suspected location of the undescended testicle. Often the testicle will be found within the inguinal canal, but sometimes it is intra-abdominal and more difficult to locate. Once located, the length of the testicular vessels will determine whether the procedure can be completed in a single surgery or if a staged approach is required to draw the testicle into the base of the scrotum. In a **staged procedure**, there is usually a **gap of 1–2 years** between procedures in order for **interval growth to occur**.

Commonly, these children are otherwise healthy. The general anesthetic can be accomplished using a laryngeal mask airway or an endotracheal tube. Pain management strategies vary and can include IV narcotics, caudal anesthesia, local anesthesia along the incision, and more recently transversus abdominis plane blocks.

Phimosis and volvulus do not have a strong association with cryptorchidism. **Phimosis** simply refers to the **inability to retract the prepuse over the glans of the penis**; severe cases have implications for hygiene as well as sexual function and must be corrected with a circumcision. **Malrotation with volvulus is a situation arising from incomplete rotation of the gut** during fetal development. It presents usually within the first year of life when the blood supply becomes twisted, leading to bowel hypoperfusion and an acute abdomen. **Umbilical hernias are associated with cryptorchidism** (~6% in one study), but not nearly as strongly associated as with prune belly syndrome, where cryptorchidism is a component of the diagnosis.

KEY FACTS

- Cryptorchidism is usually unilateral on the right but can be bilateral in one third of cases.
- Gastroschisis, posterior urethral valves, and prune belly syndrome are all associated with cryptorchidism.

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Kliegman RM, Stanton B, St. Geme J, Schor N, Behrmann RE, eds. *Nelson Textbook of Pediatrics*. 19th ed. Philadelphia, PA: Saunders Elsevier; 2011:1280–1, 1852–8.

9. ANSWER: B

Uretopelvic junction (UPJ) obstruction is due to a **stricture in the ureter** that leads to an **obstructive uropathy**; in fact, it is the **most common cause of urinary obstruction in neonates**. It is often discovered in utero by the presence **of hydronephrosis without dilated ureters** due to the location of the stricture. It is **usually unilateral** with the **left side being more common than the right.**

Despite the increasing numbers of prenatally diagnosed suspected UPJ obstruction, it can often be diagnosed later. The **typical presentation** is of a **flank mass, hematuria, abdominal pain, or urinary tract infections**, which prompt further imaging tests and ultimately the diagnosis. The hydronephrosis can be quite significant, usually grade 3–4. When suspected prenatally, it is generally because of the presence of hydronephrosis (usually unilateral) but without dilated ureters due to the location of the stricture.

As with any instances of severe hydronephrosis, **renal function can ultimately be impaired**, but this does not always occur if discovered early enough. Also, since the disease is usually unilateral, the contralateral kidney should be completely normal and therefore renal function is almost never significantly impaired.

The surgical approach depends heavily on the surgeons at one's institution, as there is no clear consensus as to the best approach to repair. The approach for surgery will certainly guide the pain management scheme chosen, but regardless of the type of surgery performed, there is little change in length of stay following a pyeloplasty. As with many other operations, the approach can be either performed open or laparoscopically, and some institutions are utilizing robotic laparoscopic approaches as well.

These children should undergo the usual preoperative evaluation, but they are generally healthy with few comorbidities. **Renal failure is rarely an issue**, **given the usually unilateral nature of the disease**. Many anesthesiologists will utilize caudal anesthesia as a component of a balanced anesthetic, with various adjuncts such as opiates and clonidine.

KEY FACTS

- UPJ obstruction leads to an obstructive uropathy, the most common obstructive uropathy in neonates.
- UPJ obstruction is usually unilateral with the left side being more common than the right.
- Patients with UPJ obstruction are usually otherwise healthy and usually have preserved renal function.

REFERENCE

Gregory GA, Andropoulos DB, eds. *Gregory's Pediatric Anesthesia*. 5th ed. Oxford, UK: Wiley-Blackwell; 2012:747–8.

10. ANSWER: B

This adolescent has a **testicular torsion, which is a true surgical emergency**. In order to salvage the ischemic testicle, a detorsion must occur within a few hours or the testicle will become necrotic and no longer support spermatogenesis.

Testicular torsion is the **rotation of the testicle on its blood supply**, which causes **venous congestion** and ultimately a **compromise in arterial blood flow**. Once suspected, this condition must be confirmed and addressed as quickly as possible in order to salvage the testicle. While there is no single diagnostic test, most institutions will use a combination of history, examination, and ultrasound imaging to confirm the diagnosis. In the case presentation, the history, physical exam, and ultrasound examination all point toward a testicular torsion, so further imaging is not warranted.

Once a diagnosis of testicular torsion is made, the patient is brought without delay to the operating room for rapid sequence induction and for detorsion as well as fixation of the testicle within the scrotum. As time is of the essence, delaying the operation until the child is appropriately fasted is incorrect. If the testicle is found to be necrotic or unviable, it is removed. Generally the contralateral testicle is also fixated, as it is not uncommon to experience the same problem in the other testicle at a later time.

The occurrence **of this condition peaks at two distinct periods**. The first is in the **neonatal** period while the testicle is still descending and is therefore far more mobile within the scrotum. The other peak occurs during **adolescence**, presumably due to the rapid growth of the testicles during this time period.

The child may present with symptoms other than testicular pain. **Referred abdominal pain, nausea, and vomiting are the most typical symptoms**. Regarding Answer C, there is no indication that this afebrile adolescent is bacteremic or suffering from a severe infection, so a blood culture is not warranted.

KEY FACTS

- Testicular torsion can quickly lead to the death of the testicular tissue and is a surgical emergency.
- Testicular torsion peaks in the neonatal period and again in adolescence.
- The child may present with symptoms other than testicular pain including referred abdominal pain, nausea, and vomiting.

REFERENCE

Gregory GA, Andropoulos DB, eds. *Gregory's Pediatric Anesthesia*. 5th ed. Oxford, UK: Wiley-Blackwell; 2012:746–7.

11. ANSWER: B

Vesicoureteral reflux (VUR) is a relatively common pediatric urologic problem and one that can be managed both medically and surgically. The most basic definition of **VUR is the flow of urine retrograde from the bladder up one or both of the ureters**. VUR has historically been diagnosed by a voiding cystourethrogram, in which the bladder is filled with radiographic contrast dyed fluid; when the child voids, the path of the fluid is captured by X-ray and the degree of reflux is used to classify the severity of VUR.

Grade I: Reflux is confined to the ureters, with or without dilation of the ureters.

Grade II: Reflux does reach the renal pelvis, but it does not cause dilation in the collecting system.

Grade III: The ureter is mildly to moderately dilated, and the collecting system is moderately dilated. The fornices can still be normal.

Grade IV: The ureter and collecting systems are both moderately dilated and the fornices are beginning to show some blunting.

Grade V: The ureter is grossly dilated and kinked, and the collecting system is dilated. The fornices are also dilated with no evidence of papillary impressions. There is also intraparenchymal reflux.

VUR is generally **suspected** when a young child has **a febrile urinary tract infection (UTI)**. In fact, studies have shown that **30%–40% of young children with febrile UTIs have some degree of VUR**. There is a large **female predominance**, but boys do suffer from this problem as well.

Management focuses broadly on **preventing recurrence of UTIs and preventing scarring and damage to the kidneys**. In the past, treatment was quickly focused on surgical correction. In recent years, however, risk stratification has allowed a more conservative approach to children with lesser degrees of reflux. Depending on the grade of reflux, conservative management may involve antibiotic prophylaxis or not.

KEY FACTS

- VUR is the flow of urine retrograde from the bladder up one or both of the ureters.
- Some degree of VUR is present in 30%–40% of children with febrile UTIs.
- VUR has a strong female predominance.
- In recent years, a more conservative medical approach to select patients with VUR has become standard.

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Lebowitz RL, Olbing H, Parkkulainen KV, Smellie JM, Tamminen-Mobius TE. International system of radiographic grading of vesicoureteral reflux. International Reflux Study in Children. *Pediatr Radiol*. 1985;15:105–9.

12. ANSWER: D

When caring for a patient receiving a surgical correction, it is important to understand the purpose and mechanism of the repair. **Vesicoureteral reflux (VUR) is, by its most basic definition, the free flow of urine retrograde from the bladder and back up the ureters**. As described in the previous question, this reflux can occur to different degrees, causing flow and dilation to occur at varying degrees based on the severity of the reflux. **VUR is graded as grade I–V, with grade V reflux being the most severe with frank dilation of the renal pelvis** and grade I reflux being the least severe with very little dilation of even the ureter. Furthermore, **low-grade reflux is more likely to spontaneously resolve** and not lead to further episodes of urinary tract infections, while high-grade reflux will probably not resolve without surgical correction and will probably lead to recurrent urinary tract infections.

The problem lies at the junction of the ureter with the bladder. The pathophysiology is not one of an obstruction to flow but the lack of a functional antireflux valve. The basic principle of ureteral reimplantation surgery involves augmenting or altering the junction of the ureter with the bladder (uretovesicular junction) so that urine will flow easily into the bladder, but not flow retrograde in the direction of the kidneys. This has been accomplished in many different ways with varying degrees of success. Some even advocate for a minimally invasive procedure involving the bulking of the area around the uretovesicular junction, which has been reported to have a ~90% success rate. Higher success rates still occur with open reimplantation repairs where the path of the ureter is lengthened within the layers of the bladder. The incision and surgical approach will depend on whether the procedure is unilateral or bilateral.

KEY FACTS

- VUR is the free flow of urine retrograde from the bladder to the ureters, with the severity depending on the level the retrograde flow reaches and the degree of dilation it causes.
- Ureteral reimplantation involves altering the uretovesicular junction to prevent this retrograde flow from occuring.
- Low-grade reflux is more likely to spontaneously resolve.

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13. ANSWER: A

Bladder extrophy repairs can be some of the most complex and lengthy surgical repairs undertaken in children, and this is especially true of single-staged repairs. These repairs will involve multiple position changes, particularly of the lower extremities, and will also **involve changes from prone to supine position**. This is one of the main reasons why **lower-extremity venous access**, such as saphenous peripheral intravenous catheters and femoral vein central lines, is much **less desirable than upper-extremity access**. Due to the length of the procedures and extensive fluid shifts anticipated, multiple upper-extremity PIVs are prudent. In addition, an upper-extremity arterial catheter is quite useful for monitoring electrolyte levels, oxygenation, ventilation, and fluid status over the long course of the repair.

While a Foley catheter would be useful for monitoring adequacy of urine output, this monitor is not possible in this condition. **Bladder extrophy is essentially a ventral opening from the level of the urethra to the bladder**. Therefore, when looking upon a child with classic bladder extrophy, you will be looking at the posterior wall of the bladder and can sometimes even see the openings of the paired ureters. This is where urine output from the kidneys will emerge and ultimately leave the surgical field via suction and sponges. Toward the end of the repair, the surgeons will place a Foley catheter as a form of a stent in the newly formed urethra and one can often begin measuring urine output at this point.

The repair is generally delicate and much care must be taken to ensure that the infant is comfortable and immobile postoperatively. One excellent method of ensuring infant comfort is a caudal epidural. A caudal epidural can also be utilized intraoperatively to decrease the depth of anesthesia required for the long intraoperative course, but it must be tunneled so it is not in the surgical field.

KEY FACTS

- Classic bladder extrophy is an abnormal ventral opening extending from the urethra to the bladder.
- Postoperative care after a bladder extrophy repair should include adequate pain control to prevent excessive movement and disruption of delicate suture lines.

REFERENCE

Gregory GA, Andropoulos DB, eds. *Gregory's Pediatric Anesthesia*. 5th ed. Oxford, UK: Wiley-Blackwell; 2012:741–4.

14. ANSWER: C

Bladder extrophy can have a **wide range of severity**, from **a simple epispadias in a male patient to complete exposure of the bladder and hind gut (termed cloacal extrophy) to the external environment**. This presents a therapeutic challenge to the surgical and anesthetic team, and many approaches have been made. In some situations, a single-staged approach to repair of classic bladder extrophy has been performed, but increased complication rates have been reported. For this reason, the staged approach to repair is now often undertaken.

In classic bladder extrophy, there is an **exposure of the bladder mucosa as it protrudes through the abdominal wall**. In addition to this extrusion is the **nonunion of the pelvic rami and rectus muscles, a clitoral cleft in females and a complete epispadias with chordee in males**.

With so much exposed mucosa, **fluid loss and infection risk are the driving forces for the early closure** of the bladder. During this first stage of the procedure, the bladder is closed, the abdominal wall is closed, and the pelvic rami are brought together via pelvic osteotomies in order to create a pubic symphysis. Following this, the children are completely incontinent because there is no external urinary sphincter. This lack of continence is addressed somewhere between **3 and 6 years of age, when the bladder neck is reconstructed in an attempt to create a functional external urinary sphincter**. For boys, the epispadias (and chordee) is usually corrected in between these two procedures.

These children are known to be **at risk of latex allergy**, and therefore they should be cared for in a latex-free environment. For this reason, a red rubber catheter would be an inappropriate stent following any urethral repair.

With such a complex condition, additional problems may arise. For instance, many of these children will also have vesicoureteral reflux and hydronephrosis, which can be surgically addressed during one of the staged procedures.

KEY FACTS

- Bladder extrophy can have a range of presentations from a simple epispadias to a complete exposure to the external environment of the bladder and hindgut, called a cloaca. In addition, there is nonunion of the pelvic rami and rectus muscles, a clitoral cleft in females and a complete epispadias with chordee in males.
- In the first stage of the procedure, the bladder is closed, the abdominal wall is closed, and the pelvic rami are brought together via pelvic osteotomies in order to create a pubic symphysis.
- The second stage repair occurs between 3 and 6 years of age, when the bladder neck is reconstructed in an attempt to create a functional external urinary sphincter.
- Early bladder closure is important to minimize fluid losses experienced prior to closure.

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15. ANSWER: A

Pediatric renal transplant patients are a very different population than adult renal transplant patients. First, they tend to **be transplanted much earlier** than their adult counterparts following the institution of renal replacement therapy (dialysis). This is because **proper global renal function is needed for normal growth and development**, which is generally not a concern with their adult counterparts. In fact, around 25% of children undergoing renal transplantation do so prior to requiring dialysis—so-called preemptive transplantation. In other words, **children are often transplanted in a state of chronic renal insufficiency (CRI), not end-stage renal disease (ESRD)**. The management is therefore different, as children undergoing renal transplantation statistically have much higher glomeruler filtration rates (GFRs) than their adult counterparts.

There is also a difference between the etiologies of ESRD among the different age groups. Younger patients tend to have **higher numbers of anatomical, congenital, and hereditary conditions leading to their ESRD**. As patients get older, disorders of inflammation and sclerosis start to play a larger role, such as focal segmental glomerulosclerosis and the various forms of glomerulonephritis. Other sources of ESRD include more rare conditions like prune belly syndrome and hemolytic uremic syndrome.

Overall, **the most common source of ESRD in the pediatric population** is the improper formation of the kidneys: **renal dysplasia and aplasia**. This is followed closely by conditions of obstructive uropathy.

As in adults, appropriate selection is important for successful transplantation. For instance, a child with an autoimmune renal disease should not be transplanted unless his or her autoimmune illness is in a state of quiescence, and a child with metastatic cancer will likely not tolerate transplantation successfully.

The **age and size of the child is also important, as this will determine the surgical approach** and subsequent anesthetic management. Older and larger children will accommodate the traditional approach used in adults of placing the kidney in the extra peritoneal space of the iliac fossa. However, in smaller children, this is physically not possible and the kidney is placed intra-abdominally.

KEY FACTS

- Renal dysplasia and aplasia are the most common causes of ESRD in the pediatric population.
- The size of the patient determines the location of the transplanted kidney: iliac fossa for older children and intra-abdominally for smaller children.

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Gregory GA, Andropoulos DB, eds. *Gregory's Pediatric Anesthesia*. 5th ed. Oxford, UK: Wiley-Blackwell; 2012:694–7.
Kliegman RM, Stanton B, St. Geme J, Schor N, Behrmann RE, eds. *Nelson Textbook of Pediatrics*. 19th ed. Philadelphia, PA: Saunders Elsevier; 2011:1826.

16. ANSWER: B

Renal transplantation is undertaken for pediatric patients (neonatal to adolescent) with both end-stage renal disease (ESRD) and chronic renal insufficiency (CRI). About 25% of the time, pediatric patients receiving a renal transplant have not yet needed dialysis—this is called preemptive transplantation.

Anesthetic management is varied and largely determined by the clinical scenario. Of the choices listed, each of them can be reasonable in certain clinical situations, but only one of them is necessary regardless of the clinical history. **Large-bore intravenous access is required in this operation** due to the potential for sudden blood loss with surgical anastamosis as well as for the reliable administration of crucial immunomodulators and antirejection medication required intraoperatively.

A **central venous catheter** can be a useful adjunct for several reasons: monitoring of central venous pressure, blood draws for laboratory evaluations, and the reliable administration of medications, including vasoactive medications. If a central line is deemed appropriate, care must be taken to not jeopordize a vessel that may be needed in the future for dialysis if the transplanted kidney is rejected. It is best to avoid the subclavian vessels for this reason.

An **arterial line** can be similarly useful, especially if the child has concomitant cardiac or respiratory disease. With it, one can more closely monitor blood pressure, fluid status, and laboratory values. However, care must be taken to avoid sites of prior arterio-venous (AV) shunts and also to avoid damage to a vessel that may be required for a future AV shunt.

Choice of neuromuscular blocking agents continues to be an area of varied clinical practice. This choice will certainly depend on the degree of renal dysfunction. Some advocate for utilizing cisatracurium for all renal transplants, due to the renal independent Hoffman degradation of the drug. Others argue that the prolongation of the partially renal metabolized nondepolarizing muscle relaxants is not sufficient to justify the increased cost of cisatracurium.

KEY FACTS

- Pediatric patients are often (25%) transplanted prior to initiating dialysis ("preemptive transplantation").
- If a CVL is deemed necessary for intraoperative management for renal transplantation, avoid vessels that may be needed for dialysis at a later date such as the subclavian vessels.

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Gregory GA, Andropoulos DB, eds. *Gregory's Pediatric Anesthesia*. 5th ed. Oxford, UK: Wiley-Blackwell; 2012:694–7.

Kliegman RM, Stanton B, St. Geme J, Schor N, Behrmann RE, eds. *Nelson Textbook of Pediatrics*. 19th ed. Philadelphia, PA: Saunders Elsevier; 2011:1826.

17. ANSWER: D

Wilms tumors are also referred to as nephroblastomas and represent the **most common type of renal neoplasm in children**. In fact, Wilms tumors make up **5% of all pediatric malignancy diagnoses**. Classically, Wilms tumors present in toddlers, 75% presenting prior to age 5 years. Most are unilateral, but they can on occasion present in both kidneys. Usually the tumor remains localized, but when it does spread, it usually spreads to the lungs by hematogenous seeding.

The presentation of a Wilms tumor can be insidious. The **most common presenting sign** is that of a **painless abdominal mass**, which can be easily appreciated in a young child, especially when undressed (like at bath time). Because the tumor is located in the retroperitoneum, there are fewer anatomic barriers to check growth and the tumor can grow to a large size relatively quickly. There are other symptoms, like malaise and fever, that can occur, but these are not consistent. Because **the tumor is usually unilateral**, renal failure is rarely a concern or presenting symptom.

Once diagnosed, the tumor is biopsied for pathology and a genotype for the tumor is established. Assuming a favorable genotype and a unilateral tumor, full recovery is expected. On pathology, children with Wilms tumor often have areas of nephrogenic rests, embryonal kidney cells that persist postnatally, where differentiation ceased in development.

Often these tumors can be quite difficult to resect, depending on size and local invasion. **These tumors can be adherent to adjacent structures,** and it is not uncommon for one to invade the inferior vena cava or even travel up into the right atrium. For this reason, a thorough preoperative evaluation should be undertaken, and if local invasion is suspected, intraoperative preparation should include large-bore intravenous access, arterial cannulation, and ready availability of blood products should hemorrhage occur. If the tumor is large and adherent, one should also anticipate a long operative time, as dissection must proceed meticulously to avoid bleeding and damage to adjacent structures.

KEY FACTS

- Wilms tumors are the most common renal neoplasms in children.
- Wilms tumors are also referred to as nephroblastomas.
- A painless abdominal mass is the most common presenting sign of a Wilms tumor.

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Gregory GA, Andropoulos DB, eds. *Gregory's Pediatric Anesthesia*. 5th ed. Oxford, UK: Wiley-Blackwell; 2012:160, 748–50.

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9.

ENDOCRINE/METABOLIC SYSTEM

Birgit Maass

1. An 8-year-old male with a diagnosis of diabetes mellitus type 1 presents with diabetic ketoacidosis (DKA). He has been vomiting for 12 hours, has abdominal pain, and is diagnosed with acute appendicitis in the emergency room. He needs an emergent appendectomy. His last solid food intake was 1 hour ago. Which of the following is true?

A. On exam he presents with the typical symptoms of hypoventilation and bradycardia.
B. Surgery should be postponed until the patient is stable.
C. As the patient is severely dehydrated, rehydration should be done with hypertonic fluid.
D. Rapid hydration in this patient can cause cerebral edema with brainstem herniation.

2. Regarding diabetes insipidus (DI) and its treatment, which of the following is most true?

A. It presents with urine osmolality greater plasma osmolality.
B. Symptoms are similar to those after mannitol administration or patients with hyperglycemia.
C. Desmopressin is the drug of choice for nephrogenic DI.
D. DDAVP has a shorter half-life than vasopressin.

3. A 13-year-old female who has no past medical history presents to the emergency room with a body temperature of 103°F, palpitations, tremor, tachycardia, exophthalmos, heat intolerance, and warm but moist skin. She is quite nervous and has brisk reflexes. The most likely diagnosis is:

A. Neuroleptic malignant hyperthermia
B. Hepatitis
C. Hyperthyroidism
D. Lupus

4. In a patient with hyperthyroidism this drug should be avoided:

A. Propanolol
B. Propofol
C. Methamizole
D. Amiodarone

5. A neonate presents with seizures. The patient is cyanotic. He was diagnosed with Tetralogy of Fallot prenatally. An attempt to place a nasogastric tube is unsuccessful. What is his most likely diagnosis?

A. DiGeorge syndrome
B. Down syndrome
C. Maternal vitamin D deficiency
D. Williams-Beuren syndrome

6. A 5-year-old female is admitted to the hospital with a traumatic brain injury after a motor vehicle accident. She is diagnosed with a subarachnoid hemorrhage. Her sodium level is 127 mEq/L. What is the cause of her hyponatremia?

A. Cerebral salt wasting
B. Central diabetes insipidus
C. Diabetes mellitus
D. Osmotic diuresis secondary to mannitol administration

7. Mauriac syndrome is related to:

A. Low insulin levels
B. Low antiduretic hormone (ADH) levels
C. High ammonium levels
D. Low cortisol levels

8. A 5-month-old female comes to hospital with nausea and vomiting. She is found to be hyponatremic with

hyperkalemic acidosis. On exam she is found to have ambiguous genitalia. What is her most likely underlying disease?

A. Gonadoblastoma
B. Primary adrenocortical insufficiency
C. Denys-Drash syndrome
D. Partial androgen insensitivity

9. Which is typically decreased in a patient with Graves' disease?

A. QTc interval
B. Inotropy
C. Decreased reflexes
D. Attention span

10. Most pheochromocytomas originate in the:

A. Adrenal zona glomerulosa
B. Adrenal zona fasciculata
C. Adrenal medulla
D. Paraverteral sympathetic chain

11. The normal response to surgical stress is:

A. Decreased endorphins
B. Increased ADH
C. Decreased ketone body formation
D. Increased protein anabolism

12. A 4-year-old male presents with abdominal pain and is found to have an abdominal tumor. A magnetic resonance image (MRI) image shows an abdominal mass, which is then surgically removed. The pathology comes back as neuroblastoma. This tumor is associated with:

A. No other disease
B. Diabetes mellitus 1
C. Neurofibromatosis 1
D. SIADH

13. A neonate with omphalocele presents with seizures and is found to have severe hypoglycemia. On exam the patient presents with a large tongue and large fontanelles. The patient's birth weight was 5.1 kg. The patient's most likely diagnosis is:

A. Diabetes mellitus type 1
B. Prader-Willi syndrome
C. Beckwith-Wiedemann syndrome
D. Achondroplasia

14. A 16-year-old male with a history of hypertension for a few months now presents complaining of palpitations, tremors, flushing, and diarrhea. He is found to have an elevated calcium level and mediastinal, cervical, and abdominal lymphadenopathy. What is his most likely diagnosis?

A. Essential hypertension
B. Multiple endocrine neoplasia type 2 (MEN 2)
C. Familial hypocalciuric hypercalcemia
D. Tertiary hyperparathyroidism

15. A patient presents with the following laboratory values:

A. Normal serum osmolality
B. Decreased serum sodium level
C. Normal urine osmolality
D. Increased urine specific gravity

What is the patient's most likely diagnosis?

A. Diabetes insipidus
B. Syndrome of inappropriate antidiuretic hormone (SIADH)
C. Mannitol treatment
D. Diabetes mellitus

16. A 17-year-old male is admitted to the emergency room with complaints of headache, muscle cramps, and weakness. He is found to have a metabolic alkalosis with mild hypernatremia and hypokalemia. His blood pressure is elevated. Otherwise his exam is normal. What is the patient's most likely diagnosis?

A. Conn's disease
B. Hypoaldosteronism
C. Diabetes insipidus
D. Acute adrenal crisis

17. A patient with DiGeorge syndrome might present with:

A. Acromegaly
B. Gastroschisis
C. Trousseau sign
D. Hyperthyroidism

18. A 16-year-old female presents with hyponatremia several days after resection of a pituitary tumor. The serum sodium level is 126 mEq/L, the serum osmolality is 266 mOsm/L, and the urine osmolality is 110 mOsm/L. Clinically, the patient does not seem to be dehydrated and is doing well. Which treatment is indicated for this patient?

A. Dextrose 5% in half normal saline bolus
B. 3% saline bolus

C. Desmopressin
D. Fluid restriction

19. Which answer regarding the thyroid and its hormones is true?

A. Thyroid hormone synthesis is catalyzed by the enzyme thyroid peroxidase.
B. Thyroid hormones are stored in the thyroid in thyroxine-binding globulin.
C. T4 is 10 times more active than T3.
D. Circulating thyroid hormones stimulate TRH production.

20. A 4-year-old female presents with the following symptoms: muscle weakness, obesity, glucose intolerance, hypertension, short stature, and hirsutism. What is the most likely cause of her symptoms?

A. Prader-Willi syndrome
B. Pheochromocytoma
C. Cushing syndrome
D. Growth hormone deficiency

21. An infant, born in an area without newborn screening programs, presents with hypotonia and is jaundiced. The parents complain that the infant is sleeping most of the day and has little interest in feeding. On exam the patient has a low temperature, a large tongue, an umbilical hernia, decreased deep tendon reflexes, and large fontanelles.
What is the infant's most likely diagnosis?

A. Congenital muscular dystrophy
B. Hypoxic-ischemic encephalopathy
C. Werdig-Hoffmann disease
D. Congenital hypothyroidism

22. Kearns-Sayre syndrome (KSS) is associated with which of the following:

A. Hirsutism
B. Episodic vomiting
C. Hydrocephalus
D. Horseshoe kidney

23. Which abnormality can be present in a child with long-standing diabetes mellitus?

A. Atlantooccipital instability
B. Myopathy
C. Hydrocephalus
D. Reduced vital capacity

24. Medullary thyroid carcinoma is most often associated with:

A. Pheochromocytoma
B. Conn syndrome
C. Sheehan syndrome
D. Graves' disease

25. A 10-year-old female has had asthma attacks in the past and is on nebulizer treatments q6h at home. She had a course of prednisone in the past and is now admitted for appendicitis. She has been wheezing in the past month but has been off steroids for over a week. The patient is dehydrated, febrile, and tachycardic. Under anesthesia the patient is found to have severe hypotension. After surgery she has nausea, is complaining of abdominal pain, and is lethargic. She is still hypotensive and needs vasopressor support. What is the likely cause of her postoperative symptoms?

A. Anaphylactic reaction to muscle relaxants
B. Adrenal crisis
C. Conn disease
D. Massive postoperative abdominal hemorrhage

CHAPTER 9 ANSWERS

1. ANSWER: D

DKA is defined as hyperglycemia, blood glucose of >200 mg/dL, and metabolic acidosis, venous pH of less than 7.3, and/or plasma bicarbonate <15 mEq/L. DKA is frequently the initial presentation of children with new-onset type 1 diabetes mellitus. In a surveillance study of almost 3000 episodes of DKA in the United Kingdom, 38% of cases occurred in patients at the time of initial diagnosis of diabetes mellitus. It often presents with abdominal pain. Older children and adolescents typically present with polyuria (due to the glucose-induced osmotic diuresis), polydipsia (due to the increased urinary losses), and fatigue. Other findings include weight loss, nocturia, daytime enuresis, and vaginal or cutaneous candidiasis. Hypovolemia may be severe if the urinary losses are not replaced.

In infants, the diagnosis is more difficult because the patients are not toilet trained, and they cannot express thirst. As a result, polyuria may not be detected, and polydipsia is not apparent. However, decreased energy and activity, irritability, weight loss, and physical signs of dehydration are common findings. **DKA patients present with severe dehydration, tachycardia, urine with ketone and glucose, and metabolic acidosis. They also present with hyperventilation to compensate for the metabolic acidosis.**

As treatment they should receive an adequate amount of isotonic fluid to replenish. Overly aggressive fluid resuscitation can lead to cerebral edema. Thus, it is important to measure serum osmolality during the fluid resuscitation and fluid administration should not exceed 4 L/m^2 per day. The usually tragic outcome of cerebral edema complicating diabetic ketoacidosis has prompted proposals for alterations in conventional fluid and insulin therapy. Though the incidence of cerebral edema is only about 1% among those with diabetic ketoacidosis, it is the most common cause of mortality, accounting for 57% to 87% of all pediatric diabetic ketoacidosis deaths. Surgery should not be delayed because it may not be possible to correct the metabolic derangements in a timely fashion when the patient presents with an emergency.

The osmotic diuresis and increased ketoacid excretion promote urinary potassium loss, while vomiting and diarrhea increase gastrointestinal potassium losses, which can lead to hypokalemia. However, the combination of insulin deficiency, which impairs potassium entry into the cells, and hyperosmolality, which pulls water and potassium out of the cells, tends to raise the serum potassium concentration. Succinylcholine should be used with caution because it increases potassium, and this patient might have acidosis-related hyperkalemia.

KEY FACTS

- DKA is frequently the initial presentation of children with new-onset type 1 diabetes mellitus and often presents with abdominal pain, polyuria, polydipsia, and fatigue.
- In infants, the diagnosis is more difficult, and signs include tachycardia from severe dehydration, urinalysis positive for ketones and glucose, and hyperventilation to compensate for the metabolic acidosis.
- It is important to measure serum osmolality during the fluid resuscitation, fluid administration should not exceed 4 L/m^2 per day, and the patient should be monitored for signs of increasing cerebral pressure.

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Edge JA, Jakes RW, Roy Y, et al. The UK case-control study of cerebral oedema complicating diabetic ketoacidosis in children. *Diabetologia*, 2006;49:2002–2009.

Horn J, Sinert R. Is fluid therapy associated with cerebral edema in children with Diabetic ketoacidosis? Ann *Emerg Med*, 2008;52:69–71.

2. ANSWER B

Diabetes insipidus (DI) is caused by inadequate production of or inadequate response to ADH. It presents with hypotonic polyuria and polydipsia, just as patients who received mannitol or with diabetes mellitus. Urine output might be 10–20 mL/kg per hour.

There are three major causes of polyuria—primary polydipsia, central DI, and nephrogenic DI—associated with an increase in water output and the excretion of hypotonic urine. Measurement of the plasma sodium concentration and the urine osmolality may be helpful in distinguishing between these disorders:

- A low plasma sodium concentration (less than 137 mEq/L) with a low urine osmolality (less than one-half the plasma osmolality) is usually indicative of water overload due to primary polydipsia.
- **A high-normal plasma sodium concentration (greater than 142 mEq/L, due to water loss) points toward DI, particularly if the urine osmolality is less than the plasma osmolality.**
- A normal plasma sodium concentration associated with a urine osmolality more than 600 mOsmol/L excludes a diagnosis of DI.

In DI, urine specific gravity is less than 1.005.

- DI usually occurs following destruction of the pituitary gland by trauma, infiltrating lesions, or surgery (most

commonly after craniopharyngioma resections) and might be transient.

Treatment of DI involves water replacement and exogenous vasopressin. Desmopressin is less potent and does not cause the severe vasoconstriction that can be seen with vasopressin. Desmopressin has a long half-life of 10–20 hours (depending on form of administration) compared to vasopressin (less than 1 hour). It is the drug of choice to treat most forms of DI. The dosage is significantly smaller than the dosage given to patients with von Willbrand disease (up to 1/40 of the dose).

Nephrogenic DI is characterized by normal ADH secretion but varying degrees of renal resistance to its water-retaining effect. Nephrogenic DI presenting in childhood is almost always due to inherited defects. The most obvious cause is a kidney or systemic disorder (amyloidosis, polycystic kidney disease, and lithium toxicity). Hydrochlorothiazide may improve symptoms. Although hydrochlorothiazide is a diuretic, in certain cases it can actually reduce urine output for people with nephrogenic DI. Desmopressin does not improve symptoms as the ADH receptors in the kidney do not respond properly to ADH.

KEY FACTS

- DI usually occurs following destruction of the pituitary gland by trauma, infiltrating lesions, or surgery (most commonly after craniopharyngioma resections) and might be transient.
- A high-normal plasma sodium concentration (greater than 142 mEq/L) points toward DI, particularly if the urine osmolality is less than the plasma osmolality.
- Treatment of DI involves water replacement and exogenous vasopressin.

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Davis PJ, Cladis FP, Motoyama EK, eds. *Smith's Anesthesia for Infants and Children*. 8th ed. St. Louis, MO: Elsevier Mosby; 2011:1103.

Holzman R, Mancuso TJ, Polaner DM. *A Practical Approach to Pediatric Anesthesia*. Philadelphia, PA: Lippincott, Williams & Wilkins; 2008:535.

3. ANSWER: C

Hyperthyroidism is caused by an excess of circulating thyroid hormones, which results in a **hypermetabolic** state. Hyperthyroidism is most commonly caused by Graves' disease in children. Its peak incidence is during adolescence and is more common in females. Most of these children have an enlarged palpable thyroid gland. **Patients present with the aforementioned symptoms, as well as diarrhea, increased appetite, sweating, and sometimes a large tongue**.

Preoperatively the patients with hyperthyroidism should be euthyroid, as morbidity and mortality are increased otherwise. The patient needs to be stable from the cardiovascular standpoint. Most hyperthyroid patients are on beta-blockers.

Treatment is with antithyroid medication, surgical removal of gland, or radioactive ablation. Long-term remission rates are greater in pubertal than prepubertal children.

The enlarged goiter can cause **tracheal deviation and compression**. Caution should be used when giving premedication. One should anticipate a potential difficult airway. The goal of intraoperative management is to achieve a depth of anesthesia that prevents an exaggerated sympathetic response to surgical stimulation. Anticholinergic drugs should be avoided because of tachycardia and they interfere with sweating.

Another cause of hyperthyroidism can be congenital hyperthyroidism. It is due to transfer of thyroid-stimulating antibodies from the mother who has Graves' disease. The neonates need to be medicated with methimazole until the maternal immunoglobulins are gone, which usually takes a few weeks to months.

KEY FACTS

- Hyperthyroidism is most commonly caused by Graves' disease in children.
- Symptoms include fever, palpitations, tremor, tachycardia, exophthalmos, heat intolerance, warm sweaty skin, brisk reflexes, diarrhea, increased appetite, and sometimes a large tongue.
- The enlarged goiter can cause tracheal deviation and compression, and it could potentially cause a difficult airway.

REFERENCE

Cote CJ, Lerman J, Anderson B, eds. *A Practice of Anesthesia for Infants and Children*. 5th ed. Philadelphia, PA: Saunders; 2013:548–9.

4. ANSWER: D

Depending on the thyroid intake, up to 13% of patients treated with amiodarone develop thyroid dysfunction (either hyper- or hypothyroidism). Approximately 40% of the drug's weight is iodine. This iodine can lead to reduced or increased synthesis of thyroxine. Amiodarone also inhibits the conversion of T4 into T3. Amiodarone contains two iodine atoms. It is estimated that amiodarone metabolism in the liver releases approximately 3 mg of inorganic iodine into the systemic circulation per 100 mg of amiodarone ingested. The average iodine content in a typical American diet is about 0.3 mg/day. Thus, 6 mg of iodine associated

with a 200 mg dose of amiodarone markedly increases the daily iodine load.

Amiodarone inhibits outer ring 5′-monodeiodination of T4, thus decreasing T3 production. Amiodarone, and particularly the metabolite desethylamiodarone, blocks T3-receptor binding to nuclear receptors and decreases expression of some thyroid hormone-related genes. And it may have a direct toxic effect on thyroid follicular cells, which results in a destructive thyroiditis.

The elimination half-life of amiodarone is highly variable, ranging from 50 to100 days. **Total body iodine stores remain increased for up to 9 months after discontinuation of the drug**. Thyroid abnormalities have been noted in up to 15% of patients receiving long-term amiodarone therapy.

Methamizole is the mainstay of the antithyroid therapy. It can cause elevated liver enzymes, neutropenia, and lymphadenopathy.

Propofol has no effect on the thyroid gland and can be given.

Propanolol, a beta-blocker, is often used in the treatment of the symptoms of hyperthyroidism that are caused by increased beta-adrenergic tone.

KEY FACTS

- Depending on the thyroid intake, up to 13% of patients treated with amiodarone develop thyroid dysfunction.
- Approximately 40% of the drug's weight is iodine, and total body iodine stores remain increased for up to 9 months after discontinuation of the drug.
- Amiodarone and its metabolite desethylamiodarone block T3-receptor binding and may have direct toxic effects on the thyroid follicular cells.

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Cote CJ, Lerman J, Anderson B, eds. *A Practice of Anesthesia for Infants and Children*. 5th ed. Philadelphia, PA: Saunders; 2013:548.

Fleisher L, ed. *Anesthesia and Uncommon Diseases*. 6th ed. Philadelphia, PA: Saunders Elsevier; 2012:412.

5. ANSWER: A

The most prevalent syndrome that includes **hypoparathyroidism is DiGeorge syndrome.** DiGeorge syndrome (DGS) is a disorder that arises from a failure of migration of neural crest cells into the third and fourth pharyngeal pouches. Affected patients typically present in the first week after birth with signs of hypocalcemia, such as tetany or seizures, secondary to hypoplastic or absent parathyroid glands.

These patients have characteristic facial features that include **choanal atresia, a small mouth, and sometimes micrognathia (>50% have otolaryngologic manifestations). Cardiac defects (75% of patients), especially abnormalities of the outflow tract or aortic arch (truncus arteriosus, Tetralogy of Fallot), are present frequently.** Thymic hypoplasia results in an immune defect that is highly variable. Thymic hypoplasia in DGS results in a range of T cell deficits. Most patients with DGS have mild defects in T cell numbers and are not clinically immunodeficient.

DGS appears to be the most severe phenotype of a group of related disorders known as CATCH 22 syndrome, an acronym for cardiac defects, abnormal facies, thymic hypoplasia, cleft palate, and hypocalcemia caused by chromosome 22q11 deletion. The classic triad of features of DGS on presentation is **conotruncal cardiac anomalies, hypoplastic thymus, and hypocalcemia (>60% of patients)**.

Williams-Beuren syndrome presents with an "elfin" facies; supravalvular aortic stenosis or other vascular anomalies; hypertension; endocrine abnormalities, including hypercalcemia, diabetes mellitus, and subclinical hypothyroidism; and genitourinary abnormalities.

Trisomy 21 (Down syndrome) is associated with heart defects (most commonly VSD, ASD, AV-canal), hypothyroidism, hypotonia, and so on. This syndrome is not associated with hypocalcemia or seizures.

KEY FACTS

- DiGeorge syndrome presents with choanal atresia, a small mouth/micrognathia, cardiac defects, and thymic hypoplasia, and hypoparathyroidism leading to hypocalcemia.
- DiGeorge syndrome is the most severe phenotype of CATCH 22 syndrome, caused by chromosome 22q11 delection.

REFERENCE

Baum VC, O'Flaherty JE, eds. *Anesthesia for Genetic, Metabolic, and Dysmorphic Syndromes of Childhood*. 2nd ed. Philadelphia, PA: Lippincott, Williams & Wilkins; 2007:105.

6. ANSWER: A

Cerebral salt wasting (CSW) is a potential cause of **hyponatremia** in those with CNS disease, particularly in patients with **subarachnoid hemorrhage** but also in **children with brain tumors.** CSW is characterized by hyponatremia and extracellular fluid depletion due to inappropriate sodium wasting in the urine. The mechanism by which cerebral disease might lead to renal salt wasting is poorly understood.

It is a primary natriuresis probably related to dysregulation of the brain or atrial natriuretic peptides. It is defined as:

- Hyponatremia (less than 135 mEq/L) with a low plasma osmolality

- An inappropriately elevated urine osmolality (above 100 mosmol/kg and often even above 300 mosmol/kg)
- A urine sodium concentration usually above 40 mEq/L
- A low serum uric acid concentration due to urate wasting in the urine

CSW must be distinguished from other causes of hyponatremia, principally SIADH.

It is only the presence of clear evidence of volume depletion (hypotension, decreased skin turgor, elevated hematocrit, possibly increased BUN/serum creatinine ratio) despite a urine sodium concentration that is not low that suggests that CSW might be present rather than SIADH. By comparison, extracellular fluid volume is normal or slightly increased with SIADH.

Treatment consists of fluid resuscitation and sometimes flucortisone. Spontaneous resolutions often occur.

KEY FACTS

- Cerebral salt wasting is characterized by hyponatremia and extracellular fluid depletion due to inappropriate sodium wasting in the urine, and it is often seen in patients with subarachnoid hemorrhage and brain tumors.
- It is defined as a serum sodium <135 mEq/L with low plasma osmolality, elevated urine osmolality, a urine sodium >40 mEq/L, and a low serum uric acid level in the presence of volume depletion.
- Cerebral salt wasting must be distinguished from SIADH, which usually presents with normal or increased extracellular fluid volume.

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Cote CJ, Lerman J, Anderson B, eds. *A Practice of Anesthesia for Infants and Children*. 5th ed. Philadelphia, PA: Saunders; 2013:177.

Davies PJ, Cladis FP, Motoyama, EK, eds. *Smith's Anesthesia for Infants and Children*. 8th ed. Philadelphia, PA: Elsevier Mosby; 2011:728.

7. ANSWER: A

Mauriac syndrome is caused by low insulin levels. Nowadays it is a rare complication in children and adolescents with diabetes mellitus type 1, characterized by **growth retardation, hepatomegaly, and cushingoid features.** Symptoms tend to rectify with attainment of euglycemia.

The incidence of this syndrome has decreased significantly with introduction of long-acting insulin and better control of blood glucose levels.

The growth retardation is often referred to as diabetic dwarfism. The cause of growth failure in Mauriac syndrome has remained obscure, although it is presumably related to the poor metabolic control of diabetes.

Growth hormone deficiency has not been found in reported cases of Mauriac syndrome.

KEY FACTS

- Mauriac syndrome is caused by low insulin levels and is characterized by growth retardation, hepatomegaly, and cushingoid features.
- The growth retardation is often referred to as diabetic dwarfism.
- The incidence of this syndrome has decreased significantly with introduction of long-acting insulin and better control of blood glucose levels.

REFERENCE

Elder CJ, Natarajan A. Mauriac syndrome – a modern reality. *J Pediatr Endocrinol Metab*. 2010;23(3):311–3.

8. ANSWER: B

Ambiguous genitalia of the female is most commonly caused by **congenital adrenocortical insufficiency,** an autosomal recessive disease resulting from a defect in one of the enzymes of cortisol biosynthesis. Ninety-five percent of the cases are caused by 21-hydroxylase deficiency. This results in overproduction of cortisol precursors, especially 17-OH progesterone, which causes excessive androgen production. About 50% of these patients also have a defect in aldosterone synthesis. If untreated, this can cause severe salt wasting and death (Addison crisis). These patients need **salt-containing IV fluids and a stress dose of cortisol** prior to surgery—for example, 2 mg/kg hydrocortisone IV.

Gonadoblastoma is a complex neoplasm composed of a mixture of gonadal elements. It does not typically demonstrate invasive behavior; however, 50% of the specimens demonstrate evidence of local overgrowth by the germinal component, and approximately 10% of these germinomas/seminomas have demonstrated metastases. The presence of Y chromosome material in patients with Turner syndrome is a risk factor for the development of gonadoblastoma.

Denys-Drash syndrome (DDS) is a rare disorder consisting of the triad of congenital nephropathy, Wilms tumor, and intersex disorders.

Partial androgen insensitivity syndrome (PAIS) is a condition that results in the partial inability of the cell to respond to androgens. The partial unresponsiveness of the cell to the presence of androgenic hormones impairs the masculinization of male genitalia in the developing fetus, as well as the development of male secondary sexual characteristics at puberty, but does not significantly impair female genital or sexual development.

KEY FACTS

- Ambiguous genitalia of the female is most commonly caused by congenital adrenocortical insufficiency, often from excessive androgen production.
- If untreated, this can cause severe salt wasting and death (Addison crisis).
- These patients need salt-containing IV fluids and a stress dose of cortisol prior to surgery.

REFERENCES

Baum VC, O'Flaherty JE, eds. *Anesthesia for Genetic, Metabolic, and Dysmorphic Syndromes of Childhood*. 2nd ed. Philadelphia, PA: Lippincott, Williams & Wilkins; 2007:82–3.

Davies PJ, Cladis FP, Motoyama, EK, eds. *Smith's Anesthesia for Infants and Children*. 8th ed. Philadelphia, PA: Elsevier Mosby; 2011:1105–6.

9. ANSWER: D

Graves' disease is more common in girls than in boys, and it is more common in adolescents. It occurs in approximately 0.02% of children (1 in 5000). Graves disease was named after an Irish doctor, Sir Robert Graves.

Graves' disease is an autoimmune disorder and the most common cause of childhood hyperthyroidism. Thyroid-stimulating immunoglobulins bind to the TSH receptors and cause hyperstimulation. Most patients present with goiter, proptosis, tachycardia, weight loss with diarrhea, tremor, brisk reflexes, heat intolerance, dyspnea, and inability to concentrate (attention-deficit disorder–like symptoms). Sometimes these patients have pretibial myxedema and ophthalmopathy. This is caused by an inflammation of the extraocular muscles, the tissue and the orbital fat, which leads to the proptosis and restricted eye movement. Special intraoperative attention to eye protection is necessary. Sometimes patients present with systolic hypertension and may have atrial fibrillation or mitral regurgitation.

Diagnosis requires identification of suppressed TSH levels and elevated levels of free thyroxine (FT4) and/or triiodothyronine (T3). Treatment is directed at alleviating symptoms and reducing thyroid hormone production. Symptoms may be improved by treatment with beta-blocking drugs alone. Most pediatric endocrinologists recommend antithyroid drug therapy as initial treatment in the hope that the patient will have a remission of Graves' disease and therefore will remain euthyroid after treatment is discontinued. There is a growing acceptance of radioactive iodine therapy for children older than 10 years and adolescents as a second, and in some cases, initial treatment. Surgical near-total thyroidectomy is an equally effective and safe treatment.

The most severe manifestation of Graves' disease is thyroid storm. Thyroid storm causes high fever, dehydration, diarrhea, rapid and irregular heart rate, shock, and potentially death, if not treated.

KEY FACTS

- Graves' disease is an autoimmune disorder and the most common cause of childhood hyperthyroidism.
- Most patients present with goiter, proptosis, tachycardia, weight loss with diarrhea, tremor, brisk reflexes, heat intolerance, dyspnea, and inability to concentrate.
- Treatment includes antithyroid drug therapy (radioactive iodine) as well as beta-blocking agents and surgical near-total thyroidectomy.

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Cote CJ, Lerman J, Anderson B, eds. *A Practice of Anesthesia for Infants and Children*. 5th ed. Philadelphia, PA: Saunders; 2013:548.

Davies PJ, Cladis FP, Motoyama, EK, eds. *Smith's Anesthesia for Infants and Children*. 8th ed. Philadelphia, PA: Elsevier Mosby; 2011:1108–9.

10. ANSWER: C

Neural crest cells migrate between endoderm and ectoderm to form the adrenal medulla and the sympathetic ganglia. Their transformation into pheochromocytes results in histologically characterized chromaffinic tumors in the medulla of the adrenal gland (pheochromocytomas) or at an extra-adrenal site (10%) of sympathetic ganglia. Only cells that stain positive for chromaffin secrete catecholamines.

The tumor cells have the ability to secrete norepinephrine, epinephrine, and dopamine. **Pheochromocytomas are 10% malignant and 10% bilateral. Approximately 10% of all pheochromocytomas are diagnosed in childhood.** Pheochromocytomas in childhood are more often benign, bilateral, and multiple in number and more often extra-adrenal. In children approximately 50% of the tumors are inherited in an autosomal dominant pattern (von Hippel-Lindau is most often the cause for familial pheochromocytoma).

Supraphysiologic secretion of catecholamines results in increased levels of norepinephrine and, to a lesser extent, epinephrine. The most obvious effects are an increase vascular resistance with hypertension and tachycardia. Due to the hypertension, circulating blood volume can be reduced. Long-standing hypertension may result in ventricular hypertrophy, cardiomyopathy, and heart failure. Patients also present with tremor, palpitations, sweating, and headache.

Catecholamines (norepinephrine, dopamine, and epinephrine) levels are elevated in the blood and urine. **Catecholamine metabolites (vanillyl mandelic acid)**

and homovanillic acid levels in the blood and urine are elevated.

The preoperative preparation consists of **fluid resuscitation and alpha-blockade** before beta-blockade (to control tachycardia and dysrhythmias). Excessive catecholamines may be associated with hyperglycemia and hypokalemia. In addition to pharmacologic preparation, children benefit from preoperative sedation to reduce the release of catecholamines.

The resection of the tumor is typically curative. Malignant tumors may require chemotherapy.

KEY FACTS

- Pheochromocytomas in childhood are more often benign, bilateral, and multiple in number and more often extra-adrenal.
- Secretion of catecholamines results in increased vascular resistance, hypertension, tachycardia, and a reduction in circulating blood volume.
- The preoperative preparation consists of fluid resuscitation and alpha-blockade before beta-blockade to control tachycardia and dysrhythmias.

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Cote CJ, Lerman J, Anderson B, eds. *A Practice of Anesthesia for Infants and Children*. 5th ed. Philadelphia, PA: Saunders; 2013:578–9.

Davies PJ, Cladis FP, Motoyama, EK, eds. *Smith's Anesthesia for Infants and Children*. 8th ed. Philadelphia, PA: Elsevier Mosby; 2011:1111.

11. ANSWER: B

Trauma, surgery, and stress can cause a complex endocrine response with an increase in so-called stress hormones. **Serum level of ADH increases with surgical stimulation and stress**. This can lead to decreased urine output under anesthesia. A small dose of furosemide can counteract this effect. Other responses to surgical stress include increased glucose level secondary to a decreased insulin level, increased cortisol, increased catecholamine level, increased endorphins, and increased renin. **Hyperglycemia is a prominent feature of the metabolic response to surgery and results from an increase in glucose production,** at the same time as a reduction in glucose utilization due to increased catecholamines and cortisol, which promote glycogenolysis and gluconeogenesis.

Also protein anabolism is inhibited in the beginning of surgery followed by enhanced catabolism. Protein catabolism is stimulated by increased cortisol and cytokine concentrations. The amount of protein degradation is influenced by the type of surgery and also by the nutritional status of the patient. Increased production of stress hormones promotes lipolysis and ketone body production. The net effect of the endocrine response to surgery is an increased secretion of catabolic hormones.

Stress response in the fetus is still not fully discovered. The nociceptive apparatus starts to develop in the 7th gestational week and is present almost in the whole body by week 20. A fetus in the second trimester can have a stress response to painful stimuli. Administration of pain medication can lessen/abolish this response. It is not yet known when noxious stimuli involve the cortex and when "consciousness" is present.

KEY FACTS

- Trauma, surgery, and stress can lead to decreased urine output due to increased ADH levels, increased glucose level secondary to a decreased insulin level, increased cortisol, increased catecholamine level, increased endorphins, and increased renin.
- The net effect of the endocrine response to surgery is an increased secretion of catabolic hormones.
- Increased production of stress hormones promotes lipolysis and ketone body production.

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Davies PJ, Cladis FP, Motoyama, EK, eds. *Smith's Anesthesia for Infants and Children*. 8th ed. Philadelphia, PA: Elsevier Mosby; 2011:604.

12. ANSWER: C

Neuroblastoma is the most common extracranial solid tumor in children. Approximately 15% of all childhood cancer mortality is secondary to neuroblastomas. Neuroblastomas arise in 50% of the cases from the medulla of the adrenal glands. The location of the other 50% is along the sympathetic chain—25% abdominal, 25% above the diaphragm. Most pediatric patients who present with the tumor are under 5 years of age (some diagnosed antenatally).

The etiology of the tumor is unknown, but it is associated with other disorders like Beckwith-Wiedemann syndrome, neurofibromatosis 1, and Hirschsprung disease.

Neuroblastomas can exhibit extreme heterogeneity. The tumor metastasizes into lymph nodes, bones marrow, and liver. Patients often present with abdominal pain due to tumor size and pressure on the adjacent organs. The tumor can cause paraneoplastic syndromes (excessive catecholamine levels, cerebellar ataxia, and others).

Approximately 90% of the patients have elevated catecholamines in the urine. But less than 50% of the patients have hypertension despite the elevated catecholamine levels.

Treatment includes surgical removal, if possible; radiotherapy; and chemotherapy.

Surgical removal of the tumor can lead to significant blood loss. It also can lead to catecholamine surge from the tumor. Despite possible mediastinal location, airway compromise is rare as the tumor usually lies in the posterior mediastinum.

The two most important factors for prognosis are age and tumor stage (younger age has a better prognosis). In rare cases spontaneous regression has been described.

KEY FACTS

- Neuroblastoma is the most common extracranial solid tumor in children, and most patients present before the age of 5 years.
- It is associated with other disorders such as Beckwith-Wiedemann syndrome, neurofibromatosis 1, and Hirschsprung disease.
- The two most important factors for prognosis are age and tumor stage (younger age has a better prognosis).

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Cote CJ, Lerman J, Anderson B, eds. *A Practice of Anesthesia for Infants and Children*. 5th ed. Philadelphia, PA: Saunders; 2013:586–7.

Davies PJ, Cladis FP, Motoyama, EK, eds. *Smith's Anesthesia for Infants and Children*. 8th ed. Philadelphia, PA: Elsevier Mosby; 2011:754–5.

13. ANSWER: C

Beckwith-Wiedemann syndrome usually occurs sporadically but is also linked to autosomal dominant inheritance. Defects in the region 11p15.5 and underexpression of the p57 gene and an overexpression of the insulin-like growth factor 2 gene (IGF2) are associated with the syndrome. Most cases are associated with a defect in chromosome 11. Beckwith-Wiedemann syndrome is a rare disease with an incidence of 1:13,700.

The patients present with macrosomia (large for gestational age), macroglossia, omphalocele, and visceromegaly. They have increased muscle mass and advanced bone age in childhood due to accelerated osseous maturation. **These patients are at increased risk of abdominal tumors (Wilms' tumor, neuroblastoma, nephroblastoma, and others)**. The five most common features are macroglossia, macrosomia, midline abdominal wall defects, ear creases, and neonatal hypoglycemia. The hypoglycemia can potentially be severe and is caused by hyperinsulinism, which is caused by enlarged pancreas islet cells. Other features are large, prominent eyes, enlarged fontanelle, and a metotopic ridge (a ridge in the forehead caused by premature closure of the bones). These patients might develop cor pulmonale secondary to chronic airway obstruction and might have mild to moderate mental retardation.

Anesthetic considerations include an increased risk of airway obstruction and possible difficult airway secondary to a large tongue.

Prader-Willi syndrome (PWS) is the most common known genetic cause of obesity in children. The patients usually present with a low birth weight and hypotonia. It eventually leads to short stature, if not treated with growth hormone, and incomplete sexual development; it can also lead to excessive eating and life-threatening obesity. Most of the patients have a below normal IQ and social and motor deficits.

Achondroplasia is the most common cause of dwarfism and is associated with large fontanelles but not associated with neonatal hypoglycemia or omphalocele.

KEY FACTS

- Beckwith-Wiedemann syndrome presents with macrosomia, macroglossia, midline abdominal wall defects (omphalocele), visceromegaly, ear creases, and neonatal hypoglycemia.
- Other features are large, prominent eyes, enlarged fontanelles, and a metotopic ridge (a ridge in the forehead caused by premature closure of the bones).
- Anesthetic considerations include an increased risk of airway obstruction and possible difficult airway secondary to a large tongue.

REFERENCE

Baum VC, O'Flaherty JE, eds. *Anesthesia for Genetic, Metabolic, and Dysmorphic Syndromes of Childhood*. 2nd ed. Philadelphia, PA: Lippincott, Williams & Wilkins; 2007:49–50.

14. ANSWER: B

MEN 2 is a subtype of multiple endocrine neoplasia (MEN). It has subtypes of its own. MEN 2 is commonly an autosomal dominant inherited disorder, which is associated with several tumors of the endocrine system. These tumors can be benign or malignant. **MEN 2 involves medullary thyroid carcinoma, pheochromocytoma, and parathyroid adenoma**. Von Hippel-Lindau disease is also associated with MEN 2. Most of the time patients present with symptoms caused by the medullary thyroid cancer (MTC). MTC accounts for 5% of all thyroid tumors. It is often malignant and is the most common cause of death in patients with MEN 2. The overall survival of patients with MTC is 86% at 5 years and 65% at 10 years. Its metastases cause lymphadenopathy in the neck and the mediastinum. It spreads to the liver, lung, and bone.

Pheochromocytoma occurs in 50% of the patients. Primary hyperparathyroidism presents with hypercalcemia and is rare in children. It usually occurs when patients are over 20 years old. Some of the patients with MEN 2 have a marfanoid habitus. Treatment is surgical and consists of thyroidectomy, adrenalectomy for pheochromocytoma, and/or resection of the parathyroid glands. Familial genetic screening is recommended.

MEN 1 is a syndrome that includes tumors of the pancreas (mostly gastrin secreting but also insulin and glucagon), tumors of the pituitary gland, and the parathyroid glands. It also is mostly inherited autosomal dominant.

Familial hypocalciuric hypercalcemia is a benign, inherited condition that causes abnormally high levels of calcium in the blood (hypercalcemia). Most cases are associated with loss of function mutations in the CASR gene, which encodes a calcium receptor. This receptor is expressed in parathyroid and kidney tissue. It is inherited in an autosomal dominant manner.

KEY FACTS

- MEN 2 is a subtype of multiple endocrine neoplasia (MEN) and typically involves medullary thyroid carcinoma, pheochromocytoma, and parathyroid adenoma.
- Medullary thyroid cancer is often malignant, with metastases to the lymph nodes, liver, lung, and bone. It is the most common cause of death in patients with MEN 2.
- MEN 1 is a syndrome that includes tumors of the pancreas (mostly gastrin secreting but also insulin and glucagon), tumors of the pituitary gland, and tumors of the parathyroid glands.

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Miller RD, Pardo M, eds. *Basics of Anesthesia*. 6th ed. Philadelphia, PA: Saunders Elsevier; 2011:470.

15. ANSWER: D

Hyperglycemia leads to normal serum/urine osmolality with a decreased sodium level and an increase in urine specific gravity due to glucosuria.

Diabetes insipidus leads to an increase in serum osmolality and serum sodium due to excessive diuresis with a decrease in urine osmolality and urine specific gravity.

SIADH leads to a decrease in serum osmolality and serum sodium with an increase in urine osmolality and urine specific gravity.

Mannitol treatment leads to an acute increase in serum osmolality, which normalizes after a while, and an increase in serum sodium, urine osmolality, and urine specific gravity.

KEY FACTS

- Hyperglycemia leads to normal serum/urine osmolality with a decreased sodium level and an increase in urine specific gravity due to glucosuria.
- Diabetes insipidus involves excessive diuresis and leads to increased serum osmolality and a decrease in urine osmolality.
- SIADH involves excessive water retention and leads to decreased serum osmolality and an increase in urine osmolality.

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Davies PJ, Cladis FP, Motoyama, EK, eds. *Smith's Anesthesia for Infants and Children*. 8th ed. Philadelphia, PA: Elsevier Mosby; 2011:1104.

16. ANSWER: A

This patient has Conn disease. **Conn disease is due to primary hyperaldosteronism.** Aldosterone is a steroid hormone that is produced in the zona glomerulosa of the adrenal gland. It mainly acts on the distal tubules and the collecting ducts of the nephrons in the kidney and causes **sodium retention, water retention, and potassium secretion**. Only 0.5%–1% of patients who have hypertension also have Conn disease, which is a form of low-renin hypertension. These patients have unilateral or bilateral adrenal adenomas. They present with high blood pressure, which can be refractory to medication. The most appropriate medication is spironolactone. Treatment consists of surgical removal of the adenoma.

Primary hyperaldosteronism presents with hypernatremia and hypokalemia leading to a metabolic alkalosis. Weakness is usually due to hypokalemia. Although hypokalemia is a classic sign of Conn disease, some patients present with hypertension with normal potassium levels. Mild hypomagnesemia might occur, which can cause muscle cramps in patients with persistent mineralocorticoid excess. How this occurs is not completely understood.

Aldosterone may raise the glomerular filtration rate (GFR) and renal perfusion pressure independent of systemic hypertension. Despite sodium and water retention, Conn disease does not typically lead to edema. This is due to spontaneous diuresis, which decreases the sodium

level. Patients with Conn disease usually have only mild hypernatremia.

Hypoaldosteronism presents with hyperkalemia and a mild hyperchloremic metabolic acidosis. Most often hypoaldosteronism is caused by acquired and sometimes by inherited disorders that affect the adrenal aldosterone synthesis or renal renin release. Plasma renin levels are usually increased.

Diabetes insipidus can lead to hypernatremia and hypokalemia but due to polyuria. These patients mostly have hypotension.

Acute adrenal crisis is a life-threatening disease caused by adrenocorticosteroid hormone deficiency. It leads to hypotension and hyponatremia with hyperkalemia.

KEY FACTS

- Conn disease is due to primary hyperaldosteronism and causes sodium retention, water retention, and potassium secretion, which leads to a metabolic alkalosis.
- Weakness can occur secondary to hypokalemia.
- Despite sodium and water retention, Conn disease does not typically lead to edema because of spontaneous diuresis.

REFERENCE

Fleisher L, ed. *Anesthesia and Uncommon Diseases*. 6th ed. Philadelphia, PA: Saunders Elsevier; 2012:422.

17. ANSWER: C

DiGeorge syndrome is caused by mutations in the gene TBX1 of the chromosome 22. Patients present with **micrognathia, short stature, hypoparathyroidism, and thrombocytopenia secondary to thymus hypoplasia**. These patients also have cardiovascular, airway, and GI complications. **Esophageal atresia, imperforated anus, and diaphragmatic hernias can be associated with DiGeorge syndrome but not gastroschisis.**

Chvostek sign is a clinical sign caused by hypocalcemia. Patients with DiGeorge syndrome often have hypoparathyroidism, which causes hypocalcemia. Hypocalcemia causes nerve hyperexcitability. When the masseter muscle of these patients is tapped (facial nerve), the facial muscles of the same side of the face will twitch (e.g., nose and lips). **Another clinical sign of hypocalcemia is the Trousseau sign.** It is more sensitive to detect hypocalcemia clinically than the Chvostek sign. To trigger the sign, one has to inflate a blood pressure cuff on the patient's arm and inflate it to a pressure greater than the patient's systolic blood pressure. The blood pressure cuff has to stay inflated for 3–5 minutes. The occlusion of the brachial artery will induce spasm of the hand and forearm. These spasms are secondary to the neuromuscular hyperexcitability, which is caused by the low calcium level. The wrist and the metacarpophalangeal joints flex and the fingers adduct.

There are many different causes for hypoparathyroidism, which leads to hypocalcemia.

Several genetic defects have been identified in patients with hypoparathyroidism; for example, Kenney-Caffey syndrome (congenital hypoparathyroidism, mental retardation, facial dysmorphism, and severe growth failure and immunodeficiency) or Kearns Sayre syndrome (ophthalmoplegia, pigmentary degeneration of the retina, and cardiomyopathy).

There is a form of autoimmune hypoparathyroidism called autoimmune polyendocrinopathy-candidiasis-ectodermal dystrophy (APECED) syndrome.

Hypoparathyroidism can also be acquired during thyroid surgery and parathyroidectomy.

Iron or copper deposition into the parathyroid glands also can cause hypoparathyroidism.

KEY FACTS

- Chvostek sign is a clinical sign caused by hypocalcemia; when the masseter muscle of these patients is tapped (facial nerve), the facial muscles of the same side of the face will twitch (e.g., nose and lips).
- Another clinical sign of hypocalcemia is the Trousseau sign. To trigger the sign, one has to inflate a blood pressure cuff on the patient's arm and inflate it to a pressure greater than the patient's systolic blood pressure for 3–5 minutes. The occlusion of the brachial artery will induce spasm of the hand and forearm.

REFERENCE

Baum VC, O'Flaherty JE, eds. *Anesthesia for Genetic, Metabolic, and Dysmorphic Syndromes of Childhood*. 2nd ed. Philadelphia, PA: Lippincott, Williams & Wilkins; 2007:103–4.

18. ANSWER: D

The patient presents with SIADH (syndrome of inappropriate ADH). It is a syndrome that presents with hyponatremia <135 mEq/L with a serum osmolality <280 mEq/L and a urine osmolality >100 mOsm/L.

These patients are normovolemic and have no renal failure and no thyroid failure. The patients have no edema and have normal adrenal function. **Major causes of SIADH are head injuries, brain tumors, cerebral hemorrhage/stroke, or cerebral infections.** It also can be caused by medications like DDAVP, carbamazepine, cisplatin, and tricyclic antidepressants. It is typically seen after pituitary

surgeries but also after major abdominal and thoracic surgeries. It can be caused by neoplasias and lung diseases (asthma). There is also a rare form of hereditary SIADH.

Typically these patients present with mild hyponatremia (sodium >125 mEq/L). If severe hyponatremia occurs (<120 mEq/L), the patients become symptomatic. Severe hyponatremia presents with confusion and general muscle weakness. These patients can present with tremor, myoclonus, and seizures. Severe hyponatremia can lead to coma. A bolus with hypertonic sodium chloride may be necessary (e.g., 2.5–5 mEq/kg per hour of 3% hypertonic saline). The sodium level is not to be corrected too rapidly, as this may lead to pontine myelinolysis. The goal is not to increase the sodium level more than 0.5 mEq/L per hour. Once a sodium level of 120–125 mEq/L is reached, the hypertonic saline infusion should be stopped.

Treatment of SIADH consists of fluid restriction. If the sodium level needs to be corrected, loop diuretics (e.g., furosemide 1 mg/kg) can be used. Vasopressin V1 and V2 receptor antagonists (e.g., Talvaptan, Conivaptan) are not (yet) the standard of care.

Desmopressin is given to treat diabetes insipidus.

KEY FACTS

- SIADH is a syndrome that presents with hyponatremia < 135 mEq/L, serum osmolality < 280 mEq/L, and urine osmolality > 100 mOsm/L.
- Major causes of SIADH are head injuries, brain tumors, cerebral hemorrhage/stroke or cerebral infections.
- Treatment of SIADH consists of fluid restriction. Severe hyponatremia can be treated with slowly with hypertonic sodium.
- The goal is not to increase the sodium level more than 0.5 mEq/L per hour to avoid pontine myelinolysis.

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Cote CJ, Lerman J, Anderson B, eds. *A Practice of Anesthesia for Infants and Children*. 5th ed. Philadelphia, PA: Saunders; 2013:546.

Davies PJ, Cladis FP, Motoyama, EK, eds. *Smith's Anesthesia for Infants and Children*. 8th ed. Philadelphia, PA: Elsevier Mosby; 2011:133–4.

19. ANSWER: A

The thyroid gland consists of two lobes that lie on either side of the ventral aspect of the trachea. The thyroid consists of follicular cells and colloid. Thyroid hormones are synthesized and stored in the thyroid.

Thyroid epithelial cells produce thyroglobulin, which is then secreted into the lumen of the follicle. Thyroglobulin consists of over 100 tyrosines. Iodine is taken up by the follicular cells from the blood by thyroid cells by active transport in exchange for sodium. Iodine uptake is the main control point for the hormone synthesis and is stimulated by thyroid-stimulating hormone (TSH) in the pituitary gland.

Thyroid peroxidase catalyzes the oxidation of iodine to form active iodine. Active iodine is then incorporated into the tyrosine of the thyroglobulin. Here the mono- and di-iodotyrosines (MIT and DIT) are formed and are transported across the follicular cells. The iodinated thyroglobulin is taken up into the colloid.

The thyroid hormone production is conducted by the enzyme thyroid peroxidase: A coupling reaction between pairs of iodinated tyrosine molecules occurs. The coupling of two tyrosine residues each iodinated at two positions (di-iodotyrosine [DIT]) produces tetra-iodothyronine or thyroxine (T4). The coupling of DIT with mono-iodotyrosine (MIT) produces tri-iodothyronine (T3).

These thyroid hormones T3 and T4 are stored in the thyroglobulin and released when thyroglobulin is taken back ino the follicular cells (TSH regulated). Then fusion of colloid with lysosomes release T3 and T4 from thyroglobulin. Approximately 10% of the T4 hormones are converted to T3 before it is secreted. (On average, 100 μg T4 and 10 μg T3 are secreted per day.)

T4 is the major circulation thyroid hormone, but T3 is the major physiologically active thyroid hormone **(T3 is 10 times more active than T4)**. Eighty percent of T4 hormone is converted in peripheral organs such as the liver and kidney to the more active T3 hormone. Thyroxine-binding globulin binds the thyroid hormones in the circulating bloodstream.

Level of T3 and T4 regulate the thyroid hormone production by inhibiting TRH (thyrotropin-releasing hormone in the hypothalamus) and TSH. Deficiency of iodine leads to a decreased production in thyroid hormones, which enlarges the thyroid gland.

KEY FACTS

- T4 is the major circulation thyroid hormone but T3 is the major physiologically active thyroid hormone.
- Eighty percent of T4 hormone is converted in peripheral organs such as the liver and kidney to the more active T3 hormone.
- Deficiency of iodine leads to a decreased production in thyroid hormones which enlarges the thyroid gland.

REFERENCES

Cote CJ, Lerman J, Anderson B, eds. *A Practice of Anesthesia for Infants and Children*. 5th ed. Philadelphia, PA: Saunders; 2013:547.

Nussey SS, Whitehead SA. *Endocrinology: An Integrated Approach*. Philadelphia, PA: CRC Press; 2001:Chapter 3, 71–81.

20. ANSWER: C

Cushing syndrome is found in children with adrenal tumors or ACTH-secreting tumors (pituitary gland), which lead to a state of hypercortisolism. But most often hypercortisolism is iatrogenic in children, usually caused by administration of excessive amounts of synthetic glucocorticoids, which are given for asthma and other diseases. **Patients with Cushing syndrome present with muscle wasting, truncal obesity, osteopenia, hypertension, hyperglycemia, growth deceleration, striae, hypokalemia, moon face, acne, thin skin, and mental changes such as depression or anxiety.** Complications of high steroid levels include diabetes mellitus, compression fractures, hypertension, infections, and psychosis.

Adrenal tumors causing Cushing syndrome have two age distributions: one in the first decade of life for both adenomas and carcinomas, and another at age 50 for adenomas and age 40 for carcinomas. Adrenal carcinoma is the cause of 50% of all cases of childhood Cushing syndrome. The tumor can secrete any combination of steroids, and it also secretes androgens, which result in hirsutism.

For diagnosis, urinary 24-hour cortisol and creatinine measurements can be obtained as well as late evening salivary cortisol levels. A low-dose dexamethasone suppression test should be obtained overnight. Treatment is removal of the tumor with possible radiation therapy.

KEY FACTS

- Cushing syndrome is found in children with adrenal tumors or ACTH-secreting tumors (pituitary gland), but most often is caused by medications.
- Patients present with muscle wasting, truncal obesity, osteopenia, hypertension, hyperglycemia, growth deceleration, striae, hypokalemia, moon faces, acne, thin skin and mental changes such as depression or anxiety.
- Adrenal carcinoma is the cause of 50% of all cases of childhood Cushing syndrome.
- Treatment is removal of the tumor or decrease in glucocorticoid therapy.

REFERENCE

Cote CJ, Lerman J, Anderson B, eds. *A Practice of Anesthesia for Infants and Children*. 5th ed. Philadelphia, PA: Saunders; 2013:553.

21. ANSWER: D

Congenital hypothyroidism occurs in approximately 1:2000 to 1:4000 newborns and is one of the most common preventable causes of intellectual disability. Congenital hypothyroidism usually presents in infancy. At birth some maternal thyroid hormones cross the placenta and the patients may have some thyroid function of their own. This combination leaves them with **25%–50% of normal thyroid hormone level at birth**—which slowly declines.

In the era before newborn screening, less than half of the cases of severe hypothyroidism were recognized in the first month of life. **As patients get older, more manifestations occur including poor growth, mental retardation, bradycardia, hypothermia, cold intolerance, and lethargy.** Very few patients have a palpable goiter.

The infants have a hoarse cry and have feeding difficulties. By several years of age, they display the recognizable facial and body features of what is called cretinism. Untreated the patients have severe mental impairment, with an IQ below 80. Severe cases with cardiovascular collapse, hyponatremia, and respiratory failure have been described.

In the United States, blood is collected 2–5 days after delivery on a filter paper. Some programs also routinely obtain a second specimen between 2 and 6 weeks after delivery. If the TSH (thyroid-stimulating hormone of the pituitary gland) filter paper test is positive, meaning the TSH is elevated—serum levels of T4 and TSH are obtained. If this test is positive (free T4 level low, TSH level high), the diagnosis of congenital hypothyroidism is made and the patient is started on L-thyroxine.

If the diagnosis of hypothyroidism is confirmed, other studies, such as thyroid radionuclide uptake and imaging, ultrasonography, serum thyroglobulin assay, tests for thyroid autoantibodies, or urinary iodine excretion, may be performed to identify the cause.

The most common cause of congenital hypothyroidism is thyroid dysgenesis. Over 80% of the cases are sporadic. If presenting later in childhood, it is most often due to an error of the thyroxine synthesis or an ectopic thyroid gland. Some patients have transient hypothyroidism, which is most often caused by maternal autoimmune thyroid disease and maternal iodine deficiency. These patients are able to discontinue their thyroid medication after 2–3 years of life.

Approximately 80%–90% of patients in the United States with congenital hypothyroidism prove to have permanent disease. They will require thyroid hormone replacement throughout life.

KEY FACTS

- Congenital hypothyroidism is one of the most common preventable causes of intellectual disability, and usually presents in infancy.
- Patients present with prolonged jaundice, umbilical hernias, poor growth, mental retardation, bradycardia, hypothermia and cold intolerance, and lethargy.
- The most common cause of congenital hypothyroidism is thyroid dysgenesis.
- Treatment is typically lifelong administration of L-thyroxine.

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Cote CJ, Lerman J, Anderson B, eds. *A Practice of Anesthesia for Infants and Children*. 5th ed. Philadelphia, PA: Saunders; 2013:547.
Davies PJ, Cladis FP, Motoyama, EK, eds. *Smith's Anesthesia for Infants and Children*. 8th ed. Philadelphia, PA: Elsevier Mosby; 2011:1107.
Fleisher L, ed. *Anesthesia and Uncommon Diseases*. 6th ed. Philadelphia, PA: Saunders Elsevier; 2012:413–4.

22. ANSWER A

Kearns-Sayre syndrome (KSS) is a mitochondrial myopathy. It usually occurs sporadically. Rarely is it inherited. Mitochondrial diseases are a group of disorders caused by pathologic dysfunction of the mitochondrial respiratory chain that present with a wide range of clinical expression. When skeletal muscle is affected, either alone or with central nervous system disease, it is called mitochondrial myopathy.

The diagnosis of a mitochondrial disease can be difficult. The evaluation and diagnostic approach vary according to age, clinical phenotype, and presumed inheritance pattern. To diagnose KSS, one should get testing for mitochondrial DNA studies. **The muscle biopsy remains one of the main tools for diagnosing a mitochondrial disorder.** When muscle cells of KSS patients are examined under a microscope, the cells contain an excess of mitochondria and are known as ragged-red fibers.

Onset of symptoms occurs typically before the age of 20. It occurs mostly sporadically but can also be familial. It is also known as oculocraniosomatic disease, as it is characterized by progressive external ophthalmoplegia that is associated with abnormal retinal pigmentation. KSS typically involves the muscles controlling the eyelid (which leads to ptosis) and eye movement. It can lead to vision loss and sensorineural hearing loss. The weakness can involve the pharynx, the respiratory muscles, and mostly the proximal muscles. This can lead to an increased aspiration risk. The muscle involvement can begin as unilateral but ultimately is bilateral and progressive.

These patients can have cardiac conduction abnormalities (AV-block), seizures, and dementia. They are known to have a short stature and kyphoscoliosis.

Hirsutism can occur secondary to a decrease in excretion of 17-ketosteroids and 11-hydroxycorticoids. Diabetes mellitus and hyperglycemia can occur.

Patients with KSS are often sensitive to medications (especially muscle relaxants). Succinylcholine should be avoided because it can cause significant hyperkalemia in patients with myopathy.

There is currently no specific treatment for KSS patients. Treatment is generally symptomatic and supportive. They may require a hearing aid. There is typically no treatment for limitation in eye movement. KSS is a slowly progressive disorder. For prognosis it is important to have the patients followed by a cardiologist, as heart block is the cause of death in approximately 20% of the patients with KSS.

KEY FACTS

- Kearns-Sayre syndrome (KSS) is a mitochondrial myopathy. It is rarely inherited.
- Onset of symptoms typically occurs before the age of 20.
- KSS typically involves the eyelid muscles and respiratory muscles, and can lead to an increase in aspiration risk.
- These patients can have cardiac conduction abnormalities (AV-block), seizures and dementia. They are known to have a short stature and kyphoscoliosis.

REFERENCE

Baum VC, O'Flaherty JE, eds. *Anesthesia for Genetic, Metabolic, and Dysmorphic Syndromes of Childhood*. 2nd ed. Philadelphia, PA: Lippincott, Williams & Wilkins; 2007:197–8.

23. ANSWER: D

The prevalence of **type 1 diabetes mellitus** in the United States is approximately 1:500 children. **It is caused by insulin deficiency following destruction of the insulin-producing pancreatic beta cells and is an autoimmune process**. Type 1 diabetes mellitus (DM) is one of the most common chronic diseases in childhood, but one fourth of cases are diagnosed in adults. Most children are diagnosed when they are approximately 5 years old. A second peak of onset is in early puberty from 10 to 14 years. There is no gender difference in patients with DM type 1. **The risk to developing DM type 1 is moderately increased in children who have a close relative with diabetes mellitus.** No factors have been definitely identified which trigger the destruction of the insulin-producing beta-cells of the pancreas.

Complications are usually the result of microangiopathy and macroangiopathy. The chronic hyperglycemic state will affect the whole body over time. It affects the eyes with cataracts, glaucoma, and retinopathy. Most patients will develop renal disease after 10 years, leading to renal failure. And most patients with DM will have retinopathy 20 years after diagnosis. Patients with DM are at risk for strokes and coronary artery disease. They have poor wound healing, which can be worsened by a peripheral neuropathy. Autonomic neuropathy and gastroparesis are also common in patients with DM.

About 20% of children with DM 1 have a significant decrease in vital capacity, which suggests restrictive lung disease. Lung elasticity and alveolar basal lamina are affected.

Abnormal tightness of small joints and stiffness of the atlantooccipital joint can be the cause for a difficult intubation. Altantooccipital instability is related to Trisomy 21 and not seen in children with DM.

There are several other musculoskeletal complications of DM. Some of them are carpal tunnel syndrome, Dupuytren's contracture, and flexor tenosynovitis. Adhesive capsulitis of the shoulder (frozen shoulder) and calcific periarthritis (calcific tendinitis) have been described in diabetic patients. Spontaneous infarction of muscle is a rare condition that usually affects patients with long-standing and poorly controlled DM. Those patients present with acute pain and swelling of the thigh. Myopathy is not linked to DM.

KEY FACTS

- Type I diabetes mellitus is caused by insulin deficiency following destruction of the insulin-producing pancreatic beta cells and is an autoimmune process.
- Complications are usually the result from microangiopathy and macroangiopathy, leading to retinopathy, renal disease, strokes and coronary artery disease.
- About 20% of children with DM 1 have a significant decrease in vital capacity which suggests restrictive lung disease. Lung elasticity and alveolar basal lamina are affected.

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Davies PJ, Cladis FP, Motoyama, EK, eds. *Smith's Anesthesia for Infants and Children*. 8th ed. Philadelphia, PA: Elsevier Mosby; 2011:1099–101.

24. ANSWER: A

Pheochromocytoma may coexist with medullary thyroid carcinoma (MTC) and hyperparathyroidism. This condition is called multiple endocrine neoplasia (MEN) type 2A. Patients with MEN 2 will get a medullary thyroid carcinoma almost 100% of the time. MEN type 2B are classified patients who have pheochromocytoma with MTC but do not have hyperparathyroidism.

MTC originates from the parafollicular cells of the thyroid. It is one of the most common thyroid carcinomas but it makes up only 3%–4% of those cases. Patients with MTC become symptomatic with diarrhea, pruritus, and flushing episodes similar to the symptoms of a carcinoid tumor. These symptoms are believed to be caused by high calcitonin levels. Calcitonin is produced by the parafollicular cells (also known as C-cells) of the thyroid. Medullary thyroid carcinoma most commonly spreads to lymph nodes, neck, mediastinum and liver, lung, and bones. At diagnosis almost 50% have some lymph node involvement. Some patients present with dysphagia or hoarseness. Most MTCs are sporadic (about 80%) and present most commonly in patients who are over 50 years old. These patients often present with a solitary thyroid nodule.

Thyroid function tests are normal in patients with MTC. Serum calcitonin and carcinoembryonic antigen (CEA) are indicators for MTC, and serum calcitonin concentrations usually correlate with tumor mass.

Treatment is a total thyroidectomy with radiotherapy in patients with extrathyroidal disease or extensive lymph node metastases. Radical neck dissections do not improve prognosis. Palliative chemotherapy has been reported to produce occasional responses in patients with metastatic disease. The 5 year survival rate is greater than 75%.

Conn syndrome is defined as primary aldosteronism due to the presence of an adrenal aldosterone-producing adenoma—with hypertension as its main symptom.

Sheehan syndrome is a form of hypopituitarism of the mother after childbirth. The hypopituitarism is caused by pituitary necrosis secondary to massive blood loss and hypovolemic shock during birth.

Graves' disease is a form of hyperthyroidism caused by an autoimmune process.

KEY FACTS

- Pheochromocytoma may coexist with medullary thyroid carcinoma (MTC) and hyperparathyroidism.
- Thyroid function tests are normal in patients with MTC. Serum calcitonin and carcinoembryonic antigen (CEA) are indicators for MTC and serum calcitonin concentrations usually correlate with tumor mass.
- Conn syndrome is defined as primary aldosteronism due to the presence of an adrenal aldosterone-producing adenoma.
- Sheehan syndrome is a form of hypopituitarism caused by pituitary necrosis secondary due to massive blood loss and hypovolemic shock during of the mother during childbirth.
- Graves' disease is an autoimmune form of hyperthyroidism.

REFERENCE

Hines RL, Marschall KE, eds. *Stoelting's Anesthesia and Co-Existing Disease*. 5th ed. Philadelphia, PA: Saunders; 2008:388–93.

25. ANSWER: B

Adrenal crisis is a life-threatening state of adrenocorticosteroid hormone deficiency leading to hemodynamic

shock. Patients with adrenal crisis present with hypotension and volume depletion secondary to mineralcorticosteroid deficiency. Adrenal crisis is a form of acute adrenal insufficiency. Most often it is caused by primary adrenal insufficiency, but secondary and tertiary adrenal insufficiency have been described as cause of adrenal crisis.

Systemic glucocorticoid intake can cause hypothalamic-pituitary-adrenal axis suppression by reducing corticotropin (ACTH) production. The suppression is dependent on the dose and the duration of the steroid intake. Secondary and tertiary adrenal insufficiency does not lead to volume depletion like the primary form does. But it leads to a deceased vascular tone, which contributes to the hypotension.

The crisis can happen during surgical stress and is associated with severe asthma. **Adrenal crisis may also occur in patients who are abruptly withdrawn from exogenous glucocorticoids.** Due to long-standing oral steroid intake, the hypothalamic-pituitary axis can be suppressed.

Adrenal crisis is a life-threatening emergency and needs immediate attention and treatment.

Patients with primary cortisol deficiency have increased blood volume and dilutional hyponatremia. The history of prior pituitary surgery, glucocorticoid therapy, or tuberculosis makes secondary adrenal insufficiency very likely. The treatment of adrenal crisis has to be immediate once the diagnosis is likely. The airway has to be evaluated, 100% O_2 to be given, and the patient needs urgent volume resuscitation. Blood should be drawn for a random cortisol and ACTH level, immediately followed by intravenous glucocorticoid administration. Dexamethasone is preferred, as it is not measured in the serum cortisol assays (unlike hydrocortisone). Electrolyte disturbances (hypoglycemia, hyponatremia, hyperkalemia, and hypercalcemia) should be ruled out.

KEY FACTS

- Adrenal crisis is a life threatening state of adrenocorticosteroid hormone deficiency leading to hemodynamic shock.
- Adrenal crisis may also occur in patients who are abruptly withdrawn from exogenous glucocorticoids.
- Treatment is intravenous glucocorticoid administration - dexamethasone is preferred.

REFERENCE

Cote CJ, Lerman J, Anderson B, eds. *A Practice of Anesthesia for Infants and Children*. 5th ed. Philadelphia, PA: Saunders; 2013:233.

10.

HEMATOLOGY/ONCOLOGY

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1. A 40-day-old otherwise healthy male infant, weighing 4 kg, was admitted to the postanesthetic care unit (PACU) after a circumcision with general anesthesia. You are called to evaluate this patient for cyanosis, which began 1.5 hours after the procedure. A dorsal nerve block with 1.5 mg/kg prilocaine was performed during the circumcision. The patient was born full term and had no perinatal problems, except neonatal screening was positive for G6PD deficiency. His hemoglobin level was 11.9 g/dL and his white blood cell count was 11,200/mm^3. The arterial blood gas analysis revealed a pH 7.28, PO_2 85 mm Hg, and oxygen saturation 87%. Which of the following would be the most likely cause of cyanosis in this patient?

A. Airway obstruction from residual inhaled anesthetics
B. Respiratory depression from narcotics
C. Negative pressure pulmonary edema
D. Methemoglobinemia

2. The most appropriate course of action to take in the scenario in Question 1 would be administration of:

A. Supplemental oxygen
B. Naloxone IV
C. Furosemide IV
D. Methylene blue IV

3. Which of the following medications is safe to use in patients with G6PD deficiency?

A. Prilocaine
B. Bupivacaine
C. Benzocaine
D. Sodium nitroprusside

4. Which laboratory result is most likely to be found in a full-term healthy newborn?

A. Normal prothrombin time (PT)
B. Normal activated partial thromboplastin time (aPTT)
C. Normal international normalized ratio (INR)
D. Normal thrombin time (TT)

5. Select the correct statement regarding developmental changes in plasma coagulation proteins during the childhood period in comparison with adult lab values:

A. Normal anti-thrombin III levels
B. Normal protein C and protein S levels
C. Normal fibrinolysis
D. Normal plasminogen level

6. What is the expected nadir hemoglobin level in preterm infants?

Hemoglobin	*Postnatal age*
A. 5–7 g/dL	1–3 weeks
B. 7–9 g/dL	3–6 weeks
C. 9–11 g/dL	6–8 weeks
D. 11–13 g/dL	8–12 weeks

7. What is the expected nadir hemoglobin level in term infants?

Hemoglobin	*Postnatal age*
A. 5–7 g/dL	1–3 weeks
B. 7–9 g/dL	3–6 weeks
C. 9–11 g/dL	6–8 weeks
D. 11–13 g/dL	8–12 weeks

8. Fresh-frozen plasma (FFP) should be used as primary therapy for which of the following specific coagulation defects:

A. Factor V deficiency
B. Factor VII deficiency

C. Factor VIII deficiency
D. Factor IX deficiency

9. What is the *most* appropriate management in patients with sickle cell disease?

A. Preoperative correction of anemia with transfusion to hemoglobin of 12 g/dL.
B. Perform an exchange transfusion to decrease hemoglobin S < 10%.
C. Maintain $ETCO_2$ between 35 and 45 mm Hg.
D. Maintain hyperthermia to promote oxygen unloading at the tissue level.

10. Which is the *most* appropriate anesthetic consideration for patients who are scheduled for central line placement for hematopoietic stem cell transplantation?

A. Nitrous oxide should be avoided during hematopoietic stem cell harvesting procedures.
B. Special filters are required in the breathing circuit.
C. Irradiated, leukocyte reduced blood component should be administered, and blood typing is dependent on engraftment of recipient antigens.
D. Graft-versus-host disease (GVHD) is the clinical manifestation of the recognition of donor alloantigens by recipient T cells.

11. Which of the following statements best describes graft-versus-host disease (GVHD)?

A. Acute GVHD is a clinical syndrome that usually develops 30 to 60 days after allogeneic HSCT.
B. Hepatic involvement generally presents with high conjugated bilirubin.
C. Chronic GVHD always occurs in the presence of preceding acute GVHD.
D. Chronic GVHD is a distinctive syndrome that resembles autoimmune collagen vascular disease.

12. Which of the following statements is the characteristic of radiation-induced lung injury?

A. The early phase occurs within 1 to 2 weeks of exposure.
B. Injury during the exudative phase is characterized by pulmonary edema.
C. Injury during the late phase is characterized by pulmonary fibrosis.
D. Among children younger than 3 years of age, toxicity does not occur until exposure to more than 30 Gy.

13. Which of the following factors is most likely to influence the development of pulmonary toxicity after thoracic radiation therapy for lung cancer?

A. Dose of each radiation therapy session
B. Interval of each radiation therapy session
C. Patient age at the time of treatment
D. Patient weight at the time of treatment

14. Which of the following is the most appropriate combination of chemotherapeutic agent and its major related side effect or toxicity?

A. Cisplatin and pulmonary fibrosis
B. Cyclophosphamide and peripheral neuropathy
C. Etoposide and hypertension
D. Tacrolimus and hyperglycemia

15. Which of the following chemotherapeutic agents is known to cause nephrotoxicity?

A. Cisplatin
B. Etoposide
C. Vincristine
D. Hydroxyurea

16. Which of the following chemotherapeutic agents is likely to cause SIADH?

A. Cyclophosphamide
B. Cyclosporin
C. Etoposide
D. Bleomycin

17. The most common manifestation of anthracycline-induced acute cardiotoxicity is:

A. Cardiac arrhythmia
B. Congestive heart failure
C. Pericarditis
D. Myocarditis

18. Which of the following is the risk factor for anthracycline-induced cardiotoxicity in a pediatric patient?

A. Patient age at treatment
B. Male gender
C. Radiation therapy to the right chest
D. Methods of administration (bolus versus 24-hour infusion)

19. A 3-year-old black girl is scheduled for an exploratory laparotomy. She has a history of gross hematuria and abdominal pain. Her physical examination was unremarkable, but a urine sample revealed gross hematuria and proteinuria. The computed tomography (CT) of the abdomen and pelvis showed a 2 × 3 cm mass in the upper pole of the right kidney. The renal

vein was not involved, and adenopathy was not present. The left kidney was unremarkable. Which of the following conditions is likely to be associated with this abdominal mass?

A. Cardiac abnormalities
B. Hepatic involvement
C. Nervous systems involvement
D. Hypertension

20. A 7-year-old boy presents to the emergency room because of new onset seizure and hyperglycemia. His history is also notable for occasional, severe headaches and episodes of sweating. His blood pressure is 180/90 mm Hg, heart rate is 130 beats/min, respiratory rate is 20/min, and O_2 saturation on pulse oximeter is 97% on room air. CT of the head is negative. The patient is now scheduled to undergo an abdominal magnetic resonance imaging (MRI)/magnetic resonance angiography (MRA) under general anesthesia. Which of the following statements is a concern when providing anesthetic care for this patient?

A. Fluid maintenance should be with 5% dextrose in normal saline.
B. The patient is at increased risk for developing congestive heart failure.
C. The patient is at increased risk of developing of hyperkalemia.
D. He will have a higher MAC than unaffected patients.

21. Which of the following medications is safe to use in the patient from Question 21?

A. Desflurane
B. Vecuronium
C. Morphine
D. Acetaminophen

22. The MRI of the abdomen for the patient from Question 21 showed a 1 × 2 cm mass in the right suprarenal mass. Which statement is most likely associated with this patient's condition?

A. The mass originated from chromaffin cells.
B. The most common site of origin is the adrenal cortex.
C. The predominant catecholamine produced is norepinephrine.
D. Plasma metanephrine and epinephrine are reliably elevated.

23. Which of the following conditions would most like for the patient from Question 21, we seen in patients with this diagnosis?

A. Multiple endocrine neoplasia type 1
B. Multiple endocrine neoplasia type 2
C. Neurofibromatosis type 2
D. Familial gangliomas

24. A 4-year-old girl presented at the emergency room a week ago with extensive bruising and bleeding gums. Her vital signs were stable. Her hemoglobin level was 6.9 g/dL, platelet count was 20,000/mm^3, and white blood cell count was 16,200/mm^3. Today she is schedule for bone marrow aspiration. Which of the following statements is a concern when providing anesthetic care for this child?

A. AML is the most common type of leukemia in children.
B. Dexamethasone should be used to minimize postoperative vomiting.
C. P**ossible upper airway edema** and **pulmonary fibrosis**.
D. Nitrous oxide can be used safely.

25. Which of the following is the most appropriate combination of cancer type and its clinical characteristic?

A. Neuroblastoma and spinal cord compression
B. Osteosarcoma and liver metastasis as the most common metastatic site
C. Ewing sarcoma, resistance to radiation therapy
D. Retinoblastoma and high incidence of metastasis at the time of diagnosis

26. Which paraneoplastic syndrome is associated with neuroblastomas?

A. Carcinoid syndrome
B. Syndrome of inappropriate antidiuretic hormone secretion (SIADH)
C. Lambert–Eaton myasthenic syndrome (LEMS)
D. Opsoclonus-myoclonus-ataxia (OMA)

27. Patient with stage 4S neuroblastoma is scheduled for central line placement under anesthesia. Which condition is most likely to present in this patient?

A. Patient is an infant below 1 year of age.
B. Primary tumor is unresectable.
C. Tumor is metastases to cortical bone and bone marrow.
D. Patient overall survival is low (below 25%).

28. What is the *most* appropriate management for a patient with retinoblastoma?

A. CT is preferred to MRI for staging studies.
B. Enucleation is usually the preferred treatment for large tumors.

C. Children who undergo enucleation for retinoblastoma do not required frequent follow-up due to low recurrent rate.
D. The metastatic evaluation should include a bone marrow examination (aspiration and biopsy), lumbar puncture, and radionuclide bone scan.

29. Which of the following is the characteristic of PANDAS (pediatric autoimmune neuropsychiatric disorder)?

A. Symptoms of obsessive-compulsive disorder (OCD) or tic disorders
B. Slow onset and episodic course of symptoms
C. Pediatric onset (between 1 and 5 years)
D. Exacerbated by group A staphylococcus (GAS) infection

30. Which of the following medications is safe to use in patients with acquired immunodeficiency syndrome?

A. Diazepam
B. Meperidine
C. Propofol
D. Pancuronium

CHAPTER 10 ANSWERS

1. ANSWER: D

Methemoglobinemia is characterizied as a condition when red blood cells contain methemoglobin at levels higher than 1%. Methemoglobin results from the presence of iron in the **ferric form (Fe 3+) instead of the usual ferrous form (Fe 2+)**. This results in a decreased delivery of oxygen to the tissues. Methemoglobinemia may be associated with exposure to **nitrate-contaminated drinking water, aniline dyes, and amide-containing medications**. **Ortho-toluidine, a metabolite of prilocaine, also can induce methemoglobinemia.**

Because the initial symptoms of methemoglobinemia can be vague, especially with low levels of methemoglobinemia, this condition can easily be misdiagnosed or go unrecognized. Lack of awareness of this condition often leads to delayed and missed diagnosis.

Cyanosis (presence of more than 5 g/dL of deoxygenated hemoglobin) associated with hypoxia may be caused by cardiac or pulmonary disease. Cyanosis may also be present in polycythemia but is generally without hypoxia. The hallmark of methemoglobinemia is **cyanosis that is unresponsive to high oxygen concentrations** in the **absence of cardiac or pulmonary disorders**. Pulmonary diseases generally respond to oxygen administration, whereas cardiac disease may not. Right-to-left shunts in the cardiovascular system, especially when large, do not respond to oxygen administration.

Acute methemoglobinemia can be life-threatening and usually is acquired as a consequence of exposure to toxins or drugs. Therefore, obtaining a detailed history of exposure to methemoglobinemia-inducing substances is important.

Symptoms are proportional to the fraction of methemoglobin. A normal methemoglobin fraction is about 1% (range, 0–3%). At methemoglobin levels of 3%–15%, a slight discoloration (e.g., pale, gray, blue) of the skin may be present. Patients with methemoglobin levels of 15%–20% may be relatively asymptomatic, apart from mild cyanosis.

Signs and symptoms at levels of 25%–50% include headache, dyspnea, lightheadedness, syncope, weakness, confusion, palpitations, and chest pain. If methemoglobin levels reach 50%–70%, patient can have the following symptoms:

- Cardiovascular—Abnormal cardiac rhythms
- CNS—Altered mental status; delirium, seizures, coma
- Metabolic—Profound acidosis

At methemoglobin fractions **exceeding 70%, death** usually results.

The presence of methemoglobin can **falsely elevate the calculated oxygen saturation** when arterial blood gases (ABGs) are obtained. One possible clue to the diagnosis of methemoglobinemia is the presence of a "saturation gap." This occurs when there is a difference between the oxygen saturation measured on pulse oximetry and the oxygen saturation calculated on the basis of ABG results.

The partial pressure of oxygen (PO_2) value of the ABG measurement reflects plasma oxygen content and does not correspond to the oxygen-carrying capacity of hemoglobin. It should be within the reference range in patients with methemoglobinemia.

Pulse oximetry is used extensively in the evaluation of patients with cyanosis and respiratory distress. Findings of bedside pulse oximetry in the presence of methemoglobinemia may be misleading. Pulse oximetry measurements with **low levels of methemoglobinemia often result in falsely low values for oxygen saturation** and are often **falsely high in those with high-level methemoglobinemia**. The reason for these inaccuracies is as follows.

The pulse oximeter only measures the relative absorbance of two wavelengths of light (660 nm and 940 nm) to differentiate oxyhemoglobin from deoxyhemoglobin. The ratio of absorption of light at each of these wavelengths is converted into oxygen saturation by using calibration curves. Methemoglobin increases absorption of light at both wavelengths (more at 940 nm) and therefore offers optical interference to pulse oximetry by falsely absorbing light.

As a result, oxygen saturations by pulse oximetry in methemoglobinemia plateau at about 85%; therefore, a patient with a methemoglobin level of 5% and a patient with a level of 40% have approximately the same saturation values on pulse oximetry (~85%). The severity of the cyanosis does not correspond to the pulse oximetry reading: A patient may appear extremely cyanotic but still have a pulse oximetry reading in the high 80s.

Co-oximetry should be performed if available. The co-oximeter is an accurate device for measuring methemoglobin and is the key to diagnosing methemoglobinemia. It is a simplified spectrophotometer that can measure the relative absorbance of four different wavelengths of light and thus is capable of differentiating methemoglobin from carboxyhemoglobin, oxyhemoglobin, and deoxyhemoglobin. Newer co-oximeters can also measure sulfhemoglobin, which can be confused with methemoglobin by older devices.

KEY FACTS

- Methemoglobinemia is characterizied as a condition when red blood cells contain methemoglobin at levels higher than 1%.
- Methemoglobin results from the presence of iron in the ferric form (Fe 3+) instead of the usual ferrous form (Fe 2+). This results in a decreased delivery of oxygen to the tissues.
- Methemoglobinemia may be associated with exposure to nitrate-contaminated drinking water, aniline dyes, and amide-containing medications.

- Ortho-toluidine, a metabolite of prilocaine can induce Methemoglobinemia.

REFERENCES

Coté CJ, Lerman J, Anderson B, eds. A Practice of Anesthesia for Infants and Children. 5th ed. Philadelphia, PA: Saunders; 2013:Chapter 9.

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2. ANSWER: A

Intravenous (IV) methylene blue is the first-line treatment agent for methemoglobinemia. It is given in a dose of **1–2 mg/kg** (up to a total of 50 mg in adults, adolescents, and older children) as a 1% solution in IV saline over 3–5 minutes. Administration **may be repeated at 1 mg/kg every 30 minutes** as necessary to control symptoms. Methylene blue is itself an oxidant at doses greater than 7 mg/kg and thus may cause methemoglobinemia in susceptible patients; hence, careful administration is essential. The presence of methylene blue **interferes** with the accurate measurement of methemoglobin by **co-oximetry**; hence, this method cannot be used to monitor methemoglobin levels after treatment with methylene blue is initiated.

Methylene blue is contraindicated in patients with G6PD deficiency. Exchange transfusion and hyperbaric oxygen treatment are second-line options for patients with severe methemoglobinemia whose condition does not respond to methylene blue or who cannot be treated with methylene blue (e.g., those with glucose-6-phosphate dehydrogenase [G6PD] deficiency). Because it requires G6PD to work, it is ineffective in G6PD-deficient patients with methemoglobinemia. Additionally, methylene blue administration **may cause hemolysis** in these patients.

Exchange transfusion (which replaces abnormal hemoglobin with normal hemoglobin) may be considered for G6PD-deficient patients who are severely symptomatic or unresponsive to methylene blue.

Hyperbaric oxygen treatment is another option for situations where methylene blue therapy is ineffective or contraindicated. This approach permits tissue oxygenation to occur through oxygen dissolved in plasma, rather than through hemoglobin-bound oxygen. Mild cases can be treated with supplemental high-flow O2 and observation.

KEY FACTS

- A normal methemoglobin fraction is about 1% (range, 0–3%). Symptoms are proportional to the fraction of methemoglobin.
- Co-oximetry is used for measuring methemoglobin, since oxygen saturations by pulse oximetry in methemoglobinemia plateau at about 85%.
- Intravenous methylene blue is the first-line antidotal agent (except in patients with G6PD deficiency), and exchange transfusion and hyperbaric oxygen treatment are second-line options.

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Cote CJ, Lerman J, Anderson B, eds. *A Practice of Anesthesia for Infants and Children*. 5th ed. Philadelphia, PA: Saunders; 2013:Chapter 9.

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3. ANSWER: B

Glucose-6-phosphate dehydrogenase (G6PD) deficiency is an **X-linked recessive enzymopathy** responsible for **acute hemolysis** following exposure to **oxidative stress**.

G6PD is an enzyme that catalyzes the first reaction in the pentose phosphate pathway, providing reducing power to all cells in the form of nicotinamide adenine dinucleotide phosphate hydrogenase (NADPH). NADPH enables cells to counterbalance oxidative stress that can be triggered by several oxidant agents and to preserve the reduced form of glutathione. Because red blood cells do not contain mitochondria, the pentose phosphate pathway is their only source of NADPH; therefore, **defense against oxidative damage is dependent on G6PD.**

Deficiency of this enzyme results in **decreased production of NADPH**. NADPH protects cells from oxidative stress; thus, defective red blood cells (RBCs) are more **susceptible to hemolysis by oxidative stress**.

Variants of G6PD deficiency were grouped into five classes based on enzyme activity and clinical manifestations:

Class I: Severely deficient, associated with chronic nonspherocytic hemolytic anemia

Class II: Severely deficient (1%–10% residual activity), associated with acute hemolytic anemia

Class III: Moderately deficient (10%–60% residual activity)

Class IV: Normal activity (60%–150%)

Class V: Increased activity (>150%)

Acute intravascular hemolysis starts 2–3 days following exposure. Recovery is marked by **reticulocytosis.** Laboratory findings following a hemolytic episode may include **anemia, reticulocytosis, decreased serum haptoglobulin, and an elevated indirect bilirubin**. Specific tests include enzyme levels in RBCs and Heinz body preparations.

The definitive diagnosis of G6PD deficiency is based on the **estimation of enzyme activity**, by quantitative spectrophotometric analysis of the rate of NADPH production from NADP.

Testing for G6PD deficiency should be considered when an acute hemolytic reaction triggered by exposure to a known oxidative drug, **infection**, or ingestion of **fava beans** happens, either in children or in adults, particularly if they are of **African, Mediterranean, or Asian descent**. Moreover, members (especially males) of families in which **jaundice**, **splenomegaly**, or **cholelithiasis** are recurrent should be tested for G6PD deficiency.

In the intraoperative setting, G6PD deficiency does not usually cause problems provided that triggering agents are avoided in susceptible patients and precipitating causes are treated or eliminated.

Although these children can reduce methemoglobin that is normally produced by these agents, G6PD-deficient children may not be able to tolerate large amounts of potent oxidizing agents produced by methemoglobin.

Drugs that induce hemolysis in these patients are often used in anesthesia and perioperative pain management. Those medications include **prilocaine, benzocaine, and sodium nitroprusside**. Administration of large or excessive doses of these medications can result in methemoglobinemia.

KEY FACTS

- Red blood cells depend on G6PD for production of NADPH, which protects cells from oxidative stress; thus, defective red blood cells (RBCs) are more susceptible to hemolysis by oxidative stress.
- Acute intravascular hemolysis occurs 2–3 days following exposure to a trigger, and laboratory findings include anemia, reticulocytosis, decreased serum haptoglobulin, and an elevated indirect bilirubin.
- Drugs that induce hemolysis (prilocaine, benzocaine, and sodium nitroprusside) should be avoided in G6PD because methemoglobinemia may result.

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Cote CJ, Lerman J, Anderson B, eds. *A Practice of Anesthesia for Infants and Children*. 5th ed. Philadelphia, PA: Saunders; 2013:Chapter 9.

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4. ANSWER: C

The coagulation system in children is distinctly different from that in adults, and this difference is regarded as physiological. The coagulation system in the newborn is considered to be **immature**, with many of the coagulation proteins reduced at birth. Coagulation factors do not cross the placental barrier but are synthesized independently by the conceptus. At birth, activities of the **vitamin K–dependent factors II, VII, IX**, and **X** and the concentrations of the contact **factors XI and XII** are reduced to about **50% of normal adult values**. The levels of the factors V, VIII, XIII, and fibrinogen are similar to adult values. Plasma concentrations of the naturally occurring anticoagulant proteins (**antithrombin, protein C, and protein S**) are significantly **lower** at birth than during the adult years. **Plasminogen** is **reduced** by approximately 50%. Platelet counts are within the normal range; regarding function, however, neonatal platelets seem to be hyporeactive. The **von Willebrand factor** concentration is **increased** (see Tables 10.1 and 10.2).

Table 10.1 PROCOAGULANT PROTEINS

PROTEIN	COMMENT
Factor II	All the Vitamin K depending clotting factors are low at birth and reach adults values by 6 months of age (See Protein C and S in Table 10.2)
Factor VII	
Factor IX	
Factor X	
Factor VIII	Normal at birth
Factor XI	Normal at birth
Factor XII	Normal at birth
Von Willebrand Factor [VWF]	Normal at birth
Factor XIII	Normal at birth
Fibrinogen	Levels are normal at birth but a fetal fibrinogen due to altered sialic acid content can prolong thrombin time

In general, a full-term neonate has a relative **polycythemia, reticulocytosis, and leukocytosis** compared with the child. The term neonate has **prolongation** of both prothrombin time (**PT**) and activated partial thromboplastin time (**aPTT**) owing to a **relative deficiency in vitamin K-dependent factors.** The neonate has decreased plasma concentration of proteins C and S, a condition that increases the likelihood of thrombosis. Compared to a term neonate, a preterm neonate has a 10% reduction in the plasma concentration of fibrinogen. The international normalized ratio (INR), a normalized PT, has an average value of 1.0 through all age groups.

KEY FACTS

- At birth, activities of the vitamin K–dependent factors II, VII, IX, and X and the concentrations of the contact factors XI and XII are reduced to about 50% of normal adult values, leading to prolonged PT and aPTT.
- In general, a full-term neonate has a relative polycythemia, reticulocytosis, and leukocytosis compared with the child.

Table 10.2 NATURAL ANTICOAGULANTS

PROTEIN	COMMENT
Protein C	Low at birth and although in many cases it is normal by 6 months of age in some individuals it may take longer. Heterozygous Protein C deficiency can be difficult to diagnose in the neonatal period due to the wide variation in levels. In contrast, homozygous deficiency is readily diagnosed due to a complete absence of Protein C.
Protein S	Total Protein S levels are low at birth. Protein S exists in the neonate primarily in the free form due to the low C4b binding protein. Free PS levels are low at birth and reach adult values at ~4 months of age.
Antithrombin	Functional antithrombin levels are low at birth and may be further reduced in the sick neonate. Levels normally reach adult values at ~3 months of age.
Factor V Leiden Prothrombin G20201A mutation	These mutations should be sought be DNA analysis (if this is indicated). APCr screening assays can be unreliable due to the variation in FVIII levels in the neonate.
Plasminogen	Plasminogen levels are low at birth (~50% that of the adult).
α_2-macroglobulin	Levels are raised in children.

- The neonate has decreased plasma concentration of proteins C and S, a condition that increases the likelihood of thrombosis.

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Cote CJ, Lerman J, Anderson B, eds. *A Practice of Anesthesia for Infants and Children*. 5th ed. Philadelphia, PA: Saunders; 2013:Chapter 9.

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5. ANSWER: D

The hemostatic system in the newborn undergoes a dynamic development and **reaches full maturity only after 6 months of age**. The diagnostic approach to many hemostatic defects in the newborn is hence challenging and requires the appropriate interpretation of coagulation test results, according to several reference values dependent on the specific postnatal age.

Many of the proteins that regulate coagulation and thrombin generation are also decreased in early infancy.

KEY FACTS

- *Antithrombin III and heparin cofactor II* are **markedly decreased** to levels that might predispose to a spontaneous thromboembolic event. By 6 months of life, AT III level exceeds levels seen in adults.
- *Alpha-2 macroglobulin levels* at birth are **greater than those of adults** and remain so until the third decade of life.
- *Protein C and protein S concentrations* at birth are also substantially less than those seen in adults and remain **low throughout childhood**.
- *Plasminogen levels* **increase to adult levels during childhood**, but the TPA/PAI-1 ratio is significantly lower than that in adults, which explains the decrease in fibrinolysis in children. Fibrinolysis is suppressed throughout childhood.

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Cote CJ, Lerman J, Anderson B, eds. *A Practice of Anesthesia for Infants and Children*. 5th ed. Philadelphia, PA: Saunders; 2013:Chapter 9.

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6. ANSWER: B

At birth, normal full-term infants have higher hemoglobin and hematocrit levels and larger red blood cells (RBCs) than do older children and adults. However, within the 1st week of life, a progressive decline in hemoglobin level begins and then persists for 6–8 weeks. The resulting anemia is known as the **physiologic anemia of infancy.** Several factors appear to be involved.

Physiologic anemia should be regarded as a developmental response of the infant's erythropoietic system due to the interaction of several factors: **a relative decrease in bone marrow erythropoietic activity** due to the downregulating effect of increased oxygen supply in extrauterine life, a relative **increase in the rate of hemolysis**, and **hemodilution** due to a rapid expansion of the blood volume. RBC count decreases until oxygen delivery is inadequate for metabolic demand and erythropoietin production is stimulated again. These factors tend to be more extreme in low-birth-weight infants and result in a more severe degree of anemia at an earlier age.

In healthy term infants, the RBC nadir typically occurs at 8 to 12 weeks of life and at a hemoglobin level of 9 to 11 g/dL.

Preterm infants also experience a decrease in hemoglobin concentration after birth, with a decline that typically is more abrupt and more profound than in term infants, reaching a hemoglobin level of 7 to 9 g/dL at 3 to 6 weeks of age. This anemia of prematurity is likely the result of lower hemoglobin levels at birth, decreased RBC life span, and a suboptimal erythropoietin response.

Hemoglobin values of this degree should be considered nonpathologic and do not require special therapy or blood transfusion. A number of pathologic processes may be superimposed upon physiologic anemia, producing a more severe degree of anemia.

Most hematologic values reach adult norms by the end of infancy, although some continue to change gradually into the second decade. All of these changes underscore the importance of laboratory reports with age-adjusted standards.

KEY FACTS

- Within the 1st week of life occurs a physiologic anemia of infancy, a progressive decline in hemoglobin level that persists for 6–8 weeks.
- Preterm infants also experience a decrease in hemoglobin concentration after birth, with a decline that typically is more abrupt and more profound than in term infants.
- Physiologic anemia occurs because there is a relative decrease in bone marrow erythropoietic activity, a relative increase in the rate of hemolysis, and hemodilution due to a rapid expansion of the blood volume.

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Cote CJ, Lerman J, Anderson B, eds. *A Practice of Anesthesia for Infants and Children*. 5th ed. Philadelphia, PA: Saunders; 2013:Chapter 9.
Davis PJ, Cladis FP, Motoyama EK, eds. *Smith's Anesthesia for Infants and Children*. 8th ed. St. Louis, MO: Elsevier Mosby; 2011:Chapter 17.

7. ANSWER: C

Please refer to answer of question #6 above.

8. ANSWER: A

Plasma or blood components are biological products prepared by differential centrifugation of whole blood or plasma in a blood center or hospital laboratory. The major plasma components used in transfusion medicine include fresh-frozen plasma (FFP), plasma frozen 24 rather than 8 hours after collection, thawed plasma, and cryoprecipitate (cryo). **FFP is employed in an initial intravenous dose of 10 to 15 mL/kg of body weight.** It should not be used as a source of albumin or other nutrients, or as a volume expander.

Guidelines for transfusion of other blood products, notably FFP, have been established. Indications for the use of FFP must be carefully followed.

KEY FACTS

- FFP may be needed for **inherited factor XI deficiency** or as a source of **factor V** in severe cases of disseminated intravascular coagulation (DIC) when platelet concentrates and cryoprecipitate do not correct the factor V, VIII, and fibrinogen consumption defects.
- FFP (or, alternatively, prothrombin complex preparations that contain adequate amounts of factor VII) may be needed to correct a bleeding condition caused by a deficiency of multiple coagulation factors, such as is seen in warfarin overdose, vitamin K deficiency, liver failure, or dilutional coagulopathy following massive transfusion, or for reversing warfarin in preparation for an invasive procedure.
- FFP should not be used as primary therapy for a specific coagulation defect (e.g., hemophilia A, hemophilia B, factor VII deficiency) when specific coagulation factor concentrates are available.
- Available studies do not support the efficacy of FFP in treating bleeding or as prophylaxis for invasive procedures in patients with a mild coagulopathy (i.e., INR < 2.0).

REFERENCES

Cote CJ, Lerman J, Anderson B, eds. *A Practice of Anesthesia for Infants and Children*. 5th ed. Philadelphia, PA: Saunders; 2013:Chapter 9.
Davis PJ, Cladis FP, Motoyama EK, eds. *Smith's Anesthesia for Infants and Children*. 8th ed. St. Louis, MO: Elsevier Mosby; 2011:Chapter 17.

9. ANSWER: C

Perioperative morbidity and mortality are greater in children with sickle cell disease than in the general population. These children often require surgical procedures, the most common being cholecystectomy, ear, nose, and throat procedures, and orthopedic procedures.

Though **cerebral infarction** is the most frequent neurological complication that occurs with sickle cell disease, a number of other potentially devastating central nervous system (CNS) sequelae have also been described. These include intracranial hemorrhage, isolated neuropathies, transverse myelitis, auditory and ocular manifestations, and spinal cord involvement.

In the group of over 600 patients managed according to standard guidelines of care and prospectively studied, the incidence of "sickle cell events," that is, ACS and pain crisis, was 10% and 5%, respectively. Patient factors (e.g., age, history of pulmonary disease, number of prior hospitalizations), as well as surgical factors (i.e., laparoscopic cholecystectomy and splenectomy), on perioperative morbidity and mortality are as yet unclear.

Although there is no evidence to support or refute many of the long-standing guidelines for perioperative care, it seems appropriate to **avoid those specific factors that may**

promote intravascular sickling: hypoxia, acidosis, hyperthermia, hypothermia, and dehydration.

It is generally recommended at this time that most children with HbSS undergoing most surgical procedures receive preoperative correction of anemia with simple transfusion to hemoglobin of approximately 10 g/dL and hemoglobin S to approximately 60%. No standard practice guidelines have been developed for patients undergoing minor procedures or for patients with hemoglobin SC disease.

A **conservative transfusion regimen** was as effective as an aggressive regimen in preventing perioperative complications in patients with sickle cell anemia, and the conservative approach resulted in only half as many transfusion-associated complications.

Children maintained on chronic transfusion programs should continue such management preoperatively. The goal of chronic transfusion therapy programs is to **maintain the hemoglobin S at 30%–50%,** depending on the specific disorder. Transfusions are usually repeated every 3–4 weeks. **Chronic transfusion therapy** for children who suffer vaso-occlusive stroke decreases the recurrent stroke rate from 90% to less than 10%. Initially, the hemoglobin S level is maintained at 30% or less for approximately 5 years.

Given the high rate and risk of alloimmunization in the sickle cell population, blood to be administered to sickle cell patients should undergo **extended phenotype matching**, leukocyte reduction, and sickle cell screening.

Anesthetic technique does not clearly have an impact on perioperative outcome in children with sickle cell disease. Hyperventilation should be avoided because of its potential to reduce cerebral perfusion in children at an increased risk of stroke. Maintenance of normal body temperature is also probably advisable during the anesthetic management of patients with SCD. Whereas hypothermia inhibits oxygen unloading at the tissue level and in this sense might be protective against Hb polymerization, it also results in vasoconstriction in vascular bed and prolongs vascular transit time, thus promoting Hb polymerization. Hyperthermia promotes oxygen unloading at the tissue level and may be associated with vasoconstriction or vasodilation. Close monitoring and maintenance of normal body thermal homeostasis are the basis tenets of critical care and anesthesia management.

KEY FACTS

- It is generally advised to avoid those specific factors that may promote intravascular sickling: hypoxia, acidosis, hyperthermia, hypothermia, and dehydration.
- Chronic transfusion therapy for children who suffer vaso-occlusive stroke decreases the recurrent stroke rate from 90% to less than 10%.
- Hyperventilation should be avoided because of its potential to reduce cerebral perfusion in children at an increased risk of stroke.
- Close monitoring and maintenance of normal body thermal homeostasis are the basis tenets of critical care and anesthesia management.

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10. ANSWER: C

Hematopoietic stem-cell transplantation (HSCT) is used primarily for hematologic and lymphoid cancers but also for many other disorders. HSCT is now a potentially curative treatment for a wide range of malignant and nonmalignant pediatric disorders. **Hematopoietic stem cells utilized in the transplantation can be obtained from bone marrow, "mobilized" peripheral blood, or umbilical cord blood**. The source of the cells may be the child (autologous), an identical twin (syngeneic), or another individual (allogeneic). Outcomes vary according to the type and stage of disease, the age and functional level of the patient, the source of the stem cells to be transplanted, and the degree of HLA mismatch.

Stem cells, including hematopoietic stem cells, have the unique capacity to produce some daughter cells that retain stem-cell properties; they do not become specialized and thus are self-renewing—a lifetime source of blood cells.

The chemotherapy used to treat cancers acts primarily on proliferating cells. Normal and malignant stem cells, however, are quiescent and therefore insensitive to therapy. Some malignant stem cells survive even lethal doses of total-body irradiation and chemotherapy given in preparation for hematopoietic stem-cell transplantation. However, such cells may be eliminated by immunologically active donor cells.

Allogeneic grafts initiate immune reactions related to histocompatibility. The severity of the reaction depends on the degree of incompatibility, which is determined by a complex biology in which polymorphic class I and class II HLA cell surface glycoproteins bind small peptides from degraded proteins. **Acute or chronic graft rejection can occur as a reaction of recipient T cells with foreign donor antigens. In contrast, during graft-versus-host disease (GVHD), donor T cells recognize recipient antigens as incompatible. In general, only irradiated, leukocyte-reduced, cytomegalovirus-negative (where the recipient is cytomegalovirus negative) blood component should be administered, and blood typing**

is dependent on engraftment of donor antigens. It is critical to coordinate the choice of blood product with the transplant service because often blood type changes from that of recipient to that of donor.

Bone marrow obtained by repeated aspiration of the posterior iliac crests while the donor is under general or local anesthesia was the first source of hematopoietic stem cells. Discomfort from the harvesting procedure usually disappears within 2 weeks, and serious effects are rare. **There is little evidence to support the avoidance of nitrous oxide for harvesting procedures**, a concern raised in the past due to the ability of nitrous oxide to affect methionine synthase activity and, thereby, DNA synthesis.

If transplantation is urgent or if suitable donors are not found, cord blood, which can be procured both easily and safely, can be used. Blood from the umbilical cord and the placenta is rich in hematopoietic stem cells but limited in volume. It is collected immediately after birth and then frozen. Because hematologic and immunologic reconstitution is slow in transplanted cord blood, **infection is common soon after transplantation**. The transplantation of cord blood requires less stringent HLA matching than does the transplantation of adult peripheral blood or marrow, because mismatched cord-blood cells are less likely to cause GVHD, without losing the graft-versus-leukemia effect.

Mucositis is an important problem of hematopoietic stem-cell transplantation. In the short term, it is the most common complication of myeloablative preparative regimens and methotrexate (used to prevent GVHD). Oropharyngeal mucositis is painful and can involve the supraglottic area and require intubation. Intestinal mucositis causes nausea, cramping, and diarrhea and may require parenteral nutrition.

The second most common acute adverse effect is a potentially fatal syndrome of painful hepatomegaly, jaundice, and fluid retention, traditionally called **hepatic veno-occlusive disease**. However, the term "sinusoidal obstruction syndrome" is more accurate, because damaged sinusoidal endothelium sloughs and then obstructs the hepatic circulation, injuring centrilobular hepatocytes. In severe sinusoidal obstruction syndrome, renal and respiratory failure may occur.

Transplantation-related **lung injury** occurs within 4 months after the procedure, and the mortality rate exceeds 60%. Risk factors include total-body irradiation, allogeneic transplantation, and acute GVHD, suggesting that donor lymphocytes target the lung.

Transplantation-related infections result from damage to the mouth, gut, and skin from preparative regimens as well as from **catheters**, **neutropenia**, and **immunodeficiency**. Host defenses, both immunologic and physical, are impaired throughout the transplantation process. Children are vulnerable to a wide range of routine and opportunistic pathogens, including bacteria, fungi, and viruses.

KEY FACTS

- In patients who underwent a hematopoietic stem-cell transplantation, only irradiated, leukocyte-reduced, cytomegalovirus-negative (where the recipient is cytomegalovirus negative) blood component should be administered, and blood typing is dependent on engraftment of donor antigens.
- Acute or chronic graft rejection can occur as a reaction of recipient T cells with foreign donor antigens.
- During graft-versus-host disease (GVHD), donor T cells recognize recipient antigens as incompatible.
- There is little evidence to support the avoidance of nitrous oxide for harvesting procedures, a concern raised in the past due to the ability of nitrous oxide to affect methionine synthase activity and, thereby, DNA synthesis.
- Problems of hematopoietic stem-cell transplantation include infections, mucositis, hepatic veno-occlusive disease, and lung injury.

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Cote CJ, Lerman J, Anderson B, eds. *A Practice of Anesthesia for Infants and Children*. 5th ed. Philadelphia, PA: Saunders; 2013:Chapter 9.

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11. ANSWER: D

Graft-versus-host disease (GVHD) is the most important complication of allogeneic hematopoietic stem-cell transplantation. GVHD is the clinical manifestation of the recognition of recipient alloantigen by donor T cells.

Acute GVHD is a clinical syndrome that usually develops in 40% to 60% of patients receiving HSCT by 60 to 100 days after allogeneic HSCT. It is characterized by the development of **erythematous skin rash**; hepatic involvement with **cholestatic jaundice**; GI disease marked by the presence of abdominal pain, excessive vomiting, ileus, bleeding, and diarrhea; fever, thrombocytopenia, and anemia; and occasional pulmonary involvement with vascular leak.

GVHD and its treatment with corticosteroids cause **profound immunodeficiency**, predisposing the patient to fatal infection. The principal risk factor is **HLA mismatch**, but GVHD may occur despite an HLA-matched donor and the use of preventive measures. If prophylaxis is not provided, serious acute GVHD affects almost every recipient. The risk of GVHD is **greatly reduced by short-term treatment with methotrexate** plus treatment with cyclosporine for several months. The incidence of GVHD can be reduced by in vitro **T-cell depletion of the graft** before transplantation, but this does not improve disease-free

survival, because the rates of graft rejection and relapse increase. **Gene modification of donor T cells** is a potential means of treating GVHD.

Most survivors of transplantation are active and healthy, but some delayed complications, particularly chronic GVHD, can be serious. Chronic GVHD is a distinctive syndrome that resembles **autoimmune collagen vascular disease**, with manifestation evident in every organ of the body. Chronic GVHD occur in 20% to 40% of patients who have undergone HSCT and may occur as an extension of acute GVHD, or it may occur in an absence of preceding GVHD. The diagnosis is occasionally made after day 100 of HSCT and is rarely made after more than 500 days after HSCT. The **risk increases with recipient and donor age** and is increased for peripheral-blood grafts or grafts from unrelated donors. Chronic GVHD is associated with loss of self-tolerance and often resembles **scleroderma** or **Sjögren syndrome**. Chronic GVHD can cause bronchiolitis, keratoconjunctivitis sicca, esophageal stricture, malabsorption, cholestasis, hematocytopenia, and generalized immunosuppression. Treatment with **corticosteroids** may be needed for **2 years or longer**. Corticosteroids can cause a variety of complications, including aseptic necrosis of bone and osteoporosis, and may predispose the patient to fatal infections. If severe hypogammaglobulinemia occurs, treatment with intravenous immune globulin can reduce infections.

KEY FACTS

- GVHD is the clinical manifestation of the recognition of recipient alloantigen by donor T cells.
- Acute GVHD is a clinical syndrome characterized by the development of erythematous skin rash, hepatic involvement with cholestatic jaundice, GI disease marked by abdominal pain, excessive vomiting, ileus, bleeding, and diarrhea, fever, thrombocytopenia, and anemia, and occasional pulmonary involvement with vascular leak.
- The risk of GVHD is greatly reduced by short-term treatment with methotrexate plus treatment with cyclosporine for several months.
- Chronic GVHD is a distinctive syndrome that resembles autoimmune collagen vascular disease, with manifestation evident in every organ of the body. Treatment with corticosteroids may be needed for 2 years or longer.

REFERENCES

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12. ANSWER: C

Normal body tissues vary in their response to radiation. As with tumors, normal tissues in which cells are quickly dividing may be affected. This causes some of the side effects of radiation treatment. Since radiation is a local treatment, side effects depend on the area of the body being treated. The early effects of radiation may be seen a few days or weeks after treatments have started and may go on for several weeks after treatments have ended. Other effects may not show up until months, or even years, later.

Fatigue is a common effect of radiation, but the exact cause is unknown. Fatigue may also be caused by anemia (a low red blood cell count), poor nutrition, pain, certain drugs such as steroids or chemotherapy, depression, and stress.

Mucositis is a short-term side effect that can happen when radiation is given to the head and neck area. It usually gets better within a few weeks after treatments end. **Dry mouth** and a **loss of taste** can be caused by radiation damage to the salivary glands and taste buds.

Radiation therapy to large areas of the brain can sometimes cause changes in brain function.

Sometimes a large area of dead cells, called ***radiation necrosis***, forms at the site of the radiation in the brain. This can happen months to years after radiation is given, and it can cause symptoms like **seizures**, **mental status changes, headaches, trouble speaking or walking, and other changes.**

When radiation treatments include the chest, it can affect the lungs. One early change is a **decrease in the levels of surfactant**. This may cause shortness of breath or a cough.

Radiation pneumonitis occurs in about 5% to 20% of people who get radiation therapy to the chest for lung cancer, breast cancer, lymphomas, or other cancers. This inflammation may occur from about 6 weeks to 6 months after completing external radiation therapy. Common symptoms include shortness of breath, chest pain, cough, and fever. Another possible effect that radiation can have on the lungs is fibrosis. This problem may show up months or even years after treatment.

Several phases of lung injury are described:

1. Latent or early phase occurs within 1 to 2 months of exposure.
2. Exudative phase occurs 4 to 6 months afterward, and symptoms of pneumonitis develop.
3. Late phase is heralded by the development of pulmonary fibrosis from 6 to 12 months after exposure.

Factors that influence the development of pulmonary toxicity include the total dose of irradiation, volume of lung treated, fraction size, and patient age at the time of treatment. Toxicity usually does not occur **until more than 30**

Gy are delivered to more than 50% of the lung when radiation is used alone in adults.

The mechanism of injury appears to be different in children younger than 3 years of age, in whom interference with lung and chest wall growth may occur. In these children, restrictive lung disease has developed with radiation doses as low as 11 to 14 Gy.

KEY FACTS

- Side effects of radiation include fatigue, mucositis, radiation necrosis, radiation pneumonitis, and pulmonary fibrosis.
- Factors that influence the development of pulmonary toxicity include the total dose of irradiation, volume of lung treated, fraction size, and patient age at the time of treatment.
- In children younger than 3 years of age, restrictive lung disease has developed with radiation doses as low as 11 to 14 Gy.

REFERENCES

Cote CJ, Lerman J, Anderson B, eds. *A Practice of Anesthesia for Infants and Children*. 5th ed. Philadelphia, PA: Saunders; 2013:Chapter 9.

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13. ANSWER: C

Please refer to answer of question #12 above.

14. ANSWER: D

Chemotherapy forms an important aspect of cancer treatment. With an increased number of patients surviving for a longer period of time, a number of patients who have received chemotherapy may be subjected to elective and emergency surgery; therefore, it is essential to know the effects of the chemotherapeutic agents on normal organ systems. The toxicity of cancer chemotherapy drugs and their relevance to perioperative anesthesia management relate to the specific agents used, their cumulative dosage, and drug toxicity. The most common toxicities to chemotherapeutic agents include cardiac, pulmonary, hematologic, bone marrow, and gastrointestinal effects. Coagulopathies, thrombocytopenia, and anemia with ulceration and bleeding of the gastrointestinal tract may often occur.

Perioperative management of patients with cancer should take into account whether they have received recent chemotherapy, in case of immunosuppression and the need to treat infection, or perioperative infection that frequently affects neutropenic cancer patients receiving emergency surgery.

Azathioprine is an antimetabolite immunosupressor frequently used during renal transplantation surgery that might interact with anesthetic drugs, such as nondepolarizing muscle relaxants.

Bleomycin is a widely used cytotoxic antibiotic. The main problem associated with the use of this drug is progressive pulmonary fibrosis. This disease is dose related, taking place more commonly at cumulative doses greater than 300,000 U and in elderly individuals. Patients who have received extensive treatment with bleomycin (e.g., a cumulative dose of more than 100,000 U) could be at risk of developing respiratory failure if a general anesthetic is given with high concentrations of inspired oxygen.

Cyclophosphamide is an alkylating drug that is extensively used in the treatment of chronic lymphocytic leukemia, lymphomas, and many solid tumors. The effects of cyclophosphamide, a pseudocholinesterase inhibitor, could last for 3–4 weeks from the end of its use.

Doxorubicin is a cytotoxic antibiotic and anthracycline that is used to treat acute leukemias, lymphomas, and various solid tumors. Supraventricular tachycardia related to use of this drug is a rare complication. High cumulative doses are associated with cardiomyopathy, and total cumulative doses are usually restricted to 450 mg/m^2 because symptomatic and potentially fatal heart failure is common at increased doses. Patients with cardiac disease, elderly people, and those given myocardial irradiation should be treated with caution.

Methotrexate is used as a maintenance treatment for childhood acute lymphoblastic leukemia. Other uses include choriocarcinoma, non-Hodgkin's lymphoma, and several solid tumors. Intrathecal methotrexate is used in CNS prophylaxis of acute lymphoblastic leukemia in childhood and as a therapy for established meningeal cancer or lymphoma. It inhibits the enzyme dihydrofolate reductase, which is essential for the synthesis of purines and pyrimidines. It is given by mouth, intravenously, intramuscularly, or intrathecally. Methotrexate used for maintenance therapy in children with acute leukemia may promote the development of hepatic cirrhosis and fibrosis.

Cisplatinum**,** a commonly used anticancer drug, has been found to produce toxic effects like nephrotoxicity, myelosuppression, neuropathy in stocking and glove distribution, and auditory and visual impairment. The dose-limiting factor for single-agent use is nephrotoxicity. Approximately 30% of patients receiving cisplatinum will develop nephrotoxicity, especially if the hydration is not properly controlled. It causes coagulation necrosis of proximal and distal renal tubular epithelial cells and in the collecting ducts, leading to a reduction in the renal blood flow and glomerular filtration rate (GFR). Acute renal failure can result within 24 hours of administration of a single dose of cisplatinum. The

newer analogues of cisplatinum, such as carboplatinum and oxaloplatinum, are less nephrotoxic with equal efficacy in controlling the malignancy. Approximately 50% of patients receiving cisplatinum will display neurotoxicity depending on dose and treatment duration. It generally takes the form of paresthesias. Continued treatment will lead to loss of deep tendon reflexes, vibration sense, and sensory ataxia.

Etoposide is a topoisomerase II inhibitor. Topoisomerase enzymes are critical for unwinding of DNA during replication. Etoposide has only mild activity as a single agent but because of its synergy with other agents is always used in combination regimens. This agent shows phase-specific activity for cells in the dividing phase. Etoposide can cause myelosuppression and has been associated with bronchospasm, hypotension, and ileus.

Tacrolimus is a calcineurin inhibitor commonly used as an immunosuppressant for organ transplantation. Patients receiving tacrolimus or cyclosporine immunosuppressive therapy should have a focused airway assessment performed, or in the event of emergent intubation, the anticipation of a possible difficult airway. Tacrolimus and cyclosporine therapy have been known to cause posttransplant lymphoproliferative disease, with a prevalence of up to 4% in the pediatric posttransplant population. Affected tissues include lymph nodes, tonsils, and extranodal organs such as the liver. Tacrolimus is also known to have effects on liver function and cause renal vasoconstriction, which may lead to a dose-related decrease in renal blood flow and glomerular filtration rate. Methotrexate causes the acute nephrotoxicity as a result of its intratubular precipitation. Before surgery, the anesthesia team should evaluate both hepatic and renal function to assess the potential impact on drug selection.

Some drugs, such as vasopressin, carbamazepine, oxytocin, vincristine, vinblastine, cyclophosphamide, phenothizianes, tricyclic antidepressant agents, narcotics, and monoamine oxidase inhibitors, can also induce SIADH.

Systems-based chemotherapy toxicities and commonly associated chemotherapy drugs are listed in Table 10.3.

Table 10.3 SYSTEMS-BASED CHEMOTHERAPY TOXICITIES AND COMMONLY ASSOCIATED CHEMOTHERAPY DRUGS

ORGAN SYSTEM	ASSOCIATED CHEMOTHERAPY DRUGS
Pulmonary toxicity	Cytotoxic antibiotics (e.g., bleomycin, mitomycin-C, and doxorubicin), nitrosureas (e.g., lomustine), alkylating agents (e.g., cyclophosphamide, ifosfamide, melphalan, chlorambucil), antimetabolites (e.g., methotrexate, azathioprine, cytarabine, fludarabine), plant alkaloids (e.g., vincristine, vinblastine, etoposide), biological response modifiers (e.g., GM-CSF, interleukin-2, interferon, BCG), others: taxol
Cardiotoxicity	Cytotoxic antibiotics; plant alkaloids; alkylating agents; others: 5-fluorouracil, cisplatin, interferon, interleukin-2, taxol
Hepatotoxicity	Nitrosureas; antimetabolites; cytotoxic antibiotics; others: 5-fluorouracil, vincristine, cisplatin
Nephrotoxicity	Nitrosureas; others: bleomycin, cisplatin, cyclophosphamide, ifosfamide, methotrexate, mitomycin C, vincristine

BCG, Bacillus Calmette–Guerin; GM-CSF, granulocyte macrophage colony-stimulating factor.

SOURCE: From Allan N, Siller C, Breen A. Anaesthetic implications of chemotherapy. *Contin Educ Anaesth Crit Care Pain*. 2012;12(2):52–6. Reprinted with permission.

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Contin Educ Anaesth Crit Care Pain. 2011;

15. ANSWER: A

Please refer to answer of question #14 above.

16. ANSWER: A

Please refer to answer of question #14 above.

17. ANSWER: A

Anthracyclines (duanorubicin, doxorubicin, and idarubicin) cause **cardiomyopathy** (presenting as clinically evident congestive heart failure in about 10% of children receiving 400–500 mg/M2), a condition potentially made worse if the precordium is involved in a radiation therapy field.

Children receiving anthracyclines should be evaluated with echocardiography at baseline and intermittently during the course of therapy and for a prolonged period after therapy because anthracycline-induced cardiac failure can take years to fully declare itself. Pediatric studies indicate a continuous deterioration of cardiac function for up to 30 years after treatment.

At first, anthracycline-associated cardiotoxicity was thought of as a cumulative dose-related form of congestive heart failure (CHF) that was rapidly progressive if use of the agent was continued. Increased awareness of subclinical cardiac impairment resulting from these agents has led to improved screening as well as a better perspective of the inherent toxicity of these agents. Today's definition has expanded from the clinical events of cardiac failure to include a wide spectrum of predefined laboratory values even when patients may be asymptomatic. These include histological changes in the cardiomyocytes and changes in left

ventricular ejection fraction (LVEF) based on either radionuclide ventriculography (RNVG) or two-dimensional (2D) echocardiography. Even transient changes previously thought to be not of any major clinical significance, for instance, daunorubicin-induced myocarditis/pericarditis will now be considered as **anthracycline-induced cardiomyopathy**. The general consensus is that a decrease in LVEF by more than 20 percentage points to a value >50%, a decrease in LVEF by more than 10 percentage points to a value <50%, or clinical manifestations with signs and symptoms of CHF constitute cardiotoxicity. Although anthracycline-induced cardiotoxicity is usually characterized by heart failure, cardiac arrhythmias might be the first manifestation in some patients.

The recognized risks in adults besides the cumulative anthracycline dose include age (elderly and young), mediastinal irradiation or radiotherapy to the left chest, other cardiac risk factors such as hypertension, female gender (especially in the pediatric population), previous exposure to any anthracycline, coadministration of other anticancer drugs, and methods of administration (bolus vs. protracted infusion).

As with adults, the main risk factor in children is the total anthracycline dose. In contrast to adults, the use of infusion as compared to bolus administration schedules has not been associated with reduced cardiotoxicity in childhood cancer survivors.

Anthracycline cardiotoxicity can be divided into acute/subacute and late/chronic:

- Acute/subacute cardiovascular complications can arise any time from the initiation of therapy to several weeks after treatment termination.
- Chronic cardiotoxicity, which is typically manifested as clinical heart failure or subclinical decline in myocardial function, may present early, within 1 year after termination of chemotherapy, or late-delayed, becoming evident beyond 1 year posttreatment.

Regardless of its timing, chronic cardiomyopathy generally begins as asymptomatic diastolic or systolic dysfunction, and progresses to heart failure, which may be fatal. The relationship between acute toxicity and the subsequent development of chronic cardiotoxicity is unclear.

Guidelines for monitoring and drug discontinuation from expert groups: Noninvasive monitoring of cardiac function during anthracycline therapy is endorsed by the American Heart Association/American College of Cardiology (AHA/ACC) in conjunction with the American Society for Nuclear Cardiology and the American Society for Echocardiography (ASE).

The use of echocardiography at baseline and for reevaluation examinations to monitor patients exposed to anthracyclines was given a class I recommendation by a 2003 task force of the ACC, the AHA, and the ASE.

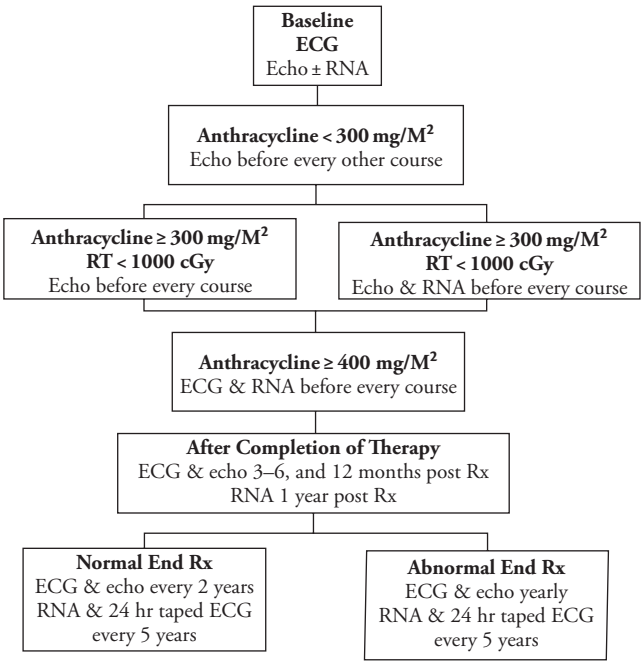

Figure 10.1 Guidelines for the use of echocardiography at baseline and for reevaluation examinations to monitor patients exposed to anthracyclines.

However, these guidelines do not provide information on the optimal parameter to be followed, how frequently monitoring should be done, or the appropriate manner in which to proceed after a patient had an abnormal reading. There is no consensus on these issues and few formal guidelines (Fig. 10.1).

KEY FACTS

- Children receiving anthracyclines should be evaluated with echocardiography at baseline and intermittently during the course of therapy and for a prolonged period after therapy because anthracyclines-induced cardiac failure can take years to fully declare itself.
- The general consensus is that a decrease in LVEF by more than 20 percent to a value >50%, a decrease in LVEF by more than 10 percentage points to a value <50%, or clinical manifestations with signs and symptoms of CHF constitute cardiotoxicity.

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Davis PJ, Cladis FP, Motoyama EK, eds. *Smith's Anesthesia for Infants and Children*. 8th ed. St. Louis, MO: Elsevier Mosby; 2011:Chapter 36.

18. ANSWER: A

Please refer to answer of question #17 above.

19. ANSWER: D

Wilms tumor or nephroblastoma is the most common renal malignancy in children and the fourth most common childhood cancer, occurring with an incidence, consistent throughout the world, of 5.0 to 7.8 per 1 million children less than 15 years of age. In contrast, renal cell carcinoma is more common in the 15- to 19-year-old age group. Wilms tumor accounts for about 6% of all malignancies in childhood.

The incidence is equal in the two genders. The risk of developing Wilms tumor varies among ethnic groups, with a greater risk in African Americans and a lower risk in the Asian population.

The peak age at diagnosis is between 1 and 3 years. Wilms tumor occurs bilaterally in 5% of patients. Wilms tumor is primarily a sporadic disease, and only 1% to 2% of individuals with Wilms tumor have a relative with the disease. In some children, Wilms tumor occurs as a part of a multiple malformation syndrome. These syndromes include WAGR, Denys-Drash, and Beckwith-Wiedemann syndromes.

WAGR syndrome—WAGR syndrome refers to the syndrome of Wilms tumor, aniridia, genitourinary (GU) anomalies, and intellectual disability (mental retardation). Children with this syndrome have a constitutional chromosomal deletion of the WT1 gene located at 11p13. The WT1 gene product is a transcription factor involved in both gonadal and renal development. Children with WT1 deletions, including WAGR syndrome, have a greater than **20% risk** of developing Wilms tumor.

Denys-Drash syndrome—The Denys-Drash or just Drash syndrome is a triad of progressive renal disease, male pseudohermaphroditism, and Wilms tumor. Affected individuals have a germline point mutation in the eighth or ninth exon of the WT1 gene, which results in an amino acid substitution, and **almost all patients (90%) will develop Wilms tumor**. The underlying renal pathology is diffuse mesangial sclerosis, which presents in infancy with proteinuria and progresses to nephrotic syndrome and renal failure.

Beckwith-Wiedemann syndrome—Patients with the Beckwith-Wiedemann syndrome have **a 5% to 10% chance of developing Wilms tumors**. The major clinical features of Beckwith-Wiedemann syndrome include macrosomia, macroglossia, omphalocele, prominent eyes, ear creases, large kidneys, pancreatic hyperplasia, and hemihypertrophy.

A number of cancers are more common in individuals who have **neurofibromatosis type 1**. These include various types of malignant brain tumors, as well as leukemia and cancerous tumors of certain muscles (rhabdomyosarcoma), the adrenal glands (pheochromocytoma), or the kidneys (Wilms tumor).

The signs and symptoms associated with Wilms tumor are variable. The most frequent finding is an **increased abdominal girth** with a palpable abdominal mass (85%). **Hypertension** occurs in 60% of patients, and **hematuria** is present in 10% to 25%.

KEY FACTS

- Wilms tumor or nephroblastoma is the most common renal malignancy in children and the fourth most common childhood cancer.
- In some children, Wilms tumor occurs as a part of a multiple malformation syndrome. These syndromes include WAGR, Denys-Drash, and Beckwith-Wiedemann syndromes.
- The signs and symptoms associated with Wilms tumor are variable. The most frequent finding is an increased abdominal girth with a palpable abdominal mass (85%). Hypertension occurs in 60% of patients, and hematuria is present in 10% to 25%.

REFERENCE

Davis PJ, Cladis FP, Motoyama EK, eds. *Smith's Anesthesia for Infants and Children*. 8th ed. St. Louis, MO: Elsevier Mosby; 2011:Chapter 23.

20. ANSWER: B

Pheochromocytoma is a **catecholamine-secreting tumor** of chromaffin cells that most commonly arises in the **adrenal medulla**. It may be found anywhere along the abdominal sympathetic chain, but it is most commonly near the aorta at the inferior mesenteric artery or the aortic bifurcation.

The abnormally high plasma levels of epinephrine and norepinephrine produce a clinical syndrome with signs and symptoms related directly to the level of each hormone present in the patient. Although pheochromocytoma can produce norepinephrine and epinephrine, **the predominant catecholamine produced in children is norepinephrine**, which leads to **chronic hypertension**. Hypertension is common and often leads to **hypertensive encephalopathy and seizures**. The classic symptom triad is **paroxysmal headaches, tachycardia, and sweating.**

Pheochromocytoma "rule of 10": 10% bilateral, 10% malignant (higher in familial cases), 10% extra-adrenal, 10% familial (now thought to be higher).

It is extremely important to establish the diagnosis of pheochromocytoma before induction of anesthesia and start of surgery.

The demonstration of increased levels of catecholamines is the most specific diagnosis test. Urine catecholamine concentrations are directly proportional to circulating levels, and determination of 24-hour urinary excretion of the primary catecholamines and their metabolites used to be the primary means of establishing the diagnosis.

The plasma free **metanephrine** determination has better sensitivity (100%) and specificity (94%). Because normal

values differ with age, it is important to use age-specific norms when interpreting results. Plasma metanephrine and epinephrine are not reliably elevated.

Hereditary forms of pheochromocytoma include multiple endocrine neoplasia type 2, von Hippel-Lindau syndrome, neurofibromatosis type 1, and familial paragangliomas. Any patient with medullary thyroid cancer should be screened for pheochromocytoma prior to surgery.

Preoperative evaluation should include the measurement of **serum electrolytes**, determination of **renal function**, and **fasting blood glucose**. Excessive serum epinephrine levels may be associated with **hyperglycemia** and **hypokalemia**. **Drugs that induce catecholamines secretion or histamine release should be avoided**.

KEY FACTS

- Pheochromocytoma is a catecholamine-secreting tumor of chromaffin cells that most commonly arises in the adrenal medulla.
- The predominant catecholamine produced in children is norepinephrine, which leads to chronic hypertension; this, in turn, often leads to hypertensive encephalopathy and seizures. The classic symptom triad is paroxysmal headaches, tachycardia, and sweating. Excessive serum epinephrine levels may be associated with hyperglycemia and hypokalemia.
- Hereditary forms of pheochromocytoma include multiple endocrine neoplasia type 2, von Hippel-Lindau syndrome, neurofibromatosis type 1, and familial paragangliomas.

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Davis PJ, Cladis FP, Motoyama EK, eds. *Smith's Anesthesia for Infants and Children*. 8th ed. St. Louis, MO: Elsevier Mosby; 2011:Chapter 36.

Kliegman RM, Stanton BF, St. Gemell JW, Schor NF, Behrman RE, eds. *Nelson Textbook of Pediatrics*. 19th ed. Philadelphia, PA: Elsevier Saunders; 2011:1941–3.

21. ANSWER: B

Please refer to answer of question #20 above.

22. ANSWER: C

Please refer to answer of question #20 above.

23. ANSWER: B

Please refer to answer of question #20 above.

24. ANSWER: C

Acute leukemia, the most common form of cancer in children, comprises approximately 30% of all childhood malignancies, with acute lymphoblastic leukemia (ALL) being five times more common than acute myeloid leukemia (AML). **The peak incidence occurs between 2 and 5 years of age**, and it occurs more commonly among boys than girls. The most common presenting symptoms of ALL are nonspecific (e.g., fever, bleeding, bone pain, lymphadenopathy). Unexplained persistence of any of these common signs or symptoms should prompt consideration of malignancy as a possible cause. Approximately 50% of children with ALL present with **lymphadenopathy**. Children with Trisomy 21 (Down syndrome) have a 10- to 20-fold increased risk of developing acute leukemia.

Most children with ALL have **anemia** and/or **thrombocytopenia** with either normal or depressed WBC counts and lymphoblasts on peripheral smear. Approximately 50% of children have WBC counts <10,000/μL, and 20% have an initial leukocyte count >50,000/μL. Approximately one half of children with ALL present with **bleeding** (including petechiae and purpura) and three quarters have a platelet count <100,000/μL at the time of diagnosis.

This evaluation will include clinical examination, and bone marrow aspiration and biopsy, which will diagnose ALL and determine the leukemia phenotype as well as the presence or absence of cytogenetic abnormalities. This initial information will be used to assign the patient to a treatment group based upon risk stratification.

Potential increase in perioperative risk among this population is due to high incidence of **multiple organ involvement** and **poor immune response** caused by pancytopenia. These conditions include interstitial pneumonitis, acute respiratory failure, opportunistic infection, and encephalopathy. Patients are at risk for developing hematoma and/or bleeding from thrombocytopenia and splenic sequestration. Other anesthetic concerns include **potential bone marrow suppression by inhaled nitrous oxide**, **possible upper airway edema** and **pulmonary fibrosis**, **difficult IV placement,** and side effects from each chemotherapeutic agent used to treated leukemia. **Dexamethasone is commonly used as an antiemetic, but it is also often used as a chemotherapy agent and should not be given intraoperatively without discussion with the oncology team, as it may precipitate tumor lysis syndrome.**

KEY FACTS

- Acute leukemia, the most common form of cancer in children, comprises approximately 30% of all childhood malignancies, with acute lymphoblastic leukemia (ALL) being five times more common than acute myeloid leukemia (AML).

- The most common presenting symptoms of ALL are nonspecific (e.g., fever, bleeding, bone pain, lymphadenopathy).
- There is a high incidence of multiple organ involvement and poor immune response caused by pancytopenia, and this includes interstitial pneumonitis, acute respiratory failure, opportunistic infection, and encephalopathy.
- Anesthetic concerns include potential bone marrow suppression by inhaled nitrous oxide, possible upper airway edema and pulmonary fibrosis, difficult IV placement, and side effects from each chemotherapeutic agent used to treated leukemia.
- Dexamethasone is commonly used as an antiemetic, but it is also often used as a chemotherapy agent and should not be given intraoperatively without discussion with the oncology team, as it may precipitate tumor lysis syndrome.

REFERENCE

Kliegman RM, Stanton BF, St. Gemell JW, Schor NF, Behrman RE, eds. *Nelson Textbook of Pediatrics*. 19th ed. Philadelphia, PA: Elsevier Saunders; 2011:1732–9.

25. ANSWER: A

Childhood cancer often is difficult to detect in its early stages because the associated signs and symptoms are nonspecific, insidious in onset, and mimic more common disorders. Although childhood cancers are rare events, they are the fourth leading cause of death in individuals between 1 and 19 years of age in the United States. Common sites include blood and bone marrow, brain, bone, lymph nodes, nervous system, kidneys, and soft tissues (see Table 10.4).

Spinal cord compression is a common complication of neuroblastomas. Osteosarcomas are primary malignant tumors of bone that are characterized by the production of osteoid or immature bone by the malignant cells. Osteosarcomas are **uncommon tumors**. Approximately 750 to 900 new cases are diagnosed each year in the United States, of which 400 arise in children and adolescents younger than 20 years of age. But osteosarcoma is the most common primary bone tumor affecting children and young adults; the peak age is between 13 and 16. In children, the majority of osteosarcomas are sporadic. A minority of cases is associated with inherited predisposition syndromes such as hereditary retinoblastoma, Li-Fraumeni syndrome, Rothmund-Thomson syndrome, and the related Bloom and Werner syndromes.

The majority of patients with osteosarcoma present with **localized pain**, typically of several months' duration. The most important finding on physical examination is **a soft tissue mass**, which is frequently large and tender to palpation. At presentation, between **10% and 20% have demonstrable metastatic disease**. CT scans are best suited to evaluate the thorax for metastatic disease, which is essential because **approximately 80% of metastatic lesions in osteosarcoma occur in the lungs**. The most common metastatic site for all bone sarcomas is pulmonary. Thin-section imaging of the chest using high-resolution helical CT is the preferred modality, detecting approximately 20% to 25% more nodules than conventional CT, and the reliable detection of nodules as small as 2 to 3 mm.

Biopsy is required for definitive diagnosis. Once the diagnosis of an osteosarcoma is established, the staging evaluation

Table 10.4 THE MOST COMMON CHILDHOOD MALIGNANCIES IN CHILDREN AND ADOLESCENTS

	AGE < 1 YEAR	AGE 1 TO 4 YEARS	AGE 5 TO 9 YEARS
CANCER TYPE	PERCENTAGE OF ALL CANCERS		
Acute leukemia	18	43	36
CNS tumors	13	19	28
Lymphoma	1	3	12
Neuroblastoma	24	9	3
Wilms tumor	6	9	4
	AGE 10 TO 14 YEARS	AGE 15 TO 19 YEARS	
CANCER TYPE	PERCENTAGE OF ALL CANCERS		
Acute leukemia	23	13	
CNS tumors	21	9	
Lymphoma	18	23	
Germ cell tumors	6	14	
Thyroid cancer	4	8	

The most common causes of cancer based upon age in the United States (1992 to 2004) from data obtained by the Surveillance, Epdiemiology, and End Results program, National Cancer Institute.

should include MRI of the entire length of the involved bone, CT of the thorax, radionuclide bone scanning with technetium, and/or a positron emission tomography (PET) scan.

Conventional osteosarcoma is relatively resistant to radiation therapy. Because of this, primary radiation therapy is not usually adequate to achieve local disease control, particularly for bulky tumors.

In contrast to osteosarcoma and other primary bone sarcomas, **Ewing sarcoma** is more **radiosensitive**, and radiation may be considered an effective option for local control. Although modern treatment protocols emphasize surgery for optimal local control, patients who lack a function-preserving surgical option because of tumor location or extent, and those who have clearly unresectable primary tumors following induction chemotherapy are appropriate candidates for radiation therapy.

KEY FACTS

- **Spinal cord compression is a common complication of neuroblastomas**
- Osteosarcoma is the most common primary bone tumor affecting children and young adults; the peak age is between 13 and 16 years.
- Most patients present with localized pain and a soft tender tissue mass. Approximately 10%–20% of patients have metastatic disease, with approximately 80% of metastatic lesions occurring in the lungs.
- In contrast to osteosarcoma and other primary bone sarcomas, Ewing sarcoma is more radiosensitive, and radiation may be considered an effective option for local control.

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Niederhuber JE, Armitage JO, Doroshow JH, Kastan MB, Tepper JE, eds. *Abeloff's Clinical Oncology*. 5th ed. Philadelphia, PA: Churchill Livingstone; 2014:1693–752.

26. ANSWER: D

The term *neuroblastoma* is commonly used to refer to a spectrum of neuroblastic tumors (including neuroblastomas, ganglioneuroblastomas, and ganglioneuromas) that arise from primitive sympathetic ganglion cells. Neuroblastoma has been associated with **central hypoventilation**, **Hirschsprung disease**, and **neurofibromatosis type 1**, and as a familial disorder associated with mutations in the ALK gene.

Neuroblastomas can arise anywhere throughout the sympathetic nervous system. The **adrenal gland** is the most common primary site (40%), followed by abdominal (25%), thoracic (15%), cervical (5%), and pelvic sympathetic ganglia (5%). Less commonly, tumors arise within the central or autonomic nervous systems.

The presenting symptoms reflect the location of the primary tumor and the extent of metastatic disease, if present. Patients with localized disease can be asymptomatic, whereas children with advanced disease appear ill at presentation, usually with systemic symptoms. Signs and symptoms of neuroblastoma may include abdominal mass, abdominal pain or constipation, proptosis, periorbital ecchymoses (caused by orbital metastases), Horner syndrome (miosis, ptosis, anhidrosis), localized back pain, weakness (from spinal cord compression), scoliosis, bladder dysfunction, and palpable nontender subcutaneous nodules. It can also present with systemic symptoms such as fever, weight loss, bone pain, anemia, and hypertension.

Between 7% and 15% of children with neuroblastoma present with **spinal cord involvement**. Spinal cord compression is considered an oncologic emergency. Prompt resolution is important to limit permanent neurologic impairment. Neurologic recovery appears to be related to the severity of presenting neurologic deficits. Chemotherapy and laminectomy have equivalent overall survival outcomes. Each therapeutic modality, however, carries inherent long-term and short-term risks and should be determined on an individualized basis. Radiation therapy is generally reserved for progressive symptoms despite chemotherapy.

Several unique **paraneoplastic syndromes** can be associated with both localized and disseminated neuroblastomas. **Opsoclonus-myoclonus-ataxia (OMA)** is a paraneoplastic syndrome that occurs in 1% to 3% of children with neuroblastoma. Almost 50% of children with OMA have an underlying neuroblastoma; neurologic symptoms precede tumor diagnosis in about half of these. The disorder is believed to have an **autoimmune** pathogenesis. The characteristic symptoms of OMA are rapid, dancing eye movements, rhythmic jerking (myoclonus) involving limbs or trunk, and/or ataxia. All children with OMA must be evaluated for neuroblastoma. If the initial evaluation is unrevealing, it should be repeated in several months. Autonomous tumor secretion of **vasoactive intestinal peptide** (VIP) is another paraneoplastic syndrome that is rarely associated with neuroblastoma. VIP secretion can cause **abdominal distension and intractable secretory diarrhea** with associated hypokalemia; these symptoms usually resolve after removal of the tumor.

Neuroblastoma metastasizes by both lymphatic and hematogenous routes. **Regional lymph node involvement** is found in 35% of children who have apparently localized disease. Involvement of lymph nodes outside the cavity or region of origin (i.e., abdomen, thorax, pelvis) is considered to represent disseminated disease.

Neuroblastomas are staged according to the International Neuroblastoma Staging System (INSS), which was initially

developed in 1986 and revised in 1993. The minimal requirements for staging include the following:

- Bilateral iliac crest bone marrow aspirate and biopsy
- Bone radiographs and either technetium radionuclide scan or I123-MIBG scan
- Abdominal imaging by CT or MRI scans with three-dimensional tumor measurements
- Chest radiograph (anteroposterior [AP] and lateral); chest CT or MRI is necessary only if the chest radiograph is positive or if abdominal mass or lymph node disease extends into the chest.
- Head CT should be considered for patients presenting with proptosis, periorbital ecchymoses, or as clinically indicated by symptoms.

KEY FACTS

- Neuroblastomas can arise anywhere throughout the sympathetic nervous system. The adrenal gland is the most common primary site (40%), followed by abdominal (25%), thoracic (15%), cervical (5%), and pelvic sympathetic ganglia (5%).
- Between 7% and 15% of children with neuroblastoma present with spinal cord involvement. Spinal cord compression is considered an oncologic emergency. Regional lymph node involvement is found in 35% of children who have apparently localized disease.
- Almost 50% of children with opsoclonus-myoclonus-ataxia (OMA) have an underlying neuroblastoma. The characteristic symptoms of OMA are rapid, dancing eye movements; rhythmic jerking (myoclonus) involving limbs or trunk; and/or ataxia.

REFERENCE

Kliegman RM, Stanton BF, St. Gemell JW, Schor NF, Behrman RE, eds. *Nelson Textbook of Pediatrics*. 19th ed. Philadelphia, PA: Elsevier Saunders; 2011:1753–7.

27. ANSWER: A

Stage 4S neuroblastoma is a special category that is reserved for infants below 1 year of age who have resectable primary tumors (stage 1 or 2) and metastases that are limited to the liver, skin, and bone marrow; infants with metastases to cortical bone are excluded from this category. The INRGSS has modified the definition of 4S (called Ms) to include patients up to 18 months of age and those with regional spread of primary tumor.

The 4S (or Ms) category is an exception to the typically dismal prognosis for children with widespread metastases from neuroblastoma. Overall survival for infants in this category is over 85%. One contributing factor is that the tumor cells in infants with stage 4S disease have the capacity to undergo spontaneous regression. However, like all stages of neuroblastomas, the tumors that make up stage 4S disease are heterogeneous, and they require heterogeneous treatment protocols.

Neonates (younger than 4–6 weeks) who have stage 4S neuroblastoma are an exception to the general rule that younger age is associated with better outcome. Among this small subset of patients, neuroblastoma in the liver can grow rapidly, resulting in pulmonary compromise and renal failure in approximately 30% of cases. Such infants must be monitored closely even after treatment initiation. In contrast, newborns that have limited adrenal disease (typically diagnosed by prenatal ultrasound) have a favorable prognosis and frequently do not need treatment.

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Kliegman RM, Stanton BF, St. Gemell JW, Schor NF, Behrman RE, eds. *Nelson Textbook of Pediatrics*. 19th ed. Philadelphia, PA: Elsevier Saunders; 2011:1753–7.

28. ANSWER: B

Retinoblastoma is the most common intraocular tumor of childhood. The majority of cases are diagnosed in children **younger than 2 years of age**. Approximately one fourth of cases are **bilateral**. Children who have a family history of retinoblastoma or a personal or family history of 13q deletion or 13q deletion mosaicism have an increased risk.

Leukocoria is the most common presenting finding, but it is not necessary for diagnosis. Other presentations may include strabismus, decreased vision, ocular inflammation, and family history.

An ophthalmologist should evaluate children at increased risk of retinoblastoma shortly after birth. **Screening** should then be conducted every 3–4 months until 3–4 years of age, and every 6 months until 5–6 years of age (unless genetic testing of the affected child reveals that he or she does not have a germline mutation, in which case follow-up examinations are not necessary). Retinoblastoma surveillance examinations are usually performed with the patient under general anesthesia to permit complete examination of the ocular fundus.

The diagnosis of retinoblastoma can usually be made during a dilated indirect ophthalmoscopic examination that is performed under anesthesia; the characteristic finding is a **chalky, white-gray retinal mass** with a soft, friable consistency. Such an examination permits complete visualization of the retina and identification of multifocal tumors

and/or subretinal or vitreous seeding. The risk of anesthesia is balanced by the benefit of improved ocular survival. Pathology is necessary to confirm the diagnosis.

Ocular ultrasonography and/or CT may demonstrate a solid intraocular tumor with characteristic intratumoral calcifications. **MRI is preferred to CT** because of the increased long-term cancer risk associated with CT scanning. Metastatic disease is rarely present at the time of diagnosis, and formal staging studies (i.e., bone marrow examination, lumbar puncture, and/or radionuclide bone scan) are not usually performed.

A variety of **treatment options** are available for children with retinoblastoma, including several "vision-sparing" therapies. The choice of treatment depends upon visual prognosis, tumor size and location, presence or absence of vitreous or subretinal seeds, and patient age. Standard therapeutic options include enucleation, external beam radiation therapy (RT), radioactive plaques (I-125 brachytherapy), cryotherapy, laser photoablation, and chemotherapy.

Enucleation usually is indicated for large tumors (>50% of globe volume) with no visual potential, blind, painful eyes, and/or tumors that extend into the optic nerve. **Enucleation** is usually the preferred treatment in eyes that have failed previous "globe-conserving" approaches. Following enucleation, using a graduated **chemotherapy** approach, adjuvant chemotherapy or brachytherapy may be considered in patients with high-risk features to prevent metastatic disease (e.g., iris, ciliary body, massive choroidal or scleral infiltration, and invasion of the optic nerve posterior to the lamina cribrosa). Children who undergo enucleation for retinoblastoma must be monitored closely for orbital relapse in the **2 years** after surgery.

The overall 5-year survival rate for children with retinoblastoma in the United States is >90%. Patients who develop metastatic disease usually do so **within 1 year** of diagnosis; a child who remains **recurrence-free for 5 years** after diagnosis is considered cured.

KEY FACTS

- Retinoblastoma is the most common intraocular tumor of childhood. The majority of cases are diagnosed in children younger than 2 years of age. Approximately one fourth of cases are bilateral.
- Metastatic disease is rarely present at the time of diagnosis, and formal staging studies (i.e., bone marrow examination, lumbar puncture, and/or radionuclide bone scan) are not usually performed.
- Patients who develop metastatic disease usually do so within 1 year of diagnosis; a child who remains recurrence-free for 5 years after diagnosis is considered cured.

REFERENCE

Kliegman RM, Stanton BF, St. Gemell JW, Schor NF, Behrman RE, eds. *Nelson Textbook of Pediatrics*. 19th ed. Philadelphia, PA: Elsevier Saunders; 2011:1768–9.

29. ANSWER: A

PANDAS (pediatric autoimmune neuropsychiatric disorder associated with group A streptococci) is a term used to describe a subset of children whose symptoms of **obsessive-compulsive disorder (OCD) or tic disorders** are exacerbated by group A streptococcal (GAS) infection. The hypothesized association between PANDAS and GAS is controversial. Children who present with abrupt onset of OCD/tic disorder be evaluated for GAS infection.

PANDAS is characterized by five working criteria:

- OCD and/or tic disorder
- Pediatric onset (between 3 years and onset of puberty)
- Abrupt onset and episodic course of symptoms
- Temporal relation between GAS infection and onset and/or exacerbation
- Neurologic abnormalities or tics during exacerbations

PANDAS is a clinical diagnosis. It may be suspected in children with an abrupt onset of neuropsychiatric symptoms, recent group A streptococcal (GAS) infection, and **remission of neuropsychiatric symptoms with antibiotic therapy**. The obsessive-compulsive disorder (OCD)/tic disorder and acute GAS infection should be treated. Patients with suspected PANDAS should be monitored for recurrence of neuropsychiatric symptoms and/or GAS infection because approximately 50% have second episodes.

Prophylactic antibiotics are an option to aid in the diagnosis of PANDAS and prevent symptom recurrences. The clinical course during prophylaxis may provide insight into the disease for the patient/family and clinician: remission of neuropsychiatric symptoms helps to establish the diagnosis of PANDAS, whereas recurrence of neuropsychiatric symptoms during prophylaxis excludes the diagnosis.

Antibiotic therapy is indicated for the treatment of acute streptococcal infection as diagnosed by a positive throat or skin culture or rapid antigen detection test. There is a recommendation that children with positive culture or rapid antigen detection test for GAS be treated with antistreptococcal therapy (whether or not they have neuropsychiatric symptoms). Antimicrobial therapy is administered to reduce the severity and duration of signs and symptoms, including suppurative complications, to reduce the incidence of nonsuppurative complications (e.g., acute rheumatic fever), and to reduce the risk of transmission.

Children with OCD and/or tic disorders should receive standard neuropsychiatric treatment for these disorders (whether or not the children have evidence of recent GAS infection). Treatment of neuropsychiatric symptoms should not be delayed pending confirmation of PANDAS (e.g., documenting rise in antistreptococcal antibodies or while monitoring for a second episode). The neuropsychiatric manifestations of children in the PANDAS subgroup respond to treatment with standard pharmacologic and behavior therapies. OCD symptoms generally respond to a combination of pharmacotherapy (typically a selective serotonin reuptake inhibitor) and cognitive behavior therapy. Motor and vocal tics can be treated with a variety of medications.

Immune modulating therapies include **glucocorticoids, plasma exchange, and intravenous immunoglobulin (IVIG).** If PANDAS is an autoimmune disorder (and this remains controversial), immunomodulatory treatments might be beneficial. Most recommend not to treat children who meet criteria for PANDAS with immune modulating therapies outside of the research setting. Immune modulating therapy may be an alternative for severely ill patients who have not responded to standard therapies. In such cases, consultation with a specialist in the treatment of neuropsychiatric and/or autoimmune disorders is recommended.

PANDAS are rare and affected children have significant anesthetic implications. These patients can present for any surgical procedure both unrelated and related to PANDAS such as plasmapheresis. Anesthesiologists should be aware of the abnormal behavior and movements with this disorder. Using premedication with oral ketamine and midazolam should be considered to help separate the patient from his or her parents and gain an intravenous access.

KEY FACTS

- PANDAS (pediatric autoimmune neuropsychiatric disorder associated with group A streptococci) is a term used to describe a subset of children whose symptoms of obsessive-compulsive disorder (OCD) or tic disorders are exacerbated by group A streptococcal (GAS) infection.
- Prophylactic antibiotics are an option to aid in the diagnosis of PANDAS and prevent symptom recurrences.
- Immune modulating therapy may be an alternative for severely ill patients who have not responded to standard therapies.

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Gabbay V, Coffey BJ, Babb JS, et al. Pediatric autoimmune neuropsychiatric disorders associated with streptococcus: comparison of diagnosis and treatment in the community and at a specialty clinic. *Pediatrics*.2008;122(2):273–8.

30. ANSWER: C

Advances in treatment for and prevention of human immunodeficiency virus (HIV) infection have resulted in dramatic improvements in the morbidity and mortality of HIV-infected children in developed settings. Although transmission of HIV from mother to child can occur before, during, or after delivery, the highest percentage of HIV-infected children **acquire the virus during delivery**, most likely through exposure to infected blood and secretion during delivery. Chance of transmission increased with preterm birth, low birth weight, low maternal CD4 counts, and IV drug use during pregnancy.

The Centers for Disease Control and Prevention (CDC) and the World Health Organization (WHO) each have established case definitions for HIV infection and AIDS in adults and children to standardize the description of HIV infection cases.

HIV infection in adults and adolescents (aged ≥13 years) is stratified into **three** mutually exclusive stages, increasing in severity from CDC stage 1 to CDC stage 3 (AIDS). Staging is based upon the measurement of CD4+ T-lymphocyte (CD4) counts and CD4+ T-lymphocyte percentage of total lymphocytes (CD4%) to describe the degree of immunosuppression.

For adults and adolescents, laboratory confirmation includes:

- A positive result from an HIV antibody screening test (e.g., enzyme immunoassay or rapid test) confirmed by a positive result from a supplemental HIV antibody test (e.g., Western blot or indirect immunofluorescence assay test)
- A positive HIV virologic test including HIV nucleic acid (DNA or RNA) detection test or HIV p24 antigen test.

In children between 18 months and <13 years of age, laboratory criteria for the definitive diagnosis of HIV is the same as for adults and adolescents. The HIV infection classification system for children age <13 years uses two axes, clinical and immunologic categories, to indicate the severity of clinical signs and symptoms and the degree of immunosuppression. Clinical categories describe the severity of clinical signs and symptoms:

- Category N: No signs or symptoms considered to be the result of HIV infection or with only one of the conditions listed in Category A, mildly symptomatic
- Category A: Mild signs or symptoms
- Category B: Moderate signs or symptoms thought to be caused by HIV infection but not specifically included in Category A or Category C
- Category C: Severely symptomatic. All AIDS-defining conditions except for LIP/PLH

Immunologic categories are based upon age-adjusted CD4 counts and CD4 percentage and include the following:

- 1—No evidence of immunosuppression
- 2—Moderate immunosuppression
- 3—Severe immunosuppression

In children <18 months of age, laboratory diagnosis of HIV is complicated by the fact that maternal antibodies that passively cross the placenta during pregnancy may persist in children until 18 months of age. Thus, the detection of antibodies in a child <18 months of age does not distinguish between maternal antibodies and true infection. Nonetheless, antibody tests may be helpful in excluding HIV infection, if the test result is negative, or confirming HIV exposure, if the test result is positive.

Because of the possibility of persistence of maternal antibody, laboratory criteria for children aged <18 months allow classification into one of four categories, presumptively or definitively HIV infected, or presumptively or definitively not HIV infected, depending on whether laboratory criteria are met.

- Presumptively HIV infected—Children with known HIV exposure whose clinical illness meets the AIDS definition on the basis of clinical criteria; laboratory criterion for definitively HIV infected is not met
- Definitively HIV infected—Children with known HIV exposure with positive virologic test results on two separate specimens
- Presumptively uninfected HIV—Two negative virologic tests from separate specimens, both of which were obtained at age ≥2 weeks and one of which was obtained age ≥4 weeks; or one negative RNA or DNA virologic test from a specimen obtained at age ≥8 weeks; or one negative HIV antibody test from a specimen obtained at age ≥6 months
- Definitively uninfected—Children with no laboratory or clinical evidence of HIV infection and at least two negative HIV or RNA virologic tests from separate specimens, both of which were obtained at age ≥1 month and one of which was obtained at age ≥4 months; or at least two negative antibody tests from separate specimens obtained at age ≥6 months and no other laboratory or clinical evidence for HIV infection

Indeterminate HIV infection status is used to describe a child age <18 months born to an HIV-infected mother for whom the criteria for "infected with HIV" and "uninfected with HIV" are not met.

There are several anesthetic considerations when taking care of patients with HIV. Because **CNS involvement is relatively common**, CNS depressants such as barbiturates, benzodiazepines, and opioids should be carefully titrated. If liver and renal dysfunction is present, drug metabolism and elimination are impaired. It is best to avoid long-acting medications, especially those medications with a termination of action that relies upon hepatic or renal clearance or those that have active metabolite.

KEY FACTS

- The highest percentage of HIV-infected children acquire the virus during delivery, most likely through exposure to infected blood and secretion during delivery.
- Chance of transmission increased with preterm birth, low birth weight, low maternal CD4 counts, and IV drug use during pregnancy.
- In children <18 months of age, laboratory diagnosis of HIV is complicated by the fact that maternal antibodies that passively cross the placenta during pregnancy may persist in children until 18 months of age.
- CNS depressant such as barbiturates, benzodiazepines, and opioids should be carefully titrated because CNS involvement is common. Drug metabolism and elimination can be impaired if liver and renal dysfunction are present, and it is best to avoid long-acting medications.

REFERENCE

Davis PJ, Cladis FP, Motoyama EK, eds. *Smith's Anesthesia for Infants and Children*. 8th ed. St. Louis, MO: Elsevier Mosby; 2011:Chapter 36.

11.

GENETICS

Monica A. Hoagland

1. A 10-year-old female with no prior medical history is undergoing a laparoscopic appendectomy for acute appendicitis. A rapid sequence induction with propofol, fentanyl, and succinylcholine is performed; the trachea is intubated uneventfully; and anesthesia is maintained with sevoflurane. Fifteen minutes into the procedure, she develops a rapidly rising end-tidal CO_2 that cannot be controlled with increased minute ventilation. She then develops tachycardia with occasional premature ventricular contractions, and her temperature begins to rise. A presumptive diagnosis of malignant hyperthermia is made and treatment with dantrolene is started. Which of the following describes the mechanism of action of dantrolene?

A. Interrupted neuromuscular transmission at the level of the neuromuscular junction
B. Stabilization of the muscle membrane to prevent further breakdown
C. Decreased myoplasmic calcium concentration
D. Prevention of acute renal failure due to myoglobinuria

2. A 5-year-old male with a family history of malignant hyperthermia in a first-degree relative confirmed by contracture testing presents for elective tonsillectomy. Which of the following is a sufficient method for preparing an anesthesia work station for this patient?

A. Placing charcoal filters on the breathing circuit of the machine
B. Draining the vaporizers
C. Flushing the machine with 10 L/min fresh gas flows
D. Changing the absorbent and breathing circuit on the anesthesia machine

3. A patient with which of the following disorders is at increased risk of malignant hyperthermia susceptibility compared to the general population?

A. King-Denborough syndrome
B. Duchenne muscular dystrophy
C. Hyperkalemic periodic paralysis
D. Neuroleptic malignant syndrome

4. An 18-year-old male with Duchenne muscular dystrophy presents for gastric tube placement. Which of the following is most likely to be found during his preoperative evaluation?

A. FEV1 40% and FVC 90% predicted on pulmonary function testing
B. Dilated cardiomyopathy with valvular regurgitation
C. Elevated creatinine
D. Respiratory alkalosis

5. A 5-year-old male with Duchenne muscular dystrophy is most likely to have which of the following complications after exposure to an anesthetic that includes sevoflurane?

A. Cardiac failure
B. Respiratory insufficiency
C. Rhabdomyolysis and hyperkalemia
D. Malignant hyperthermia

6. A 16-year-old female presents for appendectomy. Her younger brother has been diagnosed with Duchenne muscular dystrophy. She has a normal physical examination and denies a history of weakness. She is at risk for which of the following perioperative events?

A. Abnormal response to nondepolarizing muscle relaxants
B. Respiratory insufficiency
C. Cardiac arrest
D. Aspiration

7. A 12-year-old male with myotonia congenita undergoing reduction and fixation of a fracture develops sustained muscle contractions intraoperatively. Which of the following interventions will relieve myotonic contractions?

A. Neuromuscular blockade with rocuronium
B. Peripheral nerve blockade with lidocaine
C. Decrease in intracellular calcium with dantrolene
D. Sodium channel blockade with procainamide

8. An 18-year-old patient with myotonic dystrophy presents for an elective orthopedic procedure. He has minimal symptoms of his disease but has family members who have developed severe systemic symptoms related to this diagnosis. Preoperative counseling regarding anesthetic risks for this patient should include which of the following?

A. No cardiac evaluation is necessary at this time.
B. Postoperative ventilation may be required.
C. Responses to sedative medications will be normal.
D. The risk for malignant hyperthermia is increased.

9. In which of the following muscular disorders is energy production not sufficient to meet demands of metabolically active tissue?

A. Central core disease
B. MELAS (mitochondrial myopathy, encephalopathy, lactic acidosis, stroke-like episodes)
C. Becker muscular dystrophy
D. Myotonia congenita

10. Which of the following strategies for management of maintenance fluids is appropriate for a 20 kg patient with a mitochondrial myopathy undergoing surgery who has been fasting for 4 hours?

A. Lactated Ringer's solution at 60 mL/hour started after incision
B. 5% Dextrose in lactated ringer's solution at 30 mL/hour started preoperatively
C. Normal saline at 30 mL/hour started after incision
D. 5% Dextrose in normal saline at 60 mL/hour started preoperatively

11. A hypotonic infant with feeding difficulties and a diagnosis of myotubular myopathy presents for gastric tube placement. Appropriate anesthetic management of this patient may include which of the following?

A. Preparation for possible difficult airway management
B. Avoidance of lactated fluids
C. Avoidance of malignant hyperthermia-triggering medications
D. Use of succinylcholine for rapid sequence intubation

12. A 5-year-old female with achondroplasia presents for a leg-lengthening procedure. Intraoperative management in this patient is expected to be complicated by:

A. Cyanotic heart disease
B. Mucopolysaccharide deposition in pharyngeal and laryngeal structures
C. Predisposition to bleeding after airway trauma
D. Foramen magnum stenosis causing cervical compression

13. An infant with osteogenesis imperfecta and failure to thrive presents for gastrostomy tube placement. A mask induction is performed and the patient is maintained on volatile anesthetic with controlled ventilation after endotracheal intubation. He remains hemodynamically stable throughout the procedure but is noted to have an elevated end-tidal CO_2 and temperature. These findings are most likely due to:

A. Sepsis
B. Malignant hyperthermia
C. Increased basal metabolic rate
D. Iatrogenic overheating and inadequate minute ventilation

14. A 2-day-old male presents for ligation of tracheo-esophageal fistula and repair of esophageal atresia. He is noted to have musculoskeletal abnormalities, including abnormal forearms and hemivertebrae noted on his chest X-ray. His oxygen saturation is above 95% on room air, his respirations are not labored, and he has had normal hemodynamics during his neonatal intensive care unit (NICU) stay. What further workup is required before this patient is taken to the operating room?

A. Echocardiogram
B. Liver function and coagulation testing
C. Head ultrasound
D. No further studies required

15. A neonate with dysmorphic facies and a history of seizures presents for repair of an interrupted aortic arch. Which of the following findings is most likely to be present in this patient?

A. Hypercalcemia
B. Atlantoaxial instability
C. Immunodeficiency
D. Renal anomalies

16. In which of the following syndromes is the difficulty of airway management expected to improve as the patient ages?

A. Pierre-Robin sequence
B. Treacher Collins syndrome
C. Goldenhar syndrome
D. CHARGE association

17. An infant with bilateral coronal synostosis and bilateral hand syndactyly presents to the preoperative clinic for evaluation prior to cranial vault reconstruction. Which of the following exam findings is likely to be present during his evaluation?

A. Hepatomegaly
B. An elongated head (increased anterior-posterior diameter)
C. Kyphoscoliosis
D. Signs of increased intracranial pressure

18. A female infant with a suspected genetic syndrome presents for a sedated echocardiogram to evaluate a murmur heard on exam. The patient is small for her gestational age and has a short, webbed neck. The murmur is systolic and heard best below the left scapula. Which finding is most likely to be present on her echocardiogram?

A. Endocardial cushion defect
B. Pulmonary valve regurgitation
C. Patent ductus arteriosus
D. Coarctation of the aorta

19. A 5-year-old child with epidermolysis bullosa presents for gastrostomy tube placement. Which of the following monitors is appropriate for this patient?

A. Standard electrocardiogram (EKG) leads
B. Noninvasive blood pressure cuff placed over padding
C. Nasopharyngeal temperature probe
D. Adhesive pulse oximeter probe

20. An 18-year-old male presents for knee arthroscopy. His examination is notable for tall stature, long digits, mild scoliosis, and a soft diastolic murmur. His history is notable for recurrent joint dislocations. He has a good exercise tolerance with no cardiac or respiratory symptoms. Which of the following tests is required prior to proceeding with the surgery?

A. Pulmonary function tests
B. Coagulation studies
C. Echocardiogram
D. Renal function tests

21. A 3-day-old neonate presents for repair of an omphalocele. He is large for his gestational age, and his examination is notable for an enlarged abdomen with visceromegaly and macroglossia. Which of the following studies should be done perioperatively?

A. Renal function tests
B. Serum glucose
C. Brain magnetic resonance imaging (MRI)
D. Spine plain films

22. A 5-year-old male with recurrent sinus infections presents for endoscopic sinus surgery. His history is significant for recurrent sinopulmonary and gastrointestinal infections consistent with an immunodeficiency. On examination, he is noted to have eczema and areas of petechiae. His labs are significant for a platelet count of 40,000 requiring transfusion prior to his procedure. The patient is at risk for which of the following transfusion reactions given his underlying medical condition?

A. Acute hemolytic reaction
B. Graft-versus-host disease
C. Anaphylactic reaction
D. Hyperkalemia

23. A 16-year-old patient with neurofibromatosis type 1 presents for resection of a large cutaneous facial lesion. After an uneventful intravenous induction, the patient is intubated and maintained on sevoflurane for the anesthetic. During the procedure she becomes abruptly tachycardic and hypertensive, followed a few minutes later by relative hypotension. Which of the following is likely to cause perioperative hemodynamic instability in this patient?

A. Intracardiac tumor
B. Primary cardiac arrhythmia
C. Pheochromocytoma
D. Vascular shunts requiring increased cardiac output

24. A 15-year-old female with spinal muscular atrophy presents to the operating room for spinal fusion. Her preoperative examination is significant for multiple joint contractures, thoracic scoliosis, and significant muscle wasting. Her electrolytes are normal and her pulmonary function tests are consistent with a restrictive lung defect. Her perioperative course is likely to be complicated by:

A. Rhabdomyolysis with hyperkalemia
B. Cardiomyopathy
C. Respiratory failure
D. Seizures

25. An 8-year-old child presents for sclerotherapy of a capillary malformation involving her lips and buccal mucosa. Her physical examination is significant for a vascular malformation involving the left side of her face. She undergoes mask induction, is intubated without difficulty, and is maintained on sevoflurane during the procedure. During her perioperative course, she is at risk for

A. High-output cardiac failure
B. Progressive upper airway obstruction
C. Consumptive coagulopathy
D. Abnormal glucose regulation

26. A 17-year-old female with a history of medullary thyroid carcinoma presents for thyroidectomy. Her physical examination is notable for multiple neuromas on her lips, tongue, and eyelids and a marfanoid body habitus. Her preoperative labs show that she is euthyroid. Which of the following disorders should be ruled out prior to anesthesia to avoid intraoperative hemodynamic instability?

A. Pheochromocytoma
B. Hyperkalemia
C. Renal artery stenosis
D. Intravascular volume overload

27. An 8-year-old female presents for appendectomy. Her medical history is significant for precocious puberty, pathologic fractures of her weight-bearing bones, and multiple pigmented skin lesions. Which of the following abnormalities is also likely present and may affect anesthetic management?

A. Abnormal respiratory control
B. Hypoglycemia
C. Obesity
D. Hyperthyroidism

28. A 6-year-old male with a past medical history significant for a urea cycle defect, well controlled with dietary restrictions, had an uneventful tonsillectomy 1 week ago and presents with posttonsillectomy hemorrhage. The patient has had poor dietary intake since surgery but has been maintaining adequate oral hydration. His blood pressure and heart rate are appropriate for his age and he appears to have adequate intravascular volume, but his physical examination is concerning for lethargy. His lab workup shows a normal lactate and glucose. His mother thinks he has swallowed a large amount of blood. Which of the following perioperative interventions will worsen this patient's neurologic status?

A. Resuming baseline dietary restrictions postoperatively
B. Administering sodium benzoate
C. Administering 5% dextrose in lactated Ringer's solution for maintenance
D. Orogastric suctioning to remove intragastric blood

29. An infant with recurrent hypoglycemia and hepatomegaly suspicious for a glycogen storage disease is undergoing liver biopsy for diagnosis. Anesthetic management of this patient is most likely to be complicated by which of the following?

A. Intrinsic lung disease
B. Seizures refractory to medical management
C. Atlantoaxial instability
D. Weakness due to myopathy

30. A 16-year-old female presents to the emergency department with a 1-day history of fever, vomiting, and abdominal pain. Her past medical history is unremarkable and her only medication is an oral contraceptive started 2 weeks ago. She is significantly anxious. She is diagnosed with appendicitis and is taken to the operating room for an appendectomy. Intraoperatively, the appendix appears normal and no obvious intra-abdominal pathology is seen. During the procedure, she develops tachycardia and autonomic instability. Her labs are significant only for hyponatremia. After hemodynamic stabilization, she is taken to the intensive care unit, where she is empirically treated with intravenous carbohydrate loading and hematin administration with improvement of her autonomic symptoms. Which drug should be avoided in subsequent anesthetics for this patient?

A. Etomidate
B. Succinylcholine
C. Propofol
D. Methylene blue

31. A 1-day-old neonate, born at 34 weeks gestational age, with a small omphalocele presents for closure of his defect. His birth history includes in utero cocaine exposure and his current vital signs are significant for tachycardia and hypertension. An echocardiogram does not demonstrate structural heart disease. Which of the following plans describes appropriate anesthetic management of this patient?

A. Anticipate increased opioid requirements due to in utero cocaine exposure.
B. Proceed with surgery under general anesthesia with sevoflurane.
C. Admit the patient to the NICU for medical stabilization prior to surgery.
D. Prepare for difficult airway management.

CHAPTER 11 ANSWERS

1. ANSWER: C

Normal muscle contraction involves multiple steps, beginning with the motor neuron and ending with muscle relaxation. When the nerve terminal of motor neuron becomes depolarized, acetylcholine is released and interacts with nicotinic acetylcholine receptors on the muscle membrane. This causes **depolarization of the muscle membrane**, which spreads to the T-tubules, where dihydropyridine receptors (DHPRs) are located. **DHPRs are voltage-gated calcium channels, which allow influx of calcium into the muscle cell** when they are activated. This calcium influx then initiates **calcium-sensitive calcium release from the sarcoplasmic reticulum via ryanodine receptors (RYRs)**. The intracellular **calcium then binds troponin**, causing a conformational change that exposes the active site on actin. This allows actin-myosin cross-linking, which **leads to muscle contraction**. Two separate processes, excitation-coupled calcium entry (ECCE) and store-operated calcium entry (SOCE), involve the movement of calcium from the extracellular matrix directly into the sarcoplasmic reticulum when calcium stores are low, which increases the amount of calcium available for intracellular release during contraction. The **process of relaxation is initiated when calcium is moved back into the sarcoplasmic reticulum** against its concentration gradient, which is an ATP-dependent process. As intracellular calcium concentrations decline, troponin returns to its resting state and the interaction between actin and myosin is blocked, resulting in relaxation.

Malignant hyperthermia (MH) is a disruption of normal calcium homeostasis, resulting in an uncontrolled rise in intracellular calcium levels. The sustained elevation in intracellular calcium levels results in a hypermetabolic state due to sustained muscle contraction and the use of ATP to move calcium back into the sarcoplasmic reticulum. **Hypermetabolism is the main derangement** during an episode of MH, and results in **rising arterial carbon dioxide levels requiring increasing minute ventilation; tachycardia with arrhythmias and hemodynamic instability; increasing temperatures; and metabolic derangements, including acidosis, elevated lactate, and hyperkalemia**. Sustained muscle contraction eventually leads to **rhabdomyolysis with elevated myoglobin and creatinine kinase (CK)**. Complications of MH include multiorgan system failure, including renal failure due to myoglobinuria, disseminated intravascular coagulopathy (DIC), cerebral and pulmonary edema, and myocardial dysfunction.

The mainstay of **treatment for MH is dantrolene (initial bolus dose 2.5 mg/kg), which works by decreasing intracellular calcium concentrations**. Mechanisms for this decrease **include decreased release from the sarcoplasmic reticulum as well as decreased movement from the extracellular matrix via ECCE**. Additional necessary treatment for MH includes **stopping the triggering anesthetic agent**, **cooling the patient**, **correcting metabolic derangements** (including acidosis and hyperkalemia), **hemodynamic support** and **termination of arrhythmias**, and **maintaining urine output** to prevent renal failure from myoglobinuria. One method of maintaining urine output is forced diuresis with mannitol. Current formulations of dantrolene include 150 mg of mannitol per 1 mg of dantrolene. Although administration of dantrolene does therefore result in administration of mannitol, the mechanism of action of dantrolene does not include prevention of acute renal failure from myoglobinuria.

Myasthenic syndromes, such as myasthenia gravis and Lambert-Eaton myasthenic syndrome, involve abnormal neuromuscular transmission due to antibodies against the nicotinic acetylcholine receptor or presynaptic voltage-gated calcium channels, respectively. These disorders are often treated with anticholinesterases, which result in increased acetylcholine at the neuromuscular junction and improved neuromuscular transmission. Nondepolarizing neuromuscular blocking drugs are competitive antagonists at the acetylcholine receptor and interrupt neuromuscular transmission of signals from the motor nerve. These drugs will not reduce the rigidity associated with MH because muscle contraction occurs independently of electrical transmission, and they do not address any of the hypermetabolic symptoms of MH.

Muscular dystrophies are characterized by abnormal structural proteins, leading to unstable cell membranes that are prone to disruption. Depending on the type of muscular dystrophy, these patients may have chronic low-grade or progressive cell membrane breakdown, leading to muscle atrophy. Succinylcholine and volatile anesthetics can further destabilize cell membranes, leading to acute worsening of rhabdomyolysis and hyperkalemia. Although these features are similar to findings in MH, there is no hypermetabolism associated with these events, and these patients are not considered to have increased MH susceptibility.

KEY FACTS

- Malignant hyperthermia is a disruption of normal calcium homeostasis, resulting in an uncontrolled rise in intracellular calcium levels.
- Hypermetabolism is the main derangement and results in rising arterial carbon dioxide; arrhythmias; hemodynamic instability; increasing temperature; and metabolic derangements, including acidosis, elevated lactate, and hyperkalemia. Sustained muscle contraction causes rhabdomyolysis.
- The primary treatment for MH is dantrolene (initial bolus dose 2.5 mg/kg), which works by decreasing intracellular calcium concentrations.

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2. ANSWER: A

MH susceptibility (MHS) is difficult to diagnose definitively. The **two possible methods of diagnosing MHS are in vitro and genetic testing**. **In vitro testing is the gold standard** for MH diagnosis. This test involves obtaining a muscle biopsy from the vastus lateralis and then testing the **force of contraction at baseline and during exposure to different levels of caffeine and halothane**. This test is only performed at a few centers nationally, which limits patients' ability to be tested. In addition, a sample of sufficient size generally **cannot be obtained from children under 20 kg, and controls for prepubescent children are not available**. Therefore, this test is rarely performed in children. According to the North American protocol, patients who have a positive response to either caffeine or halothane are designated as MHS. In the European protocol, a positive response to both agents is required for a MHS diagnosis, and patients with a response to only one agent are designated MH equivocal (MHE). The North American protocol therefore has a decreased specificity with more false positives but fewer false negatives. A negative result on the contracture test rules out MHS.

Multiple genes have been associated with MHS. The **most commonly implicated gene is the ryanodine receptor gene (RYR1) on chromosome 19**. However, even within this gene multiple mutations have been found. The **genetic test** involves screening the patient's genes for only the most common mutations. Therefore, a **negative test rules out common mutations, but it does not completely rule out MH susceptibility**. Due to the difficulties in performing the in vitro test as well as the limitations of genetic testing, many patients are not definitively tested for MH after a suspicious episode. It is therefore common to have patients present with a history suspicious for MH without a definitive diagnosis, and further information about the reaction must be collected from the patient and family before deciding how to proceed with the anesthetic. In this case, MHS has been proven in a first-degree relative and the patient should be treated as if he is MH susceptible as well.

The preoperative preparation of MHS patients is the same as those without MHS. There is **no indication for prophylactic oral dantrolene administration** in this situation. The preparation of anesthetic equipment and drugs requires special attention. Succinylcholine should not be available during induction of this patient. If an anesthesia machine that has not been exposed to volatile anesthetics (a "clean machine") is available, it may be used for this patient without further preparation. If such a machine is not available, a contaminated anesthesia machine must be appropriately prepared. The **vaporizers must be removed or labeled clearly** so that they will not be mistakenly used during the case. Draining the vaporizers without further preparation of the machine is insufficient to purge the system of residual anesthetic vapor. The **machine can then be flushed with high flows (10 L/min) of fresh gas flow for a duration specified by the manufacture**r. Because of the complexity of modern anesthesia machines, some manufacturers require longer flush times and the replacement of certain internal parts prior to proceeding. The **carbon dioxide absorbent and breathing circuit should also be changed at this time**. **As an alternative to flushing the system, charcoal filters can be placed on the breathing circuit**. These filters will absorb volatile anesthetics still present in the machine. Manufacturer recommendations regarding minimum gas flows and maximum duration for each filter should be followed. The actions listed in Answers B, C, and D are all part of the process to prepare anesthesia work station. However, none of those actions is sufficient as the only preparation for an MH-susceptible patient.

Postoperative management of MHS patients depends on the intraoperative course. If these patients display evidence of hypermetabolism or require dantrolene administration intraoperatively, they should be closely monitored postoperatively, likely in an intensive care setting. If the anesthetic proceeds uneventfully, the patient should be monitored in the PACU, as MH can occur postoperatively. Hemodynamics and EKG monitoring are helpful, and a urine dipstick for myoglobin should be considered if there are concerning signs for development of MH. Depending on the institution's protocol, once these patients have met a minimum duration for postoperative monitoring without any signs of hypermetabolism, they may be sent home on the day of surgery.

KEY FACTS

- The two possible methods of diagnosing MHS are in vitro and genetic testing. In vitro testing is the gold standard, but it is not easily obtained. Negative genetic testing rules out common mutations but does not completely rule out MH susceptibility.
- Adequate preparation of a contaminated anesthesia work station involves purging the machine with high gas flows and replacing the carbon dioxide absorbent and breathing circuit. Placing charcoal filters on the breathing circuit is an alternative to purging the machine.

- Vaporizers should be removed or disabled, and succinylcholine should not be available in the operating room to prevent accidental administration.

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3. ANSWER: A

Although malignant hyperthermia (MH) has previously been linked to multiple neuromuscular disorders, many of those associations have been proven to be untrue. **The only neuromuscular disorders proven to have an increased association with MH are central core disease (CCD), multiminicore disease (MmD), and King-Denborough syndrome (KDS)**. **CCD is a congenital myopathy** and was the first myopathy with a proven link to MH. It is also caused by mutations of the RYR1 gene. "Central core" refers to a histologic pattern with an area of decreased staining extending along the center of the muscle fibers due to decreased mitochondria and other organelles. The **clinical presentation is variable and includes hypotonia, lower limb and pelvic weakness, and delayed motor milestones**. Similarly, **MmD is a myopathy with histologically abnormal muscle cells** that have isolated cores of decreased staining. This disease may progress to CCD over time and manifests with variable degrees and distribution of motor weakness, joint laxity, and scoliosis. **Patients with KDS also have abnormal RYR1 receptors. Their presentation includes abnormal facies, proximal muscle weakness, pectus deformity, scoliosis, joint laxity, cryptorchidism, and mental delay**.

Patients with Duchenne muscular dystrophy have deficiencies in the protein dystrophin, which leads to unstable cell membranes. Exposure to volatile anesthetics further destabilizes these membranes, and forceful contraction associated with succinylcholine causes increased mechanical stress on the membranes. Exposure to either anesthetic agent can therefore lead to increased **cell breakdown leading to rhabdomyolysis and hyperkalemia**, which can lead to renal failure and cardiac arrest. These events are similar to those seen in an MH episode and had previously been interpreted as patients being at increased risk for MH susceptibility (MHS). However, **there is no hypermetabolism** seen during these events, which is the cornerstone of MH. It is now believed that **there is no increased MHS** in these patients.

Patients **with myotonia have delayed relaxation of skeletal muscle** after voluntary contraction or electrical stimulation. This stiffness associated with exacerbations of myotonia under general anesthesia may be difficult to distinguish from the generalized stiffness associated with MH and has also led to an erroneous association with MH. Most myotonic syndromes, including myotonic dystrophy, myotonia and paramyotonia congenita, and hyperkalemic periodic paralysis, are not associated with any increase in MHS. Hypokalemic periodic paralysis has a possible, though unproven, increase in MHS.

Neuroleptic malignant syndrome (NMS) has many features in common with MH, including **hypermetabolism, muscle rigidity, autonomic instability, increased CK and myoglobin, altered mental status, and progression to multiorgan failure**. However, unlike MH, neuroleptic malignant syndrome progresses over days. In addition, the underlying problem in neuroleptic malignant syndrome is thought to be **central dopamine deficiency** (due to administration of dopamine antagonists or withdrawal of dopamine agonists) and is not linked to calcium homeostasis. **The treatment for NMS is bromocriptine (a dopamine agonist)**, though there are case reports of effective treatment with dantrolene. **Patients with a history of NMS tolerate anesthetic drugs that are MH triggers** without an increased incidence of MH.

KEY FACTS

- The only neuromuscular disorders proven to have an increased association with MH are central core disease, multiminicore disease, and King-Denborough syndrome.
- Although patients with muscular dystrophies and myotonic disorders can have similar findings to those with MH (rhabdomyolysis and hyperkalemia or sustained muscle contractions, respectively), there is no association between MH and those disorders.
- Neuroleptic malignant syndrome has a similar presentation to MH. However, NMS is caused by central dopamine deficiency, progresses over days, and treatment is with a dopamine agonist. Patients with NMS can receive anesthetic drugs that are MH triggers without adverse effects.

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4. ANSWER: B

The muscular dystrophies are a group of genetic muscle disorders in which structural abnormalities of the muscle cytoskeleton lead to progressive muscle degeneration and replacement with fibrous or fatty tissue. The **most common muscular dystrophies are the dystrophinopathies**. **Duchenne muscular dystrophy (DMD)** is caused by a gene deletion leading to **complete absence of dystrophin**, whereas **Becker muscular dystrophy (BMD)** is caused by a gene mutation leading to **partial absence of this protein**. **Patients with DMD have symptom onset at 3–5 years old**, though they may have slightly delayed motor milestones prior to that time. These patients have painless muscle degeneration that is progressive and symmetric, typically involving the lower extremities before the upper and proximal muscles before distal. **Patients initially present with pelvic weakness**, including abnormal gait and difficulty climbing stairs or rising from a sitting position, and **calf pseudohypertrophy**. They are typically **wheelchair bound by 10–12 years old** and develop upper-extremity weakness and difficulty performing ADLs by their mid-teens.

As the disease progresses, they develop **fixed skeletal deformities,** which complicate their care. These patients develop a **restrictive respiratory defect** that is exacerbated by **scoliosis** and are **prone to aspiration** due to pharyngeal weakness. Cardiac muscle is also affected and patients may develop **dilated cardiomyopathy with valve regurgitation, conduction defects and arrhythmias, and right ventricular dysfunction**. Of note, **cardiac dysfunction does not correlate with the degree of muscle weakness and may be more significant than expected** based on the patient's musculoskeletal symptoms. Death usually occurs by the late teens or mid-20s and is usually from respiratory (75%) or cardiac (25%) causes. **BMD** has many of the same features of DMD but a **milder course, including later onset, slower progression, and longer life expectancy**. Defects in other structural proteins cause other muscular dystrophies with variable presentations. **Emery-Dreifuss muscular dystrophy** is of particular concern to anesthesiologists because these patients have **severe cardiac defects and may have sudden cardiac death**.

The **perioperative evaluation and management of DMD patients** should focus on the extent of involvement of **musculoskeletal, respiratory, cardiac, and gastrointestinal systems**, especially in advanced stages of the disease. Muscular weakness may lead to **respiratory insufficiency or a decreased ability to handle secretions and protect the airway** and will also **increase sensitivity to nondepolarizing muscle relaxants**. **Contractures** may make patient positioning for intravenous access, regional anesthesia, and surgical procedures difficult. DMD patients develop restrictive lung disease due to both muscular weakness and scoliosis. **Pulmonary function testing (PFTs), chest X-ray, and arterial blood gas measurements should be considered** during preoperative evaluation of these patients. These patients may be **chronically hypoxemic and hypercarbic**, predisposing them to **right ventricular failure** over time. This may affect the decision to control ventilation both intra- and postoperatively for these patients. In addition, **airway management may be difficult** due to contractures of the cervical spine and jaw as well as tongue hypertrophy.

DMD patients may have significant cardiac involvement, even relatively early in the course of the disease. Patient history may be unreliable in detecting cardiac involvement, as these patients typically have very limited physical exertion. Therefore, an **EKG and/or echocardiogram should be considered** in the preoperative evaluation of these patients. **Dilated cardiomyopathy with valve regurgitation** and **abnormal cardiac conduction** are common findings. **Invasive cardiac monitoring should be considered** for patients with advanced disease. Gastrointestinal hypomotility and pharyngeal weakness predispose these patients to **aspiration** and should be assessed.

The PFTs presented in Answer A are consistent with an obstructive defect. Rather, a restrictive defect due to muscle weakness and scoliosis would be expected in this patient. This patient is expected to have **respiratory acidosis** due to inadequate alveolar ventilation, not respiratory alkalosis (Answer D). Creatinine kinase (CK) is dramatically elevated in DMD patients, especially early in the course of the disease. During an **acute exacerbation** of **rhabdomyolsis**, patients may develop **renal failure** from **myoglobinuria**. However, creatinine (Answer C) is not expected to be elevated at baseline in DMD patients.

KEY FACTS

- Muscular dystrophies are genetic muscle disorders in which structural abnormalities of the muscle cytoskeleton lead to progressive muscle degeneration.
- The dystrophinopathies (Duchenne and Becker muscular dystrophy) are due to abnormalities of dystrophin and are the most common muscular dystrophies.
- In addition to musculoskeletal abnormalities, many patients have cardiac involvement, which may be more severe than the musculoskeletal symptoms. Patients with Emery-Dreifuss muscular dystrophy, in particular, have severe cardiac defects and may have sudden cardiac death.
- The perioperative evaluation and management of DMD patients is determined by the extent of involvement of musculoskeletal, respiratory, cardiac,

and gastrointestinal symptoms. Consideration should be given to cardiac and pulmonary preoperative evaluation, invasive cardiac monitoring, difficult airway management, and possible postoperative ventilation.

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5. ANSWER: C

Duchenne muscular dystrophy (DMD) is caused by an absence of dystrophin, a structural protein in muscle cells. This absence leads to **decreased membrane stability during the mechanical stress of contraction and relaxation**, leading to muscle breakdown and replacement with fibrous or fatty tissue. In addition, dystrophin plays a role in organizing postsynaptic acetylcholine receptors. Its absence leads to **abnormal type, number, and location of acetylcholine receptors**, similar to what is seen in denervated muscle.

Exposure of DMD patients to succinylcholine and volatile agents, including sevoflurane, can lead to **rhabdomyolysis and hyperkalemia**, which in turn causes **myoglobinuria** and **renal failure, arrhythmias,** and **cardiac arrest**. The hyperkalemia from acute rhabdomyolysis is **refractory to treatment and may require prolonged resuscitation**. Administration of **succinylcholine in the setting of abnormal, extrajunctional acetylcholine receptors leads to hyperkalemia**. In addition, the **force of contraction from fasciculations caused by succinylcholine may be sufficient to disrupt the fragile cell membranes**. **Volatile agents cause further destabilization of the already unstable muscle membrane**, resulting in cell breakdown. The **risk of rhabdomyolysis and hyperkalemia from these agents is highest in young children** who may be previously undiagnosed or who are early in the course of their disease and **still have normal muscle mass**. **Fatal hyperkalemia and cardiac arrest** has been documented after **succinylcholine exposure** in previously healthy children who were later determined to have **undiagnosed muscular dystrophy**. This led the FDA to issue a black box warning against the elective use of succinylcholine in children. Older patients with significant muscle wasting may not have sufficient muscle mass to cause clinically significant hyperkalemia after cell breakdown. Of note, these complications **can occur postoperatively after an uneventful anesthetic**, so careful postoperative monitoring is required. Although this pattern of events is similar to malignant hyperthermia (MH), there is no disruption in calcium homeostasis and no hypermetabolism, which is the hallmark of MH. There is **no link between muscular dystrophy and MH**.

Older patients with advanced disease can have significant respiratory and cardiac involvement. DMD patients develop **restrictive lung disease** and chronic **hypoventilation**, predisposing them to **respiratory failure after administration of respiratory depressants or muscle relaxants**. Cardiac involvement may include dilated cardiomyopathy, valve regurgitation, and conduction system defects. These patients are prone to **cardiac failure or arrest after administration of cardiac depressant medications, including volatile anesthetics, or arrhythmogenic drugs**. **Invasive cardiac monitoring should be considered** for these patients and resuscitation medications should be available. These complications would be unlikely in a 5-year-old child who is early in the course of his disease.

KEY FACTS

- The absence of dystrophin in patients with DMD causes decreased muscle membrane stability during mechanical stress and leads to an abnormal type, number, and location of acetylcholine receptors on the muscle membrane.
- Exposure of DMD patients to succinylcholine and volatile agents causes rhabdomyolsis and hyperkalemia, resulting in arrhythmias and cardiac arrest. Young patients with nearly normal muscle mass are the most susceptible to these complications, while older patients may not have sufficient muscle mass to generate clinically relevant hyperkalemia from rhabdomyolysis.
- DMD patients with advanced disease are likely to have baseline cardiac and respiratory disease and are prone to respiratory or cardiac failure after exposure to anesthetics.

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6. ANSWER: C

Duchenne and Becker muscular dystrophy (DMD and BMD) are x-linked abnormalities of the dystrophin gene that result in unstable muscle cell membranes, leading to progressive muscle breakdown and replacement with fibrous or fatty tissue. These diseases are characterized by **progressive muscle wasting and weakness with significant cardiac and respiratory involvement**. **DMD is a complete absence of dystrophin** that occurs in 1:3500 live male births with **up to one third of cases due to a spontaneous mutation, meaning there will be no family history** of the disease. BMD is a partial absence of dystrophin with a less severe clinical course. In both cases, **female carriers of the disease may be asymptomatic or have only subclinical weakness.** They can, however, have **significant cardiomyopathy** despite a lack of musculoskeletal symptoms.

This patient is a female with a first-degree male relative with DMD. She is, therefore, a possible carrier of the disease. If she is a carrier, she **may have an underlying cardiomyopathy significant enough to result in intraoperative cardiac failure,** and she is also **at risk for rhabdomyolysis and hyperkalemic arrest after exposure to succinylcholine or volatile anesthetics**. Both events can lead to cardiac arrest. She is unlikely to have muscle weakness that is significant enough to result in respiratory failure, aspiration, or abnormal response (such as increased sensitivity or prolonged duration) to nondepolarizing muscle relaxants. She is most likely to have an uneventful anesthetic despite her carrier status.

KEY FACTS

- Duchenne and Becker muscular dystrophy are x-linked abnormalities of the dystrophin gene. Up to one third of DMD patients have a spontaneous mutation, so there will be no family history of the disease.
- Female carriers of these disorders are usually asymptomatic but may have significant cardiomyopathy. These patients may have significant perioperative cardiac complications related to their underlying cardiomyopathy or due to rhabdomyolysis and hyperkalemic arrest after anesthetic exposure.

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7. ANSWER: D

Myotonia is defined as temporary involuntary muscle contraction caused by transient membrane hyperexcitability. These contractions generally occur after the muscle undergoes voluntary contraction or electrical stimulation. **The underlying pathology is prolonged depolarization of the muscle due to abnormal electrolyte channels**, including chloride, sodium, calcium, or potassium channels. Myotonic disorders are characterized as dystrophic or nondystrophic. **Dystrophic forms include myotonic dystrophy types 1 (Steinert disease) and type 2 (previously named proximal myotonic myopathy or PROMM)**. In addition to myotonia, these patients have dystrophic muscle fibers, display muscle wasting and are **susceptible to many of the same anesthetic complications as muscular dystrophy patients**. **Nondystrophic forms include myotonia congenita, paramyotonia congenita, and both hyper- and hypokalemic periodic paralysis**.

Each of these diseases has a **unique clinical presentation in terms of onset, duration, and triggers for myotonic contractions**. **Prolonged contractions may interfere with the ability to intubate and ventilate the patient** and may affect positioning and ability of the surgeons to complete their procedure. **Triggers may include pain or stress, hypothermia, and abnormal electrolytes or glucose levels**. In general, the anesthetic plan should include adequate anesthetic depth for the surgical procedure, as well as **maintenance of normothermia and normal electrolyte levels to prevent the onset of myotonic contractions**. **Additional triggers under anesthesia include** the administration of **succinylcholine and possibly anticholinesterases** given for reversal of neuromuscular blockade as well as the **use of electrocautery** by the surgical team. In dystrophic forms of myotonic disorders, succinylcholine may also cause hyperkalemia.

If myotonic contractures occur intraoperatively, the administration of **sodium channel blockers, such as procainamide, can help restore the normal muscle membrane potential and therefore terminate the sustained contraction**. Nondepolarizing muscle relaxants and local anesthetics applied to a peripheral nerve will both interrupt neuromuscular transmission. However, the sites of action of these drugs are too proximal in the signaling pathway and will not stop the downstream effects of membrane excitability that cause myotonic contractions (Answers A and B). Dantrolene works by decreasing intracellular calcium levels and is used for the treatment of malignant hyperthermia (MH). Although it may diminish the force of myotonic contractions, it will not reverse the underlying membrane hyperexcitability that is causing the contractions (Answer C). **Myotonic contractions are not a symptom of MH,** and there is no link between myotonic disorders and MH.

KEY FACTS

- Myotonia is a temporary involuntary muscle contraction caused by transient membrane hyperexcitability due to

prolonged depolarization caused by abnormal electrolyte channels.
- Triggers for myotonia are variable but can include pain or stress, hypothermia, abnormal electrolyte or glucose levels, succinylcholine, and possibly anticholinesterase administration and surgical electrocautery use.
- Anesthetic management should be directed at preventing myotonic contractures. If they occur, sodium channel blockers can terminate sustained contraction by re-establishing normal membrane potentials.

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8. ANSWER: B

Myotonic dystrophy, also called dystrophica myotonia (DM), is a **multisystem disorder that affects skeletal, smooth, and cardiac muscle as well as the central nervous system (CNS) and endocrine systems**. DM 1 (Steinert disease) is the most common form of the disease. Symptom onset is usually in the 20s–30s, but patients may begin to show muscular symptoms at an earlier age. **Musculoskeletal symptoms include distal and bulbar muscle weakness and wasting with myotonia**. **Cardiac involvement, including conduction defects, cardiomyopathy, and valve regurgitation** that may result in early death, **are common and do not correlate with the degree of muscular symptoms**. Patients are also prone to **obstructive sleep apnea with abnormal central responses to hypercarbia, endocrinopathies**, including insulin resistance and testicular failure, and cataracts. Symptom progression can cause significant disability and may result in death by the fifth to sixth decade from respiratory or cardiac failure. **DM 2** is a more **mild form of the disease** with less prominent symptoms and a normal life expectancy. However, these patients can **still be at risk of sudden cardiac death**. The congenital form manifests as severe hypotonia at birth with a high mortality rate from respiratory failure. Patients who survive past infancy show improvement in their motor function, but then develop a progressive myopathy and mental retardation. Myotonic dystrophy has an autosomal dominant transmission and diagnosis by DNA testing is 100% sensitive.

Patients with myotonic dystrophy are at risk for **multiple anesthetic complications both intra- and postoperatively**. As with nondystrophic myotonic patients, these patients may develop **myotonic contractures** intra- or postoperatively due to pain or stress, hypothermia, abnormal electrolytes, or the use of succinylcholine and possibly anticholinesterases as part of the anesthetic. Baseline muscle weakness and wasting must be assessed prior to the anesthetic. Patients with significant weakness should have **careful titration of nondepolarizing muscle relaxants and may require postoperative ventilation**. Patients with significant pharyngeal weakness may be at risk for **aspiration** and should be treated appropriately. Due to their baseline tendency for obstructive sleep apnea as well as abnormal central response to hypercarbia, DM patients are **exquisitely sensitive to all intravenous anesthetics, including propofol, benzodiazepines, and opioids** (Answer C). Even small doses of these medications can produce **profound and long-lasting respiratory depression** and should be titrated carefully. A regional anesthetic for pain control may be beneficial where appropriate. As previously mentioned, these patients may have cardiac disease out of proportion to their musculoskeletal symptoms and may be at increased risk for **cardiac decompensation and arrhythmias** intra- or postoperatively. A cardiac evaluation with EKG or echocardiogram should be considered. There is no link between myotonic dystrophy and malignant hyperthermia.

KEY FACTS

- Myotonic dystrophy affects skeletal, smooth, and cardiac muscle as well as the CNS and endocrine system. Musculoskeletal symptoms include weakness, wasting, and myotonia.
- Cardiac symptoms include conduction defects, cardiomyopathy, and valve regurgitation and are often out of proportion to musculoskeletal findings. Cardiac evaluation should be considered prior to anesthesia even in patients without musculoskeletal symptoms.
- DM patients are prone to obstructive sleep apnea and have abnormal central responses to hypercarbia. They are profoundly sensitive to the respiratory depressant effects of all intravenous anesthetics and may have profound and long-lasting respiratory depression even after small doses.

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9. ANSWER: B

The **mitochondrial myopathies are a group of disorders caused by defects in the respiratory chain and oxidative phosphorylation pathways**. Defects in these pathways cause **disrupted energy metabolism**, free radical damage, and alterations in protein phosphorylation. These patients have a **decreased ability to use oxygen and generate ATP effectively**. **Metabolically active tissues, such as the brain, heart, muscle, liver, and kidney, are affected first**. Mitochondrial function is determined by a combination of nuclear and mitochondrial genetics. Unlike nuclear genes, **mitochondrial genes are entirely maternally derived**. Mitochondria are randomly partitioned during mitosis between dividing cells, leading to different populations of mitochondria in each daughter cell, causing extreme variability between offspring and even between different tissues within the same patient. In addition, mitochondrial DNA is more prone to spontaneous mutation than nuclear DNA. Given these factors, the inheritance of mitochondrial disorders, as well as the onset and severity of the disease, is difficult to predict.

The **manifestations of mitochondrial disorders are dependent on the mutant mitochondrial load within each tissue and can therefore be very variable between patients**. The presenting symptoms typically involve the **central nervous system** (seizure, stroke-like episodes, dementia, ataxia, myoclonus, dystonia, peripheral neuropathy, visual and auditory deficits), **musculoskeletal system** (hypotonia, myopathy, myoglobinuria, respiratory insufficiency), and **cardiovascular system** (cardiomyopathy, conduction defects). In addition, patients may have endocrine, gastrointestinal, hepatic, and renal findings. These patients may be prone to the development of **lactic acidosis when energy demands are high or supplies are limited, such as during times of physiologic stress or fasting**. These disorders may be managed with dietary restrictions and supportive care.

Specific mitochondrial myopathies include MELAS (mitochondrial myopathy, encephalopathy, lactic acidosis, and stroke-like episodes), MERRF (myoclonic epilepsy, ragged-red fibers), Kearns-Sayre syndrome, Leigh disease, and Leber hereditary optic neuropathy. Patients with Kearns-Sayre syndrome in particular are prone to heart block during anesthesia and must be monitored closely. Patients with Leigh disease can have brainstem involvement leading to abnormal respiratory control and dysautonomia.

Central core disease is a congenital myopathy. "Central core" refers to a histologic pattern of an area of decreased staining along the center of muscle fibers due to decreased mitochondria and other organelles. The defect for central core disease lies within the ryanodine receptor, not mitochondrial DNA. Patients with **Becker muscular dystrophy have a partial absence of dystrophin**, a cytoskeletal protein, which leads to cell structural abnormalities. These cells are prone to breakdown, leading to progressive muscle degeneration and replacement with fibrous or fatty tissue. **Myotonia congenita** is a nondystrophic myotonia. Patients with this disease may have **uncontrolled sustained contractions after a voluntary motion (myotonia)** and muscle hypertrophy. The defect in these diseases is not related to deficient energy production.

KEY FACTS

- Mitochondrial myopathies are disorders that result in a decreased ability to use oxygen and generate ATP effectively. Metabolically active tissues, such as the brain, heart, muscle, liver, and kidney, are primarily affected.
- Mitochondrial genes are maternally derived. They are randomly partitioned during mitosis, resulting in extremely variable mitochondrial populations between offspring and between tissues within the same patient. The inheritance and clinical presentation of mitochondrial disorders is highly variable.
- Patients with mitochondrial disorders develop lactic acidosis when energy demands exceed the supply, which may occur during times of physiologic stress and fasting.

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10. ANSWER: D

Patients with **mitochondrial myopathies** have defects in their respiratory chain and oxidative phosphorylation pathways. These defects cause **inefficient oxygen use and ATP generation**, which **affects mostly metabolically active tissues**, such as the brain, heart, muscle, liver, and kidney. In a situation where energy requirements are increased by physiologic stress or supplies are limited by fasting, these patients are **prone to the development of lactic acidosis**. The **perioperative goals** for managing these patients are to **maintain metabolic stability and energy production and to decrease perioperative stressors that could increase energy demands**.

Preoperative evaluation of these patients should include **documentation of baseline neurologic and motor function, cardiac and respiratory evaluation, and an assessment of the patient's dietary management and response**

to fasting. To maintain metabolic stability and decrease the risks for hypoglycemia and hypovolemia, patients with mitochondrial myopathies should have **minimal fasting times**. If possible, they should be scheduled early in the day or be admitted prior to their procedure for intravenous hydration. **Intravenous fluids should contain dextrose as an energy supply and should not contain lactate** to minimize the development of **lactic acidosis**. These patients may develop endocrine issues, such as diabetes, which may complicate glucose management. In this case, starting 5% dextrose in normal saline at the patient's normal maintenance rate preoperatively would be appropriate. Fluid restricting the patient to 30 mL/hour would not be appropriate. **Perioperative stressors** such as **hypothermia with shivering and inadequate pain control** will increase energy demands and should be avoided. **Anemia and hypotension** will both lead to decreased oxygen supply to tissues and should also be avoided. Drug choice is also important, as **all general anesthetics depress mitochondrial function to some extent**. However, many different techniques have been used successfully. Patients with abnormalities of complex I may have increased sensitivity to volatile agents. Patients with **some subsets of mitochondrial disorders may develop findings similar to propofol infusion syndrome** after high doses or prolonged infusion of the drug due to the effects of the lipid carrier on fatty acid oxidation and the mitochondrial respiratory chain. However, small doses and short infusions of propofol have been used in these patients. Neuromuscular blocking drugs and sedative medications should be titrated carefully to prevent respiratory complications. **Succinylcholine should be avoided in myopathic patients** due to increased hyperkalemic response, though there is no link between mitochondrial myopathies and malignant hyperthermia.

KEY FACTS

- The perioperative goals for patients with mitochondrial myopathies are to maintain metabolic stability and energy production and to decrease perioperative stressors that could increase energy demands.
- Fasting times should be minimized and intravenous fluids should be given during prolonged fasts.
- Fluids should contain dextrose as an energy supply and should not contain lactate.
- Perioperative stressors that should be avoided include hypothermia with shivering, inadequate pain control, anemia, and hypotension.
- All general anesthetics inhibit mitochondrial function to some extent, but many techniques have been successfully used. Some subsets of patients with mitochondrial disorders can develop findings similar to propofol infusion syndrome after prolonged exposure to the drug.

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11. ANSWER: A

Congenital myopathies are a heterogeneous group of genetic disorders of muscle fibers. These disorders may have a number of different causes, including abnormalities in the internal structure of muscle cells (central core disease, minicore disease, and myotubular myopathy), protein accumulation (nemaline myopathy), or variation in muscle size (congenital fiber type disproportion). These disorders are very **variable in terms of inheritance, age of onset, severity of symptoms, and pattern of progression**. General features of these diseases include **hypotonia, weakness, and reduced deep tendon reflexes**. In the more severe disease forms, this can progress to the development of **restrictive lung disease, respiratory insufficiency, and contractures or scoliosis**. Patients **commonly have dysmorphic facies**, including a **high-arched palate, mid-face or mandibular hypoplasia, and dental malocclusion that can make airway management difficult** (Answer A). Cardiac involvement, manifest as **cardiomyopathy or conduction abnormalities**, may be present.

The **anesthetic management** of these patients is complicated by their **baseline muscular, respiratory, and cardiac issues**. **Preoperative** evaluation should include an assessment of their cardiac and respiratory status, including **EKG, echocardiogram, chest X-ray, pulmonary function testing, or arterial blood gas analysis**, as indicated. Patients with severe respiratory involvement or scoliosis may require **postoperative ventilator support**. The **airway anatomy** should be carefully assessed as management **may be difficult**. Contractures and scoliosis may affect **positioning**, vascular access, and regional anesthetic technique. **Nondepolarizing muscular blockade and respiratory depressants should be carefully titrated and succinylcholine should be avoided** due to risk for rhabdomyolysis.

Central core disease and minicore disease are caused by mutations on chromosome 19 at the ryanodine receptor and **are both associated with malignant hyperthermia** susceptibility. **Other congenital myopathies**, such as myotubular myopathy, are **not associated with malignant hyperthermia** and **do not require trigger-free anesthetics**. Patients with mitochondrial myopathies are prone to

lactic acidosis during times of stress and should not have lactate-containing fluids. This is not the case for congenital myopathies.

KEY FACTS

- Congenital myopathies are a heterogeneous group of genetic muscle fiber disorders. They are variable in terms of onset, symptom severity, and pattern of progression.
- Patients generally have hypotonia and weakness and in severe cases can develop respiratory insufficiency and contractures.
- These patients commonly have dysmorphic facies, which can cause difficult airway management. They may have cardiac abnormalities.
- Central core disease and minicore disease are associated with malignant hyperthermia. Other congenital myopathies are not.

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12. ANSWER: D

Dwarfism is a term used to describe the phenotype of short stature with associated limb deformities. It can be caused by over 350 disorders, including osteochondrodysplasias and mucopolysaccharidoses. **Achondroplasia is an osteochondrodysplasia and is the most common form of dwarfism**. It is caused by mutations of fibroblast growth factor-3 (FGFR-3) and is usually a sporadic mutation, though autosomal dominant inheritance is possible. Patients with achondrodysplasia have a short stature, due to short extremities and a normal trunk, and have a normal mental status and life expectancy.

These patients have **multiple head and neck abnormalities that affect both their airway and neurologic systems**. Patients have **macrocephaly** with **midface hypoplasia**, causing narrow nasal passages or choanal stenosis, and micrognathia (though their mandibles may appear prominent due to midface hypoplasia). In addition, they have **tonsil and adenoid hypertrophy**, **macroglossia**, **high-arched palates**, and **decreased temporomandibular joint mobility**. The **combination of midface hypoplasia and micrognathia with soft tissue enlargement predisposes these patients to upper airway obstruction and obstructive sleep apnea**. Patients may have airway obstruction with the neck in a flexed position even while they are awake. In addition, patients with achondroplasia have short necks and are predisposed to **foramen magnum stenosis**. This stenosis **may cause hydrocephalus and increased intracranial pressure as well as brainstem compression leading to upper motor neuron weakness, central sleep apnea, and respiratory distress that becomes acutely worse during extremes of positioning**.

Scoliosis and abnormalities of the rib cage can cause restrictive lung disease with further worsening of the respiratory status. Patients with achondroplasia typically do not have congenital heart disease, though they may develop **right-sided heart failure due to chronic hypoxemia and hypercarbia** associated with sleep apnea and restrictive lung disease. The upper airway obstruction and restriction to jaw and neck movement caused by the physical abnormalities of achondroplasia have a **significant impact on airway management**. Upper airway obstruction leads to difficult mask ventilation, and restricted joint movement may make laryngoscopy difficult. Extreme caution should be exercised during neck positioning both during airway management and intraoperatively.

Mucopolysaccharidoses are a group of inherited metabolic disorders that lead to mucopolysaccharide deposition in a variety of tissues throughout the body. Some of these disorders, such as **Hurler syndrome, Hunter syndrome and Morquio syndrome, are causes of dwarfism** and, like achondroplasia, are associated with **micrognathia and narrow nasal passages**. In addition, these patients have **mucopolysaccharide deposition in the airway leading to enlarged tonsils and adenoids, thickened and abnormal appearing glottic structures, and tracheal and bronchial narrowing**. Mucopolysaccharide deposition severely complicates airway management, but it is not part of the presentation of achondroplasia.

Osteogenesis imperfecta and osteopetrosis are both bone disorders associated with pathologic fractures. Patients with these disorders **can suffer damage to the teeth, mandible, and cervical spine during airway management**, necessitating extreme care during manipulation. They may also have **platelet defects or other coagulopathies predisposing them to bleeding after airway trauma**. This, however, is not a finding of achondroplasia.

KEY FACTS

- Patients with achondroplasia have multiple head and neck anomalies, including midface hypoplasia, micrognathia, macroglossia, tonsil and adenoid hypertrophy, and foramen magnum stenosis, which affect their airway and neurologic systems. The brainstem compression caused by foramen magnum stenosis can be position dependent. Extreme caution should be used during head and neck positioning.
- Airway management in patients with mucopolysaccharidoses is complicated by tonsil and

adenoid enlargement, thickened glottic structures, and tracheal and bronchial narrowing due to mucopolysaccharide deposition.
- Patients with osteogenesis imperfecta and osteopetrosis can suffer damage to their teeth, mandible, and cervical spine during airway manipulation and may have bleeding after airway trauma due to platelet defects or other coagulopathies.

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13. ANSWER: C

Osteogenesis imperfecta (OI) is a disorder characterized by extremely frail bones that are prone to fracture. This disorder is caused by **collagen mutations** and may be either autosomal dominant or recessive. **OI type I is the most common and mildest form** of this disease, **type II is the most severe and is usually lethal in the neonatal period**, while **types III and IV are intermediate in severity**. Patients have fragile bones that are prone to **fracture after minimal trauma, predisposing them to bone malformations,** including long bone bowing and short stature, scoliosis, kyphosis, and joint hypermobility.

Patients with type I disease have fractures starting in childhood that improve after puberty, those with type III and IV have fractures in infancy with variable degrees of malformation, while those with type II disease are born with multiple severe antenatal or intrapartum fractures. **Type I patients may also have blue sclerae, otosclerosis with hearing loss, platelet dysfunction, and hyperthyroidism**, but they tend to have normal cardiac valves and teeth. Patients with **type III and IV disease may have abnormal facies with micrognathia and abnormal dentition (dentinogenesis imperfecta), and they can develop acquired cardiac valvular disease as well as pulmonary hypertension** due to restrictive lung disease.

Anesthetic implications of OI relate to the prevention of intraoperative fractures as well as the management of any cardiac, hematologic, or endocrine disease that may be present. **Intraoperative fractures may occur during airway manipulation (dental, mandible, or cervical spine injury) and positioning**. In addition, **surgical tourniquets and noninvasive blood pressure cuffs** can cause fractures, which may necessitate an arterial line for monitoring. **Succinylcholine is relatively contraindicated**, as fasciculations may also cause fractures. Patients with OI have an **increased metabolic rate**, which may necessitate an increased minute ventilation to achieve normocarbia and can result in hyperthermia during surgical procedures. There is **no link between OI and malignant hyperthermia** (Answer B).

Osteopetrosis is also characterized by abnormal bone. Patients with this disorder have **normal bone formation in the presence of deficient bone resorption**, leading to an inability to replace immature bone with mechanically stronger lamellar bone. This results in **hard, brittle bones that fracture easily and obliteration of medullary spaces with decreased hematopoiesis**. Patients present with **growth retardation, pathologic fractures, macrocephaly, and restricted joint motion**. **Airway abnormalities include obstruction** due to bony encroachment, **mandibular overgrowth, and decreased temporomandibular joint and cervical spine motion**. Patients are also prone to nerve entrapments, brainstem compression, and increased intracranial pressure. Bone marrow failure leads to pancytopenia with increased infectious and bleeding risks. Associated **electrolyte abnormalities, including low calcium and elevated phosphate, can lead to abnormal cardiac conduction**. Anesthetic implications of osteopetrosis relate to **difficult airway management, prevention of perioperative fractures, and management of electrolyte abnormalities**.

KEY FACTS

- OI is caused by collagen mutations that result in extremely frail bones that are prone to fracture after minimal trauma. Depending on the type, patients may have associated abnormal dentition, platelet dysfunction, hyperthyroidism, increased metabolic rate, and cardiac valvular disease.
- Intraoperative fractures can occur during airway management (dental, mandibular, or cervical spine injury) and positioning or with the use of surgical tourniquets and noninvasive blood pressure cuffs.
- Succinylcholine is relatively contraindicated, as fasciculations may also cause fractures.
- Osteopetrosis is caused by deficient bone resorption, which results in hard, brittle bones that are prone to fracture. Bony overgrowth can complicate airway management, cause bone marrow failure due to medullary space obliteration, and lead to electrolyte abnormalities with associated cardiac conduction defects.

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14. ANSWER: A

This child presents with at least four of the findings present in **VACTERL syndrome**, which includes **vertebral, anal, cardiac, tracheal, esophageal, renal, and limb anomalies**. The cause of the syndrome is unknown and is likely due to a combination of genetic and environmental factors. **Vertebral anomalies**, such as hemivertebrae or hypoplastic vertebrae, occur in 70% of patients and can cause spinal deformities. **X-ray imaging of the spine should be performed before considering neuraxial anesthesia** in these patients. **Limb anomalies** occur in 65% of patients and can include forearm anomalies, such as radial aplasia, and poly- or syndactyly. These findings **may affect both venous and arterial access** in those extremities. Gastrointestinal findings, including **tracheo-esophageal fistula (TEF), esophageal atresia (EA), and anal atresia**, occur in 70%–80% of patients. As in this scenario, TEF ligation may be the initial procedure for which these patients present to the operating room. **Patients with TEF and EA are at high risk of aspiration of oral secretions as well as reflux of gastric contents into the lungs**. Baseline oxygen saturations and respiratory status should be assessed preoperatively. Approximately **50% of patients will have congenital heart disease**. The **most common findings in these patients are septal defects, patent ductus arteriosus, and Tetralogy of Fallot**. Although the patient is currently hemodynamically stable with a normal oxygen saturation, **induction of anesthesia and institution of positive pressure ventilation can cause shunt reversal or cardiovascular decompensation in the presence of undiagnosed congenital heart disease**. Therefore, these patients should be screened with an echocardiogram prior to arrival in the operating room (Answer A). Genitourinary findings, such as **renal agenesis or dysplasia, horseshoe kidneys, hydronephrosis, or hypospadias**, are present in 50% of patients. The liver and central nervous system are not usually affected in this syndrome, so there is no need to proceed with liver function and coagulation testing or head imaging in the absence of other indications (Answers B and C).

KEY FACTS

- The VACTERL syndrome includes vertebral, anal, cardiac, tracheal, esophageal, renal, and limb anomalies.
- Induction of anesthesia and institution of positive pressure ventilation can cause shunt reversal and cardiovascular decompensation in the presence of undiagnosed congenital heart disease.

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15. ANSWER: C

Chromosome 22q11 microdeletions are the most common gene deletion after Trisomy 21 and the second most common genetic cause of congenital heart disease. **Velocardiofacial syndrome and diGeorge syndrome are two disorders caused by 22q11 microdeletions**. These deletions **affect the 3**rd **and 4**th **pharyngeal pouches, which give rise to the thymus, parathyroid glands, and great vessels**. The findings in these disorders can be summarized by the **mnemonic CATCH-22**, which refers to **cardiac disorders, abnormal facies, thymic hypoplasia, cleft palate, and hypocalcemia**. The majority of patients with this gene deletion have **cardiac abnormalities, which are most commonly conotruncal or outflow tract anomalies**, such as double-outlet ventricles, transposition of the great arteries, truncus arteriosus, or, as in this case, an abnormal or interrupted aortic arch. Facial abnormalities include **micro- or retrognathia, a high-arched or cleft palate, midface hypoplasia,** and a cupid-bow mouth (or fish mouth), all of which can impact airway management. Other airway anomalies in diGeorge syndrome include a **short trachea, abnormal thyroid cartilage, and laryngo-, tracheo-, and bronchomalacia**. Eye and ear abnormalities may also be present. The **thymus, adenoids, and tonsils are small or absent in these patients**. **Thymic hypoplasia causes immunodeficiency,** which manifests as recurrent infections starting in infancy. Strict asepsis is required during invasive procedures, and blood products should be irradiated and CMV negative to prevent graft-versus-host disease. **Hypoparathyroidism leads to hypocalcemia, which can manifest as tetany and seizures starting in the neonatal period**. Electrolytes and thyroid function should be evaluated prior to anesthesia.

Williams syndrome is a genetic syndrome caused by a deletion on chromosome 7. Patients with this disorder have **abnormal facies** (typically described as "elfin" facies with a flat nasal bridge, mandibular hypoplasia, dental anomalies, and a tendency to keep the mouth open), a **friendly personality,** and mild mental retardation. These patients can have **neonatal hypercalcemia, which predisposes to nephrocalcinosis** and should be monitored carefully (Answer A). **Cardiac disease, especially valvar or supravalvar aortic stenosis and coarctation of the aorta, is common** in these patients. Supravalvar aortic stenosis may also affect the origin of the coronary arteries. These patients can have **severe biventricular outflow tract and coronary obstruction leading to sudden death from myocardial ischemia, decreased cardiac output, and arrhythmias**.

Trisomy 21, or Down syndrome, is the most common human chromosomal syndrome and occurs in 1:800

live births. Typical head and neck abnormalities in these patients include **midface hypoplasia (causing small nasal passages), macroglossia, high-arched palate, hypertrophic lymphatic tissue (including tonsils and adenoids)**, eye and ear abnormalities, and **antlantoaxial instability** (Answer B). Patients also have a **narrow hypopharynx and subglottic stenosis**. These patients are prone to **obstructive sleep apnea** and may be **difficult to mask ventilate due to upper airway obstruction**. Care must be taken not to overextend the neck during laryngoscopy, as **antlantoaxial instability** predisposes these patients to subluxation with extremes of neck position. Due to subglottic stenosis, a **smaller endotracheal tube size** than predicted by age may be necessary for intubation. Approximately 40%–50% of Down syndrome patients have **congenital heart disease, commonly including endocardial cushion defects, patent ductus arteriosus, and Tetralogy of Fallot**. These patients are prone to **bradycardia during anesthetic inductions** and should be monitored appropriately. Other systemic issues with Down syndrome include hand anomalies, short stature, hypotonia, duodenal atresia, hypothyroidism, and an increased incidence of leukemia.

CHARGE association refers to a collection of anomalies that occur as a sporadic mutation. The mnemonic includes **coloboma, heart defects, choanal atresia, retardation of growth and development, genitourinary anomalies, and ear anomalies**. Diagnosis of this association requires four out of seven of these findings. Head and neck abnormalities that affect airway management in these patients include **midface hypoplasia, micrognathia, cleft lip or palate, choanal atresia or stenosis, laryngomalacia, laryngeal cleft, subglottic stenosis,** and cranial nerve palsies that may impair swallowing. **Choanal atresia is bilateral in 50% of patients** and causes **neonatal respiratory distress and cyanosis that resolves with crying or oral airway placement**. The majority of patients have **congenital cardiac disease, which usually involves conotruncal or aortic arch abnormalities**. Genitourinary problems in these patients can include horseshoe or absent kidney, hydronephrosis, and genital hypoplasia (Answer D).

KEY POINTS

- Velocardiofacial syndrome and diGeorge syndrome are chromosome 22q11 microdeletions, which result in abnormal development of the thymus, parathyroids, and great vessels. Findings in these syndromes are summarized in the mnemonic CATCH-22, which includes cardiac disorders, abnormal facies, thymic hypoplasia, cleft palate, and hypocalcemia.
- Patients with Williams syndrome have abnormal facies and a friendly personality and may have hypercalcemia. Cardiac disease, including valvar or supravalvar aortic stenosis and coarctation of the aorta, is common. Patients are at risk for severe biventricular outflow tract and coronary artery obstruction, leading to myocardial ischemia, decreased cardiac output, arrhythmias, and sudden death.
- Airway management in Trisomy 21 patients is complicated by upper airway obstruction, hypopharyngeal and subglottic stenosis, atlantoaxial instability, and hypotonia. Patients also commonly have congenital heart disease (especially endocardial cushion defects) and are prone to bradycardia during anesthesia induction.
- CHARGE association includes coloboma, heart defects, choanal atresia, retardation of growth and development, genitourinary anomalies, and ear anomalies. Choanal atresia is bilateral in 50% of patients and results in neonatal respiratory distress.

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16. ANSWER: A

Pierre-Robin sequence refers to a collection of findings including **micrognathia, glossoptosis, and cleft palate**. Patients with this syndrome have early **mandibular hypoplasia** causing posterior positioning of the tongue in utero. The position of the tongue prevents appropriate palate closure and results in cleft palate. The combination of **micrognathia and glossoptosis** causes **severe upper airway obstruction in neonates and infants, especially when supine**. Obstruction during sleep or mask ventilation can be **relieved by positioning the patient prone or inserting a nasal airway**. In some cases, the tongue is sutured to the lip to relieve obstruction from glossoptosis, or a tracheostomy may be necessary. **As these children grow, their mandibular profile improves and airway obstruction decreases**, typically making both mask ventilation and laryngoscopy easier (Answer A).

Goldenhar syndrome and Treacher Collins syndrome are both anomalies that involve **disruption of the 1st and 2nd branchial arches,** leading to **mandibular, maxillary, auricular, ophthalmologic, and facial nerve defects. Goldenhar syndrome refers to hemifacial microsomia.** This disorder is usually sporadic, though familial transmission is possible. Patients with Goldenhar syndrome have unilateral face and neck abnormalities, including hypoplastic maxilla, mandible, tongue and palate, macrostomia with limited mouth opening, cleft palate, microphthalmia, microtia, hearing loss, vertebral dysplasia,

and cervical subluxation. The contralateral head and neck have a normal morphology.

Treacher Collins syndrome involves bilateral abnormalities and is usually transmitted in an autosomal dominant fashion. These patients have bilateral hypoplastic zygomatic arches and mandible, choanal atresia, macrostomia, cleft palate, eye abnormalities, microtia, and cervical vertebral malformations. Patients with both syndromes may have upper airway obstruction during mask ventilation and are difficult to intubate via direct laryngoscopy. **Treacher Collins patients are more difficult to intubate than Goldenhar patients due to their bilateral abnormalities, and their airway management tends to get more difficult with age**.

CHARGE association refers to the collection of coloboma, heart defects, choanal atresia, retardation of growth and development, genitourinary anomalies, and ear anomalies. Head and neck abnormalities include midface hypoplasia, micrognathia, cleft lip or palate, choanal atresia or stenosis, laryngomalacia, laryngeal cleft, and subglottic stenosis. **Difficulties with mask ventilation and direct laryngoscopy also tend to worsen with age in these patients.**

KEY FACTS

- Patients with Pierre-Robin sequence have micrognathia, glossoptosis, and cleft palate. This combination results in severe upper airway obstruction, especially while supine. The airway obstruction improves with age as the mandible grows.
- Goldenhar syndrome and Treacher Collins syndrome are caused by abnormalities of the 1st and 2nd branchial arches. The upper airway is affected by abnormalities in the maxilla, mandible, and cervical spine. Patients with Goldenhar syndrome have hemifacial microsomia, while those with Treacher Collins syndrome have bilateral abnormalities. The difficulty of airway management worsens with age in both syndromes.

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17. ANSWER: D

Craniosynostosis refers to premature closure of at least one cranial suture. Ossification of the cranial vault usually begins at the eighth week of conception. Suture closure begins in utero and progresses after birth with final fontanelle closure at 2 years of age. **Premature suture closure causes growth failure perpendicular to the suture with compensatory overgrowth parallel to the suture**. The final skull morphology is determined by the number and type of sutures involved. Sagittal synostosis results in an elongated head with increased anterior-posterior diameter. Unilateral coronal synostosis results in facial asymmetry, while bilateral coronal synostosis causes a flattened, wide face with a short anterior-posterior diameter.

In addition to abnormal skull morphology, patients may develop **increased intracranial pressure** (15% incidence with single suture synostosis versus 35% incidence when two or more sutures are involved), **hydrocephalus, and developmental delay**. Surgical correction in infancy is indicated to allow normal skull growth and brain development, relieve increased intracranial pressure, and achieve best cosmetic results. The **majority of craniosynostoses are isolated findings, usually involving one suture** with no other systemic findings. The **sagittal suture is most commonly affected**, followed by coronal, then metopic sutures. A minority of craniosynostoses are syndromic. At least 150 associated syndromes have been described. **Syndromic patients are more likely to have multiple sutures involved** (most commonly, the coronal suture) **and to have neurologic sequelae** of synostosis.

Acrocephalosyndactyly syndromes are a collection of disorders that present with **craniosynostosis along with hand and foot anomalies**. These syndromes are often due to FGFR2 (fibroblast growth factor receptor) mutations, which cause abnormal osseous development. Many cases are sporadic, though some are transmitted in an autosomal dominant manner. Common subtypes of **acrocephalosyndactyly syndromes include Apert syndrome (type I), Crouzon syndrome (type II), and Pfeiffer syndrome (type V)**. These patients are likely to present with **dysmorphic facies**. Findings can include midface hypoplasia (including choanal stenosis or atresia, sinus abnormalities, and maxillary retrusion), relative mandibular prognathism, palate abnormalities, dental crowding, and orbital anomalies (hypertelorism and shallow orbits causing proptosis). **Airway management may be difficult** due to poor face mask fit, nasal and upper airway obstruction and difficult laryngoscopy. Proptosis predisposes these patients to intraoperative ocular injury. As previously mentioned, these patients are likely to have neurologic sequelae of their craniosynostosis requiring operative repair. In addition, **chronic cerebellar tonsil herniation and Arnold-Chiari malformation** may be present in Crouzon and Pfeiffer patients, respectively. Musculoskeletal anomalies commonly include **syndactyly, brachydactyly, or polydactyly of the hands and feet**. Patients with these findings typically have **difficult vascular access.** These abnormalities are typically absent in Crouzon syndrome. Patients may also have

partial cervical spine fusion, which affects airway management and intraoperative positioning. Kyphoscoliosis is not a typical finding in these syndromes. In addition to the upper airway anomalies already described, these patients may have **lower respiratory tract anomalies**, including tracheal stenosis, abnormal tracheal cartilage, airway malacia at multiple levels, and tracheo-esophageal fistula. Up to one third of these patients experience intraoperative respiratory problems related to these findings. A **variety of congenital cardiac and renal anomalies may also be present**. Hepatomegaly is not associated with these syndromes.

KEY FACTS

- Craniosynostosis refers to premature closure of at least one cranial suture. This results in growth failure perpendicular to the suture with overgrowth parallel to the suture.
- The majority of craniosynostoses are isolated findings and involve only one suture. Syndromic craniosynostoses are more likely to involve multiple sutures and have neurologic sequelae, including increased intracranial pressure, hydrocephalus, and developmental delay.
- Acrocephalosyndactyly syndromes present with craniosynostosis and hand and foot anomalies. Patients commonly have dysmorphic facies and may have cervical spine anomalies, both of which result in difficult airway management. Limb anomalies make vascular access difficult.

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18. ANSWER: D

This patient's physical exam findings are consistent with Turner syndrome. **Turner syndrome** is an X-linked disorder resulting from the **absence of one functional X chromosome**. Patients can have either complete absence of one X chromosome (45, XO) or a mosaic karyotype (45, XO/46, XX). Complete chromosome X monosomy is associated with a high rate of spontaneous abortion in utero, while those with mosaic karyotypes may have milder symptoms. Typical physical features of Turner syndrome patients include **short stature (or small size for gestational age); a short, broad, and webbed neck with a low posterior hair line**; broad chest with widely spaced nipples; and scoliosis. **Facial abnormalities may also include micrognathia, midface hypoplasia**, **high arched palate, and occasional cleft palate**. These findings, along with a short neck and **cervical spine vertebral hypoplasia**, may make airway management difficult.

Turner patients may have **congenital cardiac disease, most commonly left-sided obstructive lesions, including coarctation of the aorta and bicuspid aortic valve**. The murmur in this scenario is consistent with coarctation of the aorta. These patients also commonly develop **hypertension, which, in combination with aortic abnormalities, predisposes them to dissecting aortic aneurysms** for which they should be periodically monitored. Other common problems include **renal and genitourinary anomalies** (renal hypoplasia, horseshoe kidneys, amenorrhea, gonadal dysgenesis, or premature ovarian failure), **endocrine abnormalities** (hypothyroidism, diabetes), **obesity**, and **lymphedema**. Intelligence is usually normal, though mental retardation can be present.

Noonan syndrome is a genetic disorder caused by abnormalities on chromosome 12 and is transmitted in an autosomal dominant manner. Patients with this syndrome appear **phenotypically similar to Turner patients** (short stature; short, webbed neck; low posterior hair line; micrognathia; midface hypoplasia; and scoliosis),but have a normal karyotype and may be male or female. **Cardiac disease, most commonly including pulmonary stenosis and hypertrophic cardiomyopathy**, is common. Other features include developmental delay, lymphedema, and coagulopathy.

Endocardial cushion defects are common in Down syndrome (Trisomy 21) patients (Answer A). Typical head and neck findings in Down syndrome patients include midface hypoplasia, macroglossia, tonsil and adenoid enlargement, and atlantoaxial instability.

Patent ductus arteriosus (PDA) is present as a normal finding at birth, but it generally closes over the first few days. Delayed closure of the ductus arteriosus may lead to heart failure and poor systemic perfusion or may be required to provide adequate circulation in some kinds of congenital heart disease. A **PDA** is associated with a **continuous machine-like murmur**.

KEY FACTS

- Turner syndrome is caused by the absence of one functional X chromosome. Patients have a short stature and a short, webbed neck. Facial anomalies in combination with the short neck can result in difficult airway management.
- Cardiovascular anomalies in Turner syndrome are most commonly left-sided obstructive lesions, including coarctation of the aorta. Patients commonly develop

hypertension, which places them at risk for dissecting aortic aneurysms.
- Patients with Noonan syndrome are phenotypically similar to Turner syndrome patients but have a normal karyotype. Common cardiac lesions include pulmonary stenosis and hypertrophic cardiomyopathy.

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19. ANSWER: B

Epidermolysis bullosa (EB) is a genetic disorder characterized by **blistering and scarring after minor trauma**. More than 20 subtypes exist, but they can be classified into three general groups. **Epidermolysis bullosa simplex (EBS) is the mildest and most common form** of the disease. Keratin mutations result in **separation within the epidermis**. Patients have a wide clinical range of severity, but most tend to live relatively normal lives with blisters that heal with minimal or no scarring. Less commonly, frequent oral and laryngeal blisters can result in feeding problems, or this disease can be associated with muscular dystrophy or pyloric stenosis. **Junctional epidermolysis bullosa (JEB) is the most severe form** of EB. Defects within the basement membrane result in **separation of the epidermis from the dermis**. Patients with JEB have severe mucous membrane involvement. Damage to the oropharyngeal and respiratory mucosa results in feeding difficulties and airway obstruction. In the most severe form of this disease, death from airway obstruction or sepsis occurs within the first year of life. **Dystrophic epidermolysis bullosa (DEB) has an intermediate presentation and is the type most commonly seen by anesthesiologists**. Collagen mutations result in **separation within the dermis just under the basement membrane**. Patients with DEB have blisters that heal with chronic scarring. Extremity blisters result in **finger and toe fusion (mitten deformity), contractures (especially involving the flexor surfaces of the neck, limbs, and digits), and extremity mutilation**. Scarring on the face results in **microstomia with severely restricted mouth opening, narrowed nasal apertures, and eyelid retractions**. Esophageal involvement results in **esophageal strictures** that lead to poor feeding and nutrition. Chronic blister formation is complicated by **infection and anemia** and easy bleeding of the gums results in poor dentition.

The anesthetic management of patients with EB should be tailored to minimizing new blister formation as well as managing the chronic effects of the disease, including contractures, anemia, malnutrition, infectious risk, and chronic steroid use. **Blisters are more likely to be caused by friction or shear forces on the skin, rather than by direct pressure**. Noninvasive blood pressure cuffs cause direct pressure and are usually well tolerated if they are placed over layers of padding. **Adhesive substances are likely to cause blister formation**. The EKG can be monitored with needle electrodes or by removing the adhesive rim from standard EKG leads and keeping them in place with bandages. Clip-on pulse oximeter probes should be used instead of adhesive monitors. In patients with severe mitten deformity, an alternative site such as an ear may be necessary. Intravenous and intra-arterial catheters should be sutured in place and endotracheal tube ties should be used instead of adhesive tape. **Nonadhesive, silicone-based dressings** can be used to cover active blisters and help secure lines and monitors. Temperature probes should be axillary to avoid damage to mucosal surfaces. The eyes should be well lubricated but not taped shut. Patients with eyelid retractions are more prone to corneal abrasions.

Airway management is likely to be difficult in these patients **due to contractures** as well as the **risk for new damage to the oropharyngeal and respiratory mucosa**. Decreased mouth opening, tongue scarring, decreased neck mobility, and poor dentition may be present. The face mask, laryngoscope blade, and endotracheal tube should be lubricated prior to contact with the patient and minimal pressure should be applied. Fiberoptic intubation may be necessary if mouth opening is severely restricted. The nasal apertures may be small due to scarring; however, nasal intubation can be considered because the **nasal respiratory tissue is not generally affected by EB and may be less prone to damage than the oropharynx**. **Rigid oral airways and blind oropharyngeal suctioning should be avoided**. **Consideration should be given to deep extubation to minimize coughing** during emergence, which can lead to trauma and bullae formation in the airway. Regional anesthesia is not contraindicated if the overlying skin is intact, but strict asepsis should be used.

KEY FACTS

- Epidermolysis bullosa is characterized by blistering and scarring after minor trauma. Dystrophic epidermolysis bullosa (DEB) has an intermediate severity and is the type most commonly seen by anesthesiologists. Chronic scarring can result in extremity deformities, contractures, microstomia and narrowed nasal passages, esophageal strictures, infection, and anemia.
- Intraoperative blister formation is more likely to be caused by friction or shear forces than by direct pressure. Monitors or surfaces in contact with the patient should be well padded. Adhesive dressings and monitors should be avoided.

- Airway management is likely to be difficult due to contractures and the risk for new damage to oropharyngeal and respiratory mucosa. Fiberoptic intubation may be necessary. Consideration should be given to nasal intubation and deep extubation.

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20. ANSWER: C

This patient's history and physical examination are consistent with a diagnosis of Marfan syndrome. **Marfan syndrome** is multisystem disorder caused by a mutation in the fibrillin-1 (FBN1) gene. This mutation results in collagen with decreased tensile strength and increased elasticity. This **abnormal collagen leads to disproportionate long bone growth, arterial cystic medial necrosis, emphysema, and ocular abnormalities**, including retinal detachment. Marfan syndrome is inherited as an autosomal dominant mutation with variable expressivity, although 15% of patients have spontaneous mutations.

Patients with Marfan syndrome are tall with long fingers and toes (arachnodactyly). They have **hyperextensible joints, kyphoscoliosis, and pectus deformities and are at risk for atlantoaxial subluxation** with extremes of neck flexion or extension due to abnormal atlantoaxial facet shape and ligament laxity. **Cardiovascular complications** of Marfan syndrome are **rare in children but increase with age** and lead to premature death in the third to fifth decade. Arterial cystic medial necrosis leads to **aortic root and main pulmonary artery dilation or aneurysm formation**, placing the patient at **risk for aortic dissection**. **Aortic and mitral valvular insufficiency** are also common. **Arrhythmias** may be due to valvular disease, dilated cardiomyopathy, or congestive heart failure. This patient has a murmur consistent with aortic insufficiency and should also be screened for aortic root dilation given his age. Patients with confirmed valvular disease may require endocarditis prophylaxis prior to surgery.

Marfan patients can develop **restrictive lung disease due to kyphoscoliosis and pectus deformities**. They also **may develop emphysema** and are at **risk for spontaneous pneumothoraces**, which can progress to tension pneumothorax during controlled mechanical ventilation. This patient has only mild scoliosis and good exercise capacity without respiratory symptoms. Pulmonary function tests are unlikely to be helpful at this time. Abnormal coagulation and renal function are not a part of Marfan syndrome. A neonatal form of Marfan syndrome presents with flexion contractures, micrognathia, and muscle hypoplasia and usually results in death before 2 years of age due to severe valve regurgitation and aortic dilation.

Ehlers-Danlos syndrome (EDS) refers to a group of inherited connective tissue disorders with a **similar presentation to Marfan syndrome**. Multiple forms of EDS exist and they are classified into six subgroups. Each type of EDS has a different genetic cause, but the end result for all disorders is abnormal collagen with reduced strength. Most disorders are autosomal dominant, though some are autosomal recessive or X-linked. The **clinical presentation varies by type but typically involves skin, musculoskeletal, cardiovascular, and ocular anomalies**. Patients with EDS have **hyperextensible and hyperelastic skin** that is thin and vulnerable to damage with minor trauma. Patients tend to bruise easily and may have impaired wound healing. Similar to Marfan syndrome, these patients have **hyperextensible joints** that are prone to **recurrent subluxation with the development of kyphoscoliosis** and **chronic pain**. Some subtypes have a Marfanoid habitus (tall stature with long digits), but others are of normal height. Cardiovascular issues include **valvular regurgitation and multiple aneurysm formation with risk for rupture and dissection**. In contrast to Marfan syndrome, aortic involvement is rare, though it can still occur and cause sudden death. The **vascular subtype of EDS is the most severe form with arterial rupture occurring** in 25% of patients by 20 years of age and increasing incidence with age. Due to vascular fragility, these lesions are difficult or impossible to repair. Ocular abnormalities include lens subluxation, globe rupture, and blindness from recurrent retinal hemorrhages. **Excessive bleeding is a feature of the classic and vascular subtypes of EDS**, though patients usually have normal coagulation tests with increased bleeding time. Anesthetic management, including cardiac and pulmonary evaluation, possible need for endocarditis prophylaxis, and risk for atlantoaxial subluxation is similar to Marfan syndrome.

KEY FACTS

- Marfan syndrome is caused by collagen abnormalities that lead to disproportionate long bone growth, arterial cystic medial necrosis, emphysema, and ocular anomalies. Cardiovascular complications include aortic root and main pulmonary artery aneurysm formation or dissection and valvular insufficiency.
- Patients with Ehlers-Danlos also have abnormal collagen and may have a similar presentation to Marfan syndrome patients. In addition, patients may have hyperelastic skin and excessive bleeding. Patients with

the vascular subtype of EDS may also have arterial rupture.
- Patients with both syndromes have hyperextensible joints that are prone to recurrent subluxation, kyphoscoliosis, and pectus deformities. These patients are at risk for atlantoaxial subluxation during airway management.

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21. ANSWER: B

This neonate has findings consistent with **Beckwith-Wiedemann syndrome**. This syndrome is characterized by **macrosomia, visceromegaly, macroglossia, and an omphalocele**. It is caused by an increase in insulin-like growth factor 2 (IGF-2) gene expression, which results in **somatic overgrowth and predisposition to tumors**. The syndrome is mostly sporadic, but it can be autosomal dominant with incomplete penetrance and variable expressivity. Patients with Beckwith-Wiedemann syndrome have visceromegaly, affecting the kidneys, spleen, liver, and adrenal glands. **Abdominal visceromegaly** is associated with omphalocele, umbilical defects, intestinal malrotation, and diaphragm eventration. **Pancreatic islet cell hyperplasia causes relative hyperinsulinemia with resulting hypoglycemia**. Hypoglycemia can be especially severe in the neonatal period and usually resolves in infancy. Prolonged hypoglycemia can result in CNS damage with subsequent developmental delay. In the absence of this complication, the brain is not affected by this disorder, and no structural abnormalities would be found on imaging. Perioperatively, patients should be managed with dextrose infusions and frequent serum glucose checks.

Facial features include **macroglossia, midface hypoplasia**, exophthalmos, and ear anomalies. Macroglossia is associated with **significant upper airway obstruction** and in combination with midface hypoplasia may make both mask ventilation and direct laryngoscopy difficult. The tongue usually becomes better accommodated inside the oral cavity as the patient grows, but partial glossectomy may be required in the face of significant airway obstruction. Somatic overgrowth can result in **gigantism, and hemihypertrophy may occur**. Beckwith-Wiedemann patients are predisposed to the development of both benign and malignant tumors, including renal (Wilms tumor), liver and adrenal tumors, neuroblastoma, and rhabdomyosarcoma. Patients with hemihypertrophy are more likely to have malignant tumors. Genitourinary anomalies may be present. Congenital cardiac disease can occur, but it is rare. **Infant mortality is 20% and is related to cardiac or respiratory failure**. In the absence of a renal tumor, this disorder is not associated with abnormal renal function, and there are no associated vertebral anomalies that would be seen on a spine plain film.

WAGR syndrome, which stands for **Wilms tumor, aniridia, genitourinary anomalies, and retardation**, is caused by Wilms tumor suppressor gene (WT1) gene mutation. It is mostly sporadic but can be transmitted as an autosomal dominant mutation. Some features, such as somatic **hemihypertrophy and Wilms tumor**, are similar to Beckwith-Wiedemann syndrome. However, there are many differences. In addition to Wilms tumor, **renal anomalies** may include **renal dysplasia or hypoplasia with resultant abnormal renal function tests**. Genital anomalies can include hypospadias, cryptorchidism and gonadal dysgenesis. **Facial abnormalities**, including microcephaly, premature synostosis, micrognathia, and a high, narrow palate may make airway management difficult in these patients, but macroglossia is not a feature of this disease. **Musculoskeletal abnormalities**, including multiple **exostoses and kyphoscoliosis** are common and may be detected on plain films of the spine. Ventricular septal defects can occur in this syndrome.

KEY FACTS

- Beckwith-Wiedemann syndrome is caused by overexpression of IGF-2, which results in macrosomia, abdominal visceromegaly, macroglossia, and predisposition to tumor growth. Pancreatic islet cell hyperplasia causes relative hyperinsulinemia with resulting hypoglycemia. Macroglossia causes significant upper airway obstruction.
- WAGR syndrome includes Wilms tumor, aniridia, genitourinary anomalies, and retardation. Although some findings are similar to Beckwith-Wiedemann syndrome (hemihypertrophy, Wilms tumor), these patients also have renal, facial, and musculoskeletal anomalies not seen in Beckwith-Wiedemann syndrome. Hypoglycemia and macroglossia are also absent.

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22. ANSWER: B

The immune system is comprised of three basic types of immunity. **Natural immunity** refers to the action of **phagocytic and NK** (natural killer) cells. These cells provide **a nonspecific response to foreign material** that does not require prior antigen exposure. **B cells provide humoral immunity** by releasing immunoglobulins in **response to a previously recognized antigen**. **T cells provide cell-mediated immunity** and can be cytotoxic cells, helper cells (enhance the activity of other lymphocytes), or suppressor cells (inhibit other parts of the immune system). There are over 70 primary immunodeficiencies that may affect some or all of these responses.

Selective IgA deficiency, common variable immune deficiency (CVID), and X-linked agammaglobulinemia (XLA) all involve **defects in humoral immunity**. **Selective IgA deficiency** is the **most common** and results in **relatively mild** recurrent respiratory, gastrointestinal, and genitourinary infections or may be asymptomatic. Patients with this deficiency produce anti-IgA immunoglobulins. When they receive **blood products, a complex forms between donor IgA molecules and the patient's own anti-IgA IgE molecules and causes an anaphylactic reaction**. **CVID** can be inherited as an autosomal or X-linked manner, while **XLA** is obviously an X-linked disease. Both diseases result in **recurrent pyogenic sinopulmonary or gastrointestinal infections after passive immunity from the mother subsides**. These disorders may require regular IVIG administration for prevention of infections.

Cell-mediated defects tend to have a more severe presentation than humoral defects. Infections may be caused by bacterial, fungal, or viral pathogens. Intracellular and opportunistic pathogens are common and may cause severe disease. **DiGeorge syndrome and velocardiofacial syndrome** are both caused by chromosome 22q11 microdeletions that lead to abnormal development of the 3rd and 4th pharyngeal pouches. This results in **hypoplastic or absent thymus and parathyroid glands as well as congenital heart disease with associated great vessel defects and mandibular hypoplasia**. Hypoparathyroidism manifests as **neonatal hypocalcemia** and seizures, and mandibular hypoplasia makes airway management difficult.

Severe common variable immunodeficiency syndrome (SCIDS), Wiskott-Aldrich syndrome, and ataxia-telangiectasia are examples of disorders with combined humoral and cell-mediated immunodeficiencies. These disorders have generally been fatal in early childhood. SCIDS can be inherited as an autosomal recessive or X-linked disease. It presents around 3 months of age with persistent candidiasis (commonly, thrush or diaper rash), recurrent pneumonia, gastrointestinal illnesses with chronic diarrhea, and failure to thrive. This patient has a presentation consistent with **Wiskott-Aldrich syndrome**. This is an **X-linked mutation affecting males**. The **classic triad includes thrombocytopenia with small platelets, recurrent infections (including orotracheal, sinopulmonary, meningitis, and gastrointestinal disease), and eczema**. In addition, patients may present with **hemorrhage**, including epistaxis, oral or gastrointestinal bleeding, and petechiae on exam. They also commonly have **autoimmune disorders**, including vasculitis (which may affect coronary and cerebral vessels), hemolytic anemia, and idiopathic thrombocytopenic purpura as well as an increased malignancy risk. Splenectomy may be required for severe thrombocytopenia. **Ataxia-telangiectasia** is an autosomal recessive disorder caused by defective DNA repair. Patients present with **recurrent infections, skin and ocular telangiectasias, neurologic findings** (including cerebellar ataxia, movement disorders with progressive weakness, and memory loss), **and endocrine abnormalities** (including hypogonadism and glucose intolerance).

Patients with defects in cell-mediated immunity can develop graft-versus-host disease (GVHD) after blood product transfusions. GVHD is an immune response caused by donor lymphocytes against the patient's own lymphoid tissue and can manifest with damage to the skin, gastrointestinal tract, and liver. In healthy patients, donor lymphocytes would be removed by the patient's T cells. However, this does not occur in patients with T cell immunodeficiencies. These patients **require irradiated blood products** to prevent this complication. Blood **should also be CMV negative to prevent infection**.

The **anesthetic management** of patients with primary immunodeficiencies must take into account the **effect of current infections as well as the prevention of new infections**. Chronic diarrhea may result in volume depletion and electrolyte abnormalities that need to be addressed. Recurrent pulmonary infections can cause bronchiectasis. Chest physiotherapy may be required preoperatively and patients may have decreased pulmonary reserve intra- and postoperatively. Prophylactic antibiotic administration should be tailored to the patient's previously known pathogens. **Strict asepsis is required for invasive procedures, including vascular access and airway management**. **Regional anesthetics, including neuraxial blocks, are relatively contraindicated** due to infectious risk. **Nitrous oxide is also relatively contraindicated due to bone marrow suppression**. In the case of Wiskott-Aldrich syndrome, baseline platelets and hematocrit should be checked.

Acute hemolytic reactions are caused by destruction of donor red blood cells by preformed recipient antibodies and **most often occur due to incorrect cross-matching**. Symptoms include fever, chills, chest and back pain, and

hemolysis. Potassium levels are elevated in packed red blood cells due to leakage from stored cells. **Clinically relevant hyperkalemia can occur after massive or rapid red blood cell transfusion**. Neither reaction would be more likely based on the patient's underlying medical condition, and this patient is receiving platelets, not red blood cells.

KEY FACTS

- Natural immunity refers to nonspecific immune responses to foreign material. Humoral immunity is mediated by B cells in response to a previously recognized antigen. Cell-mediated immunity is mediated by T cells, which may be cytotoxic, helper, or suppressor cells.
- Patients with defects in humoral and cell-mediated immunity present with recurrent infections. Patients with cell-mediated defects tend to have more severe infections than those with humoral defects. In addition, patients with cell-mediated defects are also at risk for developing graft-versus-host disease (GVHD) after exposure to nonirradiated blood products.
- Selective IgA deficiency is the most common defect in humoral immunity. These patients have relatively minor recurrent infections. They are at risk for anaphylaxis after blood product transfusion due to complex formation between donor IgA molecules and their own anti-IgA IgE molecules.
- DiGeorge and velocardiofacial syndromes present with cell-mediated immune defects due to thymic hypoplasia. These patients also have parathyroid and mandibular hypoplasia and great vessel defects.
- Wiskott-Aldrich syndrome is a combined cell-mediated and humoral immune defect. This disorder is X-linked and presents with a classic triad of thrombocytopenia, recurrent infections, and eczema. Patients may also develop signs of hemorrhage and autoimmune disorders.

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23. ANSWER: C

Phakomatoses are a group of **multisystem disorders** that present with **CNS, ocular, and skin lesions**. Neurofibromatosis, tuberous sclerosis, von Hippel Lindau syndrome, and Sturge-Weber syndrome are all examples of these disorders. **Neurofibromatosis** is divided into two types (NF-1 or von Recklinghausen disease and NF-2) and is inherited in an autosomal dominant manner. The abnormal proteins for NF-1 and NF-2 are neurofibromin and schwannomin, respectively, both of which are **tumor suppressor genes**. **Neurofibromas are nerve sheath tumors that may be cutaneous, subcutaneous, or nodular plexiform (involving nerve roots or plexuses)**. The tumors are **benign, but growth with age causes significant functional or anatomic complications due to compression or invasion**. Common presentations include pain, disfiguration, and bleeding due to their vascularity. Neurofibromas **can occur in the oropharynx, resulting in airway obstruction**. Patients with **NF-1** present with caf é-au-lait spots, neurofibromas, skin-fold freckling, lisch nodules (benign iris hamartomas), optic pathway tumors, or bony lesions. Patients with **NF-2** have fewer peripheral and cutaneous manifestations than NF-1 but instead have vestibular schwannomas and a higher incidence of intracranial or paraspinal tumors. **Neurologic manifestations** can include **seizures and signs of spinal cord compression** depending on tumor location. Patients may also have significant **cardiovascular complications, including arterial vasculopathy presenting as renal artery stenosis and systemic hypertension or pheochromocytoma (present in 5% of these patients)**. Pheochromocytoma should be ruled out if there is any question of hemodynamic instability, and it is the likely cause of problems in this patient. **Musculoskeletal** complications include long bone bowing, thoracic scoliosis, cervical vertebral anomalies, and pathologic fractures. Patients are at increased risk for a number of other malignancies as well. Anesthetic management of these patients should include a detailed airway examination, hemodynamic and respiratory assessment, and documentation of neurologic symptoms and involvement. **Airway management can be complicated by oropharyngeal tumors as well as restricted neck motion related to cervical vertebral abnormalities and spinal cord compression**. Restrictive lung disease may be present if scoliosis is severe. Due to the possible presence of spinal cord lesions, **neuraxial blockade should be performed only if recent imaging demonstrating an absence of spinal cord pathology** is available.

Tuberous sclerosis is characterized by the **triad of seizures, mental retardation, and fibroangiomas**. It is caused by an autosomal dominant mutation of **tumor suppressor genes**, though many cases are spontaneous. It **presents shortly after birth and progresses with age, resulting in a 50% mortality by 20–25 years of age**. Tuber lesion formation in the brain leads to **seizures (often intractable), obstructive hydrocephalus, and mental retardation**. These lesions may undergo malignant transformation or calcify. Lesions may also be present in the **heart, kidney, eyes, lungs, and skin**. **Cardiac tumors**

may involve the cardiac conduction system, resulting in ectopic beats, heart block, or pre-excitation. **Intracardiac rhabdomyomas are present in 50% of neonates, but they may regress with age**. These patients have **decreased cardiac output due to obstruction to intracardiac flow**. Abdominal aortic aneurysms can also be seen in infants. Renal lesions can cause polycystic kidney disease and pulmonary lesions cause fibrous changes leading to pneumothoraces. Skin involvement may present as adenomas, angiofibromas, areas of hypopigmentation, or caf é-au-lait spots. **Airway management in these patients may be difficult if oral or laryngeal nodular tumors, fibromas, or papillomas are present**. Anesthetic management should also include an assessment of baseline seizure activity, cardiac, pulmonary, and renal function.

Von Hippel Lindau syndrome is characterized by **multiple clear cell neoplasms** and is also related to a mutation in a **putative tumor suppressor gene**. **CNS manifestations**, including hemangioblastomas of the retina, cerebellum, and spinal cord, are key findings of this disease. **Spinal cord lesions are prone to bleeding** during hypertensive episodes, while **cerebellar lesions** more commonly present **with increased intracranial pressure** (though subarachnoid hemorrhage can occur). Other common tumors include **renal cell carcinoma, pheochromocytoma, and pancreatic endocrine tumors**. Hemangiomas may also be present on the adrenals, lung, and liver. Visceral tumors may be present on the kidneys, pancreas, and epididymis. As with neurofibromatosis, pheochromocytoma should be ruled out prior to anesthesia, and **spinal cord involvement may complicate both airway management and the potential use of neuraxial blockade, which is relatively contraindicated in the presence of lesions**.

Sturge-Weber syndrome is nearly always a **sporadic mutation** that results in **ipsilateral vascular anomalies**. Patients present with **vascular facial tumors that are present at birth** corresponding to the **ophthalmic division of the trigeminal nerve**. Typical lesions include facial hemangiomas (capillary or cavernous) and nevus flammeus (port-wine stains). These lesions **can involve hypertrophy of the nasopharynx and also result in hypertrophy of adjacent bones and soft tissues**. **CNS angiomas of the meninges and choroid** as well as intracranial calcifications can cause **anoxic injury, resulting in seizures, mental retardation, and contralateral hemiparesis or hemianopia. Intraoral angiomatosis** can involve the buccal mucosa, lips, tongue, palate, larynx, and pharynx, resulting in **distorted airway anatomy and bleeding**. **Visceral angiomatosis** can be present in all organs. The **presence of multiple vascular anomalies causes high-output cardiac failure due to shunting**. Airway management in these patients may be difficult due to distorted anatomy and bleeding, and **nasal intubation should be avoided due to the possible presence of vascular anomalies** in the nasopharynx. Baseline cardiac function should be established prior to anesthesia and **blood pressure should be tightly regulated, as these vessels have abnormal autoregulation**. **Neuraxial blockade should be avoided** due to the risk of meningeal hemangiomas and hematocrit and coagulation studies should be assessed due to the associated risk of thrombosis or bleeding with these lesions.

KEY FACTS

- Phakomatoses are multisystem disorders that present with CNS, ocular, and skin lesions. Abnormal lesions can involve the airway and spinal cord in most of these disorders. Airway management may be difficult in these situations and neuraxial blockade is relatively contraindicated in the presence of lesions.
- Neurofibromatosis is characterized by the development of multiple nerve sheath tumors, which cause central and peripheral neurologic symptoms due to local compression or invasion. Tumors may also occur in the oropharynx and lead to airway obstruction. Other signs include skin lesions, renal artery stenosis, systemic hypertension, and pheochromocytoma.
- Tuberous sclerosis is characterized by a classic triad of seizures, mental retardation, and fibroangiomas involving multiple organs and the airway. Intracardiac rhabdomyomas, which cause decreased cardiac output by obstructing flow, may occur. These are present in 50% of neonates but may regress with age.
- Von Hippel Lindau syndrome involves clear cell neoplasms of multiple organs. Patients may also develop spinal cord lesions, which are prone to bleeding.
- Sturge-Weber syndrome results in ipsilateral vascular anomalies. Patients present with ipsilateral vascular facial tumors in the distribution of the ophthalmic division of the trigeminal nerve as well as central nervous system angiomas and visceral angiomatosis. Blood pressure should be tightly controlled as these blood vessels have abnormal autoregulation.

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24. ANSWER: C

Spinal muscular atrophy (SMA) is an autosomal recessive disorder caused by mutations in the survival motor neuron (SMN) gene. Patients have **progressive degeneration of motor neurons in the anterior horns of the**

spinal cord and sometimes the brainstem. This leads to **lower motor neuron signs**, including symmetric wasting and weakness, flaccid paralysis, and loss of deep tendon reflexes. At least three types of SMA have been described. **SMA I, or Werdnig-Hoffmann syndrome**, **presents in infancy and is the most severe** form. Patients are typically alert and interactive with good facial expressions and eye movements but are otherwise **weak and hypotonic with abnormal (diaphragmatic) breathing patterns, tongue fasciculations, absent deep tendon reflexes,** and feeding difficulties. These patients never sit or walk independently and most **do not survive their first year** due to respiratory complications. **SMA II is the most prevalent form and has an intermediate severity**. Onset of symptoms is usually before 18 months of age, and patients **may survive into adolescence or early adulthood**. Patients have milder weakness and less common tongue fasciculations than type I patients. They sit independently, but never bear weight or walk. SMA II patients commonly develop **joint contractures and scoliosis**, which often requires operative stabilization after puberty. **Progressive weakness** and **scoliosis** lead to **feeding difficulties** and **respiratory issues, including restrictive lung disease, recurrent infection, and the need for nocturnal support**. **SMA III (Kugelberg-Welander disease) is a mild variant** with onset after 18 months of age. Patients develop flaccid and areflexic extremity weakness, but they are able to walk independently. They may develop joint contractures and need respiratory support, but the long-term prognosis is good. **Other areas of the nervous system, including the brain and sensory pathways, are unaffected**. Intelligence and sensory function are normal in SMA patients and seizures are not an expected part of the clinical presentation. In contrast to many other neuromuscular disorders, including muscular dystrophy and mitochondrial or metabolic myopathies, **cardiac muscle is not directly affected** by this disorder. Cardiomyopathy would not be expected in this patient (Answer B). **SMA III patients**, however, **may develop arrhythmias** requiring pacemaker placement.

Preanesthetic evaluation of these patients should involve evaluation of motor and respiratory function and, in the case of SMA III patients, a cardiac evaluation for primary arrhythmias. **Pulmonary complications are the most common perioperative problem** in these patients. Elective general anesthetics are contraindicated in the setting of severely reduced pulmonary function. Pharyngeal weakness increases the **aspiration risk** in these patients and restrictive lung disease with muscle weakness contributes to **respiratory insufficiency**. Neuromuscular blocking agents and opioids should be carefully titrated and postoperative ventilation should be anticipated. Serum potassium and possibly CK should be assessed preoperatively in the setting of muscle wasting. **Succinylcholine administration may increase rhabdomyolysis** in these patients, causing acute increases in serum potassium. However, **patients with significant muscle atrophy**, such as this patient, **may not have sufficient muscle mass to cause a clinically significant increase in potassium** (Answer A). There is no link between SMA and malignant hyperthermia.

Spinocerebellar ataxia (SCA) refers to a collection of genetic disorders that lead to **neuron loss at different points in the spinocerebellar pathway**. At least 25 subtypes exist, each with a different constellation of symptoms. The majority of these disorders have an autosomal dominant inheritance, though autosomal recessive and X-linked inheritance can also occur. **Ataxia is a prominent symptom** in all these disorders. **Other cerebellar symptoms, including dysarthria, explosive speech, dysmetria, and abnormal eye movements**, are also common. Other neurologic symptoms, including cognitive impairment, seizures, and movement disorders, reflect **variable involvement of other areas of the neurologic system**, including extrapyramidal tracts, brainstem, and cerebral cortex. The **primary anesthetic concern is related to aspiration** due to pharyngeal dysfunction **and alveolar hypoventilation** due to respiratory weakness. **Myopathy is not a feature** of these diseases, and response to succinylcholine is not expected to be abnormal.

KEY POINTS

- SMA is caused by progressive degeneration of motor neurons in the spinal cord and sometimes the brainstem. Patients develop lower motor neuron signs, including wasting, weakness, and flaccid paralysis. Sensory and cognitive functions are unaffected.
- The most common perioperative problem for SMA patients is pulmonary complications, including aspiration and respiratory insufficiency. Succinylcholine can cause rhabdomyolysis in these patients. Unlike many other neuromuscular disorders, cardiac muscle is not directly affected in SMA patients.
- SCA is caused by neuron loss in the spinocerebellar pathway. Patients develop cerebellar symptoms and usually have prominent ataxia. The primary anesthetic concerns are aspiration and hypoventilation. Myopathy is not a feature of this disorder.

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25. ANSWER: B

Overgrowth syndromes are genetic disorders in which patients present with **disproportionate growth of vascular**

or bony structures or of specific organs. **Sturge-Weber, Klippel-Trenaunay, and Kasabach-Merritt syndromes** are examples of disorders featuring **vascular overgrowth**. This patient's presentation is consistent with **Sturge-Weber syndrome**. Patients with this syndrome have **ipsilateral vascular anomalies of the face and CNS.** Facial anomalies are commonly in the distribution of the **ophthalmic division of the trigeminal nerve, but they may also involve multiple parts of the airway**, including the nasopharynx, buccal mucosa, lips, tongue, palate, larynx, and pharynx. **CNS anomalies can result in anoxic injury, seizures, and focal neurologic deficits**. **Klippel-Trenaunay syndrome** presents with **asymmetric soft tissue and bone hypertrophy with associated vascular and lymphatic malformations**, often occurring in the extremities. Vascular and lymphatic malformations may also be present in the brain, spinal cord, and gastrointestinal and genitourinary tracts. Patients with **Kasabach-Merritt syndrome** have **apparent capillary hemangiomas** that are **prone to platelet trapping, leading to consumptive coagulopathy and rapid enlargement of the malformation**. The **proximal extremities and trunk** are commonly involved, and significant muscle and bone infiltration can be present. Head and face involvement is less common.

The systemic manifestations of vascular overgrowth depend on the type of lesions present. **Arterial malformations are high-flow lesions that can result in limb hypertrophy and high-output cardiac failure**. Low-flow lesions, including capillary, venous, and lymphatic malformations are less likely to result in heart failure. **Vascular lesions are prone to bleeding from direct damage or during episodes of hypertension** due to abnormal vasomotor control. Acute bleeding can result in airway compromise or the development of neurologic deficits from brain or spinal cord hemorrhage. Patients may also be prone to the formation of **deep venous thrombosis leading to pulmonary embolism**. **Lymphatic malformations** commonly involve the head, neck, chest, and axilla. They affect the skin and underlying muscle and have the **potential to become infected or enlarged**. Airway lesions may result in obstruction, difficult mask ventilation or intubation, or uncontrolled bleeding. Treatment of these malformations depends on the type, location, and extent of lesions present. Patients may present to the anesthesiology service for sclerotherapy, tumor resection, debulking, or limb amputation. **Lesions may temporarily increase in size after sclerotherapy management**, which potentially increases the difficulty of airway management if airway lesions are present. Anesthetic management should include an **evaluation of airway involvement, cardiac function, baseline hemodynamics, and coagulation status (including hematocrit, platelets, and coagulation factors)**. Blood pressure should be tightly controlled intraoperatively to prevent spontaneous bleeding from malformations, and preparations should be made for massive transfusion. Neuraxial anesthesia is contraindicated in the presence of spinal cord vascular malformations, and regional anesthesia may be difficult or impossible if malformations are present near the site of blockade.

Simpson-Golabi-Behmel, Sotos, and Proteus syndromes are examples of disorders with **skeletal overgrowth**. The exact presentation differs between syndromes, but it usually includes macrocephaly with coarse facies, **mandibular overgrowth, macroglossia, cervical vertebral anomalies with restricted joint motion, pectus deformities, and scoliosis**. **Airway** management is complicated **by obstruction due to a combination of bony encroachment and soft tissue hypertrophy and restricted joint motion**. Pulmonary mechanics are often abnormal due to thoracic skeletal deformation. These syndromes may also be associated with **congenital heart defects, endocrine abnormalities (including abnormal thyroid function and glucose regulation), and vascular malformations**. Osteopetrosis is caused by normal bone growth in the presence of deficient bone resorption. It presents with many of the same musculoskeletal abnormalities as overgrowth syndromes, including airway obstruction and restricted motion, and is also associated with the development of pathologic fractures.

KEY FACTS

- Sturge-Weber, Klippel-Trenaunay, and Kasabach-Merritt are examples vascular overgrowth syndromes. Patients with Sturge-Weber syndrome have ipsilateral facial and CNS vascular anomalies. Klippel-Trenaunay patients have asymmetric soft tissue and bone hypertrophy with vascular and lymphatic malformations, often occurring on the extremities. Kasabach-Merritt syndrome involves vascular lesions that are prone to platelet trapping with subsequent consumptive coagulopathy, often on the trunk and extremities.
- Manifestations of vascular overgrowth syndromes include high-output cardiac failure (especially for arterial lesions), bleeding due to direct trauma or hypertension, DVT formation, infection with enlargement, consumptive coagulopathy, and airway obstruction.
- Bony overgrowth syndromes result in anatomic distortion and restricted joint motion. Airway obstruction can occur due to mandibular overgrowth and bony encroachment, macroglossia, cervical vertebral abnormalities, and restricted temporomandibular joint motion. Cardiac, endocrine, and vascular anomalies may also be present.

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26. ANSWER: A

This patient's presentation is consistent with a subtype of multiple endocrine neoplasia (MEN). **MEN syndromes feature tumors of multiple endocrine glands, which** are divided into three subtypes. Patients with **MEN type I (Wermer syndrome)** have tumors of the **parathyroid gland, pancreas, and pituitary**. Parathyroid adenomas or hyperplasia are usually the first presenting sign and result in **hypercalcemia** and nephrolithiasis. Pancreatic islet cell tumors are **commonly β-cell insulinomas, which result in fasting hypoglycemia**. **Other pancreatic tumors** include gastrinomas, resulting in peptic ulcer disease, and VIPomas, resulting in watery diarrhea, hypokalemia, and achlorhydria. **Pituitary tumors are commonly prolactinomas**, but they may also be ACTH-secreting adenomas, which cause acromegaly, or nonfunctioning tumors, which can cause **symptoms related to mass effect** on surrounding tissue.

MEN type IIA (Sipple syndrome) features **medullary thyroid carcinoma, pheochromocytomas, and hyperparathyroidism**. **Medullary thyroid carcinoma** is derived from parafollicular C cells and **produces calcitonin, which decreases calcium levels**. This thyroid tumor is usually the first sign of MEN type II and presents as neck pain or mass between 15 and 20 years of age. **Pheochromocytoma** occurs in 50% of patients and is **usually multicentric and bilateral**. **MEN type IIB (also called MEN type III or mucosal neuroma syndrome)** also features **medullary thyroid carcinoma and pheochromocytoma, but patients do not have parathyroid involvement. Patients present with multiple mucosal neuromas** on the lips, tongue, buccal mucosa, eyelids, conjunctiva, and cornea, resulting in distinctive facies with enlarged lips. Neuromas may also be present along the gastrointestinal tract and result in abdominal distention, megacolon, constipation, and diarrhea. Patients with MEN type IIB may also have **marfanoid body habitus**. This patient's presentation is consistent with MEN type IIB.

For patients with **MEN type IIA and IIB, pheochromocytoma must be ruled out prior to induction of anesthesia**. Patients with an undiagnosed pheochromocytoma are prone to sudden hypertensive crisis and intraoperative death. These patients are chronically vasoconstricted due to catecholamine release and therefore have volume depletion, not volume overload (Answer D). Patients should be treated with α-adrenergic blockade to allow **vasodilation and correction of intravascular volume prior to surgery**. β-blockade may be required to prevent tachycardia after α-blockade is instituted. **Electrolyte abnormalities**, usually related to calcium, should be corrected prior to surgery to prevent conduction abnormalities. Hypokalemia may occur in MEN type I patients with VIPomas. Hyperkalemia is not a feature of MEN syndromes (Answer B). **Oral mucosal neuromas may affect airway management, and chronic thyroid enlargement may result in airway compression or tracheomalacia**.

Patients with neurofibromatosis (NF) have a 5% incidence of pheochromocytoma. Histologically, the tumors present in MEN type III are pure neuromas, not neurofibromas. Patients with NF may also present with renal artery stenosis, but this is not an expected association with MEN syndromes (Answer C).

KEY FACTS

- MEN type I (Wermer syndrome) presents with parathyroid, pancreas, and pituitary tumors. Hyperparathyroidism causes hypercalcemia. Pancreatic tumors can be insulinomas, gastrinomas, or VIPomas. Pituitary tumors may cause mass effects or endocrine abnormalities.
- MEN type IIA (Sipple syndrome) presents with medullary thyroid carcinoma, pheochromocytoma, and hyperparathyroidism. Medullary thyroid carcinomas produce calcitonin, which decreases calcium levels. Pheochromocytomas are usually multicentric and bilateral.
- MEN type IIB (also called MEN type III or mucosal neuroma syndrome) also presents with medullary thyroid carcinoma and pheochromocytoma, but without parathyroid involvement. These patients have multiple mucosal neuromas, which may interfere with airway management.

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27. ANSWER: D

This patient's presentation is consistent with **McCune-Albright syndrome**. This syndrome is defined by a triad of **autonomous endocrine hyperfunction, polyostotic fibrous dysplasia, and caf é-au-lait skin pigmentation**. It is an autosomal dominant disease that is caused by constitutive activation of G protein–coupled receptors. The

severity of disease is highly variable. Examples of endocrine hyperfunction in this disease include **precocious puberty, hyperthyroidism, hypercortisolism, hyperglycemia, gigantism, and acromegaly**. Bone disease in this disorder manifests as hypophosphatemic osteomalacia, **pathologic fractures, and deformities of weight-bearing bones and bony skull base lesions resulting in cranial nerve compression**. Patients with this disease may have **sudden death due to arrhythmias**. Acromegaly and skull lesions can lead to **upper airway obstruction** and make airway management difficult in these patients, and **large thyroid goiters can cause airway compression or tracheomalacia**. Patients with untreated hyperthyroidism are at risk for thyroid storm and hemodynamic instability during anesthesia. **Hypercortisolism results in hypokalemia, hypertension, and hyperglycemia,** which also must be addressed perioperatively.

Prader-Willi syndrome also features endocrine anomalies and is caused by a chromosome 15 microdeletion. Neonates present with low birth weight, hypotonia, poor feeding, and failure to thrive. However, during childhood these patients develop **uncontrolled hyperphagia with subsequent obesity and development of type II diabetes mellitus**. Obesity leads to restrictive lung disease, ventilation-perfusion mismatching, and obstructive sleep apnea. Patients also have **abnormal respiratory control with decreased sensitivity to hypoxia and hypercarbia**. Chronic hypoxia and hypercarbia cause polycythemia, systemic and pulmonary hypertension, and eventual right ventricular failure. Patients are also prone to **conduction abnormalities**. Other endocrine anomalies include hypogonadism and delayed puberty. Patients also present with **neurologic and psychiatric abnormalities**, including emotional lability and poor motor and cognitive skills, and **musculoskeletal abnormalities**, including hypermobile joints, kyphoscoliosis, short stature, and small hands and feet. **Anesthetic management** in these patients is complicated by **chronic cardiac and pulmonary disease, difficult airway management and aspiration risk, postoperative respiratory insufficiency, and abnormal glucose control**.

Many genetic disorders are associated with endocrine abnormalities. **Neonatal hypoglycemia** due to insulin hypersecretion or increased activity of insulin-like growth factors is a feature of **some overgrowth syndromes (including Beckwith-Weidemann syndrome and Simpson-Golabi-Behmel syndrome) and congenital hyperinsulinism (nesidioblastosis)**. These patients require careful glucose monitoring and glucose infusions perioperatively. In the case of congenital hyperinsulinism, glucose requirements can vary dramatically intraoperatively depending on pancreatic activity. **Hypothyroidism is commonly seen in Trisomy 21** patients, while **hyperthyroidism may be seen in osteogenesis imperfecta**. **Parathyroid hypoplasia with hypocalcemia is seen in chromosome 22q11 microdeletions (velocardiofacial syndrome, diGeorge syndrome)** while **hypercalcemia is found in multiple endocrine neoplasia (MEN) type I and Williams syndrome**.

KEY FACTS

- McCune-Albright syndrome presents with a triad of autonomous endocrine hyperfunction, skeletal abnormalities, and caf é-au-lait skin pigmentation. Patients may have airway compression due to skull and thyroid abnormalities and may have endocrine and electrolyte abnormalities that may affect intraoperative management.
- Patients with Prader-Willi syndrome develop uncontrolled hyperphagia that results in obesity, type II diabetes, obstructive sleep apnea, and abnormal respiratory control.

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28. ANSWER: C

Inborn metabolic disorders are characterized by an **inherited deficiency in any critical step in metabolism**. The **majority of these disorders are autosomal recessive, though some are X-linked recessive or mitochondrial disorders**. These deficiencies can cause symptoms through a variety of mechanisms, including accumulation of a toxic substrate, deficiency of a critical reaction product, or inadequate energy production. Patients with metabolic disorders are **generally normal at birth because toxic substrates are cleared by the maternal circulation** in utero. A number of metabolic disorders can be detected on routine neonatal screening, but testing varies from state to state and is not comprehensive. Many metabolic disorders present as **acute decompensation in the neonatal period**. **Symptoms are generally nonspecific, including poor feeding, lethargy, vomiting, respiratory distress, and encephalopathy, and may initially be attributed to sepsis or shoc**k. Decompensation may be triggered by specific food ingestions, prolonged periods of fasting, or intercurrent illness. A key feature is that these symptoms generally do not resolve with standard therapies.

Other metabolic disorders have a more **indolent course with onset any time from birth to adulthood**. Findings may include **neurologic abnormalities, specific organ involvement, or development of dysmorphic features**. The most common neurologic finding is developmental or psychomotor delay. The **delays are usually global and regression with loss of previously attained milestones is commonly seen.** Other common findings are seizures refractory to treatment, movement disorders (including dystonia and chorea), blindness, deafness, and rarely stroke. **Liver and spleen** involvement can present with hypoglycemia, cholestasis, liver failure and cirrhosis. **Cardiac involvement** can include dilated cardiomyopathy due to myocardial energy deficiency, hypertrophic cardiomyopathy due to intramyocardial deposition of complex molecules, or conduction abnormalities. Other commonly involved organ systems include the **kidneys, muscles, and eyes**. Initial workup for metabolic disorders generally includes assessment of serum pH, lactate, electrolytes, liver function, glucose, ketones, and ammonia. More comprehensive screening includes testing for specific metabolic substances and brain MRI.

Amino acid metabolism disorders and urea cycle defects are deficiencies in protein metabolism. The four most common amino acid disorders are phenylketonuria, tyrosinemia, maple syrup urine disease, and homocysteinuria. **Phenylketonuria** is a disorder of phenylalanine metabolism. Excessive accumulation of phenylalanine in untreated patients leads to **neurologic deterioration** (psychomotor retardation with significant intellectual disability, seizures, increased reflexes, abnormal gait and posture), **episodic vomiting, and a musty odor**. **Tyrosinemia**, caused by abnormal tyrosine metabolism, **has three presentations**. Type I disease presents with hepatic and renal failure, peripheral neuropathy with weakness, pain crises, and hypertrophic cardiomyopathy. Type II disease has mainly oculocutaneous findings. Type III disease presents with neurologic impairment, including seizures and ataxia. **Maple syrup urine disease** is a disorder of branched chain amino acid metabolism. Patients with this disease present within days of birth with **lethargy and poor feeding that progresses to apnea and coma**. The urine is characteristically sweet smelling. Patients with **homocysteinuria** have a **marfanoid body habitus** due to disordered collagen production and have **cardiovascular abnormalities**. These patients develop **premature coronary artery disease** with myocardial ischemia and are also prone to **spontaneous arterial and venous thromboembolic events** that can result in early death and stroke. Other neurologic complications include mental retardation and seizures. Many of the features of these diseases are **preventable with early and strict dietary restrictions that limit the accumulation of toxic metabolites**. Workup shows an **anion gap acidosis with or without abnormal lactate, ketones, ammonia, and glucose**. Diagnosis can be made by measuring plasma and urine amino acids. **Ammonia produced by amino acid degradation is converted to urea for renal excretion by the urea cycle**. Six **urea cycle defects** are known and usually present within days of birth with **poor feeding, vomiting, tachypnea, lethargy, and coma**. Workup shows **hyperammonemia without acidosis or hypoglycemia**.

Patients with amino acid metabolism disorders and urea cycle defects are protein intolerant. Management includes **a protein-restricted diet** that provides essential amino acids without causing overload of the protein metabolic pathways. Dietary restrictions should be resumed postoperatively as soon as possible. It is also important to **prevent perioperative catabolism of endogenous protein stores. Fasting time should be limited and patients should be given adequate calories intravenously to prevent catabolism**. This can be done with dextrose infusions, but **complete suppression of catabolism requires relatively high-dose infusions (10% dextrose in 0.45% normal saline at 1–2 times the maintenance rate**). Supplemental intravenous fat emulsions can be given to supply calories while limiting the glucose load. **Other sources of protein loads, such as heme absorption after gastrointestinal bleeding or hematoma resorption**, can also cause problems. **Patients having oral or nasal surgery should have throat packs in place, and gastric blood should be aspirated prior to emergence**. **Nitrous oxide is contraindicated in homocysteinuria**, as inhibition of methionine synthase will increase homocysteine levels. **Avoidance of nitrous oxide should be considered in other amino acid and urea cycle disorders** because patients on strict dietary restrictions may be vitamin B12 deficient. Other anesthetic considerations for these patients include management of medical sequelae of their metabolic disorder, including neurologic, hepatic, renal, and cardiac disease.

This patient has not had adequate caloric intake since his surgery to prevent protein catabolism and is absorbing a protein load from the blood in his stomach. He is likely **lethargic due to hyperammonemia and resultant encephalopathy**. He will require high-dose dextrose infusions to suppress catabolism and should maintain a protein-restricted diet postoperatively. Using 5% dextrose at maintenance is not sufficient to prevent catabolism, and lactated fluids should be avoided. Therefore, Answer B will worsen his neurologic status. Orogastric suctioning will prevent further protein loading from heme absorption. This patient will require clearance of the ammonia already accumulated in his system. This can be accomplished with medications such as sodium benzoate or with hemodialysis. Management of this aspect of the patient's care will likely require consultation from a metabolic specialist.

KEY FACTS

- Inborn errors of metabolism can present as acute decompensation in the neonatal period or can have an

indolent course with presentation any time from birth to adulthood. Symptoms of neonatal decompensation are generally nonspecific, including poor feeding, lethargy, vomiting, respiratory distress, and encephalopathy. Findings in disorders with an indolent onset include neurologic delays or regression, dysmorphic features, and involvement of liver, spleen, heart, kidneys, muscles, or eyes.

- Amino acid metabolism disorders (including phenylketonuria, tyrosinemia, maple syrup urine disease, and homocysteinuria) and urea cycle defects are disorders of protein metabolism. Patients are protein intolerant and require stringent dietary restrictions to prevent decompensation. Perioperatively, fasting times should be limited, protein loads avoided, and adequate calories provided to prevent catabolism of endogenous protein (often requiring 10% dextrose at 1–2 times the maintenance rate).

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29. ANSWER: D

Disorders of carbohydrate metabolism include deficiencies in gluconeogenesis (glucose formation from pyruvate) and glycolysis (glycogen breakdown to glucose). The **glycogen storage diseases (GSD)** are a group of disorders that are caused by an **inability to break down glycogen with resultant deposition in various tissues**. Patients present with **hypoglycemia, ketosis, possible lactic acidosis, and variable hepatomegaly, cardiomegaly, and myopathy**. Ketosis is due to the appropriate breakdown of fatty acids as a source of energy in the absence of glucose. Severe hypoglycemia can manifest as seizures, lethargy, or coma. GSD types I (von Gierke disease, most common GSD), III, VI, and IX present with prominent hepatomegaly. Type III disease may also involve myopathy, and types I and III can have associated platelet dysfunction. Types VI and IX have a more benign course with less hypoglycemia and resolution of hepatomegaly after puberty. Type IV disease has particularly severe liver involvement with cirrhosis requiring transplant in infancy. Types V (McArdle disease) and VII primarily have muscle involvement. These disorders may present in adolescence with exercise intolerance and myoglobinuria with or without hypoglycemia. Patients with type VII disease also have hemolytic anemia. GSD type II (Pompe disease) is also a lysosomal storage disorder. It is characterized by massive glycogen deposition in multiple tissues (heart, muscle, brain, spinal cord, kidney, liver, spleen, and tongue) and causes prominent cardiomegaly and myopathy without hypoglycemia. In general, these patients should have **minimal fasting times with close perioperative glucose monitoring. Perioperative fluids should include dextrose and should not include lactate**. Patients with cardiac involvement may have **hypertrophic cardiomyopathy or conduction abnormalities**, and those with liver involvement may have **coagulation abnormalities, liver failure with cirrhosis, and a restrictive lung defect due to severe liver enlargement**. Glycogen deposition does not generally occur in the lungs, so intrinsic lung disease is not expected. **Myopathies may result in significant weakness**, predisposing patients to respiratory failure and aspiration. **Succinylcholine and tourniquets should be avoided** in patients with myopathies. With the exception of Pompe disease, the central nervous system is not usually directly affected in this disease. Severe recurrent hypoglycemia may cause neurologic injury with seizures. However, refractory seizures that may be seen in other metabolic disorders are not a feature of GSDs, and structural CNS disease is not expected (Answer B). The airway is not generally affected by these disorders, with the exception of Pompe disease, which may be associated with difficult airway management due to macroglossia. Atlantoaxial instability is not a feature of these disorders (Answer C).

Patients with **defects in catabolism of complex molecules present with storage diseases**. Lysosomes are cellular organelles that contain the enzymes responsible for this process. Enzyme deficiencies lead to accumulation and storage of an intermediate compound with cellular damage. **Initial normal development followed by subsequent regression is a common characteristic** of these disorders. Important lysosomal storage diseases include mucopolysaccharidoses and sphingolipidoses. **Mucopolysaccharidoses (MPSs) are caused by storage of glycosaminoglycans, commonly in the heart, brain, liver, and airway**. Common types of MPS include Hurler syndrome (MPS I); Hunter syndrome (MPS II, which has a less severe course and slower progression than Hurler syndrome); Sanfilippo syndrome (MPS III, which has severe CNS involvement); and Morquio syndrome (MPS IV), though up to nine types exist. Symptoms include a **progressive neurologic deficit** (developmental delay followed by regression, intellectual disability, increased intracranial pressure, or seizures), **hepatosplenomegaly, musculoskeletal anomalies** (short stature, dysostosis multiplex, kyphoscoliosis, pectus deformities,

and joint contractures), and **coarse facial features**. **Airway management is typically very difficult in these patients and becomes worse with age**. **Soft tissues**, including lips, tongue, tonsils, and adenoids, are **enlarged by glycosaminoglycan deposition and cause significant obstruction**. Oral airways may worsen obstruction by positioning the epiglottis over the larynx. Nasal airways may help but can be difficult to place due to narrowing of the nasal passages. Patients typically have restricted mouth opening, short neck, and narrow trachea with an anterior larynx. Neck motion may be restricted by joint contractures and patients are also prone to **atlantoaxial instability and cord compression with extension**. **Cardiovascular involvement can include coronary artery narrowing with ischemia and thickened, dysplastic valves**. Anesthetic management of these patients should include plans for difficult airway management, anticipation of postoperative airway obstruction or respiratory insufficiency, difficult positioning and intravenous access due to contractures and assessment of neurologic and cardiac function.

Sphingolipidoses are caused by lipid accumulation in viscera (including brain, spleen, liver, kidneys, and lungs) and bone marrow. Examples include Gaucher disease (the most common lysosomal storage disorder), Niemann-Pick disease, Tay-Sachs disease (or GM2 gangliosidosis), and various leukodystrophies, each of which has a different presentation. **Common neurologic symptoms** include psychomotor delay and regression, seizures, behavioral changes, myoclonus, hyper- or hypotonia, extrapyramidal and cerebellar symptoms, and movement disorders. In leukodystrophies, accumulation of complex molecules particularly affects the growth and development of myelin and results in progressive demyelination. **Hematologic findings** include anemia, thrombocytopenia, and platelet dysfunction and lymphoid tissue enlargement. Patients may also have **hepatosplenomegaly and restrictive pulmonary disease** (due to both liver enlargement and lipid deposition), which can result in **right heart failure**. Patients with Gaucher disease may have decreased bone density and are prone to pathologic fractures and kyphoscoliosis. These patients are at increased risk for aspiration and postoperative respiratory insufficiency due to hypotonia and restrictive lung disease. Patients may also have a **difficult airway** due to lymphoid tissue hyperplasia, trismus, and, in the case of Gaucher disease, possibility of vertebral fracture with neck extension. Patients with movement disorders should not receive dopamine antagonists for nausea prophylaxis because this may worsen their symptoms. **Succinylcholine should be avoided in patients with muscle denervation**.

KEY FACTS

- GSDs are caused by an inability to break down glycogen with resultant deposition in various tissues. Patients present with hypoglycemia, ketosis, possible lactic acidosis and variable hepatomegaly, cardiomegaly, and myopathy.
- Mucopolysaccharidoses are caused by storage of glycosaminoglycans, commonly in the heart, brain, liver, and airway. Patients typically have very difficult airways, which worsen with age. Other manifestations include progressive neurologic deficits, hepatosplenomegaly, musculoskeletal anomalies, and coronary artery and valve involvement.
- Sphingolipidoses are caused by lipid accumulation in viscera (brain, spleen, liver, kidneys, and lungs) and bone marrow. Patients have neurologic and hematologic abnormalities, hepatosplenomegaly, and restrictive pulmonary disease leading to right heart failure. Airway management may be difficult.

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30. ANSWER: A

The clinical findings in this patient are consistent with a diagnosis of porphyria. The **porphyrias are a group of disorders caused by defects in heme biosynthesis**. Decreased heme production reduces negative feedback to ALA synthetase, which results in stimulation of porphyrins and an overproduction of heme precursors proximal to the block. The disorders are characterized as **erythropoietic or hepatic depending on the major site of heme overproduction**. Some disorders are chronic, but some, such as acute intermittent porphyria, present with acute attacks. **Chronic disorders can present with hepatic disease and cutaneous photosensitivity with bullae and scar formation**. **Acute attacks are characterized by nonspecific abdominal and back pain** (which may lead to inappropriate surgical intervention), **vomiting, neuropsychiatric changes** (including disorientation, hallucinations, paranoia, and anxiety), **weakness and neuropathy** (including cranial nerve and bulbar dysfunction leading to respiratory failure), **seizures, and electrolyte disturbances** (including hyponatremia). Patients are usually normal between attacks but may have residual weakness with delayed recovery. Attacks occur **primarily in women between puberty and**

menopause and carry a **mortality rate of 10%, mostly due to infection, respiratory failure, and arrhythmias**. **Triggers** for attacks include **starvation or dehydration, infection, estrogens** (in this patient, the attack was likely triggered by starting oral contraceptives), **physiologic and psychologic stress, and some drugs**. Cytochrome P450 stimulators cause increased heme incorporation into cytochromes, reducing serum levels of heme and leading to increased ALA synthetase activity. Treatment of an acute attack involves carbohydrate loading and heme administration to decrease ALA synthetase activity, correction of electrolytes and fluid deficits, and management of hemodynamic alterations.

Anesthetic management of patients with porphyria includes **avoidance of known attack triggers, including dehydration, physiologic and psychologic stress, and certain drugs**. Single, acute exposures to ALA inducers in an otherwise healthy patient are unlikely to trigger an attack. However, single exposures to a patient under physiologic stress or multiple exposures in a latent patient are unlikely to be tolerated. **Known anesthetic triggers that should be avoided are barbiturates, etomidate, and mepivacaine**. **Safe anesthetics include midazolam, lorazepam, propofol, nitrous oxide, isoflurane, succinylcholine, vecuronium, neostigmine, scopolamine, atropine, morphine, fentanyl, bupivacaine, and lidocaine**. The effects of **ketamine, diazepam, sevoflurane, desflurane, pancuronium, rocuronium, sufentanil, and prilocaine are unclear**. Other medications used perioperatively, including cardiovascular and antiemetic medications, may also have interactions with porphyria and should be evaluated prior to administration. Elective surgical procedures during an acute porphyria attack should be delayed.

Glucose-6-phosphate dehydrogenase (G6PD) deficiency is unrelated to porphyrias. However, these patients can also have acute exacerbations of their disorder related to drug administration, which may affect anesthetic management. G6PD deficiency is the most common enzymopathy in humans. It is an **X-linked disorder, though female patients can also have symptoms**. G6PD is required for NADPH production in mature red blood cells (RBCs). NADPH supplies reducing energy to protect RBCs from oxidative damage. **Exposure to a trigger results in increased oxidative stress that cannot be repaired** due to limited NAPDH stores. Patients present with **episodic hemolysis starting 2–3 days after trigger exposure and recovering on day 8**. **Known triggers include some analgesics, antibiotics, and other medications. Analgesic triggers include high-dose aspirin (and possibly other nonsteroidal anti-inflammatory medications), phenacetin, and prilocaine (a component of EMLA cream)**. Nitrofurantoin, **sulfonamides,** and some antimalarial medications should be avoided in these patients. Other triggering medications include **methylene blue, nitrates, nitroprusside, and hydralazine**.

KEY FACTS

- Porphyrias are disorders of heme biosynthesis. Chronic disorders present with hepatic and cutaneous disease. Acute attacks present with nonspecific abdominal and back pain, vomiting, neuropsychiatric changes, weakness and neuropathy, seizures, and electrolyte disturbances.
- Triggers for an acute porphyria attack include starvation and dehydration, infection, estrogens, stress, and some drugs. Anesthetic drugs that should be avoided include barbiturates, etomidate, and mepivacaine. Appropriate drugs for use in these patients are listed herein.
- G6PD deficiency results in a decreased capacity of red blood cells to recover from oxidative stress. Patients present with episodic hemolysis starting 2–3 days after exposure to a trigger. Known triggers include some analgesics (nonsteroidal anti-inflammatory medications, phenacetin, and prilocaine) some antibiotics (including sulfonamides), methylene blue, nitrates, nitroprusside, and hydralazine.

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31. ANSWER: C

Maternal drug use during pregnancy has significant effects on the developing fetus. Drug use is associated with poor maternal health and prenatal care, which can have direct effects on the baby. In general, these pregnancies can be complicated by **spontaneous abortion, stillbirths, fetal distress, intrauterine growth restriction, prematurity, and placental abruption**. Neonates **may be born with malformations and neurobehavioral dysfunction, and they may undergo withdrawal syndromes**. Women who use one substance are more likely to use other substances as well, which is a significant confounding factor in studies looking at the effects of specific drugs on the developing fetus. General determinants of the effect of drug exposure include **gestational age at exposure, amount consumed, and pattern of consumption**.

Cocaine decreases reuptake of dopamine and norepinephrine, leading to **increased circulating catecholamine levels**. This causes **tachycardia, vasoconstriction, hypertension, and arrhythmias in the mother** with resultant **decreased uteroplacental blood flow** and fetal hypoperfusion. **Transplacental passage of cocaine** prior to birth **increases catecholamines in the neonate**,

resulting in **tachycardia and arrhythmias, hypertension, and decreased cardiac output**. These babies are **prone to vascular complications** including hypoxic-ischemic cerebral injuries and necrotizing enterocolitis. The autonomic abnormalities associated by cocaine **exposure resolve after birth as catecholamine levels normalize, usually by the second day of life. Nonemergent surgeries should be delayed until hemodynamic abnormalities resolve**. In this case, the patient should be **managed medically in the NICU until tachycardia and hypertension resolve**. Proceeding with general anesthesia is not the correct option at this time. In an emergent situation, anesthetics should be narcotic based with **avoidance of halothane, desflurane, and direct-acting sympathetic agents**. Patients will have abnormal responses to indirect-acting sympathetic agents due to depletion of endogenous catecholamine stores. This mother may have abused opiates during her pregnancy (use of one illicit substances makes use of a second substance more likely), which would increase the patient's opioid requirements, but cocaine exposure itself would not increase opioid requirements. Cocaine exposure is not associated with any specific physical malformations and difficult airway management would not be anticipated.

In utero exposures to alcohol, tobacco, and opiates can also have significant effects on the developing fetus. **Early alcohol exposure causes defective organogenesis and craniofacial development, while sustained exposure leads to growth deficiency and neurodevelopmental effects**. Patients with fetal alcohol syndrome have dysmorphic facies (microcephaly, midface hypoplasia, ptosis, micrognathia, cleft lip or palate, and short neck), which may lead to difficult airway management. Other issues include structural brain abnormalities, cognitive impairment, motor dysfunction, and irritability or hyperactivity. Musculoskeletal, renal, and cardiovascular anomalies are also possible, but they are less common. **Tobacco** is the most common in utero drug exposure. It causes **vasoconstriction and carbon monoxide exposure, which leads to fetal hypoxemia**. These babies have an increased risk of sudden infant death syndrome **(SIDS)** and ongoing secondhand exposure after birth can cause significant **reactive airways disease**. **Opiate exposure** is also associated with fetal hypoxia, and the effect of opioid exposure on the developing brain is unknown. These patients can experience **significant withdrawal symptoms**, involving the neurologic, respiratory, and gastrointestinal systems, which **peak during the first week for heroin exposure and at 3–4 weeks of life for methadone exposure**. Long-term effects of these substances are variable. It appears that there is no difference in growth or overall health after early childhood. Studies regarding neurobehavioral effects have conflicting results.

Neonatal abstinence syndrome describes the constellation of symptoms experienced by neonates who are withdrawing from a substance to which they were exposed in utero. The exact symptoms and timing of presentation vary depending on which substances were used during pregnancy. Common presentations include **neurologic** (irritability, hyperactive reflexes, increased muscle tone, seizures, and sleep disturbances), **gastrointestinal** (feeding problems, regurgitation), autonomic dysfunction (fever, sweating, and sneezing), and **respiratory** problems (tachypnea and nasal stuffiness). Nonpharmacologic interventions include swaddling, decreased environmental stimulation, and avoiding unnecessary handling. Pharmacologic treatments include **opioids or clonidine for narcotic withdrawal and phenobarbital for polydrug exposure with slow tapers of these medications**.

KEY FACTS

- Neonates born after recent cocaine exposure present with hemodynamic and vascular manifestations of increased catecholamines. Nonemergent surgeries should be postponed until these hemodynamic abnormalities resolve, usually on the second day of life.
- Fetal alcohol syndrome results in dysmorphic facies, structural brain abnormalities, and cognitive impairment and motor dysfunction. Neonates and children with tobacco exposure have an increased risk of SIDS and reactive airways disease.
- Opiate exposure in utero causes significant withdrawal symptoms in neonates. Neonatal abstinence syndrome manifests with neurologic, gastrointestinal, and respiratory symptoms.

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SECTION III

CLINICAL SUBSPECIALTIES

12.

FETAL

Matthew C. Wang

1. A 34-year-old G3P2 female at 40 weeks with an uncomplicated pregnancy presents to your obstetrics floor for induction of labor. Her first pregnancy involved an ex utero intrapartum treatment (EXIT) procedure for a fetal goiter with low-lying anterior placenta. Her medical history is otherwise insignificant. The labor nurse notices a sudden increase in pain and vaginal bleeding. After an uneventful placement of an epidural and a bolus of bupivacaine 0.0625% 10 cc, the fetal heart tracing is noted (see Fig. 12.1).
What is the most likely diagnosis?

A. Uterine rupture
B. Placenta previa
C. Prolapsed umbilical cord
D. Epidural-induced hypotension

2. Which of the following statements about hypoplastic left heart syndrome (HLHS) with severe aortic stenosis (AS) prenatal intervention is most accurate?

A. Postpartum management includes multiple-staged cardiac surgeries with a high mortality rate of over 50%.
B. In utero, fetoscopic intervention is considered a viable option with the potential to prevent the arrest of left ventricular growth.
C. Neuroaxial anesthesia is often used instead of general anesthesia.
D. Prenatal intervention is often done at gestational ages between 10 and 16 weeks.

3. During a fetoscopic cardiac intervention for a Tetralogy of Fallot with pulmonary atresia and hypoplastic pulmonary arteries, it is noted on echocardiogram that the fetal ventricular volume is low with a heart rate of 90 bpm. Which of the following maneuvers would be most effective in reducing fetal acidosis?

A. Administer 100% oxygen to the mother.
B. Intracardiac transfusion of 10 cc/kg of O negative irradiated blood.

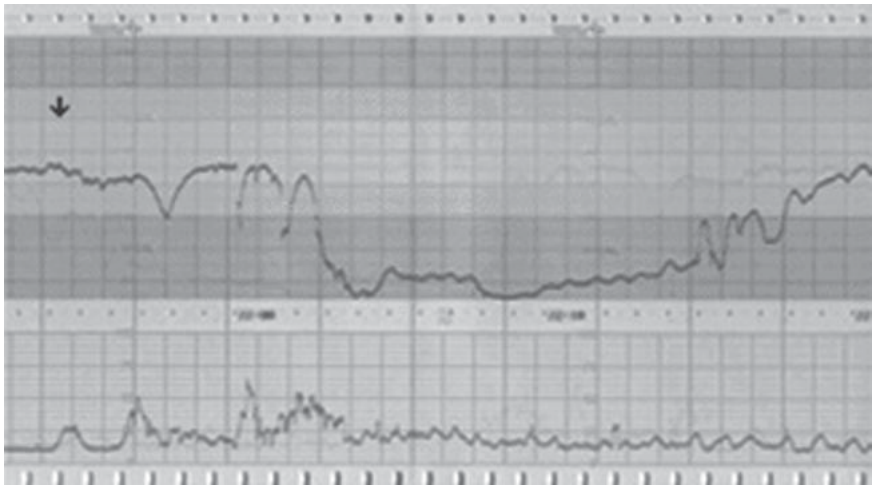

Figure 12.1 From Avila WS, Gouveia AM, Pomerantzeff P, et al. Maternal-fetal outcome and prognosis of cardiac surgery during pregnancy. *Arq Bras Cardiol*. 2009;93(1):9–14.

C. Emergent delivery of fetus with activation of PALS protocol.
D. Increase maternal mean arterial pressure by 25% above awake baseline with ephedrine.

4. A 37-year-old G1P0 female at 20 weeks has a fetal diagnosis of pulmonary atresia with intact ventricular septum on ultrasound. After consultation by an interventional pediatric cardiologist, she is scheduled for a cardiac catheter balloon dilation of the pulmonary valve. Which of the following statements about fetoscopic intervention are accurate?

A. Amniotic membrane puncture with a fetoscope will close by itself after removal of scope.
B. Post fetoscopic intervention risk of preterm premature rupture of membranes (PPROM) can be as high as 60%.
C. Tocolytic requirements are no different with open hysterotomy and fetoscopic surgery.
D. Postoperative monitoring with fetal electrocardiography on maternal abdomen is standard of care.

5. Which fetal disease process would benefit the most by the ex utero intrapartum treatment (EXIT) procedure?

A. Pyloric stenosis
B. Myelomeningocele
C. Hypoplastic left heart syndrome
D. Twin-twin transfusion syndrome (TTTS)

6. Which of the following statements about cesarean section and ex utero intrapartum (EXIT) procedure is most likely true?

A. EXIT procedures have a significantly lower surgical blood loss compared with cesarean sections.
B. Hysterotomy incision is always low and transverse in EXIT procedure.
C. Short-term maternal outcomes show significant increases in hospital stay and estimated blood loss when comparing EXIT procedure to cesarean section.
D. Anesthetics techniques used to minimize maternal hemorrhage in a cesarean section may conflict with the surgical needs of an EXIT procedure.

7. Which of the following commonly used anesthesiology medications has the lowest fetal to maternal drug ratio in regard to uteroplacental transfer in a parturient?

A. Ephedrine
B. Vecuronium
C. Ketamine
D. Nitrous oxide

8. Which of the following can improve fetal oxygenation?

A. Terbutaline
B. Oligohydramnios
C. Fetal catecholamine production
D. Epidural bolus of bupivacaine

9. Which of the following is most likely a benefit of fetal anesthesia and analgesia during fetal surgery?

A. Volatile anesthetics reduce fetal acidosis
B. Improved postnatal neurological development
C. Improved APGAR scores
D. Increased uterine contractility

10. Which of the following about fetal pain consciousness is most likely accurate?

A. Fetal thalamocortical circuits are developed by the third trimester.
B. The fetal withdrawal reflex only occurs during painful stimuli.
C. The fetal electroencephalogram (EEG) cannot be accurately measured.
D. The fetal endocrine response to pain does not occur until after delivery.

11. A 22-year-old G1P0 at 40 weeks who is otherwise healthy presents for induction of labor. The patient is currently on an oxytocin drip that has been gradually increased over the past few hours. After an uneventful placement of an epidural, a bolus of bupivacaine 0.25% 5 cc is given and ropivicaine 0.2% 12 cc/hr is initiated. After half an hour, you are called back in because the nurse has started to notice late decelerations with moderate baseline variability on the fetal heart tracing. What is the most likely next step in management?

A. Bolus the epidural in preparation for emergent cesarean section.
B. Administer terbutaline.
C. Transfuse 2 units of PRBC.
D. Refresh the blood pressure cuff and consider phenylephrine or ephedrine if the parturient is hypotensive.

12. Which of the following increases the risk for preterm labor after fetal surgery?

A. Short surgical time
B. Administration of magnesium
C. Multiple fetoscopic ports
D. Lack of maternal muscle relaxants

13. Which of the following drugs is the most effective in reducing uterine contractions?

A. Dobutamine
B. Indomethacin
C. Calcium chloride
D. Dexmedetomidine

14. Serial ultrasonographic surveillance of a pregnant woman who is otherwise healthy with a fetus complicated by noncystic extralobar pulmonary sequestration is an important part of fetal management because:

A. Spontaneous regression of mass may occur.
B. Emergent in utero laser ablation of mass may be needed.
C. Blood transfusion may be needed.
D. Intra-amniotic infusion may be needed.

15. Which of the following increases the risk of fetal demise during congenital cystic adenomatoid malformation (CCAM) in utero resection?

A. Maternal gestational diabetes
B. Low tumor-to-head circumference ratio
C. Advanced maternal age
D. Mediastinal shift

16. Which of the following are potential concerns of in utero resection of sacrococcygeal teratomas (SCTs)?

A. Hypothyroidism
B. Fetal high output cardiac failure
C. Down syndrome
D. Congenital heart disease

17. Which of the following shows the correct path of maternal oxygenated blood to vital fetal organs?

A. Placenta→umbilical vein→ductus venosus/liver→IVC→right atrium→ foramen ovale→left atrium→left ventricle→aorta
B. Placenta→umbilical artery→ductus venosus/liver→IVC→right atrium→Foramen ovale→left atrium→left ventricle→aorta
C. Uterine vein→placenta→umbilical vein→ductus arteriosus/liver→IVC→right atrium→foramen ovale→left atrium→ left ventricle→aorta
D. Uterine artery→placenta→umbilical vein→ductus arteriosus/liver→ IVC→right atrium→ foramen ovale→left atrium→ left ventricle→aorta

18. Normal fetal umbilical vein oxygenation is ~30 mm Hg. Which of the following most likely explains how a fetus can survive with such a low oxygenation supply?

A. Fetal P_{50} is higher than maternal P_{50}
B. Fetal hemoglobin concentration is lower than adult
C. Fetus has a high combined ventricular output
D. Fetus has a high 2,3 diphosphoglycerate concentration

19. Fetal heart rate (FHR) monitoring of a fetus was noted to have diminished variability with recurrent variable decelerations. Fetal scalp blood sampling (FSS) is obtained with a pH of 7.28. What should be the next clinical step?

A. Emergent cesarean section with general anesthesia
B. Emergent cesarean section with a spinal
C. Continue fetal heart rate monitoring
D. Intravenous fluid bolus

20. During an ex utero intrapartum treatment procedure to correct myelomeningocele, it is noted that the fetal SpO_2 readings have been fluctuating between 55% and 65% with FHR of 150–160 beats per minute (bpm). These vitals signs are an indication of:

A. Fetal asphyxia
B. Anemia
C. Fetal tachycardia
D. Normal fetal well-being

21. Which of the following monitors would be most useful during a fetoscopic repair of aortic stenosis with hypoplastic left heart syndrome (HLHS)?

A. Fetal pulse oximetry
B. Fetal echocardiogram
C. Fetal electrocardiogram
D. Fetal heart rate monitor

22. Survivors of twin-twin transfusion syndrome (TTTS) are most likely to develop what kind of complications?

A. Cerebral palsy
B. Tetralogy of Fallot
C. Gastroschisis
D. Necrotizing enterocolitis

23. Which of the following fetal diseases would be most likely to benefit from ex utero intrapartum treatment (EXIT) to extracorporeal membrane oxygenation (ECMO) management?

A. Congenital diaphragmatic hernia
B. Sacrococcygeal teratomas
C. Tracheoesophageal fistula
D. Gastroschisis

24. Which of the following fetuses is eligible for EXIT to ECMO management?

A. 28-week gestational age, 1.5 kg, sacrococcygeal teratoma (SCT)
B. 32-week gestational age, 2.5 kg, total anomalous pulmonary venous return (TAPVR)
C. 37-week gestational age, 4 kg, cervical teratomas
D. 31-week gestational age, 3.5 kg, myelomeningocele

25. A parturient with a fetal goiter is scheduled for EXIT procedure and is seeing you for a preoperative evaluation. Which of the following information is most likely to help in predicting uterine irritability for the surgery?

A. Fetal weight
B. History of preterm labor
C. History of acetylcholineesterase deficiency
D. Oligohydramnios requiring amniotransfusion

CHAPTER 12 ANSWERS

1. ANSWER: A

Uterine rupture is a rare and emergent complication of childbirth with an incidence of 0.03%–0.06%. However, the risk increases significantly with patients who have had a p**revious cesarean section with a trial of labor** compared with an elective repeat cesarean section. **Other risk factors** that also increase the risk of uterine rupture include **malpresentation and labor dystocia**.

Traditional presentation of uterine rupture includes sudden tearing abdominal pain, vaginal bleeding, recession of fetal presentation, and fetal distress. Modern studies, however, show that the majority of these signs and symptoms may not be the most accurate in quickly diagnosing uterine rupture. **Prolonged fetal deceleration or fetal bradycardia** does have the highest incidence of association with uterine rupture.

This patient has multiple risk factors for uterine rupture and should have been scheduled as a cesarean section. Most concerning is the previous uterine incision made from the EXIT procedure. Low-lying anterior placenta with a large neck mass would make it almost impossible to utilize a low transverse incision, thus placing the patient in a high-risk category for subsequent uterine rupture. The clinical presentation with fetal bradycardia on fetal heart tracing confirms that immediate transfer to the operating room for cesarean section is needed.

Placenta previa is an obstetrical complication where the placenta grows on the lower portion of the uterus and covers the cervix. Symptoms associated with this include painless bleeding and some cramping. Diagnosis is from imaging with either transvaginal ultrasound or transabdominal ultrasound. Parturients will often times require scheduled cesarean section if the os and placenta are too close. Os-to-placenta edge distance greater than 2 cm can be considered for trial of labor. Neuraxial anesthesia is considered safe for placenta previa patients. Even though the risk of placenta previa correlates directly with the number of previous cesarean sections, it is not the most likely choice.

Umbilical cord prolapse is when the cord descends into the cervix with the presenting fetal head either next to or above it. It is considered a life-threatening condition where umbilical blood flow to the fetus is compromised and an emergency cesarean section or vaginal delivery within 20–30 minutes is indicated to prevent fetal acidosis and death. Risk factors for cord prolapse include multiple births in one pregnancy, premature rupture of membranes, long umbilical cord, breech position, and polyhydramnios. Clinical presentation may occur with no symptoms and normal fetal heart tracing. Diagnosis is determined by vaginal examination.

Epidural placement is not associated with an increased risk of emergent cesarean sections. However, administration of local anesthetics in the epidural space does block sympathetic nerve fibers in the preganglionic region, resulting in vasodilation. This may cause a reduction in uteroplacental perfusion, leading to fetal hypoxia and bradycardia. Early administration of vasopressors such as ephedrine or phenylephrine is indicated. Clinical presentation of sudden pain and increased vaginal bleeding are not associated with epidural-induced hypotension.

KEY FACTS

- Uterine rupture is a rare and emergent complication of childbirth with an incidence of 0.03%–0.06%.
- The risk increases significantly with patients who have had a previous cesarean section with a trial of labor compared with an elective repeat cesarean section.
- Other risk factors that also increase the risk of uterine rupture include malpresentation and labor dystocia.
- Traditional presentation of uterine rupture includes sudden tearing abdominal pain, vaginal bleeding, recession of fetal presentation, and fetal distress.
- Prolonged fetal deceleration or fetal bradycardia does have the highest incidence of association with uterine rupture.
- Placenta previa is an obstetrical complication where the placenta grows on the lower portion of the uterus and covers the cervix.
- Symptoms associated with placenta previa include painless bleeding and some cramping.
- Umbilical cord prolapse is when the cord descends into the cervix with the presenting fetal head either next to or above it.
- Epidural placement is not associated with an increased risk of emergent cesarean sections.

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2. ANSWER: B

Despite improving technology, **routine prenatal screening for fetal anomalies** at the earliest occurs between 16 and 24 weeks, so intervention would have to be after the diagnosing time period. **Fetal intervention** is more likely to occur at gestational ages of 20–29 weeks.

Current postnatal surgical management for hypoplastic left heart syndrome usually requires a three-stage operation to correct the imbalance of deoxygenated and oxygenated blood flow to and from the heart. Other options include a heart transplant or a hybrid procedure. In the first stage of the hybrid procedure, band are placed around the pulmonary arteries to restrict their blood flow, the patent ductus arteriosus (PDA) is stented open, and a balloon atrial septostomy is carried out if there is not a large enough atrial septal defect. In the second stage of the hybrid procedure, the PDA stent and pulmonary artery bands are removed. Then, the aortic arch is reconstructed and the superior vena cava is connected to the pulmonary artery (Glenn shunt, see below). The final stage of the hybrid procedure is a Fontan procedure (see below).

Stage 1: **Norwood Procedure**
Occurs during the first 2 weeks of life. This procedure reconstructs the aorta and connects it to the right ventricle for systemic blood flow distribution. Either a modified Blalock-Taussig (subclavian artery to pulmonary artery conduit) or a Sano shunt (right ventricle to pulmonary artery conduit) is performed to provide pulmonary blood flow. Atrial septectomy is performed to mix the systemic and pulmonary venous return and thus oxygen saturation for the neonate will remain low. This procedure has by far the highest risk of postsurgical mortality among the three stages with a national average of 24%.

Stage 2: **Bidirectional Glenn Procedure**
Occurs between 4 to 12 months of life. At this age the patient will outgrow the pulmonary supply provided by the Blalock-Taussig/Sano shunt. This shunt is ligated and disconnected from the pulmonary artery. The superior vena cava is subsequently connected to the pulmonary artery. This procedure has a 2.7% postsurgical mortality rate.

Stage 3: **Fontan Procedure**
Occurs between 18 months and 3 years of age. This procedure connects the inferior vena cava to the pulmonary artery through either a lateral tunnel in the right atrium or through an extracardiac graft. A fenestration in the tunnel is placed as a pop-off valve for venous blood to the left side if there are high right-sided pressures. At this time the systemic and pulmonary venous circulations are completely separate. This procedure has a 3%–3.2% postsurgical mortality rate.

Without intervention, evolving HLHS with aortic stenosis will subsequently lead to diminished blood flow to the left heart and an arrest of left ventricular growth. It is hypothesized that fetal intervention will allow the left heart to be conditioned so that they can avoid a single ventricle physiology. In a study done at Boston Children's Hospital in 2004, out of 24 fetuses with HLHS and AS, 4 declined treatment and 14 of them had technically successful balloon dilation. Of these 14, 3 had two-ventricle physiology, 2 had two-ventricle physiology after subsequent cardiac surgery, 2 died post procedure, and the last 7 developed HLHS. All of the fetuses that did not undergo the procedure had halted left ventricular growth and developed HLHS.

Local anesthesia, monitored anesthesia care, regional neuraxial blockade, and general anesthesia can all be used for fetoscopic surgery. General anesthesia has many advantages, including airway protection for the mother, halogenated inhaled gases providing uterine relaxation and fetal anesthesia, and narcotics that readily pass through the placenta. The major drawback is if there is difficulty with maternal intubation. Neuraxial blockade does not help with uterine relaxation and does not provide the fetus with anesthesia or analgesia.

KEY FACTS

- Routine prenatal screening for fetal anomalies occurs between 16 and 24 weeks, so fetal intervention is more likely to occur at gestational ages of 20–29 weeks.
- Current postnatal surgical management for hypoplastic left heart syndrome requires a three-stage operation to correct the imbalance of deoxygenated and oxygenated blood flow to and from the heart.

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3. ANSWER: B

Fetal myocardium operates along a narrow portion of the ascending limb of the Frank-Starling curve and is unable to efficiently increase stroke volume above a certain end diastolic volume load. Thus, heart rate is vital to maintain cardiac output. A heart rate of 90 bpm is considered **fetal bradycardia** and requires immediate intervention since cardiac output is not being maintained. Fetal bradycardia can be caused by fetal hypoxia. Most likely fetal bleeding during the surgery led to a dramatic drop in oxygen-carrying capacity, which is causing the worsening of fetal acidosis and bradycardia. Immediate transfusion of O-irradiated blood is the most appropriate first response. This blood type is chosen to avoid ABO incompatibility, prevent maternal sensitization to Rh protein, and prevent transfusion-associated graft versus host secondary to the fetus's undeveloped immune system. Administration of 1–2 μg/kg IC/IM of epinephrine would also be appropriate but would only be a short-term fix until volume resuscitation occurs.

Fetal oxygenation is dependent on effective maternal oxygenation to promote healthy uteroplacental gas exchange. In general, during fetal interventions, maternal oxygenation is maxed at 100% in the hopes that it will optimize oxygen delivery to the fetus. Dildy et al. noted that in a study of 20 healthy parturients, maternal oxygenation of 100% for 20 minutes showed significant increases in fetal SpO_2. In contrast, lower concentrations of oxygen did not show any improvement in fetal oxygenation. Another way fetal oxygenation can be optimized is through increases in uterine perfusion pressures or decreases in uterine vascular resistance to improve uterine flow. Increasing maternal mean arterial pressure by 25% above awake baseline and/or administering medications that cause uterine relaxation can improve fetal oxygenation. Neither of these maneuvers, however, significantly improves the fetus's ability to increase oxygen-carrying capacity.

Fetoscopic surgery's most common complication is preterm premature rupture of membranes (PPROM). PPROM incidence for a single-port fetoscopic procedure can be as high as 5%–10% and even higher if multiple ports are used. **Other complications of fetoscopy** include chorionic membrane separation, preterm labor, and chorioamnionitis. Preterm labor must be prevented at all costs because fetoscopic intervention usually occurs at gestational ages that are either noncompatible with life or associated with high morbidity. Fortunately, fetoscopic surgery has a significantly lower risk for premature contractions and labor compared to open hysterotomy. This is supported by the decreased requirements of tocolytics needed for fetoscopic surgery. Fetoscopic cardiac intervention for Tetralogy of Fallot with pulmonary atresia that leads to emergent or unexpected delivery will ultimately lead to fetal demise since prenatal intervention usually occurs between 20 and 29 weeks gestation.

KEY FACTS

- Fetal myocardium operates along a narrow portion of the ascending limb of the Frank-Starling curve and is unable to efficiently increase stroke volume above a certain end diastolic volume load.
- Fetal heart rate is vital to maintain cardiac output.
- A heart rate of 90 bpm is considered fetal bradycardia and requires immediate intervention since cardiac output is not being maintained.
- Fetal bradycardia can be caused by fetal hypoxia.
- Fetoscopic surgery's most common complication is PPROM.
- Other complications of fetoscopy include chorionic membrane separation, preterm labor, and chorioamnionitis.

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4. ANSWER: B

Pulmonary atresia with intact ventricular septum (PA-IVS) is a right-sided heart defect that leads to hypoplastic right ventricles. This cardiac defect can progress to fetal hydrops and death. **Prenatal interventions of pulmonary valvuloplasty** can lead to improved fetal hemodynamics, continued right ventricle development, and subsequent biventricular circulation. Unfortunately, prenatal interventions will usually require further postnatal valvuloplasties. Restenosis of the pulmonary valve is almost inevitable, but prenatal dilation may provide the fetus time it needs to extend pregnancy and further develop vital premature organs.

Fetoscopic surgery's most common complication is preterm premature rupture of membranes (PPROM). PPROM incidence for a single-port fetoscopic procedure can be as high as 5%–10%. With the addition of multiple fetal ports or multiple puncture attempts, the risk can go as high as 60%. Unfortunately with amniotic membrane puncture during fetoscopic placement, the wound does not close by itself, which is why they are at high risk for

membrane rupture and amniotic fluid leak. Attempts to reduce PPROM rates by using collagen plugs to seal off fetoscopic-made holes have been unsuccessful. Engels et al. showed that out of 141 patients that underwent CDH fetoscopic surgery, 48% of patients who received a collagen plug had PPROM compared with 39% when no intervention was used.

Fetoscopic surgery compared with open hysterotomy has an overall lower risk of contractions and premature labor. The larger the hysterotomy, the more risk there is of uterine contractions and preterm labor. Thus, tocolytic requirements are in general lower for fetoscopic surgery.

Access to the fetus is obviously limited during fetoscopic surgery. **Often, echocardiography is the only monitoring device.** This monitor provides accurate time-sensitive readings of the fetal heart rate, rhythm, cardiac function, and volume status. ECG monitoring is impossible because placements through the small ports are impractical. Even during open fetal surgery, fetal ECG monitoring is difficult because of the surrounding amniotic fluid that disperses the reading. The same is true with fetal pulse oximetry where placement for fetoscopic surgery is impractical and accurate readings require immobility and an aluminum covering to prevent penetration from outside light. Intermittent follow-up with ultrasonography and fetal heart rate monitors is performed in the postoperative setting.

KEY FACTS

- PA-IVS is a right-sided heart defect that leads to hypoplastic right ventricles.
- Prenatal interventions of pulmonary valvuloplasty can lead to improved fetal hemodynamics, continued right ventricle development, and subsequent biventricular circulation.
- Fetoscopic surgery's most common complication is PPROM.
- Fetoscopic surgery compared with open hysterotomy has an overall lower risk of contractions and premature labor.
- Access to the fetus is obviously limited during fetoscopic surgery, and often, echocardiography is the only monitoring device.
- Intermittent follow-up with ultrasonography and fetal heart rate monitors is performed in the postoperative setting.

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5. ANSWER: B

Myelomeningocele is a defect in the spine with a lesion that contains cerebrospinal fluid and neural tissue. It is often associated with hydrocephalus and Arnold Chiari malformations. Live born newborns have a 10% mortality rate and oftentimes will have long-term neurological deficits, including paralysis and bladder and bowel dysfunction. **Postnatal surgery** is required within the first 48 hours of birth, often requiring a **ventriculoperitoneal shunt**. Myelomeningocele can often be diagnosed prenatally on ultrasound, allowing them the opportunity for **an EXIT procedure repair**. Adzick et al. compared prenatal and postnatal surgical management of 183 patients with myelomeningocele. The randomized control trial showed equivalent rates of mortality with both groups having 2 deaths. The prenatal group, however, had significantly lower rates of ventriculoperitoneal shunt requirements (40% vs. 82%) and moderate to severe hindbrain herniation (25% vs. 67%) at 12 months follow-up. They also had improved mental and motor function at 30 months follow-up. The prenatal group, however, had higher fetal and maternal morbidity rate, including preterm labor (34.1 weeks vs. 37.3 weeks gestation), uterine dehiscence/rupture, chorioamniotic separation, placenta abruption, and pulmonary edema.

Pyloric stenosis initially presents early after birth with nonbilious projectile vomiting. It is a result of hypertrophied pyloric muscles leading to gastric outlet obstruction. Pyloric stenosis does not require an emergent surgical intervention. Medical management to optimize infant volume status and correct electrolytes imbalances should be completed first in addition to diagnostic imaging to determine whether there are associated genetic abnormalities.

Hypoplastic left heart syndrome involves an underdeveloped aorta, left ventricle, or valves, which prevents the adequate systemic oxygenation of the newborn. Current postnatal intervention would require multiple-staged cardiac surgeries that involve switching a normal two-ventricle system to a right ventricle (single-ventricle system) that provides all of the energy for forward blood flow. Subsequent cardiac procedures are based on the fetal pulmonary development and ability to handle pulmonary blood flow. Early prenatal diagnosis allows the potential for fetoscopic

intervention to dilate the obstruction and improve chances of prenatal left ventricle development.

TTTS is a pathologic process where an imbalance of blood flow between monochorionic twins leads to a donor and a recipient twin. The donor twin will subsequently have lower blood flow, decreased growth and development, oligohydramnios, and decreased urine output. The recipient twin will have the opposite problem with hypervolemia, polyuria, polyhydramnios, and congestive heart failure. Fetoscopic laser photocoagulation of the communicating vessels can stop the worsening of circulatory imbalance, and potentially improve survival rates while reducing neurological complication rates.

KEY FACTS

- Myelomeningocele is a defect in the spine with a lesion that contains cerebrospinal fluid and neural tissue. It is often associated with hydrocephalus and Arnold Chiari malformations.
- Postnatal surgery is required within the first 48 hours of birth oftentimes requiring a ventriculoperitoneal shunt.
- Myelomeningocele can often be diagnosed prenatally on ultrasound, allowing them the opportunity for an EXIT procedure repair.
- Pyloric stenosis initially presents early after birth with nonbilious projectile vomiting.
- Hypoplastic left heart syndrome involves an underdeveloped aorta, left ventricle, or valves, which prevents the adequate systemic oxygenation of the newborn.
- TTTS is a pathologic process where an imbalance of blood flow between monochorionic twins leads to a donor and a recipient twin.

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6. ANSWER: D

Noah et al. (2002) compared short-term maternal outcomes in patients who underwent EXIT procedure ($n = 34$) versus nonlaboring elective cesarean section ($n = 52$). They found that there was no difference between the groups in regard to postpartum hospital stay, postoperative hematocrit level change, and rates of chorioamnionitis and endometritis. The EXIT arm did have more postpartum wound complications (15% vs. 2%) and a higher estimated blood loss (1104 mL vs. 883 mL).

The majority of cesarean sections are performed with a neuraxial anesthetic in the effort to avoid instrumenting the airway. **Narcotics and benzodiazepines are often avoided** until after the delivery to reduce fetal respiratory depression. **Medications such as oxytocin, methylergonovine, and carboprost are used to promote uterine contractions** after delivery of the baby to reduce maternal hemorrhage. The EXIT procedure has different anesthetic goals than a cesarean section and thus the anesthetic is often quite different. **Maximal uterine relaxation is needed to get the fetal head, shoulder, and large neck mass out of the uterus and to prevent fetal expulsion during the EXIT procedure.** General anesthesia works well for these goals with halogenated anesthetics (sevoflurane, isoflurane, desflurane) run at minimum alveolar concentrations greater than 2. Halogenated gases also diffuse easily through the placental barrier and provide effective fetal anesthesia for the surgery. The same is true with the administration of narcotics to blunt the neuroendocrine response of the fetus. It is important to note that high doses of anesthesia gases will increase the risks of maternal hemorrhage and hypotension, resulting in fetal hypoxia. Invasive blood pressure monitoring and vasopressors should be readily available. Neuraxial anesthesia may also be used for EXIT procedures, but the anesthesiologist must be aware that **uterine relaxation and fetal anesthesia and analgesia will not be covered with an epidural or spinal**. Other medications that effectively reduce uterine contractions include nitroglycerin, magnesium, calcium channel blockers, and beta2 agonists.

During a cesarean section, it is common for obstetricians to use a low transverse hysterotomy to quickly get access to the baby. This technique also heals better and potentially leads to a lower risk of future uterine complications. Even if a low anterior placenta is noted on ultrasound, an obstetrician could safely cut through the placenta as long as he or she is able to get the baby out of the uterus quickly. **With the EXIT procedure, a low anterior placenta would require a different suboptimal incision to safely extract the fetus and maintain uteroplacental exchange.** This has significant implications for the uterine patency with subsequent manipulations and pregnancies.

KEY FACTS

- The majority of cesarean sections are performed with a neuraxial anesthetic in the effort to avoid instrumenting the airway.

- Narcotics and benzodiazepines are often avoided during cesarean sections until after the delivery to reduce fetal respiratory depression.
- Medications such as oxytocin, methylergonovine, and carboprost are used to promote uterine contractions after delivery of the baby to reduce maternal hemorrhage.
- The EXIT procedure has different anesthetic goals than a cesarean section and thus the anesthetic is often quite different.
- Maximal uterine relaxation is needed to get the fetal head, shoulder, and large neck mass out of the uterus and to prevent fetal expulsion during the EXIT procedure.
- During an EXIT procedure, uterine relaxation and fetal anesthesia and analgesia will not be covered with an epidural or spinal.
- With the EXIT procedure a low anterior placenta would require a different suboptimal incision to extract the fetus safely and to maintain uteroplacental exchange.

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7. ANSWER: B

Maternal blood and fetal blood do not normally mix because of the placental barrier. Fetal blood flows through the **chorionic villi,** while the maternal blood flows through the **intervillus space**. The majority of drugs that enter the maternal bloodstream will be transferred to the fetus. The actual amount that makes it to the fetus, however, may be clinically insignificant depending on its ability to get through the placental barrier. Adequate uterine blood flow will determine the rate at which maternal drugs get to the placenta. Afterward, **the mechanisms with which drugs transfer across the placenta include simple diffusion, active diffusion, facilitated diffusion, phagocytosis, and pinocytosis**. The majority of maternal drug transfers will be through simple diffusion. Simple diffusion through partial pressure gradients is also how oxygen and carbon dioxide are exchanged across the placenta.

Fick's law of diffusion states that the rate of transfer will correlate directly with concentration gradients and surface area but inversely with diffusion distance. Other variables affecting diffusion are based on the physical and chemical characteristics of the drug. Larger molecular weights, protein-bound, more highly ionized, and increased hydrophilic states will make it more difficult for a drug to pass through the placental barrier. Simple diffusion requires no energy to move across the placental barrier. This barrier includes syncytiotrophoblast, cytotrophoblast, connective tissue, and endothelium. This barrier actually evolves throughout the pregnancy with reductions in thickness as the fetus gets older. The surface area also increases as the fetus weight increases. Thus, simple diffusion transfer of drugs becomes easier as the fetus becomes closer to term.

Inhaled agents readily pass through the placenta secondary to high lipid solubility and small molecular weight. Induction agents also easily pass through the placenta because of high lipid solubility and a nonionized state during physiologic pH. Both **depolarizing and nondepolarizing neuromuscular blocking drugs** are quaternary ammonium salts, which make them highly ionized at physiologic pH and unable to pass efficiently into the fetal circulation. **Narcotics** in general pass freely into the fetal circulation because of high lipid solubility and low molecular weight. Morphine is hydrophilic but utilizes active placenta transfer. Benzodiazepines are highly nonionized and lipid soluble with a high placental transfer. **Anticholinergics** such as atropine and scopolamine are tertiary amines and easily cross through the placental barrier because of its nonionized state. **Glycopyrrolate** is a quaternary ammonium salt and has minimal fetal blood access. **Acetylcholine esterase** inhibitors such as neostigmine are highly ionized because they are quaternary ammonium salts and have limited transfer. (See Table 12.1.)

KEY FACTS

- Maternal blood and fetal blood do not normally mix because of the placental barrier.
- Fetal blood flows through the chorionic villi while the maternal blood flows through the intervillus space.
- The majority of drugs that enter the maternal bloodstream will be transferred to the fetus.
- The mechanisms with which drugs transfer across the placenta include simple diffusion, active diffusion, facilitated diffusion, phagocytosis, and pinocytosis.
- Fick's law of diffusion states that the rate of transfer will correlate directly with concentration gradients and surface area but inversely with diffusion distance.
- Both depolarizing and nondepolarizing neuromuscular blocking drugs are quaternary ammonium salts, which

Table 12.1 DOCUMENTED FETAL/MATERNAL RATIOS OF SELECTED DRUGS

DRUG	FETAL/MATERNAL RADIO	DRUG	FETAL/MATERNAL RATIO
Nitrous oxide	0.85	Dexmedetomidine	0.84
Isoflurane	0.71	Alfentanil	0.3
Etomidate	0.04–0.5	Fentanyl (epidural)	0.37–0.94
Ketamine	1.2	Merperidine	1.0
Propofol (bolus)	0.22–0.7	Morphine	0.61
Propofol (infusion)	0.5–0.76	Reminfentanil	0.73–0.88
Thiopental	0.37–1.08	Sufentanil	0.81
Diazepam	0.57–2.0	Ephedrine	0.7–1.13
Lorazepam	1.0	Phenylephrine	0.7
Midazolam	0.62		

SOURCE: Suresh MS, Segal BS, Preston R, Fernando R, Mason CL. *Shnider and Levinson's Anesthesia for Obstetrics*. 5th ed. Philadelphia, PA: Lippincott, Williams, & Wilkins; 2012:787, Table 49-4.

make them highly ionized at physiologic pH and unable to pass efficiently into the fetal circulation.

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8. ANSWER: A

Fetal oxygenation depends on maternal oxygenation content and the ability to deliver this oxygen with adequate blood flow to the uteroplacental circulation. **Maternal blood perfusion** is therefore an important factor, so maternal blood volume must be maintained to supply the uterus. **Maternal hemorrhage** would adversely affect fetal oxygenation and require emergent transfusion. Aortocaval compression from the uterus could hinder uterine arterial blood flow and systemic venous return to the heart. **Left uterine displacement** is the common maternal position to avoid great vessel compression. Uterine contractions can also reduce uterine blood flow, and thus tocolytics can improve uterine perfusion. **Uterine incision** will also dramatically reduce uteroplacental blood flow, although it is important to note that fetoscopic procedures do not. **Anesthetic medications** can also reduce uteroplacental blood flow by causing hypotension. Epidural boluses and volatile agents are just a couple of examples of anesthetics that can decrease uterine perfusion. Both ephedrine and phenylephrine can be used effectively to counter these effects to the maternal blood pressure without further reducing uteroplacental flow.

From the fetal perspective, umbilical **blood flow is essential for proper fetal oxygenation**. Any procedures and manipulation off the umbilical vessels can cause vasospasm, leading to a significant decrease in fetal oxygenation. Huge shifts in amniotic fluid can also cause problems. **Oligohydramnios** can lead to the kinking of the umbilical cord, whereas **polyhydramnios** can increase amniotic pressure, impairing uteroplacental perfusion. **Reduced fetal cardiac output or hemoglobin concentration** will also cause significant problems. The fetus is unable to increase cardiac stroke volume well but is able to counter decreases in cardiac output with increases in heart rate.

Adequate maternal and fetal pain management during any procedure is essential because pain will cause increases in catecholamine release. Elevated circulating stress hormones result in two main problems for a fetus. First, placental vascular resistance increases, making it more difficult for fetal perfusion. Second, increases in stress hormones can lead to increases in progesterone, which will increase intracellular calcium, leading to elevated risk in preterm labor. Anand et al. studied 45 neonates scheduled for cardiac surgery and placed them in either a deep anesthesia arm (sufentanil) or a lighter sedation arm (morphine). The study was small, but deep anesthesia groups had fewer incidences of sepsis, metabolic acidosis, disseminated intravascular coagulation, and deaths. The lighter sedation arm had higher incidence of hyperglycemia and lactic acidemia. Other studies have shown that administration of narcotics for intubated neonates reduced heart rates, stress hormones, and episodes of hypoxia. **Without proper pain management, increases in the morbidity and mortality of the fetus are possible**.

KEY FACTS

- Fetal oxygenation depends on maternal oxygenation content and the ability to deliver this oxygen with adequate blood flow to the uteroplacental circulation.
- Maternal blood perfusion is therefore an important factor, so maternal blood volume must be maintained to supply the uterus.
- From the fetal perspective umbilical blood flow is essential for proper fetal oxygenation.
- The fetus is unable to increase cardiac stroke volume well but is able to counter decreases in cardiac output with increases in heart rate.
- Adequate maternal and fetal pain management during any procedure is essential because pain will cause increases in catecholamine release.
- Without proper pain management, increases in the morbidity and mortality of the fetus are possible.

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cortical regions can start as early as 16 to 24 weeks gestation. It is during this time period that the fetus is capable of responding to noxious stimuli, which leads to increased plasma levels of stress hormones and localized inflammation. This **noxious stimulus** has the potential to alter neurological development involving the fetus's perception to pain and even possibly changing behavioral patterns in the future. Without proper fetal anesthetics for surgery, elevated stress hormones are released that can lead to changes in the placenta that increase fetal estrogen and progesterone levels, which will ultimately lead to increased uterine contractility and subsequent preterm labor. **Analgesics** such as narcotics have been shown to blunt the hormonal stress response to pain.

Unfortunately, administration of fetal anesthetics does not come without potential side effects. Maintaining maternal oxygenation and uteroplacental perfusion is necessary for fetal well-being. **Maternal hypercapnia, hyperventilation, hypotension, and hypoxemia must be avoided because they can all affect fetal perfusion.** When volatile anesthetics are used to provide anesthesia for the fetus and mother, a secure airway is desired to prevent aspiration risk and other pulmonary complications. Vasopressors such as ephedrine or phenylephrine should be readily available in case of maternal hypotension secondary to drops in systemic vascular resistance from volatile anesthetics. High doses of volatile anesthetics for uterine relaxation can also cause a depression in the fetal cardiovascular system, resulting in fetal acidosis. **Systemic narcotics and induction agents can cause a decrease in fetal heart variability** but will not cause fetal acidosis as long as normal maternal hemodynamics are maintained.

9. ANSWER: B

Fetal anesthesia for either fetoscopic procedures or an EXIT procedure may include placental transfer from maternal volatile anesthetics and narcotics or a direct fetal intravenous/intramuscular injection of muscle paralytics, narcotics, and anticholinergics. **Neuraxial anesthesia is only effective for the** mother and does not provide fetal anesthesia or analgesia.

It was not too long ago that neonates, much less fetuses, were considered incapable of feeling pain, and anesthesia for painful procedures was not recommended. Fetal consciousness of pain continues to be a controversial topic with far-reaching medical, ethical, and political implications. What is known for sure is that there are a multitude of reasons to administer anesthetics for the fetus during surgery. **Failure to do so could lead to poor outcomes for the fetus**.

The fetal physiological response to pain begins as early as 16 to 24 weeks gestation, and normal EEG readings can begin in neonates as early as 24 weeks. Neurodevelopment of pain pathways that connect to the

KEY FACTS

- Fetal anesthesia for either fetoscopic procedures or an EXIT procedure may include placental transfer from maternal volatile anesthetics and narcotics or a direct fetal intravenous/intramuscular injection of muscle paralytics, narcotics, and anticholinergics.
- Neuraxial anesthesia is only effective for the mother and does not provide fetal anesthesia or analgesia.
- Failure to administer anesthetics for the fetus during surgery can lead to poor fetal outcomes.
- The fetal physiological response to pain begins as early as 16 to 24 weeks gestation, and normal EEG readings can begin in neonates as early as 24 weeks.
- This noxious stimulus has the potential to alter neurological development evolving the fetus's perception to pain and even possibly changing future behavioral patterns.
- Maternal hypercapnia, hyperventilation, hypotension, and hypoxemia must be avoided because they can all affect fetal perfusion.

- Systemic narcotics and induction agents can cause a decrease in fetal heart variability but will not cause fetal acidosis as long as normal maternal hemodynamics are maintained.

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10. ANSWER: A

Understanding of consciousness will often coincide with the understanding of how anesthesia is able to provide amnesia, immobility, and suppress states of awareness. There are multiple theoretical interrelated pathways as to how human consciousness exists. **The ascending reticular activating system (ARAS)** is central to this and contains several neuronal networks that connect the brainstem to the cortex. It is responsible for receiving sensory spinal information and distributing it to the thalamus and ultimately to the cortex for processing. It **is theorized that anesthetics work** by initially depressing the ARAS, which sets off a neurophysiologic cascade that ultimately depresses the prefrontal cortex and thus states of awareness. Determination of fetal ability to process painful stimuli will start with the development of the neuroanatomical development of the spinothalamocortical pathways.

The **spinothalamocortical** circuits start off with the perception of pain through peripheral cutaneous sensory receptors. These afferent fibers synapse on the dorsal root ganglion and cross over the midline of the spinal cord. The axons ascend through the ARAS toward the thalamus, where they eventually project to the cerebral cortex for pain perception. It is through this connection that pain is formally perceived. The development of the pain pathway starts as early as 8–15 gestational weeks when peripheral cutaneous sensory receptors are developed. The spinal reflex arc for pain and the dorsal root ganglion do not develop until 8 and 19 gestational weeks, respectively. Thalamic afferents to the cortical plate are developed at 23–24 gestational weeks. And lastly, cortical function with detected somatosensory evoked potentials and meaningful EEG patterns starts around 29–30 weeks.

Behavioral studies are used to determine if a fetus can perceive pain based on withdrawal reflexes and facial expressions. This is controversial because reflex withdrawal arcs to pain do not require cortical input. It is also uncertain that triggering a withdrawal reflex from an immature fetus proves that he or she is experiencing pain because neonates often activate their withdrawal reflex to nonpainful stimuli. **Facial movements** that mimic adult pain occur at weeks 28–30 post-conceptual age (PCA).

EEG is a measurement of synaptic potential of cortical neurons. Neonates can have normal EEG readings as early as 24 weeks PCA. Another consideration with EEG readings is that "wakefulness" is required to prove conscious pain perception since it is a reflection of brainstem and thalamic communication with the cerebral cortex. This occurs in preterm neonates no earlier than 30 weeks PCA.

Intrauterine needling of intrahepatic veins has been shown to increase fetal plasma concentrations of cortisol, beta-endorphin, and noradrenaline as early as 18 weeks gestational age. **Administration of narcotics has been proven to blunt this response and reduce stress hormones.**

KEY FACTS

- It is theorized that anesthetics work by initially depressing the ARAS, which sets off a neurophysiologic cascade that ultimately depresses the prefrontal cortex and thus states of awareness.
- Administration of narcotics has been proven to blunt the fetal stress response and reduce stress hormones.
- Facial movements that mimic adult pain occur at weeks 28–30 PCA.

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11. ANSWER: D

Late decelerations with moderate baseline variability are considered an ACOG (American College of Obstetricians and Gynecologists) category 2 electronic fetal monitoring tracing. **Category 1** tracings are considered healthy and do not require anything more than routine management. **Category 3** tracings are considered abnormal with a higher risk of fetal acidemia and hypoxia. Emergent delivery is often necessary. **Category 2** tracings require more frequent evaluations and surveillance with intrauterine resuscitative measures. This includes lateral positioning, maternal oxygen administration, intravenous fluid bolus, vasopressors, and reduction of uterine contraction frequency.

Fetal heart monitors are used to determine if there is fetal distress in parturients with high-risk fetuses and/or parturients in the laboring process. Despite widespread use, fetal heart monitoring has not been shown to reduce perinatal mortality or reduce the incidence of cerebral palsy. It has, however, led to increased cost of care with increased rates of cesarean sections. There are currently two types of fetal heart monitors. External monitors are placed on the mother's abdomen and are effective in determining uterine contractions and fetal response while being noninvasive. Internal monitors require placement of a scalp electrode to the fetus's head and a pressure-sensing catheter to determine uterine activity and strength of contraction. The internal monitors are more accurate and provide more information on the fetus but have the drawback of a higher risk profile and a requirement of a ruptured membrane.

Normal fetal heart rates (FHRs) range from 120–160 beats per minute (bpm). **Fetal tachycardia** is when the heart rate surpasses 160 bpm. Common causes of this include maternal fevers, chorioamnionitis, hyperthyroidism, maternal/fetal anemia, and drug side effects (terbutaline, atropine). Fetal tachycardia could be a sign of fetal distress if it is associated with decreased variability. **Fetal bradycardia** is any heart rate below 120 bpm. Some causes include cord compression, cord prolapse, tetanic uterine contractions, epidural/spinal anesthesia, congenital heart disease, and conduction defects. Severe prolonged bradycardia (<80 bpm) signifies severe hypoxia and will require emergent delivery or intervention.

Normal FHR fluctuates around a baseline heart rate. **Variability** is a good indicator in fetal nervous and cardiac system well-being. Fetal hypoxia, congenital cardiac anomalies, prematurity, and medications (narcotics, benzodiazepines, magnesium) can cause a flattening of variability. It can also be benign with fetal quiescence leading to nonthreatening diminished variability as long as spontaneous recovery of variability occurs after 30 minutes. **Fetal accelerations**, which consist of increases in FHR by at least 15 bpm lasting at least 15 seconds, are a sign of fetal well-being. **Early decelerations** show a drop in FHR that starts and ends with the uterine contraction. It is often an indication of fetal head compression causing a vagal response. **Late decelerations** are a fall in FHR that begins at or after the peak of the uterine contraction and ends at the end of the contraction. It is associated with uteroplacental insufficiency. **Variable decelerations** are FHR with acute falls and variable FHR recovery with no relation to uterine contractions. It is associated with compression of the umbilical cord.

KEY FACTS

- Category 1 tracings are considered healthy and do not require anything more than routine management.
- Category 2 tracings require more frequent evaluations and surveillance with intrauterine resuscitative measures.
- These measures include lateral positioning, maternal oxygen administration, intravenous fluid bolus, vasopressors, and reduction of uterine contraction frequency.
- Category 3 tracings are considered abnormal with a higher risk of fetal acidemia and hypoxia. Emergent delivery is often necessary.
- FHR variability is a good indicator in fetal nervous and cardiac system well-being.
- Fetal hypoxia, congenital cardiac anomalies, prematurity, and medications (narcotics, benzodiazepines, magnesium) can cause a flattening of variability.

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12. ANSWER: C

Preterm labor is defined as labor before 37 weeks of pregnancy. It is of particular concern because preterm delivery **significantly increases the fetal risk of morbidity and mortality**. **Maternal risk factors for preterm labor** can be categorized by demographics, lifestyle habits, and medical history. Demographic risks include women who are less than 17 and greater than 35 years old, African Americans, and lower socioeconomic status women. Working in a high-stress environment, being underweight, and being involved in tobacco use, alcohol use, and/or illicit drug use will also increase risk. Lastly, mothers with a history of in vitro fertilization, hypertension, diabetes mellitus, preeclampsia, clotting disorders, sexually transmitted diseases, or vaginal/urinary infections will increase the preterm labor risk.

The mother's uterus has multiple types of receptors (adrenergic, prostaglandin and oxytocin) whose activation can lead to increased intracellular calcium and subsequently uterine contractility. **Infections, multiple gestations, and premature rupture of membranes are the most common causes of preterm labor.**

Fetal surgery adds another dimension to preterm labor risk. Surgery increases the stress levels of the fetus and mother in addition to exposing the amniotic membrane to risk of rupture or damage. Both of these will lead to an

increased chance of premature contractions. Fetoscopic surgery has lower tocolytic requirements and a lower rate of premature contractions and labor compared to an open hysterotomy. Unfortunately, this reduction in risk is offset by an elevation in risk of premature rupture of membranes and amniotic leak secondary to multiple port placements that puncture the amniotic membrane without closure. Intraoperative factors that can increase risk of preterm labor include polyhydramnios, larger numbers of fetoscopic ports, larger uterine incision, longer duration of surgery, and membrane closure technique. Postoperative factors include premature rupture of membranes, infection, and maternal and fetal stress response, which can cause an increase in prostaglandins, leading to premature uterine contractions.

There are many classes of medications that can be used to prevent uterine contraction and preterm labor. They include **volatile anesthetics (isoflurane, sevoflurane, desflurane), beta2 adrenergics (ritodrine, terbutaline), nitrates (nitroglycerin), prostaglandin inhibitors (indomethacin), calcium channel antagonists (nifedipine), and magnesium**. These medications all have a range of different mechanisms that ultimately increase the intracellular calcium levels needed for a uterine contraction. Medications such as volatile anesthetics and magnesium still have unclear mechanisms of action; however, they have an established effectiveness as a tocolytic. Unfortunately, all of these medications have an extensive list of side effects and must be considered before administration.

KEY FACTS

- Preterm labor is defined as labor before 37 weeks of pregnancy.
- Preterm delivery significantly increases the fetal risk of morbidity and mortality.
- Infections, multiple gestations, and premature rupture of membranes are the most common causes of preterm labor.
- Volatile anesthetics (isoflurane, sevoflurane, desflurane), beta2 adrenergics (ritodrine, terbutaline), nitrates (nitroglycerin), prostaglandin inhibitors (indomethacin), calcium channel antagonists (nifedipine), and magnesium can all be used to prevent uterine contraction and preterm labor.

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13. ANSWER: B

Volatile anesthetics (isoflurane, sevoflurane, desflurane) cause dose-dependent uterine muscle relaxation. MAC levels over 2 will almost completely abolish uterine contractions. At equivalent MAC levels, sevoflurane has a greater effect in decreasing the amplitude of uterine contraction. The exact mechanism of action is unknown. Concerns with high doses of inhaled agents include hypotension and tachycardia with desflurane.

Beta2 adrenergics (terbutaline, ritodrine): Beta2 agonist activates the receptors on the myometrium to increase cAMP levels, which ultimately inhibit sarcoplasmic reticulum calcium release. They are the most common class of medication used to prevent preterm labor. They unfortunately have a wide range of side effects associated with use. These include tachycardia, hypotension, pulmonary edema, hyperglycemia, and hypokalemia.

Nitrates (nitroglycerin): Nitroglycerin is a highly effective short-acting uterine relaxant used when sustained uterine contractions occur, cephalic versions, or in cases of retained placenta and difficulty in getting an entrapped head out during cesarean section. Nitroglycerin increases cGMP in the myometrium reducing the intracellular calcium.

Magnesium: Magnesium is another strong tocolytic widely used in the obstetric field. It can be used for preeclampsia, ecclampsia, and prevention of preterm labor. It has multiple mechanisms of action that are not well understood. Magnesium unfortunately has a wide range of side effects. It can potentiate neuromuscular relaxing agents and must be used with paralytics carefully. It can also cause hypotension, pulmonary edema, weakness, nausea, reduction in reflexes, bradycardia, and drop in atrioventricular conduction. Extreme high doses will cause cardiovascular collapse.

Prostaglandin inhibitor (Indomethacin): Prostaglandins activate phospholipase C and releases sarcoplasmic reticulum calcium to increase uterine contractions. NSAIDS such as indomethacin inhibit cyclooxygenase, reducing the prostaglandin levels and decreasing uterine contractions. Unfortunately this class of medications has serious side effects for the fetus, potentially causing a premature closure of the ductus arteriosus, cardiac dysfunction, pulmonary hypertension, renal damage, and oligohydramnios. Maternal side effects include platelet dysfunction, gastrointestinal ulcers, and renal injury.

Calcium channel antangonist (nifedipine): Calcium is a vital part of uterine contraction. Drugs like nifedipine bind to plasma membrane calcium channel, receptors and

decrease intracellular calcium. Side effects include hypotension, tachycardia, and flushing.

KEY FACTS

- Volatile anesthetics (isoflurane, sevoflurane, desflurane) cause dose-dependent uterine muscle relaxation.
- MAC levels over 2 will almost completely abolish uterine contractions.
- Beta2 agonists, nitrates, magnesium, prostaglandin inhibitors, and calcium channel antagonists can all be used as tocolytics but also have important side effects.

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14. ANSWER: A

Pulmonary sequestration lesions are completely nonfunctional lung tissue that have no connections to the bronchial airway and thus do not participate in gas exchange. They usually derive their blood supply from the distal thoracic/abdominal aorta. The majority of pulmonary sequestrations are intralobar as opposed to extralobar. They may also be associated with other congenital anomalies such as **congenital diaphragmatic hernias** and other complications such as **fetal hydrops**. This is in stark contrast **to congenital cystic adenomatoid malformations** (CCAMs), where there are direct connections to bronchial airways and pulmonary vasculature. This differentiation is vital for postnatal airway management where positive pressure ventilation can exacerbate pulmonary function.

After prenatal diagnosis of a pulmonary lesion, the mothers will often be followed with serial ultrasonography. This is to observe the evolution of the lesion and to determine if fetal surgical intervention is necessary. In a retrospective analysis of 41 extralobar pulmonary sequestration cases, 28 of them had dramatic regression on serial prenatal ultrasonography without any intervention. Another retrospective analysis done in Canada with a total of 41 cases with congenital cystic adenomatoid malformation of the lung (CCAM) showed 56% of the pregnancies had spontaneous regression. Interestingly, higher risk Stocker type 3 CCAM also showed 42% mediastinal corrections without intervention. It is for this reason that current management of pulmonary lesions without fetal hydrops includes serial ultrasonography and conservative management. **Pulmonary sequestration with fetal hydrops** will require either an EXIT procedure for resection of mass or immediate delivery depending on the fetus's gestational age. Unfortunately, those fetuses with spontaneous regression will continue to have respiratory issues postnatal and will require high acuity care after delivery.

Multiple studies have shown that with **fetal hydrops**, the postnatal mortality rate is close to 100% and thus fetal intervention is recommended for these specific cases. Either percutaneous decompression of the cystic component of the tumor or ex utero resection of the pulmonary mass at an early stage may be indicated to assist the fetal pulmonary development and reduce mortality rates. **Thoracoamniotic shunts** for antenatal effusions may be more practical than percutaneous thoracentesis in preventing fetal hydrops since reaccumulation of fluids is common.

In utero laser ablation has not been shown to be effective for CCAM management, much less an emergent procedure. Serial ultrasounds are not an indication for blood transfusion. Stocker type 3 CCAM could cause compression to the fetal esophagus leading to polyhydramnios secondary to the fetus's inability to swallow amniotic fluid. Oligohydramnios requiring intra-amniotic infusion would be less of a concern.

KEY FACTS

- Pulmonary sequestration lesions are completely nonfunctional lung tissue that has no connections to the bronchial airway and thus does not participate in gas exchange.
- They may also be associated with other congenital anomalies such as congenital diaphragmatic hernias and other complications such as fetal hydrops.
- With CCAMs there are direct connections to bronchial airways and pulmonary vasculature.
- Pulmonary sequestration with fetal hydrops will require either an EXIT procedure for resection of mass or immediate delivery, depending on the fetus's gestational age.

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15. ANSWER: D

Congenital cystic adenomatoid malformation is a congenital lung lesion consisting of multicystic masses with origins from pulmonary tissue that connect to the bronchial airway; it derives its blood supply through the pulmonary circulation. CCAM, however, does not participate in gas exchange. It is a rare disorder (1 in 25,000 to 1 in 35,000) that can affect any lobe of the lung in a usually unilateral manner. CCAM is associated with congenital heart defects, renal agenesis, and pectus excavatum.

Stocker classification is a postnatal rating for CCAM based on gross appearance and microscopic criteria. **Type 1** is associated with the best prognosis consisting of a single cyst or multiple cysts 2 cm or greater in diameter. **Type 2** are smaller multiple cysts that are less than 1 cm in diameter. **Type 3** lesions have the worst prognosis with the lesions being larger and bulky with a mass effect. This classification should only be one part of the evaluation with regard to in utero prognosis. Measurements of tumor volume adjusted for gestational age (congenital cystic adenomatoid malformation volume ratio: CVR) to head circumference has also been used to determine CCAM fetuses at high risk for fetal hydrops. CVR > 2.0 has shown statistical significance in increased fetal hydrops and required fetal intervention. Serial ultrasounds to observe the evolution of appearance throughout the pregnancy of fetuses with CCAM is often recommended.

General anesthesia with or without a lumbar epidural is usually the anesthetic technique of choice for a CCAM resection under EXIT procedure. Anesthesia concerns begin with intubation under full stomach precautions. Arterial line will be needed for the mother because of high levels of anesthetic gases used to prevent uterine contraction. Additional large-bore intravenous access is needed because of the potential for significant hemorrhage during the hysterotomy. Maternal FiO_2 is kept at 100% for optimal fetal oxygenation. Once adequate uterine relaxation is determined by surgical palpation, a hysterotomy is performed and the fetal hemithorax and upper extremity are delivered. **Continuous fetal echocardiography in addition to fetal oximetry is used for fetal monitoring.** Fetal narcotics, anticholinergics, and paralytics are administered through intramuscular injections. Afterward, intravenous access is obtained in case additional anesthetics or transfusions are needed. Maternal hemodynamics is carefully followed to maintain optimal uteroplacental perfusion with confirmation from fetal monitors for fetal well-being. After completion of fetal surgery, the fetus is placed back into the uterus and warm lactated Ringer's solution is used to replace lost amniotic fluids. Magnesium bolus and infusion are administered to the mother to prevent postoperative preterm labor. The mother is extubated and transferred to the obstetric intensive care unit for full monitoring.

Mortality rates can be as high as 5% for strictly postnatal management. Fetal surgery for CCAM includes fetuses already in the highest mortality risk category with components of fetal hydrops where death is imminent. Larger pulmonary masses that cause mediastinal shifts can compress the structures that lead to cardiovascular compromise. **Complications of CCAM are often sequelas of respiratory issues.** Larger masses will compress the lungs during key stages of fetal development, resulting in fetal lung hypoplasia. If fetal hydrops occurs, mortality rates are the highest with the majority of them dying either in utero or shortly after birth.

Maternal complications from fetal CCAM resection surgery include wound infections, wound seroma, pulmonary edema, and uterine dehiscence. Advanced maternal age alone does not increase the risk of CCAM fetal complications.

KEY FACTS

- Congenital cystic adenomatoid malformation is a congenital lung lesion consisting of multicystic masses with origins from pulmonary tissue that connect to the bronchial airway; it derives its blood supply through the pulmonary circulation.
- Stocker classification (Type 1, 2, and 3) is a postnatal rating for CCAM based on gross appearance and microscopic criteria.
- General anesthesia with or without a lumbar epidural is usually the anesthetic technique of choice for a CCAM resection under EXIT procedure.
- Continuous fetal echocardiography in addition to fetal oximetry is used for fetal monitoring.
- Complications of CCAM are often sequelas of respiratory issues.

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16. ANSWER: B

Congenital heart disease is not a major concern of SCTs. However, **high-output cardiac failure** can be a complication of SCTs.

SCTs are the most common tumors (1 in 27,000–40,000) of the newborn, affecting females four times more than males. These tumors are usually benign, external to the body, and include both solid and cystic components.

Mortality rates for SCTs can be extremely high with some literature citing rates as high as 20%. Although the fetus can die from malignant degeneration, the majority of deaths are secondary to its large blood supply and mass effect of the tumor. Large SCTs are **highly vascular and can act like an arteriovenous fistula,** leading to a high-output cardiac failure. Fetal hydrops is thus associated with SCTs and placentomegaly; pleural and pericardial effusions may be present and another contributor to its high mortality rate. Other variables associated with higher mortality rates include immature teratoma histology, higher ratios of solid tumor to fetal mass, and premature delivery.

Surgical intervention for SCTs can range from percutaneous cyst/bladder decompression and bladder shunt placement to in utero mass resection. Anesthetic goals for the mother include maintenance of uteroplacental perfusion, relaxation of uterine walls, prevention of maternal pain, and prevention of preterm labor. Primary anesthetic goals for the fetus include preventing fetal bradycardia, fetal pain, and fetal movement.

Because of the highly vascular nature of the SCT, preoperative fetal blood transfusion may be considered. Case reports show that preoperative **interventional embolization of the teratomas** has been successful in minimizing operative blood loss. However, vigilance is still needed for the fetus because of concerns of continued transfusion needs, potential air embolus, and hyperkalemia associated with tumor manipulation. Patients with polyhydramnios requiring multiple amnioreductions will also need more aggressive tocolytic therapy to prevent preterm labor.

During in utero resection of the tumor, ultrasonography of fetal well-being is determined before induction of the mother. General anesthesia with rapid sequence induction and epidural for postoperative pain is usually performed for the mother. ASA monitors, additional IV access, and invasive blood pressure monitors are placed. Fetal echocardiography is continuously monitored throughout the surgery. **Volatile anesthetics are increased to 2 MAC for uterine relaxation during hysterotomy. After exposure to the fetus, intramuscular/intravascular administration of anticholinergic, muscle paralytic, and narcotics can occur.** Once resection of the tumor is completed and the uterine walls are closed, magnesium bolus and infusion are started. Extubation for the mother can then be planned after recovery from paralytics. Postoperative concerns include preterm labor, amniotic leak, pulmonary edema, and fetal demise.

KEY FACTS

- High-output cardiac failure can be a complication of SCTs because they are highly vascular and can act like an arteriovenous fistula.
- Although the fetus can die from malignant degeneration, the majority of deaths are secondary to its large blood supply and mass effect of the tumor.
- Surgical intervention for SCTs can range from percutaneous cyst/bladder decompression and bladder shunt placement to in utero mass resection.
- Volatile anesthetics are increased to 2 MAC for uterine relaxation during hysterotomy.
- After exposure to the fetus, intramuscular/intravascular administration of anticholinergic, muscle paralytic, and narcotics can occur.

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17. ANSWER: A

Uteroplacental gas exchange starts with the mother's oxygenated blood distributed to the uterine arteries, where the placenta is perfused. In general, the fetus will have **one umbilical vein, which will carry the oxygenated blood**

to the fetus. As the oxygenated blood arrives at the liver, 50%–60% of the blood is shunted directly to the inferior vena cava (IVC) with the rest continuing to the liver. The oxygenated blood (SpO_2 80–90%) tends to stream separately from the deoxygenated blood (SpO_2 25–40%) of the lower extremity. This is related to the faster flow of oxygenated blood compared to the slower moving deoxygenated blood. As the oxygenated blood reaches the right atrium, more deoxygenated blood will merge from the superior vena cava (SVC) and coronary sinus. At this point the blood can travel one of two routes. It can go to the right ventricle and to the pulmonary vasculature with the majority of the blood reaching systemic circulation through the ductus arteriosus secondary to the extremely high pulmonary vascular resistance. The alternative is to shunt through the foramen ovale. The **Eustachian valve** located at the junction of the IVC and right atrium tends to shunt the faster moving oxygenated blood toward the foramen ovale and ultimately to the left side of the heart (SpO_2~65%), where distribution of the oxygenated blood to the fetal brain, coronary circulation, and other vital organs can occur. The return of **deoxygenated fetal blood** to the placenta comes from the two umbilical arteries.

Because the fetal lungs are underdeveloped and unable to obtain oxygen independently, the circulation is adapted to optimize oxygen delivery from the maternal supply to the fetus. Fetal circulation has **three major shunts** that help deliver oxygen to the fetal organs. The **first** is the ductus venosus, which shunts the oxygenated blood away from the liver and directly to the IVC. The **second** is the foramen ovale that shunts oxygenated blood to the left side of the heart and leads to supplying the upper extremity and brain through the aortic arch. The **last** is the ductus arteriosus, which shunts blood from the pulmonary vasculature to the aorta to supply the lower extremity with oxygenated blood. All of these shunts naturally close off after the birth of the fetus. In addition to the shunts, **fetal hemoglobin** (18 g/dL) has a higher concentration than in adults, which increases its oxygen-carrying capacity. **Hemoglobin F** is also a component of fetal blood that allows it to have a larger affinity for oxygen than maternal blood. There is also less 2,3 diphosphoglycerate in the fetal blood, which naturally binds to deoxyhemoglobin. This further shifts the oxygen dissociation curve to the left, giving the fetus a lower P_{50} (PO_2 at which 50% of hemoglobin is saturated with oxygen) compared to the mother (20 vs. 27 mm Hg).

KEY FACTS

- Uteroplacental gas exchange starts with the mother's oxygenated blood distributed to the uterine arteries, where the placenta is perfused.
- In general, the fetus will have one umbilical vein, which will carry the oxygenated blood to the fetus.
- Approximately 50%–60% of the blood is shunted directly to the IVC with the rest continuing to the liver.
- The Eustachian valve located at the junction of the IVC and right atrium tends to shunt the faster moving oxygenated blood toward the foramen ovale.
- The return of deoxygenated fetal blood to the placenta comes from the two umbilical arteries.
- The first shunt to deliver oxygenated blood to fetal organs is the ductus venosus, which shunts the oxygenated blood away from the liver and directly to the IVC.
- The second shunt, the foramen ovale, shunts oxygenated blood to the left side of the heart and leads to supplying the upper extremity and brain through the aortic arch.
- The third shunt, the ductus arteriosus, shunts blood from the pulmonary vasculature to the aorta to supply the lower extremity with oxygenated blood.

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18. ANSWER: C

Fetal oxygen needs are significantly different in the womb compared to adults. The main reason is the reliance on the maternal oxygenated blood to supply vital fetal organs as opposed to independently breathing in oxygen through the lungs. Thus, the placenta becomes the focal point in gas exchange between the mother and fetus. It is not uncommon to have umbilical vein oxygen partial pressures as low as 30 mm Hg.

To compensate for the different environment, the fetus utilizes multiple mechanisms to properly perfuse the vital organs. **Fetal hemoglobin** is the primary oxygen carrier for fetuses throughout the pregnancy with adult hemoglobin rapidly created during the last weeks before birth. The primary structure of fetal hemoglobin consists of four protein chains (two alpha and two gamma subunits). This differs from adult hemoglobin, which consists of two alpha and two beta protein subunits. The difference in hemoglobin structure leads to a drastically different affinity toward oxygen.

As shown in Figure 12.2, **fetal hemoglobin has a significantly higher affinity for oxygen,** leading to 50% hemoglobin oxygen saturations (P_{50}) at low oxygen partial pressures of 20 mm Hg. This reflects the placenta's ability to enhance its extraction of oxygen from the maternal circulation. Adult hemoglobin requires a much higher partial pressure of oxygen (27 mm Hg) to bind 50% of the hemoglobin,

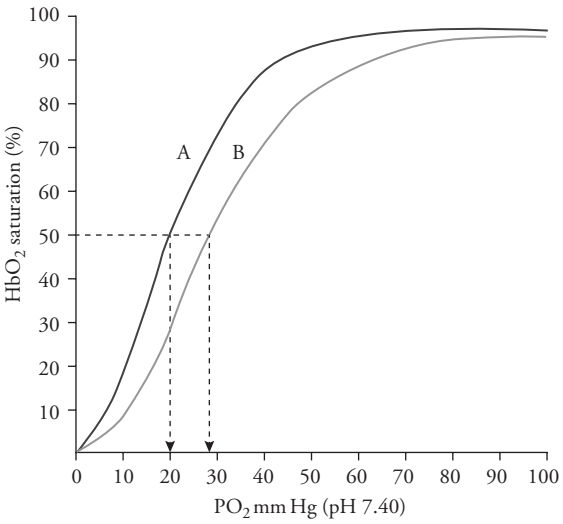

Figure 12.2 Fetal/adult hemoglobin saturation curve. (Reprinted with permission from Motoyama EK, Davis PJ, eds. *Smith's Anesthesia for Infants and Children*. 7th ed. St. Louis, MO: Elsevier Mosby; 2006:80–115.)

with this usually occurring in the lungs. The fetus tends to have **lower levels of 2,3 diphosphoglycerate (DPG),** which is an organic phosphate that binds to deoxygenated hemoglobin and decreases the affinity of fetal hemoglobin for oxygen. In adults, DPG levels are elevated in situations where there is a lack of peripheral tissue oxygen availability such as hypoxia or chronic lung disease. This causes a right shift in the oxygen dissociation curve, allowing the release of more oxygen to the tissue. **Other factors** that increase the affinity of hemoglobin for oxygen include higher pH levels, hypothermia, carbon monoxide, and methemoglobinemia.

Fetal hemoglobin levels are much higher than adult hemoglobin levels. This elevates the fetal oxygen-carrying capacity. In addition to this, high fetal cardiac output is maintained primarily by heart rate since the fetal heart is not mature enough to significantly alter stroke volume. Combined ventricular output is how fetal cardiac output is measured since the fetal circulation runs in parallel secondary to fetal shunts. The fetal shunts are necessary to direct the oxygenated blood to vital fetal organs.

KEY FACTS

- Fetal umbilical vein oxygenation is ~30 mm Hg.
- Fetal hemoglobin is the primary oxygen carrier for fetuses throughout the pregnancy with adult hemoglobin rapidly created during the last weeks before birth.
- The primary structure of fetal hemoglobin consists of four protein chains (two alpha and two gamma subunits).
- Fetal hemoglobin has a significantly higher affinity for oxygen, leading to 50% hemoglobin oxygen saturations (P50) at low oxygen partial pressures of 20 mm Hg.
- The fetus has lower levels of 2,3 diphosphoglycerate (DPG), leading to increased affinity of fetal hemoglobin for oxygen.
- Other factors that increase the affinity of hemoglobin for oxygen include higher pH levels, hypothermia, carbon monoxide, and methemoglobinemia.
- Fetal hemoglobin levels are much higher than hemoglobin levels in adults.

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19. ANSWER: C

Based on the ACOG guidelines, this is a category 3 FHR tracing that requires closer evaluation to determine the cause of the nonreassuring reading. **Initial treatments** may include administration of maternal oxygen, change in maternal positioning, discontinuation of oxytocin, cervical check, and a refresh of maternal vital signs.

FHR monitoring is known to have false positives, leading to an increase in cesarean section rates. **Fetal scalp blood sampling (FSS)** can be used to confirm the potential diagnosis of fetal acidosis from an abnormal FHR tracing. Haverkamp et al. have shown that there is a reduction in cesarean rates when FHR monitoring is combined with FSS, as opposed to FHR monitoring alone. A **pH below 7.2** is considered abnormal and emergent cesarean section or vaginal delivery is most likely indicated. If the **pH levels are above 7.26**, labor is continued without intervention as long as the FHR tracing does not worsen. Borderline pH values may require repeat testing in 20–30 minutes and further close observations of FHR tracing. Fetal scalp blood sampling is contraindicated if the membranes are intact or if the cervix is not dilated enough. Complications of the procedure include infection, bleeding, and potential scarring at the sample site, although these risks are low.

Criticism for FSS use in a laboring patient is that it is an invasive procedure with questionable overall fetal benefit. Goodwin et al. showed that a reduction of FSS usage of 1.76% to 0.03% did not decrease the cesarean section rate or decrease perinatal asphyxia rate. **Alternative methods of fetal well-being confirmation** have been proven to be just as effective. This includes scalp stimulation and vibroacoustic stimulation tests, which work on the principle that a positive

response (15 bpm accelerations sustained over 15 seconds) represents an intact autonomic system with a nonacidotic fetus. In a study with 100 fetuses with poor FHR tracings, all 51 fetuses who responded to the scalp stimulation had scalp pH > 7.19. Of the remaining fetuses that did not respond to the stimulation, 19 out of 49 had scalp pH < 7.19.

Unfortunately during a fetal procedure, stimulation tests would be ineffective with an anesthetized fetus. There are limited monitoring opportunities beyond FHR and fetal echocardiogram. FSS would be an effective way to determine if the fetus was acidotic when concurrent FHR tracings are worrisome. Another added benefit is that it avoids blood draws from the umbilical vasculature, which has the potential of causing vasospasm or kinking. Lactate tests can also be done in the same manner to determine acidosis. This has been shown to be just as effective in predicting acidosis with a higher success rate in test completion since it requires significantly less blood and results can be rapidly processed within 1 minute. EXIT procedures can have FSS, but a fetoscopic procedure would require blood drawn from the umbilical vasculature. Cardiac procedures will have a needle or catheter directly in the heart to draw blood.

KEY FACTS

- Initial treatments of a nonreassuring fetal HR tracing include administration of maternal oxygen, change in maternal positioning, discontinuation of oxytocin, cervical check, and a refresh of maternal vital signs.
- FHR monitoring has a large number of false positives, leading to an increase in cesarean section rates.
- Fetal scalp blood sampling can be used to confirm the potential diagnosis of fetal acidosis from an abnormal FHR tracing.
- Any pH below 7.2 is considered abnormal, and emergent cesarean section or vaginal delivery is most likely indicated.
- If the pH levels are above 7.26, labor is continued without intervention as long as the FHR tracing does not worsen.
- Criticism for FSS use in a laboring patient is that it is an invasive procedure with questionable overall fetal benefit.
- Alternative methods of fetal well-being confirmation have been proven to be just as effective. This includes scalp stimulation and vibroacoustic stimulation tests that works on the principle that a positive response (15 bpm accelerations sustained over 15 seconds) represents an intact autonomic system with a nonacidotic fetus.

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20. ANSWER: D

Normal preductal fetal SpO_2 ranges from 30% to 70% with **normal fetal heart rates** ranging from 120 to 160 bpm. **Fetal SpO_2 < 50%** should indicate further assessment of maternal and fetal well-being and treatment. This may include initiating 100% O_2 to the mother, optimizing maternal hemodynamics, assessing uterine tone, and rechecking umbilical vessel patency for kinks and vasospasm. **Fetal SpO_2 < 30%** is considered a dire precurser for fetal hypoxia and potential future cardiovascular collapse. The readings from this question are within normal fetal hemodynamic ranges and continued present management is recommended.

Pulse oximetry technology is based on spectrophotometry to determine the ratios of oxyhemoglobin to deoxyhemoglobin in a patient's blood. The LED light is shined through a vascular region and a photodetector on the other side determines how much of the light has been absorbed by the hemoglobin. Because **oxyhemoglobin and deoxyhemoglobin absorb light at different wavelengths**, pulse oximeters are able to differentiate between them and provide a numerical value that represents the partial pressures of oxygen in the blood. The difference with fetal SpO_2 monitoring comes from the different fetal physiology and anatomy. Fetal blood vessels are smaller and also have smaller pulse pressures, which make it more difficult for the monitors to pick up pulsations. In addition to that, **fetal oxygen partial pressures** are much lower with increased affinity levels toward oxygen secondary to the presence of fetal hemoglobin and reduced 2,3 diphosphoglycerate. Normal fetal oxygen saturation lies on a steep portion of the dissociation curve; therefore, minute changes in the partial pressures of oxygen can cause wide variances in fetal SpO_2 readings, making it more difficult to assess. For these reasons it was found that adjusting the wavelength of fetal

pulse oximeters to 735/890 nm yielded more accurate readings. **Fetal pulse oximeters** will also require a lack of fetal movement, direct contact to the fetal skin, and aluminum covering of the monitor to prevent artifact absorption.

According to the Academy College of Obstetricians and Gynecologists (ACOG), **fetal pulse oximetry is currently not considered the standard of care for laboring patients**. Bloom et al. had the largest randomized control trial of over 5000 parturients who were all monitored with fetal pulse oximetry. The first arm masked the pulse oximetry data to clinicians with the second arm allowing clinicians the data to affect medical decisions. There was no statistical difference between the two arms with regard to overall cesarean section rates, cesarean section rates with nonreassuring fetal heart rates, and newborn well-being. Further studies are required to determine if there is a place in fetal monitoring for fetal pulse oximetry. However, there may be benefits during fetal surgery where continuous assessment of fetal oxygenation and heart rate can be extremely valuable.

KEY FACTS

- Normal preductal fetal SpO_2 ranges from 30% to 70% with normal fetal heart rates ranging from 120 to 160 bpm.
- Fetal SpO_2 < 50% should indicate further assessment of maternal and fetal well-being and treatment.
- Treatments include initiating 100% O_2 to the mother, optimizing maternal hemodynamics, assessing uterine tone, and rechecking umbilical vessel patency for kinks and vasospasm.
- Fetal SpO_2 < 30% is considered a dire precurser for fetal hypoxia and potential future cardiovascular collapse.
- Pulse oximetry technology is based on spectrophotometry to determine the ratios of oxyhemoglobin to deoxyhemoglobin in a patient's blood.
- Oxyhemoglobin and deoxyhemoglobin absorb light at different wavelengths.

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21. ANSWERS: B

Fetal monitoring for surgery has many limitations. The limitations include the inability to access and fully monitor the fetus properly. **Fetoscopic repair for HLHS with AS** does not allow monitors that require direct access to the fetus. The surgical trocars are too small to deliver ECG and pulse oximetry leads. Thus, placement of fetal pulse oximetry or ECG would require rupture of membranes in order to place the monitors on the skin. This would be unacceptable since these procedures are performed around 20–26 weeks gestation. Thus, **anesthetic goals include prevention of premature rupture of membranes and premature labor**.

Fetal cardiac imaging is useful for advance diagnosis of fetuses with congenital heart defects as early as 16–24 weeks gestation. It is effective in visualization of cardiac structures and blood flow directions to determine if there are valvular or septal defects. **Fetal echocardiogram** is often the only fetal monitor available for fetoscopic procedures. It is initially useful in providing visualization of the fetal heart so that percutaneous access to the heart can be obtained for injection of fetal anesthetics and deployment of balloons. It also allows visualization of the placenta, umbilical cord, and amniotic membranes to determine patient and fetoscope positioning. Parturients with anterior placentas are considered technically more challenging and require more uterine manipulation and relaxation. General anesthesia would then be the preferred method over neuraxial anesthesia to fulfill these goals. **Throughout the surgery, continuous echocardiographic readings are performed through a sterile sleeve. It can provide vital information about fetal stroke volume, heart rate, rhythm, and contractility.** Volume status and cardiac output can be determined in real time, giving better information on blood transfusion management and when emergency medications for inotropic support of the fetal heart are needed. Fetal bradycardia can occur during the surgery secondary to fetal acidosis, and thus maneuvers to improve fetal oxygenation through the mother can also be initiated. This includes optimizing maternal hemodynamics by placing the mother on 100% oxygen and maintaining maternal mean arterial pressures above 25% of baseline readings. Pericardial effusion and/or tamponade may also be a problem during the surgery and can be visualized by echocardiography. Percutaneous drainage of the fluids may be necessary if it affects fetal cardiac output.

Postoperative management will require intermittent ultrasonographic examination in addition to continuous fetal heart rate and uterine contraction monitoring. For these patients, preterm labor risk is much less than an open hysterotomy but is still a major concern that requires close monitoring.

KEY FACTS

- Fetoscopic repair for HLHS with AS does not allow monitors that require direct access to the fetus.
- Placement of fetal pulse oximetry or ECG would require rupture of membranes to place the monitors on the skin, which is unacceptable given the risk of preterm labor.

- Anesthetic goals include prevention of premature rupture of membrane and premature labor.
- Fetal cardiac imaging is useful for advance diagnosis of fetuses with congenital heart defects as early as 16–24 weeks gestation.
- Fetal echocardiogram is often times the only fetal monitor available for fetoscopic procedures.
- Volume status and cardiac output can be determined in real time, giving better information on blood transfusion management and when emergency medications for inotropic support of the fetal heart are needed.

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22. ANSWER: A

Twin-twin transfusion syndrome is a placental vascular anastomosis abnormality within a monochorionic diamniotic placenta (MCDA), which results in a circulatory imbalance between the twin fetuses. It is normal for MCDA to have vascular connections that can be arterioarterial or venovenous. **Arteriovenous anastomosis** is rare and unidirectional, which in theory can be the cause of the imbalance in vascular flow between the fetuses. **Arterioarterial connections** are bidirectional, and its presence can help reduce the incidence of TTTS from 42% to 15% but does not completely protect the fetuses from it. This one-sided vascular flow can cause the recipient twin to develop hypertension, cardiomegaly, and right-sided heart failure. The **donor twin** will have hypotension, hypovolemia, and decreased growth.

TTTS affects 8%–10% of MCDA births and has a prevalence of 1–3 per 10,000 births. This syndrome develops in the second trimester and thus MCDA placentation should be monitored by serial ultrasounds starting at 16 weeks with a follow-up frequency as soon as every 2 weeks until delivery. The close monitoring is a result of the rapid nature with which the syndrome can progress to advanced Quintero stages.

Quintero developed a prognostic staging criterion based on ultrasound findings to help with clinical management of TTTS. Increasing stage indicates worsening fetal outcome. **Stage 1** shows a significant difference in amniotic fluid between the donor and recipient twin. **Stage 2** is when there is a loss of visualization of bladder of the donor twin. **Stage 3** is when the donor twin loses umbilical artery diastolic flow. **Stage 4** is fetal hydrops. Stage 5 is the fetal demise of one or both twins.

Stage 1 can progress to more advanced stages 10%–30% of the time. However, fetal intervention has not been shown to improve morbidity or mortality, so conservative management with weekly ultrasound follow-up is advised. Once Quintero stage 2–4 is reached, the mother should be counseled for **fetal intervention**. Current options include **serial amnioreductions, septostomy with or without amnioreduction, selective fetocide, controlled bloodletting, and fetoscopic laser photocoagulation (FLP)**. FLP is used to disrupt the vascular anastomosis in the placenta and is currently the recommendation of choice for TTTS stage 2–4 management. This procedure can result in preterm rupture of membranes, preterm delivery, amniotic fluid leakage, chorioamnionitis, and fetal death.

A European randomized controlled trial of 142 women with TTTS compared clinical intervention of FLP versus amnioreduction and found significant reductions in overall perinatal death (44% vs. 61%) and improvements in 6 months survivorship without neurological complications (52% vs. 31%). Long-term neurological benefits, however, were equivalent by 6 years of age. Meta-analyses with other randomized controlled trials have not been as conclusive with a smaller randomized controlled trial trial done in America showing no significant perinatal mortality benefit at 30 days of age (55% vs. 40%) and a significant increase in recipient twin death (70% vs. 35%). Survival rates for both fetuses after FLP is approximately 50%. And even with successful FLP, **long-term neurodevelopmental deficits (mental retardation, cerebral palsy, periventricular leukomalacia)** will occur 5%–20% of the time.

KEY FACTS

- Twin-twin transfusion syndrome is a placental vascular anastomosis abnormality within an MCDA, which results in a circulatory imbalance between the twin fetuses.
- Arteriovenous anastomosis is rare and unidirectional, which in theory can be the cause of the imbalance in vascular flow between the fetuses.
- Arterioarterial connections are bidirectional, and its presence can help reduce the incidence of TTTS from 42% to 15% but does not completely protect the fetuses from it.
- Once Quintero stage 2–4 is reached, the mother should be counseled for fetal intervention, which includes serial amnioreductions, septostomy with or without amnioreduction, selective fetocide, controlled bloodletting, and FLP.
- Even with successful FLP, long-term neurodevelopmental deficits (mental retardation,

cerebral palsy, periventricular leukomalacia) will occur 5%–20% of the time.

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23. ANSWER: A

Congenital diaphragmatic hernia (CDH) is a rare developmental disorder that results in an incomplete formation of the diaphragm. It most commonly occurs in the posterolateral region of the diaphragm known as the Bockdalek hernia with **~85% of the hernias located on the left side**. It is associated with a **wide range of systemic and organ disease processes, including chromosomal, craniofacial, neurological, gastrointestinal, skeletal, pulmonary, urological, and cardiac anomalies**. Even without these problems, CDH newborns will commonly have extensive pulmonary issues related to abdominal organs displaced into the thorax, preventing adequate development of the lungs. **Pulmonary hypoplasia** of the defect and **pulmonary hypertension** are potential variables for long-term morbidity and mortality, which can be as high as 50%–60%.

Prenatal CDH intervention to improve pulmonary development has not been shown to improve morbidity or mortality. In fact, intervention for fetuses with high-risk incarcerated livers led to immediate death secondary to vascular compression. Current management for CDH newborns with respiratory issues is to intubate as soon as possible to prevent bag mask ventilation and intestinal insufflation. Decompression of the stomach, paralytics, and sedation should all be considered to minimize distension of the stomach and intestines in the hopes of preventing worsening pulmonary function. Emergent surgery to correct CDH has not been shown to improve mortality rates. Therefore, stabilization of respiratory and cardiovascular function is far more important before surgery is considered.

High-risk newborns with CDH will have difficulties even with the aforementioned maneuvers to optimize oxygenation and ventilation. Prenatal testing can determine if a fetus will have a poor neonatal outcome. This includes identifying fetuses with a substantial amount of liver herniated into the thorax. These fetuses compared to fetuses where the liver stayed in the abdomen had a statistically significant increase in ECMO requirements (53% vs. 19%) and drop in survival rates (43% vs. 93%). A meta-analysis of studies showed similar results with intrathoracic liver herniation versus abdominal liver yielding survival rates of 45.4% and 73.9%, respectively. Contralateral lung to head ratio has also been shown to predict mortality rates. In small studies, fetuses with ratios higher than 1.4 were shown to survive, whereas scores below 1.0 all led to neonatal death even with ECMO support. EXIT to ECMO management becomes a viable alternative during these high-risk situations to minimize hypoxia and organ damage from lack of perfusion. **During the EXIT procedure**, fetal oxygenation is maintained through uteroplacental gas exchange. It is during this time that the fetal hemodynamics can be monitored and intubation can occur. If during this time period, maintaining an adequate fetal oxygenation is challenging and the echocardiogram shows increased right ventricular volumes with diminished lung volumes, fetal ECMO catheter cannulation should be strongly considered before the umbilical cord is clamped and severed. **Venovenous ECMO** can provide temporary stabilization of oxygenation and ventilation in preparation for CDH repair.

KEY FACTS

- CDH is a rare developmental disorder that results in an incomplete formation of the diaphragm.
- CDH most commonly occurs in the posterolateral region of the diaphragm known as the Bockdalek hernia with ~85% of the hernias located on the left side.
- CDH is associated with a wide range of systemic and organ disease processes, including chromosomal, craniofacial, neurological, gastrointestinal, skeletal, pulmonary, urological, and cardiac anomalies.
- Pulmonary hypoplasia of the defect and pulmonary hypertension are potential variables for long-term morbidity and mortality, which can be as high as 50%–60%.
- Prenatal CDH intervention to improve pulmonary development has not been shown to improve morbidity or mortality.
- During the EXIT procedure, fetal oxygenation is maintained through uteroplacental gas exchange.

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24. ANSWER: C

EXIT procedures were originally designed to maintain uteroplacental circulation and fetal gas exchange during critical moments so that physicians would have additional time for fetal management at the time of delivery. Since then, utilizing it for prenatal care has been explored. Disease processes that cause newborn respiratory distress are usually eligible for the EXIT procedure. **Congenital diaphragmatic hernias** can benefit from ECMO because of concerns with pulmonary hypoplasia and pulmonary hypertension. **Upper airway neck masses such as a cervical teratoma or a congenital high airway obstruction** may need an EXIT procedure to maintain fetal oxygenation while the physicians secure an airway before clamping off the umbilical cord.

Transition from EXIT to ECMO can be performed if there is an immediate risk for cardiovascular or pulmonary collapse after separation from the parturient. **Venoarterial ECMO** is used if there is both cardiac and respiratory support needed. It requires two cannulas and has a higher complication risk because of carotid artery cannulation. **Venovenous ECMO** is used if only respiratory support is needed. It requires one larger cannula in the internal jugular vein that takes deoxygenated blood and returns filtered oxygenated blood into the right atrium. **Some disease processes that may benefit from additional ECMO support** include CDH, congenital heart disease, and potential airway compromises. ECMO requires the newborn to have a reversible disease process. If the disease has a lethal component, ECMO should not be used to delay death. **Premature infants less than 34 weeks gestational age are not eligible for ECMO** because they have a significant increased risk in morbidity and mortality associated with intracranial bleeding. A **minimum weight requirement of 2 kg for venoarterial ECMO and 3 kg for venovenous ECMO** is necessary because of the large cannula size needed for adequate flow. Last, there must be a failure of medical management before ECMO should be instituted. Although ECMO has been shown to significantly reduce the neonatal mortality, significant complications are associated with ECMO and should be used as a last resort. Anticoagulation is required and can complicate the newborn with hemorrhage and intracranial bleeding. Infection, sepsis, renal failure, cardiac arrhythmias, and thromboembolic events can all occur with ECMO.

EXIT procedure for repair of myelomeningocele, which is not considered an emergent procedure, has been found to improve neurological outcomes. EXIT procedures have been done with high-risk SCT with hydrops. TAPVR can be extremely unstable and may need cardiovascular and pulmonary support with ECMO immediately after birth. These newborns tend to need emergent surgery. EXIT benefits for cervical teratomas lead to more time available to secure an airway. ECMO respiratory support can be utilized if the airway is unobtainable and the neck vasculature is still accessible or if the newborn needs support after completion of mass removal. The limiting factor for ECMO utilization is the low gestational age and premature weight.

KEY FACTS

- EXIT procedures were originally designed to maintain uteroplacental circulation and fetal gas exchange during critical moments so that physicians would have additional time for fetal management at the time of delivery.
- Transition from EXIT to ECMO can be performed if there is an immediate risk for cardiovascular or pulmonary collapse after separation from the parturient.
- Disease processes that cause newborn respiratory distress, such as CDH and upper airway neck masses, are usually eligible for the EXIT procedure.
- Venoarterial ECMO is used if there is both cardiac and respiratory support needed.
- Venovenous ECMO is used if only respiratory support is needed.
- Some disease processes that may benefit from additional ECMO support include CDH, congenital heart disease, and potential airway compromises.
- Premature infants less than 34 weeks gestational age are not eligible for ECMO because they have a significant increased risk in morbidity and mortality associated with intracranial bleeding.
- A minimum weight requirement of 2 kg for venoarterial ECMO and 3 kg for venovenous ECMO is necessary because of the large cannula size needed for adequate flow.
- EXIT procedure for repair of myelomeningocele, which is not considered an emergent procedure, has been found to improve neurological outcomes.

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25. ANSWER: B

One of the main anesthetic goals for an EXIT procedure is to maintain complete uterine relaxation. This is effective in **reducing uteroplacental resistance to maintain perfusion and effective gas exchange between the mother and fetus**. In addition to optimizing fetal oxygenation, maximal uterine relaxation is important in allowing the fetus with a large neck mass to be partially delivered without structural damage. An inopportune uterine contraction during this time period could cause the fetus to be completely delivered. Efforts are made to avoid this to prevent kinking of the umbilical cord and complete separation of the placenta. Preoperative evaluation is an important component to determine what kind of anesthetics will be required to maintain uterine relaxation. **Fetuses with a large neck mass** not only obstruct the airway but also the esophagus, leading to polyhydramnios and an elevated premature contraction risk. Thus, a detailed history **of preterm labor, frequency of amnioreductions, volume withdrawn, and uterine contractions during the procedure** may help determine the amount of uterine irritability the parturient will have. These patients may need additional tocolytics in addition to having potentially higher risks of fetal acidemia after delivery. **Current anesthetics that are effective in producing uterine relaxation** include volatile halogenated agents, nitroglycerin, nifedipine, indomethacin, magnesium sulfate, and terbutaline.

Maternal safety is always the first priority, so a detailed history and physical examination of the airway, cardiac history, and pulmonary risk factors should be completed. **Any factors that significantly increase the morbidity and mortality of the parturient would potentially be a contraindication for fetal surgery.** A parturient's current medication list is also important if she is already on a large number of tocolytics such as magnesium or terbutaline, which has a large side effect profile and will interact with the anesthetics used during the surgery.

Fetal preoperative evaluation includes amniocentesis to determine if there is any associated genetic abnormality and to evaluate fetal lung maturity. Amnioreduction can also be performed to reduce the risk of unexpected preterm labor. Fetal ultrasound is used to rule out congenital heart defects, evaluate cardiac function, and determine if fetal hydrops is present. Fetal weight estimation is also important so that proper drug dosages can be administered.

Discussions with the parturient about medical and surgical options for her and the fetus should be done well in advance of the procedure. Risks and benefits for both patients should also be discussed. Preparation for operating room management includes a multidisciplinary team involving obstetrics/gynecologists, pediatric surgeons, anesthesiologists, neonatologist, and ultrasonographer. The operating room should be kept warm for the neonate. Advanced airway equipment, invasive monitors, and blood products should also be readily available for both mother and fetus. Anesthetic doses and emergency drugs based on fetal weight should also be prepared in advance.

KEY FACTS

- One of the main anesthetic goals for an EXIT procedure is to maintain complete uterine relaxation in order to reduce uteroplacental resistance to maintain perfusion and effective gas exchange between the mother and fetus.
- Fetuses with a large neck mass not only obstruct the airway but also the esophagus, leading to polyhydramnios and an elevated premature contraction risk.
- A detailed history of preterm labor, frequency of amnioreductions, volume withdrawn, and uterine contractions during the procedure may help determine the amount of uterine irritability the parturient will have.
- Current anesthetics that are effective in producing uterine relaxation include volatile halogenated agents, nitroglycerin, nifedipine, indomethacin, magnesium sulfate, and terbutaline.
- Any factors that significantly increase the morbidity and mortality of the parturient would potentially be a contraindication for fetal surgery.

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13.

NEONATAL

Matthew C. Gummerson, Maria Irwin, Laura Leduc, and Jennifer Dearden

1. An otherwise healthy male infant is born full term and voids urine within the first 24 hours after birth. At what age after birth would you expect his glomerular filtration rate to attain a normal adult value?

A. 6 weeks
B. 6 months
C. 1 year
D. 2 years

2. You are consulted by the preoperative clinic to evaluate a 6-month-old infant with Streeter anomaly (amniotic band sequence), who is undergoing surgery the following day. Which of the following clinical signs or features is most likely to be found in this child?

A. Intestinal malrotation
B. Vascular ring
C. Unilateral nevus flammeus
D. Amputation of digits

3. You are assisting your partner on the labor-and-delivery ward and observe the delivery of a full-term newborn after having just given the mother a bolus of local anesthetic through her epidural (5 mL of lidocaine 1%). At 1 minute after time of delivery, the neonate has a heart rate of 80 bpm and has slow, irregular breathing. His extremities are flexed, and he is not actively crying but has a facial grimace. His extremities are cyanotic but his body is pink. What is his 1-minute Apgar score?

A. 4
B. 5
C. 6
D. 7

4. You are caring for a woman in the L&D operating room who is undergoing an elective repeat C-section under continuous spinal/epidural. At 5 minutes after delivery of a full-term newborn, the baby has a heart rate of 110 bpm, is actively crying and coughing with good respiratory efforts, and is vigorously moving all four extremities. The baby's SpO_2 is 70% on supplemental oxygen via blow-by mask and has cyanosis of the face, trunk, and extremities. What is this baby's 5-minute Apgar score?

A. 6
B. 7
C. 8
D. 9

5. You are assisting your partner on the labor-and-delivery ward and observe the delivery of a full-term newborn through thick meconium. The labor-and-delivery nurse asks for your assistance in the initial care of this baby. The infant's face is meconium stained; he has good muscle tone and vigorous respiratory efforts. You first suction his mouth and pharynx with a bulb syringe and then dry, warm, and stimulate him. His heart rate is 115 bpm. What else would you do in the initial management of this newborn?

A. Manage expectantly with oxygen as needed.
B. Provide positive-pressure ventilation via mask.
C. Intubate, then provide positive-pressure ventilation.
D. Intubate, then suction meconium from the trachea until clear.

6. You are assisting your partner on the labor-and-delivery ward and overhear a commotion coming from the obstetric triage bay. You rush over and witness the precipitous delivery of a full-term newborn through clear amniotic fluid to a multiparous, otherwise healthy 30-year-old woman. The labor-and-delivery nurse asks for your immediate assistance in the initial care of this baby, while the pediatrics delivery team is on the way. You quickly provide an initial assessment of

the newborn and find that the baby is gasping, is limp with poor muscle tone, and has central cyanosis. You first position his airway in a "sniffing position," clear his airway by suctioning his mouth and pharynx with a bulb syringe, and then dry, warm, and stimulate him. His heart rate is 70 bpm, assessed via palpation of the umbilical cord. What would be your *next* step in the management of this newborn?

A. Obtain IV access and administer epinephrine 0.01 mg/kg.
B. Intubate and administer epinephrine 0.1 mg/kg via endotracheal tube.
C. Begin chest compressions at a rate of 100/min.
D. Begin positive-pressure ventilation via mask at a rate of 40 breaths/min.

7. You are asked by your pediatric surgeon colleague to assess a 2-day-old, full-term neonate for an add-on thoracic surgery case tomorrow. The surgeon tells you that this procedure is somewhat urgent as the lesion communicates with the airways such that gas trapping, lung overdistension, and development of respiratory distress are real concerns in the baby's first few days of life. In addition, the surgeon describes the lesion as similar to bronchioles in structure, but lacking in any associated cartilage, bronchial glands, or alveoli (and thus does not participate in gas exchange). The surgeon plans on resecting the affected lobe via an open thoracotomy. What is this neonate's most likely diagnosis?

A. Bronchopulmonary dysplasia
B. Congenital diaphragmatic hernia
C. Cystic adenomatoid malformation
D. Pulmonary sequestration

8. Which choice best matches the age (weeks after birth) *and* normal value (in g/dL) of the physiologic nadir of hemoglobin concentration (anemia) that is reached in an otherwise healthy full-term infant?

A. 5–8 weeks old; 7–8 g/dL
B. 5–8 weeks old; 10–11 g/dL
C. 9–12 weeks old; 7–8 g/dL
D. 9–12 weeks old; 10–11 g/dL

9. You are called to assist in the scheduled cesarean delivery of a 37-week postconceptual age male infant with a known prenatal diagnosis of congenital diaphragmatic hernia (CDH). Your partner is caring for the mother so that you can focus your attention on the infant. Which of the following best describes the features of a CDH?

A. The majority (90%) of CDHs occur as the right anterior Morgagni-type defect.
B. The left posterolateral Bochdalek-type defect is more likely to have concurrent congenital heart defects.
C. The Bochdalek-type defect often presents later in childhood with symptoms of bowel obstruction.
D. The Morgagni-type defect has a significant female preponderance (90%).

10. You are at the neonatal intensive care unit (NICU) bedside of an infant male who is having significant respiratory distress and tachypnea. He was born about 12 hours ago at 36 weeks postconceptual age to a mother who received routine prenatal care with the exception of a prenatal ultrasound. His physical exam reveals a scaphoid abdomen and absent breath sounds on the left side of his chest. A 24 g peripheral IV was placed in his right hand and a chest X-ray was obtained that shows bowel loops in the left hemithorax and deviation of the mediastinum to the right. A transthoracic echocardiogram was obtained that did not reveal any structural cardiac defects and showed normal cardiac function. It also confirmed that the heart was deviated to the right side of the chest. Current vital signs include a pulse rate of 195 beats per minute, respiratory rate of 95 breaths per min, preductal pulse oximetry of 76% on 8 L of oxygen via infant face mask, and blood pressure of 62/41 mm Hg. Regarding management of this neonate's current pulmonary condition, what would be the *next* appropriate step?

A. Perform lung recruitment maneuvers with assisted bag-mask ventilation and 100% inspired oxygen.
B. Perform tracheal intubation and institute high-frequency oscillatory ventilation.
C. Institute humidified, high-flow nasal cannula at 50% inspired oxygen.
D. Institute humidified, high-flow nasal cannula at 100% inspired oxygen.

11. You are consulted to preoperatively evaluate a 3-day old, now 26-week postconceptual age male, who was born with hypoplastic left heart syndrome (HLHS). He is on mechanical ventilation and has had no other congenital defects or chromosomal abnormalities discovered on his initial workup. Which of the following best describes the physiologic response to a noxious stimulus or painful surgery in a fetus or neonate?

A. High-dose fentanyl (>50 μg/kg) has been shown to reduce the stress-induced hyperglycemic response to surgery in the neonate.
B. Increases in plasma concentrations of cortisol and β-endorphin in response to noxious stimuli are demonstrated in the fetus once it reaches approximately 26 weeks gestational age.
C. When compared to a neonate undergoing a similar major surgical procedure, an adult mounts

a hormonal response that is 3–5 times more pronounced.
D. In contrast to adults, the circulatory response to noxious stimuli in a neonate is systemic and pulmonary hypotension.

12. You are evaluating a 4-month old male, ex-32-week premature infant (now 48 weeks postconceptual age) for a scheduled laparoscopic Nissen fundoplication and G-tube placement. The infant has severe failure to thrive secondary to gastroesophageal reflux disease and frequent vomiting episodes. The infant's mother is very concerned about her son receiving anesthesia for his upcoming surgery because she heard from a friend that "anesthesia causes brain damage in babies." Based on current evidence regarding anesthesia and neurotoxicity in the developing brain, which would be the best response to address the mother's concerns and identify your anesthetic plan?

A. "Both animal and human studies have demonstrated no increased risk of neurotoxicity to the developing brain nor increased risk of developing future learning disabilities after prolonged exposure to inhalational anesthetics. Therefore, the most appropriate technique for your baby's surgery is general endotracheal anesthesia."
B. "Both animal and human studies have demonstrated no increased risk of developing future learning disabilities or suffering cognitive dysfunction when spinal anesthesia is used alone without other sedatives. Therefore, the most appropriate technique for your baby's surgery is spinal anesthesia without sedation."
C. "Animal studies have shown evidence of neurotoxicity in the developing brain after prolonged exposure to some anesthetic agents, but preterm infants experience more morbidity and mortality if exposed to surgery without adequate anesthesia. Therefore, the most appropriate technique for your baby's surgery is general endotracheal anesthesia."
D. "Intravenous anesthetic agents, such as ketamine, midazolam, and propofol, have been shown to be neuroprotective (preventing apoptosis) in animal studies—especially during periods of hypoxic-ischemic injury if administered before an inciting event. Therefore, the most appropriate technique for your baby's surgery is general endotracheal anesthesia utilizing these agents."

13. At what age is it acceptable to plan an elective, outpatient anesthetic for a child born at 28 weeks of gestation?

A. Elective anesthetics are not acceptable in children under the age of 2 years due to the increased risk of behavioral disorders.
B. Elective anesthetics can be performed at any time provided the patient is admitted postoperatively.
C. Elective anesthetics can be performed most safely after 44 weeks postconceptual age.
D. Elective anesthetics can be performed most safely after 56 weeks postconceptual age.

14. The category of drugs most likely to be used in the treatment of apnea of prematurity is:

A. Catecholamines
B. Narcotics
C. Methylxanthines
D. Diuretics

15. In a healthy infant, born full-term, hemoglobin levels will be lowest at what age?

A. 4 weeks
B. 12 weeks
C. 4 months
D. 12 months

16. What is the calculated allowable blood loss for a 5 kg infant assuming a starting hematocrit of 40% and a lowest allowable hematocrit of 24%?

A. 25 mL
B. 50 mL
C. 100 mL
D. 200 mL

17. The introduction of exogenous surfactant has significantly decreased the incidence of respiratory distress in the preterm infant. Surfactant improves pulmonary mechanics by:

A. Increasing surface tension
B. Decreasing surface tension
C. Increasing compliance
D. Decreasing compliance

18. A baby born at 7 pounds is expected to be approximately how many pounds at 1 year of age?

A. 10
B. 15
C. 20
D. 25

19. The most common cause of failure to thrive in babies in developed nations is:

A. Prematurity
B. Infection

C. Inborn errors of metabolism
D. Food allergies

20. A germinal matrix hemorrhage describes what grade of intraventricular hemorrhage?

A. Grade I
B. Grade II
C. Grade III
D. Grade IV

21. The test most likely to confirm a diagnosis of intraventricular hemorrhage in a preterm infant is:

A. Magnetic resonance imaging
B. Ultrasound
C. Complete blood count
D. CAT scan

22. A child with which of the following syndromes is most likely to suffer from kernicterus?

A. Crigler-Najjar syndrome
B. Gilbert syndrome
C. Fanconi syndrome
D. Lesch-Nyhan syndrome

23. Which of the following statements describes hyperbilirubinemia in the preterm infant?

A. Neurologic damage is most likely to be caused by conjugated bilirubin.
B. Neurologic damage is most likely to be caused by unconjugated bilirubin.
C. Neurologic damage does not occur in babies who do not exhibit overt symptoms of acute bilirubin encephalopathy.
D. Neurologic damage from hyperbilirubinemia is usually temporary in preterm neonates because of the elasticity of their central nervous system.

24. Which of the following is most likely true regarding the ductus arteriosus and foramen ovale in a neonate with persistent pulmonary hypertension?

A. Ductus arteriosus is patent and foramen ovale is patent.
B. Ductus arteriosus is closed and foramen ovale is patent.
C. Ductus arteriosus is patent and foramen ovale is closed.
D. Ductus arteriosus is closed and foramen ovale is closed.

25. A baby born at 28 weeks of gestation suffered from meconium aspiration and developed persistent pulmonary hypertension. Nitric oxide therapy was initiated. Nitric oxide causes pulmonary vasodilation via inhibition or activation at which enzyme?

A. Adenylate cyclase inhibition
B. Adenylate cyclase activation
C. Guanylate cyclase activation
D. Guanylate cyclase inhibition

26. Near term, the oxygen saturation of blood in the fetal ascending aorta is approximately:

A. 40%
B. 25%
C. 80%
D. 65%

27. Which patient is most likely presenting with persistent fetal circulation?

A. Pink upper extremities, cyanotic lower extremities
B. Pink right upper extremity, cyanotic left upper extremity
C. Pink left upper extremity, cyanotic right upper extremity
D. Pink lower extremities, cyanotic upper extremities

28. The two most important contributing factors to the development of retinopathy of prematurity are:

A. Supplemental oxygen administration and gestational age at birth
B. Supplemental oxygen and maternal age at birth
C. Supplemental oxygen and weight for gestation at birth
D. Supplemental oxygen and maternal substance use

29. The optimum oxygen saturation for premature neonates is:

A. 98%–100%
B. 92%–96%
C. 88%–92%
D. Not yet determined

30. A 3-day-old baby girl is scheduled for repair of a large lumbar myelomeningocele. She does not have other associated congenital anomalies. What is the *most* likely complication for this infant perioperatively?

A. Latex allergy
B. Cerebrospinal fluid (CSF) leak
C. Difficult intubation
D. Difficult IV access

31. A 6-year-old boy with a history of a repaired lumbar myelomeningocele presents for port-A-cath replacement. After uneventful induction and intubation you confirmed endotracheal tube (ETT) position. As you are securing ETT, you noticed that heart rate is 190 bpm, blood pressure is 41/12, $EtCO_2$ is 12, and the patient is difficult to ventilate. What is the *most* likely reason for these postinduction clinical findings?

A. Autonomic dysfunction
B. Latex anaphylaxis
C. Anesthetic overdose
D. ETT displacement

32. A 3-week-old baby born at 29 weeks of gestation was diagnosed with necrotizing enterocolitis and scheduled for emergent laparotomy. The baby is on high-frequency oscillator ventilation and high-dose dopamine infusion. What is the next step in your anesthetic plan?

A. Transport patient to operating room on transport ventilator.
B. Perform spinal anesthesia to avoid general anesthetic toxicity.
C. Perform procedure at bedside as the patient is too sick to transport.
D. Keep patient on room air to avoid O_2 toxicity.

33. What is the *most* likely contributing factor to development of necrotizing enterocolitis in infants?

A. NPO status
B. Low Apgar scores
C. Extreme prematurity
D. Low birth weight

34. A 2-month-old baby boy is scheduled for a laparoscopic pyloromyotomy. He was born at term and has been healthy until 3 weeks ago when he started having projectile nonbilious vomiting. He was admitted for IV hydration 24 hours ago. What would indicate that the baby is underresuscitated?

A. Hematocrit 59
B. Potassium 4.1
C. pH 7.46
D. Chloride 99

35. A 6-week-old baby boy has been vomiting for 3 weeks now and is admitted with the diagnosis of pyloric stenosis. Which of the following is an unlikely finding in this patient?

A. Metabolic alkalosis
B. Metabolic acidosis
C. CSF alkalosis
D. CSF acidosis

36. A 3-week-old 4.1 kg neonate is scheduled for resection of large sacroccocygeal teratoma. What access is the most desirable access for this patient?

A. 24 G hand PIV
B. 4 Fr femoral CVL
C. 4.5 Fr IJ CVL
D. 24 G scalp PIV

37. A 2-week-old 4.1 kg infant is scheduled for resection of large sacrococcygeal teratoma. Intraoperatively there is extensive hemorrhage, and you proceed with rapid transfusion. You are able to maintain the serum hematocrit and pH within normal ranges. Suddenly, the patient becomes bradycardic and then asystolic. What is the *most* likely cause of cardiac arrest?

A. Hypercalcemia
B. Hypoglycemia
C. Hyperkalemia
D. Hypernatremia

38. A term 6-day-old 2.7 kg baby with vein of Galen malformation is scheduled for diagnostic and possibly interventional angiography. The baby does not have associated congenital anomalies. You came to the NICU to preop the patient: he is intubated and has appropriate venous and arterial access (UVC, UAC), heart rate 190 bpm, blood pressure 52/19, saturation 81% on 100% O_2. Patient has been receiving IV hydration; glucose, electrolytes, and Hgb are normal; ventilation is adequate; and patient is well sedated. What is the most likely reason for his blood pressure and saturation?

A. Patent ductus arteriosus
B. High-output cardiac failure
C. Equipment malfunction
D. Normal blood pressure and saturation

39. What is the main goal of medical therapy in a stable neonate with large vein of Galen malformation?

A. Cerebral vasodilation
B. Cerebral vasoconstriction
C. Systemic vasodilation
D. Systemic vasoconstriction

40. A 2-day-old term baby is scheduled for laparotomy and repair of duodenal atresia. What is the most likely chromosomal abnormality duodenal atresia is associated with?

A. Edward syndrome
B. Down syndrome

C. Patau syndrome
D. Turner syndrome

41. A 3-day-old baby with vomiting and "double-bubble sign" on KUB was recently transferred to your hospital and scheduled for laparoscopy. He was born prematurely at 34 weeks of gestation. Pregnancy was complicated by oligohydramnios. You came to the NICU to assess the baby: he has almond shaped eyes, flat nose, protruding tongue, small ears, and short stubby fingers. Genetic tests are pending. He is in no acute distress, on nasal cannula with room air, heart rate 160, blood pressure 68/31, saturation 83%, with established IV access and nasogastric tube in situ. What is the most likely cause of the desaturation?

A. Pulmonary hypoplasia
B. Congenital heart disease
C. Low cardiac output state
D. Genetic disorder

42. A 3-week-old infant with congenital diaphragmatic hernia is scheduled for surgical repair in the operating room. He was recently decannulated from extracorporeal membrane oxygenation (ECMO). What will be part of your anesthesia plan for this patient?

A. Use of large tidal volumes
B. Permissive hypercapnea
C. Avoid placing PIVs in hands
D. Use only inhaled anesthetics

43. What is the most beneficial intervention for a critically ill 2-day-old infant with large congenital diaphragmatic hernia?

A. Lung protective ventilation
B. Avoidance of nitric oxide
C. Early surgical repair
D. Cardiopulmonary bypass

44. A 2-day-old neonate is scheduled for tracheoesophageal fistula (TEF) repair. You established an airway and are ready to position the patient for thoracotomy. What could be the reason for placing the patient in right decubitus position instead of left decubitus?

A. Long esophageal gap
B. Associated Tetralogy of Fallot
C. Bidirectional shunt across patent ductus arteriosus (PDA)
D. Large right pleural effusion

45. A 2-day-old neonate is scheduled for TEF repair. Birth weight is 1.6 kg. Your surgeon is planning to start the procedure with gastrostomy tube placement. What would be a contraindication for gastrostomy?

A. Type C TEF
B. Severe Respiratory Distress Syndrome (RDS)
C. Patient's weight
D. Pig bronchus

46. A 5-day-old neonate is scheduled for repair of gastroschisis. What is the most likely cause of this defect?

A. Abdominal cavity underdevelopment
B. Thoracic cavity underdevelopment
C. Right omphalomesenteric artery ischemia
D. Failure of exocelomic space closure

47. A 2-week-old neonate with omphalocele is scheduled for a final abdominal closure. What would alert you intraoperatively that the patient is not ready for the closure?

A. Hypothermia
B. Hypotension
C. Respiratory acidosis
D. Decreased urine output

48. A 2-week-old term neonate with congenital lobar emphysema is scheduled for urgent thoracotomy. The patient's IV infiltrated and he currently does not have intravenous access. What is the safest way to induce anesthesia in this patient?

A. Rapid sequence induction
B. Awake intubation
C. Mask induction
D. IM ketamine + local

49. A 2-month-old 4.5 kg infant with congenital emphysema presents for thoracoscopic lobectomy. Your surgeon requests lung isolation. What is the best way to isolate lung in this patient?

A. Place double-lumen ETT
B. Place Univent ETT
C. Place bronchial blocker intraluminally
D. Place bronchial blocker extraluminally

50. Compared to clamping the umbilical cord immediately after delivery of a normal 1 kg preterm newborn, which of the following is *most* likely to be decreased as a result of delaying cord clamping by 2–3 minutes?

A. Hematocrit
B. Risk of intraventricular hemorrhage
C. Apgar score
D. Blood volume

51. You are called to assist at an emergent caesarean delivery. The neonate has just been delivered, and

you begin to assess its vital signs. Despite opening the airway, providing tactile stimulation, and initiating positive-pressure ventilation, the neonate remains apneic and has a heart rate of 50 beats per minute. According to the 2010 American Heart Association Neonatal Resuscitation guidelines, which of the following interventions is *most* appropriate at this time?

A. Administration of epinephrine
B. Administration of atropine
C. Administration of vasopressin
D. Initiation of chest compressions

52. A 6-week-old child with Tetralogy of Fallot is scheduled for a pyloromyotomy. Which of the following would be the best drug for induction of anesthesia in this baby?

A. Propofol
B. Ketamine
C. Sevoflurane
D. Thiopental

53. A healthy infant is undergoing a bilateral herniorrhaphy. After inducing general anesthesia and with the baby breathing spontaneously, a caudal block was placed for postoperative analgesia. The anesthesiologist suspects that the local anesthetic was inadvertently injected into the intrathecal space. Which of the following would be the *most* likely manifestation of total spinal anesthesia in an infant?

A. Bradycardia
B. Hypertension
C. Hypotension
D. Apnea

54. Which of the following is *most* likely to result from the administration of intravenous caffeine to an infant for the prevention of postoperative apnea?

A. Irritability
B. Hypoxemia
C. Hypothermia
D. Bradycardia

55. You are called to evaluate an infant in the NICU in preparation for surgery. The baby is a 6-hour-old, full-term, 2.5 kg girl with hydrocephalus and myelomeningocele. Which one of the following is associated with myelomeningocele?

A. Sleep-disordered breathing
B. Double collecting urinary system
C. Hyperkalemia after succinylcholine administration
D. Genu valgum

56. Which one of the following statements describes caudal blocks in neonates?

A. It is a less commonly used regional technique than epidurals in neonates and infants.
B. Epinephrine is not added to local anesthetic caudal solutions.
C. A "pop" is felt when the sacrococcygeal ligament is accessed.
D. Bupivicaine has a less cardiodepressant effect than ropivicaine.

57. Which of the following conditions is *most* likely to contribute to the reversion to fetal circulation in a neonate?

A. Hyperthermia
B. Hypokalemia
C. Hyperoxia
D. Acidosis

58. An 8-week-old infant who was born at 34 weeks postconceptual age presents with an incarcerated inguinal hernia. Results of preoperative laboratory testing include a hemoglobin concentration of 8 g/dL. Which of the following statements describes the neonate's anemia?

A. The nadir of hemoglobin concentration due to "physiologic anemia" would be expected to occur at approximately 18 weeks following birth.
B. The severity of "physiologic anemia" is unrelated to gestational age at birth.
C. The shorter duration of red blood cell survival contributes to the development of physiologic anemia.
D. Iron deficiency is likely a contributing factor.

59. Which of the following is the most appropriate anesthetic management for a 3-week-old neonate scheduled for pyloromyotomy?

A. Avoidance of atropine
B. Administration of 25 μg/kg of fentanyl
C. Gastric decompression prior to induction of anesthesia
D. General anesthesia via laryngeal mask airway

60. Which of the following values is *most* likely normal for a 3 kg newborn of term gestation in the first 12 hours of life?

A. Heart rate 160 beats/min
B. Blood pressure 65/45 mm Hg
C. Respiratory rate 20 breaths/min
D. Blood volume 150 mL

61. Which of the following is a component of the Apgar score for assessment of the newborn?

A. Serum glucose
B. Muscle tone
C. Blood pressure
D. Temperature

62. Which one of the following neonatal problems has an increased incidence in premature infants?

A. Hypermagnesemia
B. Hypercalcemia
C. Thrombocytosis
D. Apnea

63. A 4.9 kg, 2-month-old, otherwise healthy male infant has a right inguinal hernia. You perform a spinal anesthetic for the inguinal hernia repair. The nurse lifts the legs to place a grounding pad on the infant. Which one of the following options is the earliest sign of a high spinal in an infant?

A. Hypotension followed by decreased ventilation
B. Apnea with no change in blood pressure
C. Hypotension with no change in ventilation
D. Bradycardia

64. An 11-month-old, 10 kg male has burns to his head, both arms, and anterior trunk. Which one of the following treatment options is the most appropriate initial fluid replacement?

A. Begin with normal saline at 135 mL/hr and titrate to urine output.
B. Begin with normal saline at 40 mL/hr and titrate to urine output.
C. Begin with albumin 5% at 40 mL/hr.
D. Begin with D5 + 0.5 normal saline at 135 mL/hr.

65. A 6-month-old neonate with craniosynostosis is scheduled for a strip craniectomy. Which one of the following statements is true about the anesthetic management?

A. This surgery is always associated with massive blood loss.
B. Surgery should be deferred until 1 year of age.
C. This procedure can be done endoscopically.
D. Airway abnormalities are rarely associated with craniosynostosis.

66. Which of the following *most* accurately characterizes the airway anatomy of a neonate compared to that of an adult?

A. The epiglottis is relatively shorter in a neonate than in an adult.
B. The larynx is located more cephalad in the neck in a neonate than in an adult.
C. The vocal cords are more perpendicular to the axis of the trachea in a neonate than in an adult.
D. The tongue is relatively smaller in a neonate than in an adult.

67. A 1-day-old, 3 kg neonate born at 38 weeks gestation presents to the operating room for congenital diaphragmatic hernia repair. Which statement about this patient is *most* likely true?

A. Positive pressure ventilation by mask should be performed prior to intubation.
B. Elevated peak inspiratory pressure predisposes to pneumothorax.
C. Orogastric suctioning is contraindicated.
D. The vast majority of diaphragmatic hernias occur on the right side of the chest.

68. A 9-month-old girl presents with a new onset of respiratory distress following a 2-day history of a viral upper respiratory tract infection manifested by rhinnorhea and cough. The infant is noted to have a respiratory rate of 45 breaths/minute, supraclavicular retractions, and nasal flaring. Her temperature is 37.8°C, and she occasionally has a high-pitched "barking" cough. Based on this information, the *most* likely diagnosis is:

A. Epiglottitis
B. Foreign body in trachea
C. Tracheomalacia
D. Croup

69. A 6 kg, 6-week-old male infant with a palpable epigastric mass presents with a 2-day history of projectile vomiting. Which of the following is the *most* appropriate initial management step?

A. Emergency pyloromyotomy
B. Intravenous administration of sodium bicarbonate
C. Intravenous administration of 0.9% sodium chloride solution
D. Oral administration of sodium bicitrate

CHAPTER 13 ANSWERS

1. ANSWER: C

Glomerular filtration rate (GFR) is only 15%–30% **of the normal adult value at birth**, but only takes 5–10 **days to improve** to 50% of the adult value. However, it takes a much longer time to gradually attain the **normal adult value**, usually by the age of **1 year**. This low GFR at birth vastly **diminishes** the neonate's **ability to concentrate urine** (to a maximum of 200–800 mOsm/L) and **excrete sodium and water loads**. Moreover, this also impairs a neonate's ability to secrete drugs.

A fetus's kidneys are not responsible for any metabolic function in utero (performed by the placenta), but only become **metabolically active after birth** and **separation from the placenta**. However, the kidneys are still very active in utero, producing large amounts of urine, which **maintains amniotic fluid volume**. In the case of **renal agenesis**, the lack of amniotic fluid production by the kidneys **causes Potter syndrome (pulmonary hypoplasia, skeletal deformities, and a disfigured face).**

Since **distal tubular function** does not develop until about 32–34 **weeks of gestation**, **preterm** infants (weighing less than 1000 g) are at risk of **hyperkalemia and dysrhythmias**. In addition to immature tubular function, **relative hypoaldosteronism** is also thought to be a contributing factor to a preterm infant's risk of developing hyperkalemia.

The vast majority of normal infants (90%) void within 24 hours after birth; all should have voided by 48 hours.

KEY FACTS

- GFR is only 15%–30% of the normal adult value at birth.
- Low GFR at birth vastly diminishes the neonate's ability to concentrate urine, to excrete sodium and water loads, and to secrete drugs.
- GFR attains normal adult value by the age of 1 year.
- Potter syndrome (renal agenesis; lack of amniotic fluid production by the kidneys): pulmonary hypoplasia, skeletal deformities, and a disfigured face.

REFERENCE

Coté CJ, Lerman J, Todres ID, eds. *A Practice of Anesthesia for Infants and Children*. 4th ed. Philadelphia, PA: Saunders Elsevier; 2009:19.

2. ANSWER: D

Amniotic band sequence, or **Streeter anomaly**, has a wide case-to-case presentation, but typically includes **self-amputation** of **limbs** or **digits** (and scarring) due to ring-like **constriction from amniotic bands** formed in utero. In addition, **distal syndactyly** is possible. This sequence can also lead to other anomalies of the **head (cleft lip/palate), brain (hydrocephaly, anencephaly, encephalocele), heart, lungs, diaphragm, gut (omphalocele, gastroschisis), kidneys, and/or gonads**. Incidence is reported to be 1:1200 live births, and the cause of the amniotic band disruption is generally unknown, although **vascular, mechanical, genetic, and germ disc disruption** are all proposed theories to explain the formation of amniotic bands. These bands disrupt embryonic growth, and if present early enough in gestation can affect the development of internal organs. Thus, these neonates can present with **unusual** and **variable malformations**.

A thorough preanesthetic workup is crucial to **identify any other organ systems** that may be **involved**, especially cardiac, pulmonary, or neurologic abnormalities. This is important even in the child who may appear to have isolated limb or digit involvement. Due to the possibility of head/neck/facial anomalies (and/or cleft lip/palate), the **airway** should be assessed in anticipation of a difficult laryngoscopy and intubation. Due to possible severe limb abnormalities, **peripheral IV access** can be challenging to obtain and proper positioning is important to **prevent ischemia in limbs** that may already have inherent vascular compromise from the disorder.

Two other associated complexes with amniotic band sequence include the (1) **ADAM complex (amniotic deformity, adhesions, and mutilation)**: presents with amniotic deformity, cleft lip and palate, and other facial malformations; and (2) **LBWD complex (limb and body wall defect)**: a very severe clinical presentation with death soon after birth from hypoplasia of all major internal organs and primary limb defects.

Unilateral nevus flammeus is the typical facial hemangioma/"port-wine stain" lesion in **Sturge-Weber syndrome**. This corresponds to the **ophthalmic division** of **cranial nerve V (trigeminal nerve)**. This neurocutaneous syndrome can also include other ipsilateral vascular **anomalies (choroid or meningeal angioma), contralateral hemiparesis/hemianopia, intracranial calcifications, and severe seizures**.

Intestinal malrotation or vascular rings are not commonly associated with amniotic band sequence.

KEY FACTS

- Self-amputation of limbs or digits (and scarring) due to ring-like constriction from amniotic bands formed in utero; distal syndactyly is possible.
- Can also lead to other anomalies of the head (cleft lip/palate), brain (hydrocephaly, anencephaly, encephalocele), heart, lungs, diaphragm, gut (omphalocele, gastroschisis), kidneys, and/or gonads.

- These bands disrupt embryonic growth and, if present early enough in gestation, can affect the development of internal organs.

REFERENCE

Bissonnette B, Luginbuehl I, Marciniak B, et al. *Syndromes: Rapid Recognition and Perioperative Implications*. New York, NY: McGraw-Hill; 2006:771–2.

3. ANSWER: B

The **Apgar score**, first described by anesthesiologist Dr. Virginia Apgar in 1953, is still used to recognize and guide management of newborns who may need active resuscitation. The newborn is **assessed at 1- and 5-minute intervals** and evaluated based on five categories: **heart rate, breathing, reflex irritability, muscle tone, and color**—with a score of 0, 1, or 2 in each category and added together to give a maximum possible score of 10. However, a 1- or 5-minute Apgar score of 10 is rare, as it is physiologically normal for the term newborn to have peripheral cyanosis (acrocyanosis) beyond 5 minutes. The pneumonic Apgar can be used to remember the five elements of the score (Table 13.1).

The newborn in the question stem scored 1 point in each category, for a total score of 5 (Answer B).

The Apgar score can be used to guide resuscitative efforts and care of the newborn. An infant with an **Apgar score of** 5–7, as in this case, likely has experienced **mild perinatal asphyxia/hypoxia** and usually requires more aggressive care in the initial resuscitation. Even though these newborns usually respond to tactile stimulation and supplemental oxygen via blow-by mask, positive-pressure ventilation of the lungs should be started with oxygen/bag-mask ventilation if the newborn does not respond within 1 minute and if the heart rate is less than 100 bpm.

An **Apgar score of 4** or below usually describes an infant who is **cyanotic with very poor respiratory efforts**. These newborns are moderately to severely depressed and need institution of positive-pressure ventilation with oxygen/bag-mask ventilation within 30 seconds if, after aggressive tactile stimulation, ventilation is still inadequate or the heart rate persists below 100 bpm. If the newborn does not begin adequate spontaneous respirations promptly or if bag-mask ventilation is ineffective, tracheal intubation or placement of an LMA should be undertaken. **Ventilation** rate should be kept around 40–60 **breaths/minute** and airway pressure should be adequate to achieve a prompt increase **in heart rate to >100** bpm and/or visible chest rise. External **chest compressions/CPR** should begin if the **heart rate** remains **below 60 bpm after 30 seconds of effective positive-pressure ventilation**, according to the AAP's Newborn Resuscitation Algorithm.

It is important to stress that initial care of the newborn, warming, drying, and providing tactile stimulation (and beginning bag-mask ventilation if indicated), should not be delayed to obtain the initial 1-minute Apgar score—it should begin immediately upon delivery.

KEY FACTS

- Recognize and guide management of newborns who may need active resuscitation.
- The newborn is assessed at 1- and 5-minute intervals and evaluated based on five categories: heart rate, breathing, reflex irritability, muscle tone, and color—with a score of 0, 1, or 2 in each category and added together to give a maximum possible score of 10 (see Table 13.1).

REFERENCES

Apgar V. A proposal for a new method of evaluation of the newborn infant. *Anesth Analg*. 1953;32:260–7.

Holzman RS, Mancuso TJ, Polaner DM, eds. *A Practical Approach to Pediatric Anesthesia*. Philadelphia, PA: Lippincott Williams & Wilkins; 2008:584–9.

Kattwinkel J, Perlman JM, Aziz K, et al. Part 15: neonatal resuscitation: 2010 American Heart Association Guidelines for Cardiopulmonary Resuscitation and Emergency Cardiovascular Care. *Circulation*. 2010;122:S909–19.

Stoelting RK, Miller RD, eds. *Basics of Anesthesia*, 5th ed. Philadelphia, PA: Churchill Livingstone; 2007:499–501.

4. ANSWER: C

The Apgar score, first described by anesthesiologist Dr. Virginia Apgar in 1953, is still used to recognize and guide management of newborns who may need active resuscitation. The newborn is **assessed at 1- and 5-minute intervals** and evaluated based on five categories: **heart rate, breathing, reflex irritability, muscle tone, and color**—with a score of 0, 1, or 2 in each category and added together to give a **maximum possible score of 10**. However, a 1- or 5-minute Apgar score of 10 is rare as it is physiologically normal for the term newborn to have peripheral cyanosis (acrocyanosis) beyond 5 minutes. The pneumonic Apgar score can be used to remember the five elements of the score (Table 13.1).

The newborn in the question stem scored 0 points in the appearance/color category, but 2 points in each of the other four categories for a total score of 8.

The Apgar score can be used to guide resuscitative efforts and care of the newborn. An infant with an **Apgar score of equal or more than 8**, as in this case, usually only needs **routine postdelivery care clearing the airway if necessary, providing active drying of the skin, tactile stimulation to promote breathing, and warming**

Table 13.1 APGAR SCORE

		0	1	2
*A*ppearance	Color	Cyanotic or pale	Extremities/periphery cyanotic, body pink	Completely pink
*P*ulse	Heart rate (bpm)	Absent	<100	>100
*G*rimace	Reflex irritability	No response	Facial grimace	Actively coughing, crying
*A*ctivity	Muscle tone	Limp	Extremities flexed	Actively moving, vigorous
*R*espirations	Breathing effort	Apnea	Slow, irregular	Crying, good effort

measures to prevent hypothermia (skin-to-skin contact with the mother, wrapping in warm blankets, and/or placing in a radiant-warmed crib).

A newborn who is otherwise doing well but has **persistent central cyanosis** should have a thorough workup to include evaluation for **possible cyanotic cardiac disease**, among other things.

It is important to stress that initial care of the newborn, to include warming, drying, and providing tactile stimulation (and beginning bag-mask ventilation if indicated), should not be delayed to obtain the initial 1-minute Apgar score—it should begin immediately upon delivery.

KEY FACTS

- Recognize and guide management of newborns who may need active resuscitation
- The newborn is assessed at 1- and 5-minute intervals and evaluated based on five categories: heart rate, breathing, reflex irritability, muscle tone, and color—with a score of 0, 1, or 2 in each category and added together to give a maximum possible score of 10 (see Table 13.1).

REFERENCES

Apgar V. A proposal for a new method of evaluation of the newborn infant. *Anesth Analg*. 1953;32:260–7.

Holzman RS, Mancuso TJ, Polaner DM, eds. *A Practical Approach to Pdiatric Anesthesia*. Philadelphia, PA: Lippincott Williams & Wilkins; 2008:584–9.

Stoelting RK, Miller, RD, eds. *Basics of Anesthesia*. 5th ed. Philadelphia, PA: Churchill Livingstone; 2007:499–501.

5. ANSWER: A

The initial management of a newborn after delivery (*neonatal resuscitation*) depends on whether the baby was born through clear or meconium stained amniotic fluid and whether the baby is depressed or vigorous at birth. The initial management of any newborn begins with **providing a warm environment** to prevent hypothermia (either skin-to-skin contact with the mother if the infant is breathing well vigorous stimulation, wrapping in warm blankets, or placing under a radiant warmer), **clearing the airway *if necessary*** (active airway suctioning may precipitate a vagal response and bradycardia in a newborn, so just wiping the baby's mouth and face is often adequate—otherwise you may use bulb suction or a suction catheter if the baby has evidence of obstruction to spontaneous ventilation or if you are planning on instituting positive-pressure ventilation), **drying** the baby, and **providing tactile stimulation**. These are often the only initial newborn care steps necessary with babies who are born **vigorous through clear amniotic fluid**. You would also manage expectantly with oxygen, if needed, based on the newborn's other vital signs, and according to the AAP's Newborn Resuscitation Algorithm.

If a baby born through clear amniotic fluid remains limp after the initial steps (warm, dry, stimulate), more **aggressive tactile stimulation** can be accomplished via **slapping/flicking the bottom of the feet** or **rubbing the back**. If a newborn has **primary apnea** (which is common following a period of tachypnea), these additional measures will stimulate the newborn to breathe. If the baby continues to have poor respiratory efforts (gasping, irregular breathing) or apnea after aggressive stimulation, this describes **secondary apnea** and the newborn will need to have **positive-pressure ventilation** via mask instituted. These babies often have **bradycardia (heart rate <100 bpm)** as well.

The newborn should show a rapid and striking improvement in his or her condition and heart rate after receiving effective positive-pressure ventilation of the lungs.

When providing **positive-pressure ventilation**, the respiratory rate should be 40–60 **breaths/min**. Adequate airway pressure is needed to gently inflate the lungs (may see visible chest rise). Effective assisted ventilation is evident by a newborn achieving a heart rate >100 bpm and sustaining that rate. There remains some controversy about the concentration of oxygen (21%–100%) delivered via positive-pressure ventilation during of newborn resuscitation. Oxygen at 21% (room air) *may* be used initially (if an oxygen blender is unavailable) but should be switched to 100% if the newborn remains bradycardic (heart rate <60 bpm) after 90 seconds of the initial resuscitation. Likewise,

Table 13.2 INITIAL NEWBORN RESUSCITATION STEPS

	VIGOROUS INFANT	DEPRESSED OR LIMP INFANT
Amniotic fluid: clear	Clear airway if necessary (wipe face and mouth), dry, warm, and stimulate Manage expectantly with O_2 if needed	Begin with same steps as for a vigorous infant; may need more aggressive stimulation May need to begin positive-pressure ventilation with oxygen if baby has secondary apnea
Amniotic fluid: meconium stained	Clear airway (suction mouth and nose), dry, warm, and stimulate Manage expectantly with O_2 if needed	Intubate and suction the trachea until clear of meconium If newborn is still limp or depressed, reintubate and provide positive-pressure ventilation with oxygen

once pulse-oximetry is utilized (which is recommended as early as possible in the resuscitation), one should titrate the oxygen concentration according to the newborn's preductal oxygen saturation as a function of minutes after birth, according to the table in the AAP's Newborn Resuscitation Algorithm. Both hypoxia and hyperoxia can be harmful during newborn resuscitation.

The resuscitation of the newborn born through **meconium-stained amniotic fluid** has changed in recent years. Currently, it is advised that *not* every newborn born through thick meconium needs to be intubated with the trachea suctioned. **If the newborn has good muscle tone and has vigorous respiratory efforts, you do not need to intubate and suction meconium from the trachea.** You should start the initial resuscitation with clearing the airway by suctioning the mouth and nose (and wipe the face), and then provide initial newborn care as you would to any baby (dry, warm, and stimulate). You should manage expectantly with oxygen if necessary. Therefore, since the newborn in the question stem is vigorous with good respiratory efforts, Answer A would be the correct response.

If the baby is born through meconium-stained amniotic fluid and is depressed or limp, you should intubate and suction the trachea until meconium is cleared. If after clearing the airway and trachea the baby is still limp or depressed, you should reintubate and provide positive-pressure ventilation while continuing to assess the baby's breathing efforts, heart rate, color, and tone.

KEY FACTS

- The initial management of any newborn begins with providing a warm environment, clearing the airway *if necessary*, drying the baby, and providing tactile stimulation.
- If a newborn has primary apnea, additional stimulation measures will be necessary to initiate breathing.
- If the baby continues to have poor respiratory efforts (gasping, irregular breathing) or apnea after aggressive stimulation, this describes secondary apnea and the newborn will need to have positive-pressure ventilation via mask instituted.
- The newborn should show a rapid and striking improvement in his or her condition and heart rate after receiving effective positive-pressure ventilation of the lungs.
- If a newborn born through meconium has good muscle tone and has vigorous respiratory efforts, you do not need to intubate and suction meconium from the trachea.
- If the baby is born through meconium-stained amniotic fluid and is depressed or limp, you should intubate and suction the trachea until meconium is cleared (see Table 13.2).

REFERENCES

Holzman RS, Mancuso TJ, Polaner DM, eds. *A Practical Approach to Pediatric Anesthesia*. Philadelphia, PA: Lippincott Williams & Wilkins; 2008:583–93.

Kattwinkel J, Perlman JM, Aziz K, et al. Part 15: neonatal resuscitation: 2010 American Heart Association Guidelines for Cardiopulmonary Resuscitation and Emergency Cardiovascular Care. *Circulation*. 2010;122:S909–19.

Stoelting RK, Miller RD, eds. *Basics of Anesthesia*, 5th ed. Philadelphia, PA: Churchill Livingstone; 2007:499–503.

6. ANSWER: D

The initial management of any newborn begins with **providing a warm environment** to prevent hypothermia (either skin-to-skin contact with the mother if the infant is breathing well and is vigorous, wrapping in warm blankets, or placing under a radiant warmer), **clearing the airway *if necessary*** (active airway suctioning may precipitate a vagal response and bradycardia in a newborn so just wiping the baby's mouth and face is often adequate—otherwise you may use bulb suction or a suction catheter if the baby has evidence of obstruction to spontaneous ventilation or if you are planning on instituting positive-pressure ventilation, as in this case), **drying** the baby, and **providing tactile stimulation**.

Practitioners involved in the initial resuscitation of the newborn need to conduct their resuscitation efforts based

on published guidelines from the AAP and their Newborn Resuscitation Algorithm. **After the initial steps have been completed (warm, clear airway if necessary, dry, and stimulate) and if the baby's heart rate is below 100 bpm, or the baby is apneic or gasping, then positive-pressure ventilation should be instituted (ideally within 30 seconds after birth)**, as in the correct Answer D.

The newborn should have a rapid and striking improvement in his or her condition after receiving effective positive-pressure ventilation of the lungs.

When providing **positive-pressure ventilation**, the respiratory rate should be **40–60 breaths/min**. Adequate airway pressure is needed to gently inflate the lungs (may see visible chest rise). To emphasize, ***effective* assisted ventilation** is evident by a newborn achieving a **heart rate >100 bpm** and sustaining that rate. There remains some controversy about the concentration of oxygen (21%–100%) to deliver via positive-pressure ventilation at the beginning of newborn resuscitation. **Oxygen at 21%** (room air) *may* be used **initially** (if an oxygen blender is unavailable), but it should be **switched to 100%** if the newborn remains **bradycardic (heart rate <60 bpm) after 90 seconds** after starting the initial resuscitation. Likewise, once pulse-oximetry is utilized (which is recommended as early as possible in the resuscitation), one should titrate the oxygen concentration according to the newborn's preductal oxygen saturation as a function of minutes after birth, according to the table in the AAP's Newborn Resuscitation Algorithm. Both hypoxia and hyperoxia can be harmful during newborn resuscitation.

If the newborn's heart rate is below 60 bpm after 30 seconds of *effective* positive-pressure ventilation with oxygen, then chest compressions are begun. The compression to ventilation ratio should be **3:1 so that 90 compressions and 30 ventilations are given in each minute.** It is important to coordinate ventilations with compressions so that they are not delivered simultaneously (thus, exhalation should occur upon delivering the first chest compression after the ventilation is given).

Tracheal intubation should be considered at several points in a newborn resuscitation:

1. If positive-pressure ventilation via mask is initially ineffective or prolonged in duration
2. When performing chest compressions
3. For initial tracheal suctioning of meconium in the depressed or limp infant born through meconium-stained amniotic fluid
4. In certain circumstances, such as prematurity (with the pulmonary administration of surfactant), or pulmonary pathology (congenital diaphragmatic hernia)

Since providing effective oxygenation and ventilation via positive-pressure ventilation with oxygen is the most effective means to resuscitate the newborn (and **bradycardia is usually the result of hypoxemia or inadequate lung insufflation**), drug administration is rarely indicated early in the resuscitation. However, if a newborn's heart rate is persistently **<60 bpm after *providing effective ventilation*** (usually confirmed via tracheal intubation and administration of 100% oxygen) *and* ***delivering high-quality chest compressions***, then **epinephrine 0.01 mg/kg IV administration** should be considered. **Volume expansion (10 mL/kg IV slowly**, which may be repeated) with an isotonic crystalloid or blood can be considered at this juncture when the above resuscitation measures have failed to improve the newborn's heart rate, and they also would be justified in the infant with signs of poor perfusion or blood loss.

Studies have shown a variable or poor clinical effect when epinephrine is administered via the endotracheal route (safety and efficacy have not been established); thus, it is overwhelmingly preferable to give **epinephrine via the IV route**. The recommended dose range is 0.01 to 0.03 mg/kg per dose (of a 1:10,000 solution, which is 0.1 mg/mL). Administering epinephrine at a higher dose (0.1 mg/kg) has shown to be harmful in the resuscitation of newborns (worse neurologic outcome, exaggerated hypertension, and depressed myocardial function) and is not recommended.

KEY FACTS

- The initial management of any newborn begins with providing a warm environment, clearing the airway *if necessary*, drying the baby, and providing tactile stimulation.
- After the initial steps have been completed (warm, clear airway if necessary, dry, and stimulate) and if the baby's heart rate is below 100 bpm, or the baby is apneic or gasping, then positive-pressure ventilation should be instituted (ideally within 30 seconds after birth).
- Respiratory rate should be 40–60 breaths/min.
- The newborn should show a rapid and striking improvement in his or her condition and heart rate after receiving effective positive-pressure ventilation of the lungs.
- If the newborn's heart rate is below 60 bpm after 30 seconds of *effective* positive-pressure ventilation with oxygen, then chest compressions are begun; compression to ventilation ratio should be 3:1 so that 90 compressions and 30 ventilations are given in each minute.

REFERENCE

Kattwinkel J, Perlman JM, Aziz K, et al. Part 15: neonatal resuscitation: 2010 American Heart Association Guidelines for Cardiopulmonary Resuscitation and Emergency Cardiovascular Care. *Circulation*. 2010;122:S909–19.

7. ANSWER: C

There are many different surgical lesions of the chest that may require operative treatment in the neonatal period. It is important to distinguish between these as they often have various responses to ventilation strategies and will likely influence clinical anesthetic management.

Congenital cystic adenomatoid malformation (CCAM) is the lesion described in the question stem and comprises about **25%** of all congenital pulmonary malformations. It is a pulmonary lesion that is **similar to bronchioles in structure but lacks any associated cartilage, bronchial glands, or alveoli (and thus does not participate in gas exchange).** In fact, it is usually caused by adenomatous "overgrowth" of terminal bronchioles (without corresponding growth of alveoli) and can resemble solid, cystic, or mixed masses in the thorax. A CCAM can even present radiographically similar to a **congenital diaphragmatic hernia (CDH)** if the CCAM is large and **contains multiple air-filled cysts**. The clinical consequence of a large CCAM can be very similar to that of a CDH—the large mass of pathologic tissue (and air-filled cysts) can compress and displace healthy lung tissue causing pulmonary hypoplasia. The **blood supply of a CCAM usually originates from the pulmonary circulation.**

Depending on the size of the lesion, the clinical presentation of CCAM can be quite variable. The vast majority of neonates **present with respiratory distress** (from pulmonary hypoplasia or compression due to mass effect and/or air trapping): **cyanosis, tachypnea, grunting/retraction with breathing, using accessory muscles for breathing, and failure to thrive**. The clinician should also strongly consider the effects of mediastinal shift or the development of a **spontaneous pneumothorax** in the neonate that has worsening respiratory insufficiency. Again, severe CCAM lesions may mimic CDH in their clinical presentation (and the neonate may need conventional or high-frequency oscillatory ventilation [HFOV])—even ECMO in extremely severe cases).

Since very large lesions can cause fetal demise or hydrops fetalis (in up to 40% of these cases), open fetal surgery should be considered at centers capable of performing such procedures. Otherwise, CCAM is an urgent lesion to address surgically after birth as **the lesion communicates with the airways such that air trapping, lung overdistension, and development (or worsening) of respiratory distress are real concerns in the neonate's first few days of life.** Prognosis after surgery for CCAM is contingent on the amount of healthy lung tissue that remains after resection (again similar to CDH), also considering that surrounding lung tissue may be hypoplastic from compression during fetal development.

Congenital diaphragmatic hernia (CDH) develops as a consequence of **failure of a portion of the fetal diaphragm to develop** in utero, which causes **herniation of abdominal contents into the chest** and subsequent **ipsilateral pulmonary hypoplasia and lung compression** (as well as possible mediastinal shift and contralateral pulmonary hypoplasia in extreme cases). CDHs are most commonly found through the posterior left portion of the diaphragm (*foramen of Bochdalek*)—an easy memory tool is to remember *"back and to the left."*

CDHs typically present either via **prenatal ultrasound** (bowel loops in the chest, hypoplasia of lung tissue, mediastinal shift) or shortly after birth with the infant exhibiting symptoms of respiratory distress and tachypnea. Distinguishing clinical signs include a **scaphoid abdomen, absent breath sounds in the ipsilateral chest (with bowel sounds present in the chest instead), radiographic findings of bowel in the chest, and mediastinal compression.**

Delivering positive-pressure ventilation via bag-mask has the potential to worsen respiratory distress if air entry into the GI system causes further enlargement of bowel in the chest. Due to significant respiratory compromise and pulmonary hypertension, **aggressive ventilation and oxygenation strategies (HFOV or ECMO)** may need to be undertaken prior to surgical correction, and immediate tracheal intubation should be performed in the neonate with significant respiratory insufficiency or distress.

Congenital lobar emphysema is a lesion that develops as a consequence of failure of cartilage development in the wall of an affected bronchus, most commonly located in the left upper lobe. Therefore, **the wall of the bronchus is weakened and prone to collapse on expiration, which can cause a "ball-valve" obstruction and subsequent air trapping/lung overexpansion.** In addition, other causes of bronchial obstruction may exist as a fetus develops, either from intrinsic (redundant bronchial mucosa, bronchial stenosis or cysts) or extrinsic (compression from anomalous vasculature or mediastinal cysts/tumors) factors.

These infants can also present with **tachypnea, tachycardia, and other signs of respiratory distress**—depending on the severity of the obstruction and air trapping. The subsequent areas of emphysematous lung can obviously compress healthy lung tissue on the ipsilateral side, but they can also cause mediastinal shift and contralateral lung compression/hypoplasia. **Delivering positive-pressure ventilation risks causing worsened lung hyperinflation and respiratory compromise; nitrous oxide is strictly contraindicated, as in most of these pulmonary lesions.** Surgical correction is usually warranted.

Pulmonary sequestration describes a nonfunctional mass of pulmonary tissue that **does *not* communicate with the tracheo-bronchial tree; thus, air trapping does *not* occur**. Patients can present in the neonatal period but also often present up to age 2 years with chronic cough, frequent pulmonary infections/pneumonia, and failure to thrive. Diagnosis is via CT, MRI, or angiography (to delineate **vascular supply, which usually originates from the**

systemic system). Since the lesion does not communicate with the airways, positive-pressure ventilation should not exacerbate any respiratory distress. However, nitrous oxide can still cause trapped air pockets within the lesion to expand and is therefore contraindicated as well.

Bronchopulmonary dysplasia (BPD) is a chronic pulmonary disease of premature infants and is diagnosed in those that **require supplemental oxygen at 36 weeks' postconceptual age *with* an abnormal chest radiograph.** This condition is most often present in premature infants that have required long-term supplemental oxygen and ventilation therapy in the neonatal intensive care unit. Overall, affected infants may exhibit abnormal lung compliance and airway resistance, which can also contribute to air trapping. BPD can linger for years after birth and cause **chronic hypoxemia, hypercarbia, and reactive airway disease.** This disease process is managed medically and through ventilator strategies and does not typically require surgical correction.

For any of these lesions, a thorough preoperative evaluation to identify any concomitant congenital defects (most important being cardiac) or chromosomal anomalies should be undertaken as they are not uncommon. For example, *congenital heart defects may be found in 20%–40% of patients with Bochdalek-type CDH.*

KEY FACTS

- CCAM:
  - 25% of all congenital pulmonary malformations
  - Similar to bronchioles in structure but lacks any associated cartilage, bronchial glands, or alveoli (and thus does not participate in gas exchange)
  - Neonates present with respiratory distress (from pulmonary hypoplasia or compression due to mass effect and/or air trapping): cyanosis, tachypnea, grunting/retraction with breathing, using accessory muscles for breathing, and failure to thrive.
  - The lesion communicates with the airways such that air trapping, lung overdistension, and development (or worsening) of respiratory distress are real concerns.

- CDH:
  - Failure of a portion of the fetal diaphragm to develop in utero, which causes herniation of abdominal contents into the chest and subsequent ipsilateral pulmonary hypoplasia and lung compression
  - Most commonly found through the posterior left portion of the diaphragm (*foramen of Bochdalek*)
  - Clinical signs include a scaphoid abdomen, absent breath sounds in the ipsilateral chest (with bowel sounds present in the chest instead), radiographic findings of bowel in the chest, and mediastinal compression.
  - Delivering positive-pressure ventilation via bag-mask has the potential to worsen respiratory distress if air entry into the GI system causes further enlargement of bowel in the chest.

- Congenital lobar emphysema
  - The wall of the bronchus is weakened and prone to collapse on expiration, which can cause a "ball-valve" obstruction and subsequent air trapping/lung overexpansion.
  - Presenting signs include tachypnea, tachycardia, and respiratory distress.
  - Delivering positive-pressure ventilation risks causing worsened lung hyperinflation and respiratory compromise; nitrous oxide is strictly contraindicated.

- Pulmonary sequestration:
  - Nonfunctional mass of pulmonary tissue that does *not* communicate with the tracheo-bronchial tree; thus, air-trapping does *not* occur.
  - Can present in the neonatal period but also often present up to age 2 years with chronic cough, frequent pulmonary infections/pneumonia, and failure to thrive.

- BPD:
  - Not a surgical lesion of the chest but a chronic pulmonary disease of premature infants and is diagnosed in those that require supplemental oxygen at 36 weeks postconceptual age *with* an abnormal chest radiograph
  - Can linger for years after birth and cause chronic hypoxemia, hypercarbia, and reactive airway disease.

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8. ANSWER: D

The normal decline in hemoglobin/hematocrit (physiologic anemia in infants) is caused by two factors:

1. A decrease in erythropoiesis
2. A diminished red blood cell life span (less significant)

This anemia usually does not cause a decrement in oxygen-delivering capacity to the tissues because the oxygen-hemoglobin dissociation curve also shifts to the right as the infant ages (due to Hemoglobin A [adult] replacing Hemoglobin F [fetal] and increased production of 2,3-diphosphoglycerate).

It usually reaches a **nadir of 10–11 g/dL** (hematocrit of 30%–33%) **at 9–12 weeks of age** in a **full-term infant.**

Preterm infants usually reach a physiologic anemia nadir **earlier (at 4–8 weeks of age)** and have **hemoglobin concentrations lower than full-term infants (as low as 8 g/dL** in infants weighing from 800 to 1000 g). Thus, Answer A would be a correct answer for a preterm infant.

Recall that anemic infants (especially premature infants) are particularly susceptible to apneic events and care should be taken in the perioperative period.

Hemoglobin levels usually remain stable from 3 months to 2 years of age at a level of 11.5 to 12 g/dL.

KEY FACTS

- Hemoglobin reaches a nadir of 10–11 g/dL (hematocrit of 30%–33%) at 9–12 weeks of age in a full-term infant.
- Preterm infants usually reach a physiologic anemia nadir earlier (at 4–8 weeks of age) and have hemoglobin concentrations lower than full-term infants (as low as 8 g/dL).

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Coté CJ, Lerman J, Todres ID, eds. *A Practice of Anesthesia for Infants and Children*. 4th ed. Philadelphia, PA: Saunders Elsevier; 2009:22.

9. ANSWER: B

Congenital diaphragmatic hernia (CDH) develops as a consequence of **failure of a portion of the fetal diaphragm to develop** in utero, which causes **herniation of abdominal contents into the chest** and subsequent ipsilateral **pulmonary hypoplasia and lung compression** (as well as possible mediastinal shift and contralateral pulmonary hypoplasia in extreme cases). CDHs are **most commonly found (90%)** through the **posterior left portion of the diaphragm (*foramen of Bochdalek*)**—an easy memory tool is to remember *"back and to the left."* This type of defect, **Bochdalek, is also much more commonly associated with other congenital defects (including a 20%–40% incidence of cardiac defects) and chromosomal anomalies (Trisomy 13 and Trisomy 18, among others).** Therefore, a thorough preoperative evaluation should be undertaken in these patients to identify any associated disease processes.

The **right anterior Morgagni-type defect is much less common (9%)**, can **present later in childhood** with **less severe signs of respiratory distress**, and often presents with **symptoms of bowel obstruction** as the major clinical feature.

There tends to be **an equal to perhaps slight male preponderance** in the incidence of CDH (which is 1:2000–5000 live births).

CDHs typically present either via prenatal ultrasound (bowel loops in the chest, hypoplasia of lung tissue, mediastinal shift) or shortly after birth with the infant exhibiting significant symptoms of respiratory distress and tachypnea. Distinguishing clinical signs include a **scaphoid abdomen, absent breath sounds in the ipsilateral chest (with bowel sounds present in the chest instead), radiographic findings of bowel in the chest, and mediastinal compression or shift.**

KEY FACTS

- Failure of a portion of the fetal diaphragm to develop in utero, which causes herniation of abdominal contents into the chest and subsequent ipsilateral pulmonary hypoplasia and lung compression (as well as possible mediastinal shift and contralateral pulmonary hypoplasia in extreme cases)
- Most commonly found (90%) through the posterior left portion of the diaphragm (*foramen of Bochdalek*)
- This type of defect, Bochdalek, is also much more commonly associated with other congenital defects (including a 20%–40% incidence of cardiac defects) and chromosomal anomalies (Trisomy 13 and Trisomy 18, among others).
- Clinical signs include a scaphoid abdomen, absent breath sounds in the ipsilateral chest (with bowel sounds present in the chest instead), radiographic findings of bowel in the chest, and mediastinal compression.
- The right anterior Morgagni-type defect is much less common (9%), can present later in childhood with less severe signs of respiratory distress, and often presents with symptoms of bowel obstruction as the major clinical feature.

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Coté CJ, Lerman J, Todres ID, eds. *A Practice of Anesthesia for Infants and Children*. 4th ed. Philadelphia, PA: Saunders Elsevier; 2009:286–8, 757–9.

Holzman RS, Mancuso TJ, Polaner DM, eds. *A Practical Approach to Pediatric Anesthesia*. Philadelphia, PA: Lippincott Williams & Wilkins; 2008:289–92.

10. ANSWER: B

This patient likely has a diagnosis of left posterolateral Bochdalek-type **congenital diaphragmatic hernia (CDH)**. Often both lungs are severely hypoplastic; therefore, providing adequate oxygenation and ventilation can be quite challenging. **Delivering positive-pressure ventilation via bag-mask has the potential to worsen respiratory distress and impair pulmonary function if air entry into the GI system causes further enlargement of bowel in the chest, aggravated mediastinal shift to the contralateral side and worsened lung compression.** ***Immediate tracheal intubation should be performed in the neonate with significant respiratory insufficiency or distress*** (Answer B).

After intubation, attempts should be made to **limit peak inspiratory pressures** while delivering **rapid low tidal volumes** in the goals of reducing the incidence of barotrauma and pneumothorax (which often occurs on the right/contralateral side of the CDH). Allowing permissive hypercapnia needs to be weighed against the possibility of exacerbating pulmonary hypertension by causing an increase in pulmonary vascular resistance (made worse by hypoxemia, significant hypercarbia, acidosis, and hypotension).

Due to significant respiratory compromise and pulmonary hypertension, aggressive ventilation and oxygenation strategies **(HFOV or ECMO)** may need to be undertaken prior to surgical correction. Inhaled nitric oxide may be beneficial in neonates who suffer from refractory pulmonary hypertension.

KEY FACTS

- Delivering positive-pressure ventilation via bag-mask has the potential to worsen respiratory distress and impair pulmonary function if air entry into the GI system causes further enlargement of bowel in the chest, aggravated mediastinal shift to the contralateral side, and worsened lung compression.
- Immediate tracheal intubation should be performed in the neonate with significant respiratory insufficiency or distress.
- Aggressive ventilation and oxygenation strategies (HFOV or ECMO) may need to be undertaken prior to surgical correction.
- Inhaled nitric oxide may be beneficial in neonates who suffer from refractory pulmonary hypertension.

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Coté CJ, Lerman J, Todres ID, eds. *A Practice of Anesthesia for Infants and Children*. 4th ed. Philadelphia, PA: Saunders Elsevier; 2009:286–8, 757–9.

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11. ANSWER: A

Most experts agree that fetuses are able to **mount a significant physiochemical/endocrine stress response from noxious stimuli as early as 18 weeks gestational age.** Various studies have been done with prolonged and repeated needling of the intrahepatic vein for intrauterine transfusion (painful stimulus) versus access via the placental cord (noninnervated and thus not painful). There was a demonstrated **increase in fetal plasma level of β-endorphin and norepinephrine after the painful stimulus evident in fetuses at 18 weeks gestation, and increases in plasma cortisol levels in fetuses from 20 weeks gestation.** Fetuses undergoing needling of the placental cord and transfusion—a nonpainful stimulus—failed to show a hormonal response. These studies show that *the hypothalamic-pituitary-adrenal axis is certainly functional in response to noxious stimuli, even at a very early gestational age.* Whether the fetus is able to perceive and be aware of the noxious stimulus as "pain" has yet to be delineated fully.

Interestingly, these hormonal responses (increases in plasma levels of β-endorphin, norepinephrine, and cortisol) can be partially (cortisol) or completely (β-endorphin) **ablated by administering fentanyl to the fetus, suggesting an "analgesic" effect via agonism at the μ-receptor.** A study done in neonates (mean gestational age of 28 weeks) who underwent patent ductus arteriosus ligation showed that fentanyl analgesia likewise prevented an increase in β-endorphin plasma levels in the treatment group versus controls. There are other studies completed in neonates that show **benefits of fentanyl analgesia for painful procedures or in ventilated patients: reduced neurologic sequelae, reduced lactate level, reduced cortisol response, and fewer complications in the postnatal period.**

These **hormonal/humoral responses to stress can be three to five times greater in neonates compared to adults** undergoing similar surgeries, with **plasma increases of catecholamines up to 400% of baseline preoperative levels in those undergoing major cardiac surgery.** In addition to increases in β-endorphin, norepinephrine, and cortisol, there is also evidence of increases in glucagon, growth hormone, glucose, prostaglandins, complement, and insulin. These hormones can show a sustained increase in plasma for several days in the postoperative period as well. To emphasize, there is an **associated increase in hospital mortality in neonates undergoing cardiac surgery who have demonstrated increases in stress hormone concentrations in the perioperative period.**

Another important consideration is the potential for **stress-induced hyperglycemia in the perioperative period to worsen neurologic outcome.** Neonates and infants can mount an extreme hyperglycemic response to major surgical stress by means of gluconeogenesis and

glycogenolysis. This hyperglycemic response has been associated with worse neurologic outcomes—especially if the neonate also suffers a corresponding period of cerebral ischemia. As introduced earlier, **the administration of high-dose fentanyl (>50 μg/kg) has also been shown to prevent the plasma level increase of many of the stress hormones and mechanisms that can lead to the development of perioperative hyperglycemia**. Therefore, by preventing hyperglycemia due to the surgical stress response, fentanyl administration may **lessen the risk of neurologic injury in the perioperative period.**

As a consequence of an increase in plasma stress hormones (namely, catecholamines as described earlier), infants and children **mount a circulatory response to noxious stimuli via systemic and pulmonary *hyper*tension**.

KEY FACTS

- Fetuses are able to mount a significant physiochemical/endocrine stress response from noxious stimuli as early as 18 weeks gestational age.
- Hormonal responses (increases in plasma levels of β-endorphin, norepinephrine, and cortisol) can be partially (cortisol) or completely (β-endorphin) ablated by administering fentanyl to the fetus, suggesting an "analgesic" effect via agonism at the μ-receptor.
- Other studies completed in neonates show benefits of fentanyl analgesia for painful procedures or in ventilated patients: reduced neurologic sequelae, reduced lactate level, reduced cortisol response, and fewer complications in the postnatal period.
- By preventing hyperglycemia due to the surgical stress response, fentanyl administration may lessen the risk of neurologic injury in the perioperative period.

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Coté CJ, Lerman J, Todres ID, eds. *A Practice of Anesthesia for Infants and Children*. 4th ed. Philadelphia, PA: Saunders Elsevier; 2009:342–3, 791–3.

12. ANSWER: C

Risk of anesthetic toxicity to the immature, developing brain is an extremely hot topic in pediatric anesthesia today. **"Accumulating evidence from juvenile animal models suggests that exposure to various anesthetic drugs above threshold doses and duration during a critical neurodevelopmental window in the absence of pain, induces widespread neuronal apoptosis, resulting in irreversible brain damage and long-term neurological sequelae which persist into adulthood"** (Bong, Allen, Kim 1419). Moreover, "taken together, the neurodegeneration precipitated by inhaled anesthetics, ketamine, and benzodiazepines **depends on the species, developmental age, the brain region, and the duration of exposure"** (Coté, Lerman, Todres 740). A thorough review of each animal study addressing this topic is beyond the scope of this text. However, references by Bong et al. and Sun at the end of this section provide in-depth discussions and cite articles for further reading. Also, the full scope of the current debate and research on this topic can be found on the SmartTots website (http://www.smarttots.org/) sponsored by SaferAnesthesia, LLC and the International Anesthesia Research Society (IARS). It contains an impressive collection of resources on this controversial topic, as well as a recent consensus statement from the U.S. Food and Drug Administration; it is an excellent educational tool for both clinicians and parents. Given the supporting evidence that anesthetic agents may cause neurotoxicity in immature animal models, Answer A would therefore be an incorrect statement.

There have been **many retrospective human cohort studies attempting to provide a causal link between exposure to general anesthetic agents and the risk of developing future neurological deficits, but *to date no causal links have been firmly proven*.** Some reports have **suggested that either multiple anesthetic exposures or prolonged anesthetic exposure in infancy predisposed to later learning disabilities and behavioral problems** compared with a single exposure or no exposure. However, other studies have **suggested potential deficits in language and reasoning at a later age when children below age 3 were exposed to a *single* anesthetic.** To further confuse the issue, other studies have even **shown no statistical difference in later academic achievement (via standardized test scores) in otherwise healthy children having anesthesia for minor surgery.** Again, see the references, as well as the SmartTots website (http://www.smarttots.org/), which provide in-depth discussions of the current human studies.

To definitively answer the question of whether anesthetic exposure during infancy (at a time of rapid brain growth and development) *directly causes* learning disabilities, diminished academic performance, and/or behavioral issues, well-designed *prospective* studies are warranted. There are two large trials that are currently underway that might help to prove or disprove a direct link between anesthesia and neurotoxicity in the developing human brain. The "GAS" study (An International Randomized Controlled Trial Comparing Regional and General Anesthesia for Effects on Neurodevelopmental Outcome and Apnea in Infants) is a randomized, *prospective* trial that will compare neurodevelopmental outcomes utilizing two different anesthetic techniques in infants undergoing inguinal herniorraphy: general anesthesia with sevoflurane versus subarachnoid block. The second study under way, the "PANDA" study (Pediatric Anesthesia and

NeuroDevelopment Assessment), is a large-scale, ambidirectional, sibling-matched cohort study that will "examine the neurodevelopmental effects of exposure to general anesthesia during inguinal hernia surgery before 36 months of age" (Sun 161). Pediatric anesthesia providers eagerly await results from these two trials. While the statement in Answer B about spinal anesthesia alone not causing future cognitive dysfunction *may* be true (the "GAS" study aims to find out), spinal anesthesia without sedation would not be an appropriate technique for the child undergoing the type and length of procedure described in the question stem.

While it might be possible that children undergoing surgery as infants later develop learning, behavioral, or neurologic issues, it may prove very difficult to attribute these problems to the anesthetic exposure alone versus the effects of the surgical procedure, physiologic response to surgery, or the debilitation of the disease state and/or hospital course. However, it has been shown in immature animal models that neuronal degeneration also occurs if an animal undergoes painful procedures *without* any anesthesia/analgesia. This has been corroborated in human studies as well; that is, **preterm infants suffer more morbidity and mortality if subjected to painful procedures without anesthesia and sedation.** Therefore, providing the patient in the question stem with general endotracheal anesthesia, as in Answer C, would be a correct response to address the mother's concerns. Given the description of the child's current poor clinical status, it would not be an appropriate medical treatment plan to delay the surgery until the child is 2 or 3 years older.

There are different animal models that demonstrate some anesthetic agents, namely volatiles, might actually possess neuroprotective properties in specific situations. Inhalational anesthetic agents (when administered at 1 MAC before and during an ischemic event) have shown some neurologic protection in neonatal pig and rat models of hypoxic-ischemic neurologic injury. It has been hypothesized that use of volatile agents in lieu of intravenous agents might be advantageous in neonatal surgeries that are high risk for periods of brain ischemia (major cardiac surgery, vein of Galen embolization, and insertion of a ventricular shunt are examples). Therefore, Answer D would be an incorrect statement.

KEY FACTS

- Animal models strongly suggest that exposure to anesthetic agents during brain development may cause neurotoxicity and increase the risk for later acquiring learning disabilities and behavior problems.
- Many retrospective human cohort studies have attempted to provide a causal link between exposure to general anesthetic agents and the risk of developing future neurological deficits, but to date no causal links have been firmly proven.
- Preterm infants suffer more morbidity and mortality if subjected to painful procedures without anesthesia and sedation.
- There are two large trials that are currently under way that might help to prove or disprove a direct link between anesthesia and neurotoxicity in the developing human brain.

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13. ANSWER: D

Please see discussion for Question 14.

14. ANSWER: C

Apnea is defined as the cessation of breathing for 20 seconds or more. For the most part apnea is a discussion for preterm and former premature infants. However, postoperative apnea has been described in infants who were born full term.

The two types of apnea relevant to the neonate are **central apnea and obstructive apnea**. Obstructive apnea is due to an infant's inability to maintain a patent airway. The primary site of airway **obstruction appears to be the pharynx,** which is the most collapsible portion of the upper airway. It may be due to incomplete maturation and poor coordination of upper airway musculature. Obstructive apnea can be treated with **changes in head position, placing an oral or nasal airway, or administering continuous positive end expiratory pressure**. Most commonly, apnea is a mixture of obstructive and central components.

Apnea of prematurity is central apnea. Anatomically, there are **decreased synaptic connections, decreased dendritic arborization, and poor myelination**. Apnea of prematurity does resolve with **maturation**. In premature infants, the central chemoreceptors have an **impaired hypercapneic ventilatory response**. Premature neonates do not respond to increasing carbon dioxide with increases in respiratory rate and tidal volume as do adults and term neonates. Preterm infants with apnea have an even greater impairment of their ventilatory response to hypercarbia.

The slope of the carbon dioxide response curve is shifted to the right in infants with apnea such that infants with apnea will have a lower minute ventilation than their counterparts without apnea at the same level of carbon dioxide.

In preterm neonates, the **peripheral chemoreceptors have an impaired hypoxic ventilatory response**. The main peripheral chemoreceptor is the carotid body. The primary carotid body receptors release transmitters in response to hypoxia, hypercapnia, and acidosis. The peripheral chemoreceptors are active only at very low oxygen levels in the fetus and are essentially silent in the immediate postnatal period because of the sudden increase in PaO_2. The chemoreceptors reset postnatally and ultimately respond to a hypoxic level of 50–70 mm Hg. Preterm infants can become apneic when the inspired oxygen is increased sufficiently to produce a physiologic denervation of peripheral chemoreceptors.

Preterm infants exhibit a **biphasic ventilatory response**. They will have an initial increase in ventilation for approximately 1 minute followed by decreased ventilation. Infants born at less than 1500 g will not have an initial period of hyperventilation. The biphasic ventilatory response to hypoxia persists for **4–6 weeks** in preterm infants. **Hyperoxia blunts the peripheral chemoreceptor response**.

Apnea is closely tied with bradycardia. In some circumstances, **bradycardia is a response to hypoxia resulting from apnea**. However, there is also evidence that bradycardia **may precede apnea** or develop simultaneously in preterm infants.

The main **treatment** for apnea of prematurity is **methylxanthine** administration. These medications (**caffeine and theophylline**) are **central stimulants** and increase respiratory output. Methylxanthines **increase minute ventilation, improve carbon dioxide sensitivity, decrease hypoxic depression, enhance diaphragmatic activity, and decrease periodic breathing**. Common side effects include tachycardia, feeding intolerance, emesis, jitteriness, restlessness, and irritability. In toxic levels there may be cardiac dysrhythmias and seizures. These medications **increase metabolic rate and oxygen consumption** and have a mild diuretic effect. **Caffeine** has essentially replaced theophylline because it has **fewer side effects,** is better tolerated, and has a greater therapeutic index. Interestingly, methylxanthines increase the cerebral metabolic rate and decrease the cerebral blood flow yet have been found to have a protective effect on chronic hypoxia-induced white matter injury. Caffeine also reduces the incidence of bronchopulmonary dysplasia and improves survival without neurodevelopmental disability in very low birth-weight infants. The mechanism of action of methylxanthines is thought to be blockade of A2A receptors on GABAergic neurons.

Additional therapies for apnea include **nasal CPAP, high-flow nasal cannula, low-flow nasal cannula, and nasal intermittent positive-pressure ventilation**. Apnea of prematurity resolves with maturation. Usually infants are symptom-free around 36 weeks post postconceptual age. Resolution of apnea is thought to be related to myelination of the brainstem.

KEY FACTS

- Apnea of prematurity resolves with maturation.
- Central chemoreceptors have an impaired hypercapneic ventilatory response.
- Peripheral chemoreceptors have an impaired hypoxic ventilatory response.
- Caffeine is a methylxanthine used for treatment of apnea of prematurity.
- Premature infants are not candidates for outpatient surgery and anesthesia until they are at least 56 weeks postconceptual age.

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15. ANSWER: B

Hemoglobin is a complex tetrameric protein that carries oxygen within the body. In healthy children and adults, hemoglobin A predominates and is composed of two alpha subunits and two beta subunits. Hemoglobin F, fetal hemoglobin, is composed of two alpha subunits and two gamma subunits. **Hemoglobin F composes 80%–90% of the hemoglobin at 10–12 weeks of gestation**. Synthesis of fetal hemoglobin occurs until approximately **38 weeks of gestation**. At birth, fetal hemoglobin comprises **70%–80%** and **decreases to 5% at 6 months of age**. Fetal hemoglobin is present in adults at approximately 2%.

In the fetus, hemoglobin carries oxygen from the chorionic villi of the maternal placenta to the tissues. Fetal hemoglobin has a greater affinity for oxygen than maternal hemoglobin due to its lower capacity to interact with 2,3-diphosphoglycerate. This enables the fetal hemoglobin to carry oxygen away from the placenta and to the fetus.

At **term**, the **neonate** has a hemoglobin concentration of about **17 g/dL**. As hemoglobin A replaces hemoglobin F, the level decreases to a **nadir of 10 g/dL**. This nadir is termed the physiologic anemia of infancy and occurs at about **8–12 weeks of age in the healthy, term neonate**. The anemia occurs **earlier in premature infants**, persists longer, and is more likely to be symptomatic with a decrease of hemoglobin

to **8 g/dL as early as the fourth week of life**. The anemia is a result of **decreased production of erythropoietin** in response to the rapid increase in oxygen tensions at birth. Low levels of erythropoietin are exacerbated by transfusion with adult blood, high in hemoglobin A because it has a lower affinity for oxygen. Thus, anemia of prematurity is a true anemia that may manifest with signs of **tachycardia, bradycardia, apnea, delayed growth, and poor weight gain**. The duration of anemia of prematurity is dependent on weight, gestational age, and the ongoing need for transfusion.

Physiologic anemia of infancy and anemia of prematurity are both anemias due to **decreased production of red blood cells**. Alternatively, anemia may be due to increased destruction of red blood cells. Anemia results in impaired oxygen-carrying capacity of the blood with relative hypoxia. Physiologic responses to anemia may include increased heart rate (for an increase in cardiac output), increased oxygen extraction, increased red blood cells (RBCs), 2,3-diphosphoglycerate, and greater production of erythropoietin. As the compensatory mechanisms are exhausted, patients will develop easy fatiguability, tachypnea, shortness of breath, and congestive cardiac decompensation.

Transient erythroblastopenia of childhood is an anemia seen in infants and children and is caused by **decreased RBC production**. The onset is usually between **6 months and 3 years of age and often follows a viral illness**. It is caused by **bone marrow suppression** on an immunologic basis. Bone marrow smear is not necessary for diagnosis but will show few to no reticulocytes and a deficiency of RBC precursors. The white blood cell (WBC) count may be normal and the platelet count may be elevated.

Another anemia caused by decreased RBC production is **congenital hypoplastic anemia**, or **diamond-blackfan anemia**. This is a severe anemia diagnosed within the first **6 months** of life. Bone marrow smear shows a **deficiency of RBC precursors**. Children with this anemia may have skeletal or craniofacial anomalies. Treatment includes steroids, transfusions, iron chelation, and stem cell transplantation.

Iron deficiency anemia can be a problem for infants who are fed cow's milk without iron supplementation, as well as adolescent females.

Hemolytic anemia is due to **increased RBC destruction**. Normal **RBC life span is 110–120 days**. In response to increased destruction of RBCs, the bone marrow will increase production, and there will be an increase in the reticulocyte count in the peripheral smear. As a result of increased hemolysis, there will be increases in the products of hemoglobin metabolism. Unconjugated bilirubin concentration will be elevated and calcium bilirubinate gallstones may form. Depending on the severity of the anemia, treatment may range from folate supplementation to transfusion or splenectomy.

Some examples of hemolytic anemia include **hereditary spherocytosis, G6PD deficiency, thalassemia, sickle cell disease, autoimmune hemolytic anemia, hemolytic uremic syndrome, thrombotic thrombocytopenic purpura, hypersplenism, DIC, and ECMO**.

KEY FACTS

- Fetal hemoglobin has a greater affinity for oxygen than maternal hemoglobin (p50 of hemoglobin F is 19 mm Hg, p50 of hemoglobin A is 27 mm Hg).
- A term neonate has a hemoglobin of 17 g/dL.
- Physiologic nadir normally occurs between 8–12 weeks with a hemoglobin of 10 g/dL.
- Premature infants develop anemia earlier than term infants and are more likely to be symptomatic from anemia.

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Holzman RS, Mancuso TJ, Polaner DM, eds. *A Practical Approach to Pediatric Anesthesia*. Philadelphia, PA: Lippincott Williams & Wilkins; 2008:517–20.

16. ANSWER: D

A 5 kg infant is likely to be a term newborn. Therefore, the estimated blood volume is 80 mL/kg or 400 mL. If this child's hematocrit decreased from 40 to 24, he or she had 200 mL blood loss. One formula for calculating this is:

$$\text{ABL} = \text{EBV} \times (\text{HI} - \text{HL}) / \text{Havg}$$

Where ABL is allowable blood loss, EBV is estimated blood volume, HI is initial hematocrit, HL is lowest hematocrit, and Havg is the average of the initial and lowest hematocrits.

KEY FACT

- Allowable blood loss = Estimated blood volume × (HI–HL)/Havg

REFERENCES

Davis PJ, Cladis FP, Motoyama EK, eds. *Smith's Anesthesia for Infants and Children*. 8th ed. St. Louis, MO: Elsevier Mosby; 2011:395–9, 409.

Holzman RS, Mancuso TJ, Polaner DM, eds. *A Practical Approach to Pediatric Anesthesia*. Philadelphia, PA: Lippincott Williams & Wilkins; 2008:517–20.

17. ANSWER: B

Bronchopulmonary dysplasia is chronic lung disease associated with prematurity. It is defined as **oxygen dependence at 36 weeks post conceptual age, including oxygen dependence for at least 28 postnatal days**. For infants born prior to 32 weeks gestation, the assessment is made at 36 postconceptual weeks. For infants born at greater than 32 weeks gestation, assessment is made at 56 days of life.

Historically, bronchopulmonary dysplasia was a fibroproliferative process with epithelial metaplasia, interstitial fibrosis, and fibrotic air space obliteration. The pattern of damage was consistent with repair and response to injury. "Old BPD" was likely caused by volutrauma. The "new BPD" is characterized by a **pattern of arrested development of the airways**. There is not prominent fibrosis but rather **dilation of the alveolar ducts,** which are the distal sites of gas exchange. Radiograpic findings show a fine, hazy parenchymal pattern with modest hyperinflation. Radiographic findings from the "old BPD" showed extensive fibrosis, cystic emphysema, and hyperinflation.

The major contributing cause of bronchopulmonary dysplasia is **prematurity**. Other contributing factors include **genetics, inflammation, infection, mechanical ventilation, and oxygen toxicity**. There are some infants who develop bronchopulmonary dysplasia after minimal exposure to oxygen, ventilation, or infection. Children with bronchopulmonary dysplasia have a higher incidence of developmental abnormalities than premature children without bronchopulmonary dysplasia.

Ventilator-induced lung injury is an important risk factor for development of bronchopulmonary dysplasia via several mechanisms. **Volutrauma** describes excessively high tidal volumes that result in alveolar distention and injury of the lung periphery. **Barotrauma** describes the injury that results from high pressures during mechanical ventilation. **Atelectotrauma** refers to the shearing forces that occur during repetitive opening and closing of alveoli. All three types of ventilator-induced lung injury lead to the initiation of an **inflammatory cascade**. Additionally, high levels of inspired oxygen cause **oxidative stress and inflammation**. Ventilatory goals in preterm neonates include avoiding volutrauma and barotrauma, maintaining positive-end expiratory pressure, and avoiding high inspired oxygen levels.

Permissive hypercapnia with CO_2 levels of 45–55 mm Hg is potentially safe to reduce pulmonary morbidity in mechanically ventilated infants, but **hypocapnia** is **not recommended** as it has been associated with the development of **periventricular leukomalacia**. Both **hypocapnia (<39 mm Hg) and hypercapnia (>60 mm Hg)** have been shown to **increase the risk of severe intraventricular hemorrhage** in preterm infants.

Volume-targeted ventilation has recently been demonstrated to be superior to other modes of ventilation in reducing the incidence of death, BPD, pneumothorax, severe cranial ultrasound abnormalities, and hypocarbia. However, the ability of the anesthesiologist to deliver appropriate volume-targeted ventilation depends upon the availability of appropriate ventilators.

KEY FACTS

- The pathology of bronchopulmonary dysplasia is that of arrested development of the airways with dilation of alveolar ducts.
- Prematurity is the major contributing cause of bronchopulmonary dysplasia.
- Children with bronchopulmonary dysplasia have a higher incidence of developmental abnormalities than premature children without BPD.
- Ventilator-induced lung injury is an important risk factor in the development of BPD via volutrauma, barotrauma, and atelectotrauma.
- Volume-targeted ventilation has recently been demonstrated to be superior to other ventilation modes in reducing death, BPD, and other morbidities.

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18. ANSWER: C

Please see answer discussion for Question 19.

19. ANSWER: A

Normal, healthy infants will double their birth weight by 4 months of age and triple their birth weight by 1 year of age.

Failure to thrive (FTT) is a broad term used to describe a situation in which a **child has inadequate caloric intake to meet metabolic demands**. In developing countries, the primary risks for failure to thrive are **infection and malnutrition**. In developed countries, the primary risks are **preterm birth and family dysfunction**. Most commonly, the clinical presentation is one of **poor growth, which may be accompanied by alopecia, reduced subcutaneous fat or muscle mass, and dermatitis**. In developing countries, patients may present with marasmus or kwashiorkor.

Marasmus is a form of severe malnutrition of all nutrients, especially protein and carbohydrates. Children with marasmus appear emaciated and may have a body weight

reduced to less than 60% of normal. The occurrence increases prior to age 1. Kwashiorkor is protein-energy malnutrition and is more common in children after 18 months of age. The caloric intake may be adequate in number but with inadequate protein for proper development. Both marasmus and kwashiorkor can lead to death in children if left untreated.

Essentially, the causes of **insufficient growth** include failure of a child to have **adequate caloric intake, failure of a caregiver to offer adequate calories, failure of a child to retain and use sufficient calories, or abnormally increased metabolic demands**. Causes of failure to thrive may involve any organ system and the diagnosis can be elusive.

Treatment for failure to thrive involves multiple disciplines and possibly hospital admission if outpatient management fails or if the malnutrition is severe. Reintroduction of an adequate diet should be initiated in a stepwise fashion to avoid refeeding syndrome.

KEY FACTS

- Most babies double their weight by 4 months of age and triple their birth weight by 1 year.
- When caloric intake does not meet metabolic demand, a child is at risk for FTT.
- In developed countries, prematurity and family dysfunction are the primary risks for FTT.
- Causes of FTT may involve any organ system, and the diagnosis can be elusive.
- Reintroduction of an adequate diet should be done slowly to avoid refeeding syndrome.

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20. ANSWER: A

There is dramatic growth and development in the central nervous system during the **third trimester** with up to a **five-fold increase in cortical gray and white matter**. Cells proliferate, differentiate, and migrate and the vascular network develops rapidly to keep pace. **Cerebral blood flow in late fetal life is 8–15 mL/kg per minute,** which is significantly lower than that of adults. Blood flow to the cerebral cortex is even lower. The preterm neonate is particularly susceptible to **hypoxic and ischemic insults**. During the third trimester of development, fetuses and preterm neonates are most vulnerable to **white matter injury**. **Periventricular leukomalacia** develops as a result of injury and inflammation to the white matter, which results in **neurodevelopmental delay**.

"Subplate" neurons are a population of cells unique to neural development. They are particularly numerous between **22 and 36 weeks gestation** and nearly **absent at term**. These neurons express neurotransmitters and growth factors that seem to orchestrate the migration of cells from the germinal neuroepithelium to distant sites such as the corpus callosum or thalamus. Injury to the subplate may result in compromised connectivity and **effect changes in behavior, cognition, and higher cortical functions**.

In the immature brain, there are highly vascularized areas of proliferation. Between **10 and 20 weeks gestation, neuroblasts (cerebral precursors for both gray and white matter) and glioblasts originate from the subventricular areas**. These areas are gelatinous in mid-gestation and solidify near term. The dense, well-developed vascular network from the middle and anterior cerebral arteries and the anterior choroidal artery drain into the venous system, which terminates near the head of the caudate nucleus where the veins join the vein of Galen. The primary bleeding site in the premature brain is where the veins and capillaries join. Between **25 and 32 weeks of gestation the germinal matrix** is most prominent at the **head of the caudate nucleus** and this is the usual site for germinal matrix hemorrhage.

The incidence and severity of intraventricular hemorrhage (IVH) increases with decreasing gestational age. There is an **overall incidence of 7%–23%.** The incidence of grade III and grade IV hemorrhages is approximately 10%–12% in very low birth-weight infants and has not changed in the last 10–15 years. **Mortality is approximately 50% with grade IV IVH**. Grade I and II IVH are not associated with severe neurologic sequelae, but up to 35% of survivors of grade III and 90% of survivors of grade IV IVH have poor neurodevelopmental outcomes. Intraventricular hemorrhage resulting in hydrocephalus that requires shunting is most likely to have severe neurocognitive impairment.

There are four grades used to describe intraventricular hemorrhage. **Grade I** refers to bleeding confined to the germinal matrix. **Grade II** is bleeding at the germinal matrix with some hemorrhage into the ventricles. **Grade III** involves dilation of the ventricles due to hemorrhage, and **Grade IV** involves bleeding that extends into the parenchyma of the brain.

21. ANSWER: B

Cranial ultrasound is the diagnostic method of choice and can be performed at the bedside in the neonatal intensive care unit. All infants younger than **30 weeks gestation should be screened** for intraventricular hemorrhage by ultrasound. CAT scans were used prior to the availability of

ultrasonography but are no longer indicated due to the risk of radiation exposure and cost. **MRI** is the diagnostic tool of choice for evaluation of **periventricular leukomalacia**. A complete blood count showing **anemia** may be the first sign of an intraventricular hemorrhage but does not confirm the diagnosis.

KEY FACTS

- Cerebral blood flow in late fetal life is 8–15 mL/kg per minute.
- The preterm neonate is particularly susceptible to hypoxic and ischemic insults.
- The most common site for germinal matrix hemorrhage is near the head of the caudate nucleus because this is where the germinal matrix is most prominent between 25 and 32 weeks of gestation.
- The incidence and severity of IVH increase with decreasing gestational age.
- IVH resulting in hydrocephalus that requires shunting is most likely to have severe neurocognitive impairment.

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22. ANSWER: A

Crigler-Najjar syndrome is a rare, hereditary form of **severe unconjugated hyperbilirubinemia** that results from a mutation in the **glucuronosyl transferase enzyme**. Activity of the enzyme is <10% of normal, which causes jaundice in the neonatal period. These children are at risk of **kernicterus**. For a child without neurologic symptoms, treatment involves **daily phototherapy treatment throughout childhood, exchange transfusion, early liver transplantation** (prior to the onset of neurologic damage), and **chronic phenobarbital therapy** to stimulate the activity of glucuronosyl transferase. Anesthesia implications for patients with Crigler-Najjar syndrome include **minimal fasting** because the stress of fasting can **increase plasma bilirubin concentration and the availability of phototherapy lights in the perioperative period**.

Gilbert syndrome is a more common cause of **hereditary hyperbilirubinemia** but is much **less severe** than Crigler-Najjar syndrome because the activity of glucuronosyl transferase is approximately one third of normal rather than 10%. While patients with Gilbert syndrome are at higher risk of kernicterus than the general population, they are unlikely to develop neurologic complications of hyperbilirubinemia without additional physiologic derangements, which stress the ability of the glucuronosyl transferase enzyme to conjugate bilirubin.

Fanconi syndrome is a disease of the proximal tubules of the kidneys. Failure of reabsorption of glucose, amino acids, uric acid, phosphate, and bicarbonate can result in multiple different complications, including **renal tubular acidosis and rickets**.

Lesch-Nyhan syndrome is a disorder of **purine metabolism** that occurs in males. The activity of the hypoxanthine-guanine phosphoribosyl transferase enzyme is decreased or absent, resulting in **excess purine production** and **increased concentrations of uric acid**. Patients are developmentally delayed and may have spasticity and self-mutilation patterns. Death may result from renal failure. Anesthesia management involves considerations of renal disease as well as caution with the administration of exogenous catecholemines due to an enhanced stress response.

23. ANSWER: B

Kernicterus is a term used to describe **chronic bilirubin encephalopathy**. Clinically, patients who suffer from kernicterus demonstrate **extrapyramidal movement disorders, including dystonia and choreoathetosis, hearing loss, and oculomotor paresis.** The pathologic basis of disease is present in the central nervous system. In particular, the globus pallidus, subthalamic nucleus, brainstem nuclei, hippocampal CA2 neurons, and cerebellar Purkinje cells are affected.

Clinical **jaundice** is present in up to 85% of newborns and is generally benign. It is caused by **high levels of unconjugated bilirubin**. Preterm neonates and babies who are particularly ill are most susceptible to permanent damage from high levels of unconjugated levels of bilirubin. Clinical signs of bilirubin toxicity may be nonspecific and essentially unapparent or may include **irritability, poor feeding, and lethargy**. More severe symptoms may include **respiratory distress, hypotonia, hypertonia, opisthotonus, twitching of face or limbs, and a shrill, high-pitched cry**. The classic sequelae of kernicterus is a tetrad, including **athetoid cerebral palsy, hearing loss, impairment of upward gaze, and enamel dysplasia of primary teeth**.

Bilirubin is a product of the degradation of hemoglobin and myoglobin. Unconjugated bilirubin is transported to the liver, where it is conjugated by the enzyme glucuronosyl transferase. **Conjugated bilirubin is water-soluble** and more easily excreted by the body. Unconjugated hyperbilirubinemia occurs with an increase in bilirubin production, decreased hepatic uptake of bilirubin, or decreased conjugation of bilirubin. Conjugated hyperbilirubinemia occurs with decreased canalicular transport of bilirubin, acute or

chronic hepatocellular dysfunction, or obstruction of the bile ducts. **Kernicterus is the result of unconjugated hyperbilirubinemia**.

Traditionally, the decision to treat hyperbilirubinemia in a newborn has been based on the total serum bilirubin level. However, this level is not predictive of the long-term neurologic impairment and potential development of kernicterus. The total serum bilirubin level measures the albumin-bound bilirubin, whereas it is likely the **unbound, or "free" bilirubin that causes damage** to the central nervous system. The unbound bilirubin will equilibrate in concentration across the immature blood–brain barrier. **Higher levels of unbound bilirubin** will be present with **decreased levels of albumin**. An algorithm to predict the extent of permanent damage to the central nervous system has yet to be designed. There is likely a complex interaction between the level and duration of central nervous system exposure to unbound bilirubin and the innate characteristics of the developing brain that may cause predilection to injury in one child but not another.

Bilirubin binds avidly to cell membranes and has a particular affinity for **myelin-rich membranes**, which explains the **vulnerability of neurons to bilirubin toxicity**. As a result of increased bilirubin levels, neurons have **decreased oxygen consumption** and increased release of calcium and caspase 3, which results in **apoptosis**. They also show decreased dendritic and axonal arborization, which suggests **impairment of the intercellular exchange**. Astrocytes, microglia, and oligodendrocytes are also affected by bilirubin toxicity in a similar manner.

The **mainstay of treatment** for hyperbilirubinmia and prevention of acute bilirubin encephalopathy is phototherapy. **Phototherapy** is generally considered benign but may be **dangerous** in preterm neonates with **extremely low birth weight**. If bilirubin levels continue to increase despite phototherapy, an underlying hemolytic process should be sought. The need for **exchange transfusion** has been greatly decreased with the advent of phototherapy. **Double-volume exchange transfusion** is recommended when signs of **intermediate to advanced stage of acute bilirubin toxicity** are present. Additional treatments that may come to light include intravenous immune globulin and pharmacologic therapies, including metalloporphyrins to reduce bilirubin production and phenobarbital to increase bilirubin clearance via enhanced bilirubin conjugation.

KEY FACTS

- Kernicterus is permanent neurologic damage resulting from chronic bilirubin encephalopathy.
- Preterm and sick neonates are the most susceptible to permanent damage from high levels of unconjugated levels of bilirubin.
- Clinical signs of bilirubin toxicity may be absent or consist of severe neurologic impairment.
- Bilirubin binds avidly to cells, especially the myelin-rich cells of the central nervous system.
- Crigler-Najjar syndrome is a rare, hereditary form of severe unconjugated hyperbilirubinemia that results from a mutation in the glucuronosyl transferase enzyme.

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24. ANSWER: B

When there is **a failure of pulmonary vascular resistance to decrease after birth**, the clinical diagnosis is **persistent pulmonary hypertension of the newborn (PPHN).** At approximately 30 weeks gestational age, pulmonary vascular resistance **is 2 mm Hg/mL/min/kg** and **falls to 0.4 mm Hg/mL/min/kg** within the first 24 hours after birth. High fetal pulmonary vascular resistance is caused by hypoxemia with an estimated PO_2 of the fetal pulmonary arteries of 20 mm Hg. After delivery, there is a marked rise in oxygen tension causing secretion of potent vasodilators nitric oxide and prostacyclin. The increased blood flow leads to an increase in the cross-sectional area of the pulmonary vascular bed, and this remodeling of the pulmonary vasculature continues until approximately 2 months of age, at which point normal pulmonary vascular resistance is estimated to be 0.2 mm Hg/mL/min/kg.

In persistent pulmonary hypertension, the ductus arterious is most likely to be closed, but the **foramen ovale would be expected to remain open** due to high pulmonary vascular resistance, causing high right-sided pressures and a resultant right-to-left shunt. This differs from **persistent fetal circulation in which both shunts remain open**. However, the circumstances that lead to both persistent fetal circulation and persistent pulmonary hypertension are similar.

Neonates who are subjected to physiologic stressors such as **hypoxia, hypercarbia, acidosis, hypothermia and hypoglycemia** are at risk for **developing persistent pulmonary hypertension from persistent fetal circulation** and continued overcirculation of the lungs. Patients who suffer from respiratory distress syndrome are particularly at risk for persistent pulmonary hypertension, and the condition may also be idiopathic. While persistent pulmonary hypertension is incompletely understood, it is known that there is increased muscularization of the pulmonary arterial vessels, which can lead to long-term sequelae.

Treatment of persistent pulmonary hypertension is aimed at **decreasing pulmonary vascular resistance**. If

airway disease is a contributing factor in situations such as meconium aspiration, then atelectasis and intrapulmonary shunting can be improved with **positive end expiratory pressure and exogenous surfactant. Nitric oxide** selectively decreases pulmonary vascular resistance and increases systemic oxygenation. The historic intervention of hyperventilation and hyperoxia is no longer indicated due to cerebral vasoconstriction and the development of neurodevelopmental problems.

Although nitric oxide has reduced the need for ECMO in patients with persistent pulmonary hypertension, there is a significant subset of patients who do not benefit from it. Additionally, use of nitric oxide has not been shown to impact development of bronchopulmonary dysplasia, neurodevelopmental deficits, mortality, or long-term outcomes.

KEY FACTS

- Persistent pulmonary hypertension of the newborn is when pulmonary vascular resistance fails to decrease after birth.
- Normal pulmonary vascular resistance is approximately 0.2 mm Hg/mL/min/kg and is generally present as of 2 months of age.
- In persistent pulmonary hypertension, the ductus is likely closed and the foramen ovale is likely open.
- Long-term sequelae in persistent pulmonary hypertension likely result from increased muscularization of the pulmonary arterial vessels.

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Hines RL, Marschall KE, eds. *Stoelting's Anesthesia and Co-Existing Disease*. 5th ed. Philadelphia, PA: Churchill Livingstone; 2008:100.

25. ANSWER: C

Nitric oxide causes pulmonary vasodilation. It is produced by pulmonary vascular endothelial cells. It activates **guanylate cyclase,** which **converts guanosine triphosphate (GTP) to cyclic guanosine monophosphate(cGMP),** thus decreasing smooth muscle contractility and causing vasodilation. Once nitric oxide diffuses into the intravascular space, it binds to hemoglobin, forming nitrosylmethemoglobin, which is rapidly metabolized to methemoglobin and is excreted by the kidneys. Adenylate cyclase catalyzes the conversion of ATP to cAMP.

KEY FACT

- Nitric oxide selectively decreases pulmonary vascular resistance and increases systemic oxygenation via activation of guanylate cyclase.

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Hines RL, Marschall KE, eds. *Stoelting's Anesthesia and Co-Existing Disease*. 5th ed. Philadelphia, PA: Churchill Livingstone; 2008:100.

26. ANSWER: D

The major problem with **persistent fetal circulation** is potentially **severe hypoxemia** and **compromise of end-organ tissue oxygenation**. The **normal oxygen saturation in the fetal aorta is 65%.** In transitional circulation in the first day of life it increases to 97% and increases to **99% within the first several days after birth**. A return to fetal circulation means that right atrial blood, with an oxygen saturation of 60%–65%, mixes with the well-oxygenated blood heading for the systemic circulation. Therefore, physiologic stress can lead to a severe downward spiral of oxygenation as decreased PaO_2 causes a further increase in pulmonary vascular resistance, which causes increased shunting and a further decrease in the PaO_2.

27. ANSWER: B

Persistent fetal circulation is **the postnatal occurrence of right-to-left shunting of blood in the presence of elevated left atrial pressure**. The right-to-left shunt may occur through the **foramen ovale or a patent ductus arteriosus** and occurs in the absence of congenital heart disease for this diagnosis.

In utero, gas exchange is performed by the placenta and not the lungs. Pulmonary vascular resistance is relatively high, and not more than 10% of the fetal right ventricular output circulates through the lungs. Blood returning from the inferior vena cava is directed by the eustachian valve across the foramen ovale into the left atrium and systemic circulation, thus providing the brain and the heart with blood with the highest oxygen concentration. Blood returning via the subclavian vein crosses the tricuspid valve, enters the pulmonary arteries, and passes through the

ductus arteriosus en route to the rest of the body, thus supplying blood with a lower oxygen content to parts of the body where the metabolic demands are quite low.

At birth, the first breaths of the neonate generate large negative intrapulmonary pressures causing inflation of the lungs and ultimately matched ventilation and perfusion. **The intrapulmonary pressure may be as large as 80–100 cm H_2O** in order to overcome the surface tension, low compliance, and high resistance of the fluid-filled fetal lungs. Of the first several breaths, only a small fraction of the inspired air is expired, which enables the formation of residual volume and functional residual capacity. Expansion of the lungs increases alveolar and arterial PO_2, causing dilation of the pulmonary arterioles, decreased pulmonary vascular resistance, and increased pulmonary blood flow.

In normal neonates, continued exposure to air, with a higher FiO_2 than present in fetal circulation and a decreased $PaCO_2$ causing an increased pH, causes continued reduction of pulmonary vascular resistance and continued increase in pulmonary blood flow. **Adult levels of pulmonary vascular resistance are reached by about 2 months of age.**

Persistent fetal circulation can occur through either a patent ductus arteriosus or patent foramen ovale. Under normal circumstances, the **ductus closes within 24 hours after birth** and completely seals within 3 weeks. The ductus closes due to increased PaO_2 and the dissipation of prostaglandins from the placenta after clamping of the umbilical cord. The foramen ovale closes functionally due to increased left atrial pressure, which occurs with the rise in pulmonary blood flow upon the first few breaths after birth. As with the ductus arteriosus, the anatomic closure is later; thus, in circumstances of severe physiologic stress, the foramen ovale and the ductus arteriosus can reopen, causing a return to a fetal circulatory pattern.

Physiologic stressors that can induce a return to fetal circulation include **hypoxia, hypercarbia, acidosis, hypothermia, sepsis, severe hypotension, and excessive airway pressures**. These conditions can be met with multiple clinical scenarios, including **meconium aspiration, diaphragmatic hernia, and group B *Streptococcus* infection**.

Continued hypoxemia despite ventilation with 100% FiO_2 after a severe desaturation can be explained by right-to-left shunting of blood and return to fetal circulation. An accurate diagnosis is made with the help of an echocardiogram to rule out cyanotic congenital heart disease. Clinically, patients may appear **well perfused in the preductal circulation** and **cyanotic in the postductal areas**. Therefore, the **right upper extremity** may be **pink** and the **left upper extremity and both lower extremities may appear cyanotic**.

The most important aspect of treatment for persistent fetal circulation in addition to supportive care is to diagnose and treat the underlying etiology. Patients who require ventilatory support will benefit from **continuous positive airway pressure (CPAP)** or the addition of **positive end expiratory pressure (PEEP)** when mechanical ventilation is necessary. Critically ill neonates may need paralysis and sedation as part of their treatment. **Nitric oxide** may be helpful as it selectively **decreases pulmonary vascular resistance and increases systemic oxygen levels**. Other arterial dilators are not specific to the pulmonary vasculature and result in hypotension, which precludes their usefulness. Severe cases of persistent fetal circulation may require the use of ECMO.

KEY FACTS

- Persistent fetal circulation is postnatal occurrence of right-to-left shunting of blood in the presence of elevated left atrial pressure.
- Right-to-left shunt is via a patent foramen ovale or a patent ductus arteriosus.
- In utero, less than 10% of the cardiac output passes through the pulmonary vasculature.
- Normally, the ductus arteriosus closes within 24 hours after birth due to increased PaO_2 and the dissipation of prostaglandins excreted by the placenta.
- The foramen ovale closes due to increased left atrial pressure, which occurs with the rise in pulmonary blood flow upon the first few breaths after birth.

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28. ANSWER: C

Low gestational age and birth weight are major risk factors for retinopathy of prematurity due to the extent of retinal development and vulnerability at birth. A lower birth weight is particularly relevant when a baby is small for gestational age. Preterm neonates experience a phase of **low levels of IGF-1**. Deficiency of IGF-1 is associated with **poor retinal vascular growth** and **poor postnatal weight gain,** which predicts the risk of retinopathy of prematurity. Hyperglycemia, insulin use, and the absence of omega-3 fatty acids all increase the risk of retinopathy of prematurity.

KEY FACTS

- Low gestetional age and birth weight (especially small for gestational age weights) are important risk factors for the development of ROP.

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Hellstrom A, Smith LE, Dammann O. Retinopathy of prematurity. *Lancet*. 2013:382;1445–7.

29. ANSWER: D

Retinopathy of prematurity was first described in the 1940s concurrent with the initiation of supplemental oxygen administration to preterm infants. While the oxygen administration did increase the survival of preterm infants, it clearly contributed to blindness as a result of retinopathy of prematurity, which was initially described as retrolental fibroplasia. The ideal oxygen saturation to balance the risk of retinopathy of prematurity against improved survival of premature infants is undetermined.

The neuronal and vascular development of the retina is disrupted in retinopathy of prematurity and compensatory vascularization of the retina can result in retinal detachment and blindness. **In utero, oxygen tension is low (20–30 mm Hg)** and vascular growth is normal. However, at **birth** the oxygen tension increases to 55–85 mm Hg, which represents a relative **hyperoxia** in the preterm infant and will result in an **arrest of normal retinal development**. From about 16 to 40 weeks of gestation, the retinal vessels grow radially outward from the center of the optic disc.

Retinopathy of prematurity is generally described in two phases. The **first phase** is the **arrest of normal retinal development**. In the preterm neonate, **hyperoxia leads to the suppression of oxygen-related angiogenic growth factors, including erythropoietin and vascular endothelial growth factor (VEGF).** This causes both cessation of the retinal growth and destruction of some of the existing retinal vessels. Other factors that likely play a role in the development of retinopathy of prematurity are insulin-like growth factor 1 (IGF-1) and omega-3 fatty acids.

The **second phase** begins when the **retina becomes hypoxic** due to the normal increase in metabolic activity combined with the poor vascularization, which is a result of phase 1. In response to hypoxia, there is a **proliferation of blood vessels**. However, the new vessels are leaky and inadequate for retinal perfusion, which results in **fibrous scar formation and retinal detachment**.

Important contributing factors for the development of retinopathy of prematurity include **supplemental oxygen, gestational age and birth weight, IGF-1 and postnatal weight gain, hyperglycemia, insulin, and nutrition as well as neonatal infections**. While hyperoxia is clearly a risk factor for arrest of retinal development, withholding oxygen and tolerating a relative hypoxia have been shown to increase mortality in the preterm neonate. Additionally, fluctuations in oxygen concentrations during the first few weeks of life can increase risk of disease development, and intermittent hypoxia has been associated with more severe disease.

Comorbidities of retinopathy of prematurity often include neurologic dysfunction, poor brain growth, necrotizing enterocolitis, intraventricular hemorrhage, and bronchopulmonary dysplasia.

Guidelines for screening for retinopathy of prematurity include infants with **birth weights of 1500 g or less**, **gestational age at birth of 30 weeks or less,** and other infants who may have had an unstable clinical course after delivery. Treatment involves laser **photocoagulation of the proliferative retinal vessels**. In addition to the risk of visual loss and blindness, patients have an **increased risk of myopia, hyperopia, astigmatism, and strabismus**.

KEY FACTS

- The incidence of retinopathy of prematurity is closely tied to the administration of supplemental oxygen in the preterm infant.
- Low gestational age and birth weight (especially small for gestational age weights) are important risk factors for the development of ROP.
- ROP is a result of arrested development of the retina followed by hypervascularization.
- Babies born at less than 30 weeks of gestation or under 1500 grams should be screened for ROP.
- Treatment of ROP is laser photocoagulation

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30. ANSWER: B

Please see answer discussion for Question 31.

31. ANSWER: B

Neural tube defects (NTDs) = dysraphism ("defective fusion") are generally **midline** defects that result from abnormal neural groove fusion during the **1st month of gestation** and are strongly associated with **folic acid deficiency**. They may occur anywhere along the neuroaxis from the head to the lower spine. Defects could be minor and affect only superficial bony and membranous structures or include large segments of malformed neural tissue (e.g., brain, spine).

There are three main types of NTDs: anencephaly, encephalocele, and spina bifida. **Anencephaly** is absence of most of the brain and calvarium. **Encephalocele** is

protrusion of brain and CSF. **Spina bifida** ("spine split") is the most common defect. It results from failure of posterior vertebral arch to fuse with subsequent herniation of spinal meninges (**meningocele**) or spinal meninges with neural elements of spinal cord (**myelomeningocele**). There are often accompanying central nervous system abnormalities at the level of the defect: **hydrocephalus, tethered cord, Arnold-Chiari type II malformation**. As the majority of myelomeningoceles are in the lumbar region, common symptoms are **urinary insufficiency with electrolyte abnormalities, bowel dysfunction, lower extremity weakness and spasticity, and thoracolumbar scoliosis** with possible pulmonary impairment.

The spinal cord must be surgically covered within a few days of birth. Surgical closure of the defect is emergent in infants with CSF leak age. *Anesthetic considerations* depend on the presence of associated congenital anomalies, location of the defect, and the age of the patient (Box 13.1).

KEY FACTS

- Usually midline defects
- Encephalocele—protrusion of brain and CSF (occipital or frontal)
- Spina bifida: (1) meningocele—herniation of spinal meninges; (2) myelomeningocele—herniation of spinal cord elements with meninges
- Associated central nervous system defects: hydrocephalus, Arnold-Chiari II, tethered cord usually at lumbar region → leg spasticity, scoliosis, bladder and bowel dysfunction → long-term problems
- *Anesthesia*:
  - Check for associated anomalies and neurologic deficits
  - Check for autonomic dysfunction
  - Anxiety (older kids)
  - Sensitivity to anesthetics
  - Assume latex allergy

Box 13.1 ANESTHETIC CONSIDERATIONS

Infants

- Preoperative assessment for associated anomalies
- Expect sensitivity to anesthetics (e.g., hydrocephalus, Chiari, etc.)
- Anticipate difficulties with positioning (to avoid pressure on the defect and meninges rupture): position patient supine on the "donut" ring or lateral
- Possible difficult intubation: in case of skull involvement or lateral positioning
- If CSF leak present: replace 3rd space deficit, continue antibiotics
- Prepare for possible blood loss if venous sinuses are entered: good IV access, possible A-line
- Assume latex allergy

Older patients

- Preoperative assessment for extent of neurologic deficits, VP shunt malfunction, autonomic nervous system dysfunction, seizure control, lower extremities contractures, allergies
- High anxiety in older patient from multiple surgical interventions: establish rapport with whole family, premedicate
- High risk of latex allergy: assume latex anaphylaxis
- Proper positioning and padding
- Expect sensitivity to anesthetics (e.g., hydrocephalus, Chiari malformation)
- If paralysis is present, avoid depolarizing muscular blockers (succinylcholine) and decrease dose of nondepolarizing relaxants
- Anticipate respiratory problems if there is OSA or severe scoliosis

These patients require lifelong monitoring and multidisciplinary treatment for urologic, intestinal, neurologic, musculoskeletal, and dermatologic problems.

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32. ANSWER: C

Please see answer discussion to Question 33.

33. ANSWER: C

Necrotizing enterocolitis (NEC) is a systemic process related to sepsis. It affects 4000–5000 infants in the United States each year and up to 30% die. Main risk factors are **prematurity** (more than 80% of patients are preterm) and **low birth weight**. Others are **bacterial exposure**, **antibiotic exposure** changing microbiome, **lack of enteral nutrition,** and **low perfusion states with hypoxemia**. Approximately one third of infants require surgical intervention. NEC is a costly condition as it leads indirectly to poor neurodevelopmental outcomes. Mortality is inversely related to gestational age.

Pathophysiology is multifactorial: **intestinal inflammation and necrosis (usually of terminal ileum, cecum, or ascending colon) with increased mucosal permeability and subsequent generalized infection and sepsis**. NEC is not seen in the fetus. Thus, microbial colonization is a prerequisite.

NEC presents differently in term infants (within the first 3 days of life) and preterm infants (after 2–3 weeks). In term infants there is greater association with congenital heart, bowel and neural tube defects, premature rupture of membranes, chorioamnionitis, and low Apgar scores. Infants with isolated intestinal perforation are distinct from those with definitive NEC.

There are **three stages of NEC** (Bell, 1978): **1—suspected (mild) disease, 2—definitive disease (requires medical management), and 3—advanced disease (requires surgical management)**. The clinical picture includes GI symptoms like **abdominal distension and discoloration**, **feeding intolerance, hematochezia**, and nonspecific signs related to systemic inflammatory response: **lethargy**, **hypo- or hyperglycemia**, **coagulopathy**, **bradycardia**, **apnea**, and **hypotension**. KUB reveals distended abdominal loops, pneumoperitoneum, and portal venous gas. Goals of surgery are to resect necrotic bowel and to decompress while preserving as much bowel as possible.

Monitoring includes arterial and central venous access. Inhalational agents are poorly tolerated. N_2O must be avoided. Total intravenous anesthesia (TIVA) with opiates and nondepolarizing neuromuscular agents are good options. Perioperative treatment focuses on evaluation and correction of the following disorders:

- Respiratory: Respiratory support often needed. NICU ventilator would provide advantages and should be considered. Some patients are too sick to be transported to the operating room (hypotension, HFO ventilation) and are operated on at the bedside.
- Circulatory: fluid resuscitation and vasopressors with inotropic effect (dopamine, epinephrine) could be required.
- Metabolic: Electrolyte and blood glucose monitoring are important as fluid shifts with electrolyte derangements and glucose intolerance are common.
- Hematologic: Coagulopathy with thrombocytopenia and anemia need to be corrected with platelets, red blood cells (irradiated leukoreduced and washed to avoid hyperkalemia), cryoprecipitate, and fresh frozen plasma.

KEY FACTS

- NEC is a systemic process related to sepsis. One third of patients require surgery. Mortality is 30%.
- Main risk factors are prematurity, low birth weight, lack of enteral feeds, and low perfusion states.
- Three stages of NEC (Bell): mild disease, definitive (require medical management), and advanced (require surgical management)
- Perioperative focus is correction of respiratory, circulatory, metabolic, and hematologic derangements.
- Postoperatively, mechanical ventilation and cardiovascular support are universally required in these infants.

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34. ANSWER: A

Please see answer discussion to Question 35.

35. ANSWER: D

Pyloric stenosis is **hypertrophy of the muscular layer of the pylorus**. It is frequent (1:500 live births) and more common in **first-born males**. There is a possible association with **maternal postnatal exposure to macrolides**. Pyloric stenosis usually manifests itself between **2 and 6 weeks** of life as **projectile nonbilious vomiting** and an **olive-shaped mass** can be palpated between midline and right upper quadrant of the abdomen.

With this GI obstruction, the child vomits gastric fluid containing hydrogen and chloride, which leads to **hypochloremic metabolic alkalosis with CSF alkalosis**. Although serum potassium may be normal, there is total body potassium depletion. The alkalosis is worsened by paradoxical aciduria. Renal response to vomiting is twofold. Initially, renal pH is preserved by excreting alkaline urine with sodium and potassium loss. Then with depletion of electrolytes, **paradoxic aciduria** develops: sodium retention in proximal tubules retains bicarbonate due to severe chloride depletion, while distal tubules retain potassium in exchange for hydrogen. Hypocalcemia may be associated with hyponatremia.

With further fluid loss **prerenal azotemia** could develop and patients present with **hypovolemic shock** and **metabolic acidosis**. **Hemo-concentration results in polycythemia**. See Table 13.3.

Pyloric stenosis is not a surgical but rather a **medical emergency**. Hypokalemic hypochloremic alkalosis and fluid loss should first be corrected, which usually takes 12–48 hours. Normal saline with potassium and glucose supplementation is used. Open or laparoscopic pyloromyotomy is curative. Usually general endotracheal anesthesia is used, but single shot subarachnoid block has been described.

Anesthetic considerations:

- Full stomach precautions: proper gastric suctioning in supine, right and left lateral and prone position and rapid-sequence intubation. Awake intubation, classic rapid-sequence intubation (controversial in neonates in general), and modified rapid-sequence intubation have been successfully used.
- Continue fluid resuscitation perioperatively: NaCl, D5 1/2NS + K. Avoid free water (D5).
- Avoid opiates and hyperventilation: narcotics and decreased $PaCO_2$ worsen CSF alkalosis which can lead to an increased risk of postoperatve apnea.
- Short-acting inhalational agents are less likely to cause postoperative apnea (desflurane vs. isoflurane).
- For postoperative pain: Acetaminophen and local anesthetic infilration by surgeon.

KEY FACTS

- Very common 1:500 births, first-born males, usually otherwise healthy.
- Sx at 2–6 weeks of life: nonbilious projectile vomiting, palpable olive-shaped mass in midline/RUQ
- $\downarrow K^+ \downarrow Cl^-$ *metabolic alkalosis* → dehydration → paradoxical aciduria → + metabolic acidosis
- *Medical emergency*: correct dehydration and electrolytes (NaCl + K^+ + glucose)
- Anesthesia: full stomach, avoid free H_2O (D5), avoid opiates and hyperventilation, and watch for postoperative apnea and hypoglycemia

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Table 13.3 DEHYDRATION IN CHILDREN

DEGREE OF DEHYDRATION	MILD	MODERATE	SEVERE
Fluid loss	Up to 5% of body weight	10% of body weight	15% of body weight
Fluid deficit	50 mL/kg	100 mL/kg	150 mL/kg
Symptoms	Alert, thirsty, restless	Lethargic but arousable, thirsty	Lethargic or comatose
Vital signs	Normal	Moderate tachycardia, borderline blood pressure, weak pulse, postural hypotension	Severe tachycardia, hypotension, weak pulses, tachypnea, cold skin, decreased turgor
UOP	1–2 mL/kg per hour	<1 mL/kg per hour	minimal
Urine specific gravity	1.02	1.025–1.030	>1.030

36. ANSWER: C

Please see answer discussion for question 37.

37. ANSWER: C

Sacrococcygeal teratomas (SCTs) are the **most common congenital neoplasm** (1:40,000 infants, 95% females). SCTs are usually **diagnosed in infancy** but may present at **2 years of age**. Most tumors are **initially benign**; however, after 2 months of age they often transform into malignancy. Teratomas usually arise from **embryologically multipotent cells from the Hensen node**, which is located in the coccyx, and vary with the amount of internal and external extension. Blood supply is from the middle sacral artery and branches of the internal iliac artery. Associated congenital anomalies are common in patients with anorectal malformations.

High perinatal mortality is a result of **high-output CHF, preterm delivery due to polyhydramnios and hydrops, anemia from hemorrhage into tumor, dystocia, and tumor rupture**. Postnatal clinical presentation includes visible tumor itself and multiple organ dysfunction if tumor extends into spine, pelvis, and/or abdomen: lower-extremity pain, numbness and weakness, respiratory compromise from diaphragm displacement, high-output CHF from AV fistulas inside the tumor, bowel obstruction, renal dysfunction from postrenal obstruction, anemia, and coagulopathy.

Treatment is surgical (prenatal or postnatal) and preoperative radiologic embolization. Treatments in utero include **cyst aspiration, open fetal surgery, endoscopic laser, and radiofrequency ablation**. **Preoperative embolization** can reduce intraoperative blood loss and enable faster and safer resection of the tumor. Surgical approach is either from rectum in prone position for small teratomas or via laparotomy to first ligate feeding vessels and mobilize larger tumors. The coccyx must be removed to avoid recurrence. Bleeding can be massive, and adjacent structures (bowel, bladder, and presacral nerve plexus) are distorted and prone to injury. Long-term issues involve lower spine and pelvic organ dysfunction and cosmetically unacceptable scars.

Anesthetic considerations:

- Possible multiple position changes intraop: supine to prone position
- GETA with IV or inhalation induction
- Modified rapid-sequence induction if GI tract is compressed
- Neuroaxial techniques are not recommended due to spinal malformations and coagulopathy
- Good IV access in SVC basin + radial A-line(s): preferably all access above the diaphragm in case of arterial and/or venous blood supply compromise around the tumor; aortic compression may be neccessary, and IVC injury is possible
- Be ready for massive blood loss and coagulopathy.
- Treat and prevent hyperkalemia from tumor lysis syndrome and rapid transfusion by using washed PRBCs.
- Correct hypocalcemia and acidosis.
- Prevent and treat hypothermia.

KEY FACTS

- Most common congenital neoplasm: initially benign → malignant after 2 months (↑ serum α-fetoprotein)
- Grows from coccyx, blood supply from sacral artery and branches of internal iliac artery
- Sx: tumor + internal and external extension + high-output CHF + anemia + coagulopathy
- Treatment: (1) fetal interventions; (2) postnatal resection of tumor and coccyx
- Anesthesia: supine and/ or prone position, GETA, rapid-sequence induction, upper body large IVs, radial A-line(s); be ready for massive blood loss and coagulopathy and watch for increased K, decreased Ca, increased temp

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38. ANSWER: B

Please see answer discussion for Question 39.

39. ANSWER: C

Vein of Galen aneurysmal malformation (VGAM) is an **arteriovenous fistula of the median prosencephalic vein (MPV)**—a precursor of the vein of Galen, occurring at 6–11 **weeks of gestation**. The MPV **fails to regress**, becomes **aneurysmal,** and drains via the straight sinus or a persistent falcine sinus as the vein of Galen does not form (while there should be no drainage into the deep venous system). It is rare (<1:25,000 deliveries) and accounts for less than 1%–2% of all intracranial cerebral vascular malformations but for ~30% of

these malformations in the pediatric population. The differential diagnosis cerebral AVMs and cerebral vascular tumors.

Diagnosis is often made with **third-trimester antenatal ultrasound**. VGAM lead to **hydrops fetalis and fetal cardiomegaly**. In the neonatal period, usual presentation is **high-output CHF** due to a large left-to-right shunt. As much as **80% of cardiac output may shunt through the fistula**. Decreased coronary perfusion (from diastolic runoff directly from aorta into carotid arteries and VGAM) and volume and pressure overload (from significant left-to-right shunt and pulmonary vasoconstriction) puts myocardium at risk for ischemia. Right-to-left shunt across PFO and PDA due to high RV and pulmonary pressures contributes to **systemic hypoxemia and pulmonary hypertension**. Excessive cerebral blood flow in VGAM leads to **(1) increased cerebral venous pressure that adversely affects regional cerebral blood flow; and (2) intracerebral arterial steal that results in watershed ischemia and periventricular leuomalacia.**

Clinical presentations vary with the type of malformation:

- Neonatal: choroidal type: cranial bruit, **high-output CHF**
- Infant: mural type: hydrocephalus due to venous HTN or aqueduct stenosis
- Child: mural type: developmental delay, hydrocephalus

Diagnostic modalities are **CT angiography, MRI/MRA, and cerebral angiography** (gold standard). Prior to endovascular intervention mortality was 100% without treatment and 90% in surgical attempts. Ideally **arterial and/or venous embolization** with coils and acrylic glue is deferred until cavernous sinus matures **(6 months)**. If CHF is refractory to medical management, embolization is performed sooner. Hydrocephalus is typically not shunted as this may exacerbate cerebral ischemia and risk of intraventricular hemorrhage (IVH). Radiosurgery is limited to patients who are not candidates for other treatment modalities. Prognosis varies based on severity of CHF, CHF-related multiorgan dysfunction (respiratory, renal, hepatic, coagulation, etc.), and associated congenital anomalies and does not exceed 60% at most.

The main goal of medical management is to **balance the circulation in a patient with intracranial vasodilation and systemic vasoconstriction, causing hypoperfusion**. **Vasodilation** (ideally in combination with **inotropic support**) lowers high systemic vascular resistance (**SVR**) and improves systemic and **coronary perfusion** and **acidosis**. Milrinone, systemic vasodilators (sodium nitroprusside [SNP], nitroglycerine [NTG]), low-dose dopamine, and prostaglandin E1 can be used. **β-adrenergic agents (dobutamine, dopamine, or epinephrine)** are not well tolerated as they induce tachycardia, shorten diastolic time, and worsen subendocardial ischemia and diastolic function. Inhaled nitric oxide alone is not helpful in reducing high PVR but can be used in combination with other agents.

CHF associated with VGAM appears **more severe** and **less manageable medically** than most congenital heart defects: in VGAM volume overload is obligatory and continues despite increases in PVR. As a result, stabilization of neonates before neurointervention or neurosurgery is difficult and cardiac failure is often resistant to treatment.

If patients survive CHF early on, complications are **developmental delay, ischemic and/or hemorrhagic strokes, hydrocephalus, vascular complications** due to repeat access for the neurointervention, and respiratory problems related to **prolonged ventilation**.

KEY FACTS

- Intracranial vascular anomaly (aneurysmal AV fistula of median prosencephalic vein = vein of Galen precursor)
- Accounts for 30% of pediatric cerebral vascular malformations
- Left-to-right shunt (up to 80% of cardiac output) through malformation leads to high-output CHF and CHF-related multiorgan failure
- Right-to-left shunt across PFO and PDA can worsen hypoxemia and pulmonary hypertension
- Therapy consists of CHF management and staged endovascular embolization
- CHF management consists of milrinone, low-dose dopamine, SNP, NTG, PgE1, ±iNO
- β-adrenergic agents may worsen myocardial ischemia

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40. ANSWER: B

Please see answer discussion to Question 41.

41. ANSWER: B

Duodenal atresia is a type of **intestinal obstruction**. It is one of the most common anomalies in newborns and infants.

The incidence is 1:10,000 to 1:40,000 and frequently **associated with Down syndrome** (~30%), **congenital heart disease, cystic fibrosis, renal anomalies, intestinal malrotation, and especially midline defects** such as **esophageal atresia and imperforate anus**. A membranous web or an annular pancreas can also be associated with obstruction of the duodenum. Symptoms vary depending on the degree of obstruction (stenosis vs. atresia). Usually neonates present with symptoms of **upper bowel obstruction: bilious vomiting (usually within first 2 days of life), decreased bowel sounds, abdominal distention, and radiographic signs of gas-filled loops of bowel** ("double-bubble sign"—air-filled and distended stomach and proximal duodenum) and no gas below duodenum. Babies may or may not pass meconium.

Mortality is low. Isolated Down syndrome or duodenal obstruction does not influence morbidity. Most deaths are attributed to associated anomalies and prematurity. Delay in diagnosis leads to disturbance of fluid and electrolyte balance, increased abdominal distention with subsequent respiratory compromise, and high risk for aspiration pneumonia, intestinal perforation, necrosis of the bowel, and septicemia. Improvement in survival rates is a result of prompt surgical repair after optimization of the metabolic status and advances in neonatal care such as high-frequency ventilation, surfactant supplementation, nutritional support, pediatric anesthesia, and sophisticated cardiac surgery.

Duodenoduodenostomy is the most commonly performed procedure to address duodenal atresia. It may be performed via a right upper quadrant incision, an umbilical incision, or laparoscopically.

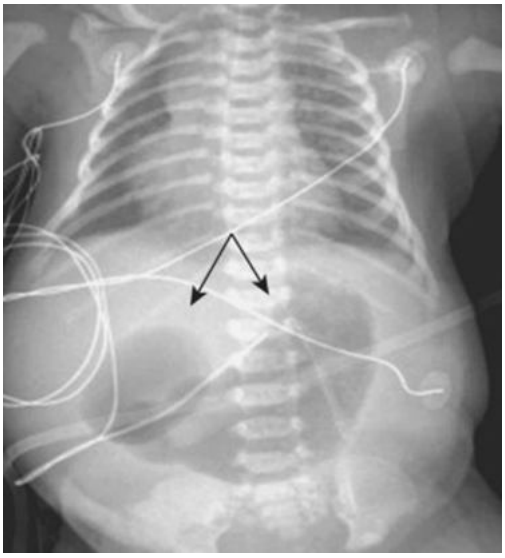

Figure 13.1 Abdominal radiograph of a neonate with congenital duodenal atresia demonstrating a classic double-bubble sign (arrows). Note that the remainder of the bowel is devoid of air, indicating complete obstruction. (From Bachiller PR. In: Cote CJ, Lerman J, Anderson B, eds. *Practice of Anesthesia for Infants and Children*. 5th ed. Philadelpia, PA: Saunders Elsevier; 2013:746–765.)

Intraoperative management is usually general endotracheal anesthesia. As with any neonatal surgery, **temperature control, electrolyte balance, adequate ventilation, and anemia correction** are paramount. Intraoperatively, a transanastomotic feeding tube is placed for enteral feeds and nasogastric tube for stomach decompression. Some patients require prolonged total parenteral nutrition due to ileus, pancreatitis, cholecystitis, and megaduodenum.

KEY FACTS

- Common type of intestinal obstruction
- Frequent associated anomalies (particularly Trisomy 21–30%)
- Bilious vomiting, dehydration, "double-bubble" sign on KUB
- Medical emergency; outcome depends on prematurity and associated anomalies

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42. ANSWER: B

Please see Answer Discussion for Question 43.

43. ANSWER: A

Congenital diaphragmatic hernia (CDH) is a defect in the diaphragm that leads to **extrusion of intraabdominal organs into the thoracic cavity**. It is a severe defect and is and associated with **pulmonary hypoplasia, pulmonary hypertension, congenital anomalies** (cardiac, GI, GU, skeletal, neural, trisomic), and significant morbidity and mortality. Incidence is 1:3000 live births. CDH is usually an isolated lesion but may be associated with other anomalies (~20%). The most common diaphragmatic defect is **left Bochdalek's hernia (posterolateral), then Morgagni (anteromedial), and paraesophageal**.

Pathophysiology: herniated midgut (sometimes with left liver lobe, stomach, spleen, and left kidney) occupies left (usually) chest cavity → interferes with lung development (bilaterally), shifts mediastinum contralaterally → persistent pulmonary HTN. Prognostic parameters for severity of pulmonary hypoplasia are LHR = lung-to-head

circumference, diameter of proximal pulmonary artery (prox PA) to descenting aorta (desc Ao), intrathoracic liver position.

Prenatal ultrasound detects up to 60% of CDH. Postnatal presentation is **cyanosis, dyspnea, dextrocardiac, scaphoid abdomen, decreased breath sounds, and bowel sounds in the chest**. Chest X-ray: mediastinal shift and bowel loops in the thorax.

Fetal interventions are experimental: fetoscopy with tracheal occlusion aims to improve lung growth by promoting lung fluid accumulation. **Postnatal treatment goals** are to **stabilize cardiorespiratory status** (oxygenate, prevent right-to-left intracardial shunt, control pulmonary HTN) first and only **then perform surgical repair**. Immediate surgery carries high risk and does not instantaneously improve pulmonary compliance and function. Preoperative **treatment employs early intubation, protective ventilation strategies in order to decrease baro- and volutrauma to both lungs (low Vt, adequate PEEP with low peak inspiratory pressures, permissive hypercapnea), alternative ventilation techniques (HFOV), use of inhaled nitric oxide (iNO; which is still controversial), inotropic and vasopressor support, and ECMO** (usually venoarterial) as a rescue pre- or postoperatively. Despite the obvious goals of therapy, there are significant variations in therapeutic approach between institutions.

Surgery should be **delayed as long as 2–3 weeks until PVR has decreased**, ventilation can be maintained with low peak inspiratory pressure (<25 cm H_2O) and low FiO_2 (<0.5) on conventional ventilator, and cardiac status is stable. As infants rarely tolerate one-lung ventilation, usually surgical approach is open via abdominal, thoracotomy, or thoracoabdominal incision with closure of diaphragmatic defect. If infants do not tolerate primary abdominal closure, patch closure is attempted in order to prevent abdominal compartment syndrome.

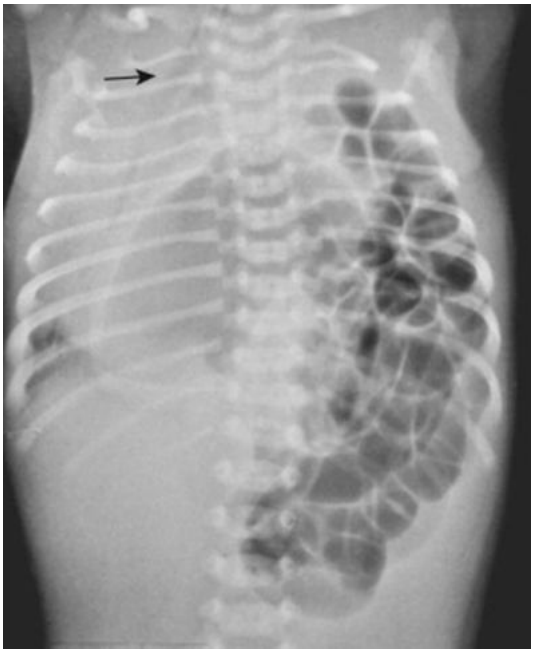

Figure 13.2 Chest radiograph of a neonate with a left diaphragmatic hernia. Note shifting of trachea and bronchi into the right chest (arrow). (From Bachiller PR. In: Cote CJ, Lerman J, Anderson B, eds. *Practice of Anesthesia for Infants and Children*. 5th ed. Philadelphia, PA: Saunders Elsevier; 2013:746–765.)

Anesthetic considerations:

- Location varies: NICU versus operating room
- Avoid lower extremities access: possibility of abdominal compartment syndrome
- Keep adequately anesthetized: usually total intravenous anesthesia
- Continue protective ventilation strategy and monitor pulmonary compliance, use ICU ventilator; communicate with surgical team
- Watch for contralateral pneumothorax
- Try to keep PVR low: ↑FiO_2, ↓$PaCO_2$ (balance with permissive hypercapnia), avoid hypothermia and light anesthesia, ±iNO
- Maintain SVR, adequate cardiac rate, and contractility
- Treat anemia, coagulopathy, pH, and electrolyte abnormalities

Patients with CDH are at high risk for long-term pulmonary (obstructive lung disease, reactive airway disease, decreased inspiratory muscle strength), GI (oral aversion, GERD, growth failure), musculoskeletal (pectus carinatum, pectus excavatum, scoliosis), and neurocognitive disorders (developmental delay, behavioral disorders with prevalent language and motor problems).

KEY FACTS

- Defect in diaphragm → extrusion of abdominal content into thorax → pulmonary hypoplasia, pulmonary HTN, associated anomalies, high mortality/morbidity
- Usual defect is *left* foramen of Bochdalek (posterolateral)
- Prognostic for pulmonary HTN: LHC, prox PA/desc Ao diameter, liver in the chest
- Bad prognosis in preemies, low birth weight, P(A-a) > 500
- Treatment: (1) stabilize cardiorespiratory status → (2) surgery in 2–3 weeks once patient is stable
- Preoperative Rx: protective ventilation strategies, HFOV, ±iNO, inotrops/vasopressor, VA ECMO
- Surgery delayed for 2–3 weeks → open repair.
- Anesthesia: NICU vs. OR, total intravenous anesthesia, no access in LEs, use ICU vent, protective ventilation strategies, monitor pulmonary compliance, keep PVR low, ±iNO, maintain SVR/HR/contractility, correct Hgb/pH/electrolytes, avoid ↓T^o, communicate with surgeon

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44. ANSWER: B

45. ANSWER: B

Tracheoesophageal fistula (TEF) and **esophageal atresia (EA)** incidence is 1:3000 to 1:4000 births. They commonly (25%) coexist with other congenital anomalies and are a part of **VACTERL (vertebral, anal, cardiac, tracheoesophageal, renal, limb) association**. Incidence of defects is particularly high in isolated EA—type F TEF (50%–70%) but less common with H-type fistula (E-type TEF). The most common anomaly includes **cardiac defects (30%–35%): VSD, ASD, Tetralogy of Fallot, AV canal, and coarctation of aorta**. Mortality associated with TEF/EA generally depends on patient's weight and the severity of the associated heart disease.

The embryogenesis of TEF/EA remains incompletely defined. Respiratory system grows from the foregut with later physical separation. As trachea and esophagus fail to separate, differentiation of both respiratory and esophageal components usually does not occur. In these conditions, distal esophagus might be of embryonic lung tissue. That explains such clinical findings as poor esophageal motility, GERD, esophageal stenosis, and pseudostratified epithelium (respiratory) rather than squamous epithelium (esophageal).

As a fetus with esophageal obstruction is unable to swallow amniotic fluid; **maternal polyhydramnios could develop and TEF would be suspected prenatally**. Postnatal diagnosis depends on the specific anatomy of the TEF/EA. Usually newborns present with **excessive drooling, cyanotic spells, coughing, and swallowing problems**. Suction catheter cannot be placed down the esophagus and advanced into stomach. When a radiopaque catheter is used, it will reveal the catheter in a blind esophageal upper pouch. If TEF is present, a plain "babygram" will reveal gas in the stomach and intestines.

Repair of TEF/EA is urgent but **not emergent except in cases of severe respiratory insufficiency**. Preoperative management includes upright positioning to minimize GERD, NPO, intermittent suctioning of the upper esophageal pouch, and antibiotic therapy to treat aspiration pneumonia and sepsis. Optimally, a total repair is accomplished as a one-stage procedure: TEF is ligated and esophagus is primarily anastomosed. If the infant is too sick to tolerate thoracotomy, **gastrostomy** is performed under local anesthesia to decompress distended stomach and patient is stabilized for 1–3 days. In neonates with **severe RDS, gastrostomy placement can compromise ventilation** due to loss of the volume from the trachea via TEF directly into the stomach instead of the diseased noncompliant lungs. In long-gap EA primary anastomosis needs to be delayed and multiple-step repair needed. If delayed anastomosis is planned, initial surgery includes TEF ligation and G-tube placement. Later on at a few months of age, the esophagus is either directly anastomosed or bridged with an interposed bowel segment or stomach graft. Currently, new approaches focus on inducing growth of esophagus by placing internal or external traction sutures, esophageal anastomosis without disruption of the wall by myotomies, and placing esophageal junction below the diaphragm.

The specific plan for fistula evaluation before the procedure should be discussed with the surgical team. **Preoperative rigid bronchoscopy** is often performed by the surgeon. Induction with preserved spontaneous ventilation is preferred in order to avoid abdominal overdistension through TEF. Then the trachea is intubated with the tip of the ETT just below the TEF or into left mainstem bronchus in preparation for the right thoracotomy (rather than left because of associated congenital heart disease and possible right sided aortic arch) or thoracoscopy. Some consider awake intubation the safest way to secure airway. Some surgeons place 2Fr Fogarty catheter into TEF to occlude it and ensure good ventilation. Many infants do not tolerate one-lung ventilation, and operative lung reexpansion during surgery helps with desaturations. Good IV access and arterial line are obtained. Use of precordial stethoscope placed on the left side of the chest is helpful in monitoring dependent lung ventilation.

Postoperatively, infants are often left intubated due to pulmonary compromise from aspiration. Regional anesthesia is an option if spinal and other skeletal anomalies have been ruled out. Long-term complications include but are not limited to tracheomalacia at the level of TEF, anastomotic leaks, esophageal strictures, esophageal dysmotility, abnormal lower esophageal sphincter, and scoliosis after posterolateral thoracotomy.

KEY FACTS

- One third are associated with heart defects; 25% with VACTERL.
- Prenatal association with maternal polyhydramnios
- C-type of TEF is the most common.
- Symptoms: drooling, cough, suction catheter "sits" in blind proximal to esophageal pouch; unable to pass into stomach
- Repair is *not* emergent unless there is severe RDS

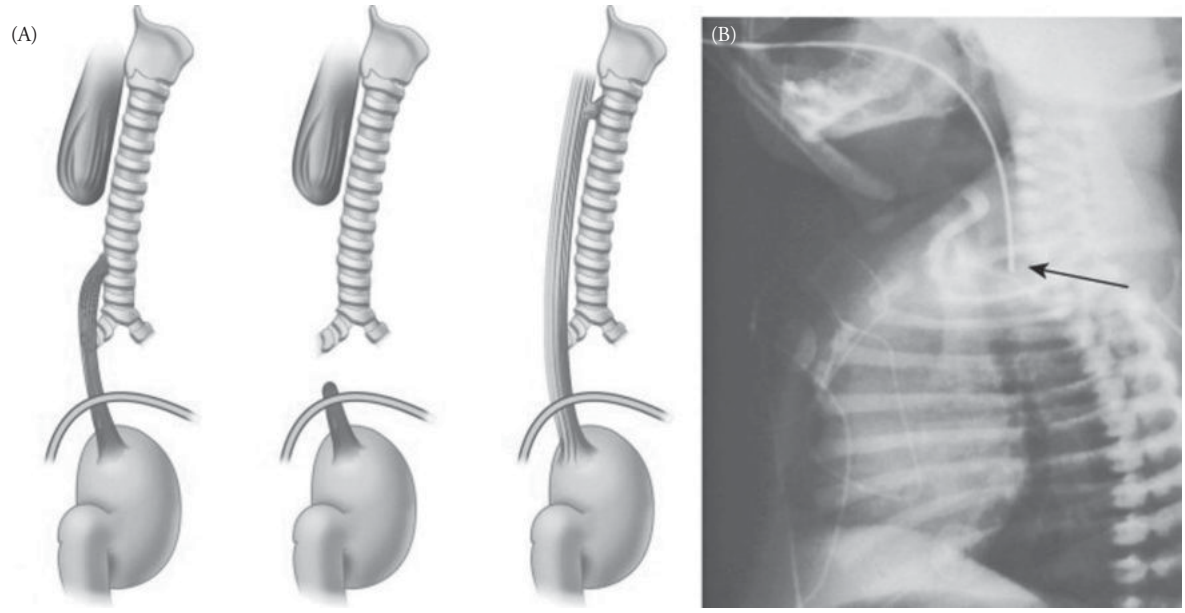

Figure 13.3 (*A*) The three most common forms of esophageal atresia are presented. The most common form (approximately 85%) consists of a dilated proximal esophageal pouch and a fistula between the distal trachea and distal esophagus (left). The second most common form consists of esophageal atresia alone (middle). Neonates with tracheoesophageal fistula alone (right) often present with pneumonia as the initial manifestation. (*B*) The classic presentation is of a newborn with excessive secretions who spits up during the initial feeding; inability to pass a nasogastric tube (arrow) is pathognomonic. (*A*, from Coran AG, Behrendt DM, Weintraub WH, Lee DC. *Surgery of the Neonate*. Boston, MA: Little, Brown; 1978:46. *B*, courtesy Dr. Daniel P. Doody. In: Bachiller PR. In: Cote CJ, Lerman J, Anderson B, eds. *Practice of Anesthesia for Infants and Children*. 5th ed. Philadelpia, PA: Saunders Elsevier; 2013:746–765.)

- In neonates with severe RDS, gastrostomy placement can compromise ventilation due to loss of the volume from the trachea via TEF directly into the stomach instead of the diseased noncompliant lungs
- Aspiration pneumonia and sepsis are major risks.
- Preoperative management: upright position, NPO, suction proximal esophageal pouch, antibiotics
- Long-gap EA: multiple-step repair: TEF ligation, possible G-tube if delayed esophageal anastomosis
- Until TEF is ligated, preserve spontaneous ventilation to avoid stomach overdistension.
- Discuss with surgeon plan to evaluate the fistula and need for rigid bronchoscopy.
- Try to position ETT just below TEF.
- Use precordial stethoscope.

See Figure 7.3 in Chapter 7, Gastrointestinal System, for anatomic classification of anomalies of the esophagus and trachea.

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46. ANSWER: C

47. ANSWER: B

The table below deliniates the differences between omphalocele and gastroschisis, defects in the abdominal wall. They are caused by occlusion of the omphalomesenteric artery during gestation in the case of gastroschisis or failure of gut migration from the yolk sac in the case of omphalocele. Preoperatively the goal is to diagnose **associated anomalies**, **minimize injury to the bowel, fluid resuscitate, maintain normothermia, and treat sepsis**. The eventual surgical goal will be to reduce protruding viscera and repair the abdominal wall defect. If the defect is small, primary abdominal repair is done. If the defect is large and a significant portion of abdominal content is externalized, a staged repair with use of silo (silastic or Teflon) and gradual return of abdominal organs into the abdomen is performed. Placement of a silo is done in delivery room or NICU and does not require the presence of an anesthesiologist.

These patients are considered to have a **full stomach**. Metabolism of drugs metabolized by the liver may be decreased if intra-abdominal pressure is too high. In gastroschisis or ruptured omphalocele there can be **large insensible fluid losses,** requiring intensive fluid resuscitation. There is also a high risk of sepsis.

Table 13.4 ABDOMINAL WALL DEFECTS

	OMPHALOCELE	GASTROSCHISIS
Definition	Midline defect of umbilical ring > 4 cm with bowels (may or may not include stomach and liver) herniating into intact umbilical sac See Figure 13.4 (A)	Right paraumbilical full thickness abdominal wall defect with evisceration of bowel (small and large) See Figure 13.4 (C)
Description	Umbilical cord inserted into sac. The gut is covered with umbilical sac: three-layer membrane (peritoneum, Wharton's jelly, amnion), unless ruptured	Umbilical cord is normal and separate from defect. Bowels are exposed and inflamed.
Cause	Abnormal fusion of myotomes forming abdominal wall musculature	Right omphalomesenteric artery or umbilical vein ischemia
Associated anomalies	Often (cardiac, vascular, renal, genital, neuro, etc.)	Rare (intestinal atresia, malrotation)
Surgical emergency?	No	No
Medical emergency?	No As long as the umbilical sac is intact	Yes High risk of sepsis as bowels are exposed
Surgical repair	For small defects: primary repair For large defects: staged repair with use of silo and gradual return of organs into abdomen	
Complications	Depends on associated anomalies (unless sac ruptured)	Depends on the bowel damage

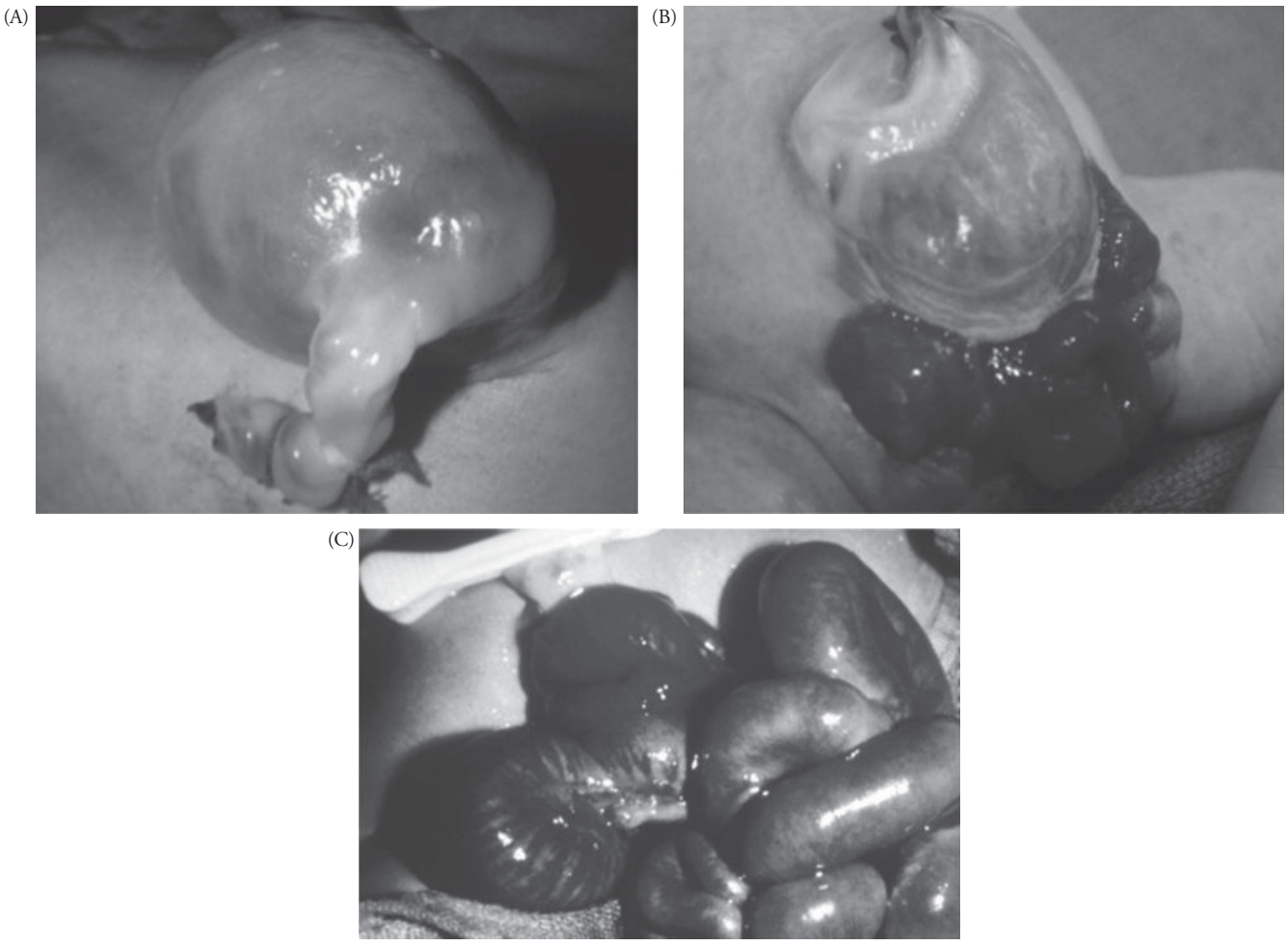

Figure 13.4 (A) Omphalocele covered with a membranous sac; the defect arises at the umbilicus. (B) Ompahlocoele with associated exstrophy of the bladder. (C) Gastroschisis; note the absence of a membranous sac. In contrast to omphalocele, the gastroschisis anomaly is periumbilical. (From Bachiller PR. In: Cote CJ, Lerman J, Anderson B, eds. *Practice of Anesthesia for Infants and Children*. 4th ed. Philadelpia, PA: Saunders Elsevier; 2013:746–765.)

Forcing viscera into the underdeveloped abdominal cavity and tight closure of the defect may produce **abdominal compartment syndrome (ACS)** and **restrict diaphragmatic excursion with compression of the lungs**. Thus, the cooperation between surgeon and anesthesiologist is important to assess feasibility of a primary closure. During closure, the anesthesiologist must **monitor airway pressures** to identify decreased pulmonary compliance, and watch for signs of ACS (**increase in intragastric pressure >20 cm H_2O, decreased renal perfusion and perfusion to lower extremities, decreased venous cardiac return**). An arterial catheter helps with blood sampling and blood pressure monitoring. After the surgery, patients are usually kept ventilated for at least 1–2 days. Due to postoperative ileus, total parenteral nutrition is usually required for days to weeks.

KEY FACTS

Omphalocele (see Table 13.4):

- Midline defect with umbilical cord inserted
- Bowels are covered with umbilical sac
- High risk of associated congenital anomalies

Gastroschisis (see Table 13.4):

- Defect of full thickness of abdominal wall to the right of umbilicus
- Bowels are *not* covered, exposed and inflamed > high risk of sepsis
- Associated anomalies are rare
- Both are medical emergencies. Both are full stomach.
- Silo is placed in NICU > staged reduction of abdominal content > eventual abdominal closure in operating room
- Intraop: watch for abdominal compartment syndrome and impaired ventilation

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48. ANSWER: B

Congenital lobar emphysema (CLE) refers to postnatal **overdistension** and **progressive air trapping of one or more lung lobes with compression of other lung tissue, contralateral mediastinal shift, impaired venous return, secondary hypoxia, and hypotension**. The key feature is communication of emphysematous low-compliance lobe with bronchial tree with presumable mechanism of an obstructive check valve mechanism at a bronchial level (obstruction, cartilage deficiency, dysplasia, and immaturity). Most cases are idiopathic. Most commonly upper lobes are involved (left upper, right middle, right upper). There is **male** predisposition 3:1.

Patients typically present with **respiratory distress between the neonatal period and 6 months of life**. Often congenital lobar emphysema is a **neonatal surgical emergency**. Surgical resection of the affected lobe is curative. Chest radiography demonstrates hyperinflation of affected lobe(s), and CLE is frequently confused with pneumothorax.

Preoperative evaluation depends of the degree of patient distress. An arterial line is indicated in addition to standard monitors. If peripheral IV access is adequate, central line is not indicated. Nitrous oxide is avoided to prevent further hyperinflation of the affected lobe. Anesthesia induction is critical and needs to be smooth. Either inhalation or intravenous agents could be used. **Positive-pressure ventilation should be minimized to prevent further hyperinflation of affected lobe**. The surgeon needs to be present for anesthetic induction in case the lobe expands suddenly and chest needs to be opened immediately to relieve the pressure. For maintenance of anesthesia, a combination of intravenous and inhalation anesthetics or total intravenous anesthesia could be used. Isoflurane is considered a preferred inhaled anesthetic due to less attenuation of hypoxic pulmonary vasoconstriction. Single-lung ventilation might be required. The addition of regional anesthesia to general is beneficial: epidural (directly placed or caudally threaded), intercostal and paravertebral blocks, and intrapleural infusions have all been described. In most cases, patients can be extubated at the end of the procedure.

Differential diagnosis includes other congenital conditions with air trapping: **congenital cystic adenomatoid malformation (CCAM)/congenital pulmonary airway malformation (CPAM), pulmonary sequestration, pulmonary arterial hypoplasia, pulmonary hypoplasia, and bronchial atresia**.

Congenital cystic lesions: bronchogenic, dermoid, cystic.

Bronchogenic cysts result from abnormal branching of the tracheobronchial tree causing lung compression, respiratory distress, recurrent pneumonias, atelectasis.

Dermoid cysts are clinically similar to bronchogenic cysts but originate from nonciliated respiratory epithelium.

Congenital cystic adenomatoid malformations (CCAMs) are structurally similar to bronchioles but lack alveoli. They are comprised of different sized air and fluid-filled cysts. They communicate with the airway and may become overdistended.

Pulmonary sequestration—nonfunctional mass of lung tissue from disordered embryogenesis supplied by ***anomalous systemic arteries*** which leads to cough, pneumonia, and failure to thrive before 2 years old. If there is no communication with the airway, there is no risk of

hyperinflation. Chest CTA or MRI/MRA can help delineate vascular supply to the lesion.

KEY FACTS

- Hyperinflation and progressive air trapping of affected lobe can cause compression of lung, mediastinal shift, impaired venous return
- Respiratory distress occurs in neonates—6 months old, could be a neonatal emergency
- Treatment: thoracotomy or thoracoscopy with lobectomy
- Induction is critical: minimize positive-pressure ventilation until chest is open and have surgeon present for induction in case of pneumothorax

49. ANSWER: D

Lung isolation and one-lung ventilation (OLV) is a challenge in pediatric patients in general and in neonates and small infants in particular. Small airway size requires appropriately small devices (tubes, blockers, fiberoptic bronchoscope [FOB]). As OLV is difficult to achieve and at times is not tolerated by neonates, **many pediatric surgeons prefer insufflation of the chest with low-flow CO_2 (1–2 L/min), peak pressure 4–6 mm Hg in 30- to 45-degree prone position to induce adequate lung collapse**. See Table 13.5.

There are fewer options to isolate the lung in neonates and infants than in older children: (1) to mainstem a regular ETT or (2) place a balloon-tipped bronchial blocker (Fogarty embolectomy catheter, arrow end-hole balloon wedge catheter, or Arndt bronchial blocker = Cook endobronchial blocker) inside or outside of regular ETT. See Table 13.6.

Use of other devices has been described for lung isolation in pediatric patients: Edwards atrioseptostomy catheter, Swan-Ganz pulmonary artery catheter as balloon-tipped bronchial blockers, and Marraro pediatric bilumen tubes (used for babies of 1.4 kg and above; not commercially available in the United States).

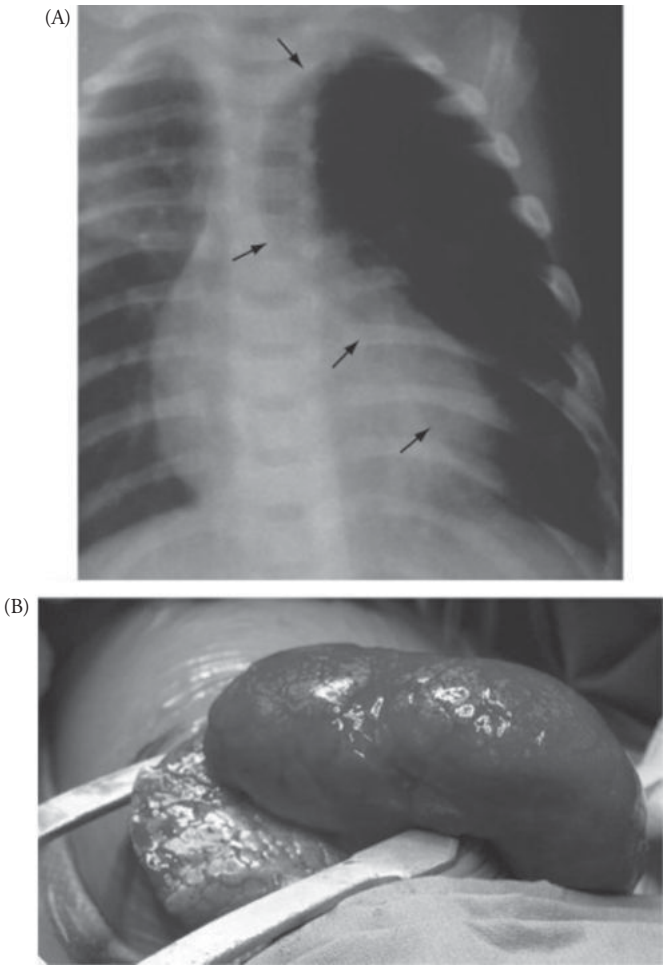

Figure 13.5 (*A*) Radiograph from an infant with congenital lobar emphysema demonstrates hyperinflation of the left lung with herniation across the midline (arrows) and mediastinal shift. (*B*) Intraoperative photograph shows the emphysematous lobe bulging through the thoracotomy incision. (From Coté CJ. The anesthetic management of congenital lobar emphysema. *Anesthesiology*. 1978;49:296.)

Table 13.5 DEVICE SELECTION FOR ONE-LUNG VENTILATION IN CHILDREN (MODIFIED)

AGE	OLV AIRWAY DEVICE
Less than 2 years	Selective endobronchial intubation Fogarty catheter (4 Fr) as a bronchial blocker
2–6 years	Fogarty catheter (4 Fr or larger) as a bronchial blocker Wire-guided endobronchial blocker (5 Fr)
6–10 years	Wire-guided endobronchial blocker (5 Fr or larger) Univent tube (3.5 ID) equivalent in size to 6.0 uncuffed ETT
Over 10 years	Wire-guided endobronchial blocker (5 Fr or larger) Univent tube Double-lumen tube (26 Fr or larger)

Table 13.6 LUNG ISOLATION IN NEONATES AND SMALL INFANTS

DEVICE	ADVANTAGES	DISADVANTAGES
Regular ETT placed into mainstem bronchus	Easy to use as does not require special equipment (+/- FOB) Technique of choice in emergent situations	Difficult to achieve good seal with uncuffed ETT Operative lung cannot be suctioned Operative lung cannot be actively deflated If used on the right side, tend to occlude origin of right upper lobe bronchus with subsequent right upper lobe atelectasis and hypoxemia If used on the right side and patient has a pig bronchus, right upper lobe cannot be deflated
5 Fr (the smallest) Arndt bronchial blocker, Cook Critical Care Can be placed inside or outside of regular ETT External diameter (ED) with balloon deflated is 2.5 mm Length of the elliptical cuff is 1.0 cm Max volume of the cuff is 3.0 mL	Suction port allows for lung suctioning and lung deflation Styletted (stylet can be bent to facilitated placement) Elliptical shape cuff conforms to bronchial lumen once inflated Comes with multiport adapter with Tuohy-Borst connector of the blocker port that allows ventilation during blocker placement and seal around the blocker Can place inside or outside of regular ETT. If ETT is too small for available FOB, blocker could be placed under fluoroscopy (if necessary with radiocontrast dye inside the balloon)	Potential for upper airway injury by compression if ETT is not properly downsized Requires small FOB to confirm the position Requires minimum 5.0 ETT for intraluminal placement to accommodate the blocker (external diameter 2.5 mm) and smallest FOB (2.2 mm). ED of blocker (with balloon deflated) is 2.5 mm which makes it unsuitable for many premature and small infants. If available FOB does not fit through ETT (with blocker placed intra- or extraluminally), blocker needs to be positioned under fluoroscopy Balloon length is 1.0 cm, which is too long for a neonate and corresponds to the length of the right mainstem bronchus of a 2-year-old child
2, 3, 4 Fr Fogarty catheter Closed tip or thru-lumen, Edwards or Baxter Can be placed inside or outside of regular ETT	Can use outside of smallest ETT on smallest patients If available FOB does not fit through ETT, blocker could be placed under fluoroscopy (if necessary with radiocontrast dye inside of the balloon) Placement oustide of ETT is preferred (easier to perform FOB) Styletted (stylet could be bent to facilitate placement)	Potential for catheter dislodgment with occlusion of trachea by catheter balloon Potential for bronchial ischemia and even rupture from low-volume, high-pressure balloon Due to closed tip, lung cannot be suctioned and deflation cannot be facilitated If placed outside of ETT, multiple steps are required for placement: 1. operative side is intubated with ETT (ETT is intentionally mainstemmed), 2. Fogarty catheter is placed through ETT, 3. ETT is removed. ETT placed outside of the blocker (alongside) into the trachea, 5. blocker position is confirmed with either FOB (if it fits through ETT) or under fluoroscopy The smallest available FOB (Olympus LF-P) has external diameter of 2.2 mm. Its ultrathin design makes it difficult to navigate and easy to break and absence of suction channel does not allow to suction secretions or insufflate O_2

ED, external diameter; ETT, endotracheal tube; FOB, fiberoptic bronchoscope.

KEY FACTS

- Lung isolation and one-lung ventilation (OLV) can be challenging in pediatric patients
- Double-lumen and Univent tubes usually are too big
- The easiest way to isolate the lung in an emergency is to mainstem a regular ETT (not ideal).
- Bronchial blocker can be placed intra- or extraluminally in relation to ETT.
- If smallest FOB is unavailable or does not fit through ETT, use fluoroscopy (C-arm) to confirm bronchial blocker position.

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50. ANSWER: B

The **timing of clamping the umbilical cord** after delivery has several potential effects on the neonate. An analysis of articles reporting the effects of early (at delivery) versus delayed (2 + minute delay) cord clamping in premature infants found that delayed cord clamping resulted in a **higher hematocrit, fewer transfusions, and a decreased risk of intraventricular hemorrhage**.

When expressed as mL/kg, the blood volume of the neonate at birth is a function of gestational age and whether the umbilical cord was clamped immediately after delivery. If there is a delay in clamping the cord or if the cord is "milked" from the placenta into the neonate, **blood volume** is routinely **increased by 20 to 30 mL/kg**. If the cord is clamped immediately after delivery, the **mean blood volume** of a term neonate is approximately **80 mL/kg**. The blood volume of **premature neonates** may easily exceed **100 mL/kg**.

Delayed clamping of the umbilical cord has **no impact on Apgar scores** of premature or term newborns.

KEY FACTS

- Delayed cord clamping may allow for a higher hematocrit, fewer transfusions, and a decreased risk of intraventricular hemorrhage.
- Delayed cord clamping can increase blood volume by 20–30 mL/kg in the neonate.

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51. ANSWER: D

The American Heart Association has a widely accepted training program for the resuscitation of the newborn transitioning from intrauterine to extrauterine environments. According to the AHA guidelines, the main steps after delivery of the newborn are to provide warmth, suction airway secretions, and if necessary, provide tactile stimulation. The newborn should then be evaluated for respirations, heart rate, and color.

If the newborn is **breathing, pink in color, and has a heart rate above 100 beats per minute**, only **routine care is indicated**. If the newborn is breathing but **cyanotic** and has a **heart rate above 100 beats per minute**, the provider should verify that the airway is clear and measure the oxygen saturation; the provider should also consider the administration of **continuous positive airway pressure**. The targeted preductal oxygen saturation values should be used as a guide to titrate an appropriate concentration of supplemental oxygen. The **oxygen saturation probe** should be placed at **a preductal location** (i.e., right upper extremity).

If the newborn has a heart **rate less than 100 beats per minute**, oxygen saturation monitoring should occur in conjunction with the **administration of positive-pressure ventilation**. If the **heart rate is less than 60 beats per minute**, **chest compressions** should be administered and consideration should be given to performing tracheal intubation. **If chest compressions are ineffective** in restoring heart rate to more than 100 beats per minute, **epinephrine** should then be administered. If the newborn has a heart rate less than 60 beats per minute despite resuscitation with a lower oxygen concentration, the inspired oxygen concentration should be increased to 100% until the heart rate returns to normal.

Vasopressin and atropine are not part of the AHA Neonatal Resuscitation guidelines.

KEY FACTS

- If the newborn breathing, is pink in color, and has a heart rate above 100 beats per minute, only routine care is indicated.

- If newborn is breathing but cyanotic and the heart rate is above 100 beats per minute, consider the administration of continuous positive airway pressure.
- If newborn has a heart rate less than 100 beats per minute, oxygen saturation monitoring should occur in conjunction with the administration of positive-pressure ventilation.
- If heart rate is less than 60 beats per minute, chest compressions should be administered and consideration should be given to performing tracheal intubation.

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52. ANSWER: B

The most common form of cyanotic congenital heart disease is the complex known as **Tetralogy of Fallot** consisting of **ventricular septal defect (VSD), obstruction of the right ventricular outflow tract (RVOT), overriding aorta, and right ventricular hypertrophy (RVH). Cyanosis** occurs as a result of **right-to-left** shunting through the VSD. The severity of the cyanosis is determined by the degree of right-to-left shunting, which is determined by the systemic vascular resistance (SVR) and the degree of RVOT obstruction.

Because **ketamine maintains SVR**, it is generally recognized as the preferred agent for induction of anesthesia in children with Tetralogy of Fallot.

Because administration of **propofol produces a decrease in SVR**, it tends to increase right-to-left shunting and is not the preferred agent for induction of anesthesia in patients with Tetralogy of Fallot. Although thiopental is less likely than propofol to produce a significant decrease in SVR, it does produce venodilation, with a consequent decrease in venous return and a reduction in pulmonary blood flow.

Children with pyloric stenosis are at an increased risk for the aspiration of gastric contents; mask induction of anesthesia is generally not recommended for this procedure. In addition, the decrease in SVR associated with the administration of sevoflurane will increase the magnitude of right-to-left shunting and consequently the severity of cyanosis.

KEY FACTS

- Tetralogy of Fallot consists of a VSD, obstruction of the RVOT, overriding aorta, and RVH.
- Ketamine maintains SVR and is the preferred agent for induction of anesthesia in children with Tetralogy of Fallot.

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53. ANSWER: D

Caudal block is frequently used to provide postoperative analgesia to infants undergoing lower abdominal surgery. One potential complication is inadvertent injection of local anesthetic into the intrathecal space, which could result in **total spinal anesthesia**. A total spinal block in an infant is typically manifested **by apnea and immobility with no initial change in the heart rate or blood pressure**. **Bradycardia** can develop in this situation but would most likely be delayed and associated with the development of hypoxemia due to the apnea. The hemodynamic stability is proposed to occur due to the relatively **low sympathetic tone** present in an infant compared with that in an adult. Treatment for a total spinal block in an infant is supportive, including supporting ventilation until the spontaneous return of respiratory function.

KEY FACTS

- Total spinal anesthesia in an anesthesized infant is manifested by apnea and immobility with no initial change in the heart rate or blood pressure.
- Hemodynamic instability is thought to be a result of low sympathetic tone.

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54. ANSWER: A

The administration of intravenous caffeine is a therapeutic option for the treatment or prevention of apnea of

prematurity and postoperative apnea in an infant. Infants may benefit from administration of caffeine for prevention of postoperative apnea if they have preoperative apnea, will receive opioids, or have a **postconceptual age less than 60 weeks (especially if <44 weeks)**. However, literature does not support the routine administration of caffeine for prevention of postoperative apnea. The administration of caffeine for prevention of postoperative apnea does not alter the need for postoperative admission or additional apnea monitoring.

Caffeine citrate is the most common formulation used in the management of apnea. Caffeine citrate can be administered **orally or intravenously**. The mechanisms of action of caffeine for the management of apnea is proposed to involve **stimulation of the central respiratory drive**, **enhanced chemoreceptor sensitivity to CO_2**, **and increased skeletal muscle contraction**.

Administration of IV caffeine to infants can have several side effects, including the development of the following:

- Sinus tachycardia
- Supraventricular tachycardia
- Tachypnea
- Hyperthermia
- Seizures
- Severe irritability
- Feeding intolerance

Administration of IV caffeine to an infant for prevention of postoperative apnea is not associated with the development of hypoxemia.

KEY FACTS

- Caffeine citrate can be a therapeutic option for the treatment or prevention of apnea of prematurity and postoperative apnea in an infant.
- Mechanisms of action of caffeine for the management of apnea involve stimulation of the central respiratory drive, enhanced chemoreceptor sensitivity to CO_2, and increased skeletal muscle contraction.

REFERENCES

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55. ANSWER: A

This question revolves around the diagnosis of **myelomeningocele** and its associated comorbidities. Myelomeningocele is a form of spina bifida, a neural tube defect in which protrusion of the spinal cord and meninges occurs without a protective skin covering. Answer B is correct, as myelomeningocele and **a compressed posterior fossa** are associated with **apnea** and **vocal cord paralysis,** leading to **sleep-disordered breathing** and occasionally **ventilator dependence**. Answer B is incorrect, as **horseshoe kidney** is associated with this disease, but not a double collecting urinary system. Answer C is incorrect because the **defect develops early in gestation**, and is not associated with muscle denervation. Answer D is incorrect as skeletal anomalies associated with this disorder include **clubfeet, hip dislocation, and kyphoscoliosis**, but not knee issues.

KEY FACTS

- Myelomeningocele is an abnormal neural tube defect in which protrusion of the spinal cord and meninges occurs without a protective skin covering.
- It is associated with apnea and vocal cord paralysis, which can cause sleep-disordered breathing.
- Associate anomalies include horseshoe kidney, clubfeet, hip dislocation, and kyphoscoliosis.

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Sladen RN, Coursin DB, Ketzler JT. *Anesthesia and Co-Existing Disease*. New York, NY: Cambridge University Press; 2007:705.

56. ANSWER: C

Caudal block is frequently used for **genito-urologic** and **abdominal surgery** in neonates and greatly assists in the anesthesia for these patients. For a caudal block, both sacral cornu are palpated. Next, a styletted needle is introduced through the sacral hiatus, and a "pop" is felt as the sacrococcygeal ligament is accessed. **Epinephrine** is often added to the local anesthetic solution to determine if an intravascular injection has taken place. A caudal is the most commonly used regional anesthetic technique in neonates and infants. Caudal anesthesia decreases the amount of volatile anesthetics needed for surgery. It has been shown that ropivicaine is less cardiotoxic and has less of a cardiodepressant effect than bupivacaine.

REFERENCE

Barash P, Cullen B, Stoelting R. *Clinical Anesthesia*. 6th ed. Philadelphia, PA: Lippincott Williams & Wilkins; 2009:1188–9.

57. ANSWER: D

Conditions that place neonates at increased risk for persistent fetal circulation (PFC) or reversion to fetal circulation include the following:

- Sepsis
- Acidosis
- Meconium aspiration
- Diaphragmatic hernia
- Prematurity
- Pulmonary disease

A common characteristic among all these conditions is **increased pulmonary vascular resistance (PVR).** The elevation in right ventricular afterload from increased PVR can produce right-to-left shunting via the foramen ovale. **Right-to-left shunting** (i.e., from the pulmonary artery to the aorta) via the ductus arteriosus can also occur if the PVR exceeds the systemic vascular resistance.

Physiologic conditions that can increase PVR and potentially produce PFC include the following:

- Hypoxemia
- Hypercapnia
- Acidosis
- Hypothermia

PFC is a life-threatening condition that can produce significant cardiopulmonary instability. Aggressive resuscitation may be required and may include the administration of **vasoactive medications, nitric oxide, mechanical ventilation, and extracorporeal membrane oxygenation**.

Neither hyperthermia nor hypokalemia is associated with the development of PFC in a neonate. Hyperoxia is associated with the development of retinopathy of prematurity in a neonate but not reversion to fetal circulation.

KEY FACTS

- Increased pulmonary vascular resistance can cause reversion to fetal circulation.
- Specific physiologic conditions that can increase PVR and potentially produce PFC include hypoxemia, hypercapnia, acidosis, and hypothermia.

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Coté CJ, Lerman J, Todres ID, eds. *A Practice of Anesthesia for Infants and Children*. 4th ed. Philadelphia, PA: Saunders Elsevier; 2009:365.

Konduri GG, Kim UO. Advances in the diagnosis and management of persistent pulmonary hypertension of the newborn. *Pediatr Clin North Am*. 2009;56:579–600.

58. ANSWER: C

Multiple factors contribute to the development of the physiologic anemia of infancy:

- Decreased erythropoietin production due to increased oxygen content (associated with increased hemoglobin saturation at birth) and increased oxygen delivery (associated with conversion to synthesis of adult hemoglobin).
- Shorter red blood cell survival—from 40 to 60 days in premature infants or 80 to 100 days in term infants as opposed to 120 days in adults.

When the anemia results in decreased delivery of oxygen to tissues, production of erythropoietin is stimulated and erythropoiesis is increased, with a resultant increase in hemoglobin concentration.

Iron deficiency is **rarely a contributing factor** in the development of physiologic anemia. One exception is in premature infants who experience significant iatrogenic blood loss associated with sampling for laboratory testing. Interestingly, infants who have received red blood cell transfusions in the neonatal period manifest a lower nadir of hemoglobin concentration.

Gestational age at birth plays a significant role in the magnitude and severity of physiologic anemia. In **term infants** the **nadir of hemoglobin concentration**, usually in the range of **9 to 11 g/dL, occurs at 8–12 weeks of age**. In **premature infants** the anemia is usually more severe, in the range of **7 to 9 g/dL, and occurs at 3–6 weeks of age**. Extremely low birth weight infants may develop even more profound anemia.

KEY FACTS

- Decreased erythropoietin production due to increased oxygen content (associated with increased hemoglobin saturation at birth) and increased oxygen delivery (associated with conversion to synthesis of adult hemoglobin)
- Shorter red blood cell survival—from 40 to 60 days in premature infants or 80 to 100 days in term infants as opposed to 120 days in adults
- Iron deficiency is rarely a contributing factor.
- In term infants the nadir of hemoglobin concentration is usually in the range of 9 to 11 g/dL and occurs at 8–12 weeks of age. In premature infants the anemia is usually more severe, in the range of 7 to 9 g/dL, and occurs at 3–6 weeks of age.

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Maxwell LG. Age-associated issues in preoperative evaluation, testing, and planning; pediatrics. *Anesthesiol Clin North Am*. 2004;22:27–43.

59. ANSWER: C

Pyloric stenosis is a medical but not surgical emergency; electrolyte disturbances should be normalized prior to proceeding with surgical intervention.

Anesthetic management for pyloromyotomy commonly includes the following:

- Anticholinergic administration to reduce the risk of bradycardia
- Gastric decompression with a large-bore orogastric tube after anticholinergic administration but prior to induction of anesthesia
- Rapid sequence induction and tracheal intubation
- Infiltration of the incision site with local anesthetic agent
- Minimal or no use of opioids
- Awake extubation

Gastric decompression is beneficial in reducing the contents from the stomach but does not reliably assure it to be completely empty. Most authors recommend that a **large-bore orogastric tube** be inserted for suctioning the stomach in **right and left lateral positions as well in the supine position**. Because residual gastric contents often remain even after this technique, the infant should still be considered at risk for aspiration of gastric contents. Accordingly, tracheal intubation is warranted.

Although most authors recommend **rapid sequence induction**, **awake intubation** is considered acceptable. At least one study demonstrated no decrease in the risk of complications related to airway management (e.g., desaturation, laryngospasm) in infants undergoing pyloromyotomy who underwent an awake intubation compared to those in whom a rapid sequence induction was performed. Disadvantages of awake intubation in neonates or infants include the production of significant physiologic stress, increased sympathetic stimulation, increased potential for airway injury, and a lower likelihood of obtaining ideal intubating conditions.

Although the use of **succinylcholine** is controversial in pediatric patients, most authors recognize this as an **acceptable agent** for infants undergoing pyloromyotomy.

Opioids are generally avoided due to the increased risk of **respiratory depression** in infants with **metabolic alkalosis**. Adequate postoperative analgesia is usually obtained simply with local infiltration of a long-acting anesthetic into incision sites and rectal acetaminophen.

KEY FACTS

- Gastric decompression with large-bore orogastric tube in both right, left lateral positions and supine is indicated
- Rapid sequence induction with succinylcholine and avoidance of opioids are key components of the anesthetic management.

REFERENCES

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Carbajal R, Eble B, Anand KJ. Premedication for tracheal intubation in neonates: confusion or controversy? *Semin Perinatology*. 2007;31:309–17.
Motomyama EK, Davis PJ, eds. *Smith's Anesthesia for Infants and Children*. 7th ed. Philadelphia, PA: Elsevier Mosby; 2006:690–1.

60. ANSWER: B

The normal **oxygen consumption** for an infant is approximately double that of an adult **(6–8 mL/kg per minute for neonates vs. 3–4 mL/kg per minute for adults)**. This is one of the contributing factors resulting in the **alveolar ventilation** (expressed as mL/kg) of a neonate being twice that of an adult **(100–150 mL/kg for neonates vs. 60 mL/kg for adults**). These factors, combined with the relative decrease in lung compliance, result in the **normal respiratory rate** for a term infant being approximately **50 breaths/min**.

When expressed as mL/kg the blood volume of the neonate at birth is a function of gestational age and whether or not the umbilical cord was clamped immediately after delivery. If the cord is clamped immediately after delivery, the mean blood volume of a term neonate is approximately 80 mL/kg. If there is a delay in clamping the cord or if the cord is "milked" from the placenta into the neonate, blood volume is routinely increased by 20–30 mL/kg. The blood volume of premature neonates is greater than that of term babies; the mean blood volume of a premature neonate may easily exceed 100 mL/kg. A meta-analysis that reviewed 15 controlled trials demonstrated that the benefits of delayed cord clamping at birth (defined as 2–3 minutes following delivery) included a higher hematocrit (95% confidence interval), increased iron stores, and a decreased risk of anemia.

A normal **heart rate** for a term neonate is approximately **120 beats/min**. The normal **blood pressure** for a term neonate is **65/45 mm Hg**.

KEY FACTS

- Oxygen consumption for an infant is approximately double that of an adult (6–8 mL/kg per minute for neonates vs. 3–4 mL/kg per minute for adults).
- Alveolar ventilation (expressed as mL/kg) of a neonate is twice that of an adult (100–150 mL/kg for neonates vs. 60 mL/kg for adults).

REFERENCES

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Hutton EK, Hassan ES. Late vs early clamping of the umbilical cord in full-term neonates: systematic review and meta-analysis of controlled trials. *JAMA*. 2007;297:1241–52.

61. ANSWER: B

One of the measures of assessment of neonatal condition at birth was devised by Virginia Apgar in 1953. The score, which now bears her name, consists of five elements, each of which is scored 0, 1, or 2, for a maximum possible score of 10. The Apgar score is usually evaluated at 1 minute after delivery. **Apgar scores of between 8 and 10 are achieved by 90% of all neonates**. A neonate with an Apgar score between **5 and 7 usually responds to oxygen and vigorous stimulation**; a neonate with a score of **3 or 4 typically requires bag-mask ventilation**. If the Apgar score is **between 0 and 2, the neonate requires immediate resuscitation**. Apgar scores are usually also recorded at 5 minutes and may be recorded at intervals thereafter if resuscitation is ongoing.

The Apgar score qualitatively measures **basic reflexes** and correlates well with the degree of neonatal depression. The correlation with asphyxia or acidosis, however, is less robust. Neonatal mortality correlates with the duration of time that the Apgar score remains depressed, but the score performs poorly in the prediction of neonatal morbidity. See Table 13.1.

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Yao FSF. *Yao and Artusio's Anesthesiology: Problem-Oriented Patient Management*. 5th ed. Philadelphia, PA: Lippincott, Williams & Wilkins; 2003:841–2.

62. ANSWER: D

A **premature** infant is one born **before 37 weeks of gestation**. The anesthesiologist should be aware of the gestational age so that potential problems can be anticipated at birth. Premature infants have an increased incidence of **apnea, hypoglycemia, hypomagnesemia, hypocalcemia, respiratory distress syndrome, thrombocytopenia**, fetal alcohol syndrome, history of maternal drug addiction, asphyxia, and aspiration pneumonia. The birth weight should also be determined as low birth weight infants also have an increased incidence of hypoglycemia, fetal alcohol syndrome, thrombocytopenia, and viral infection.

KEY FACTS

- Prematurity is defined as delivery before 37 weeks of gestation.
- There is an increased incidence of apnea, hypoglycemia, hypomagnesemia, hypocalcemia, respiratory distress syndrome, and thrombocytopenia.

REFERENCE

Miller RD, ed. *Miller's Anesthesia*. 6th ed. Philadelphia, PA: Churchill Livingstone; 2005:2368.

63. ANSWER: B

Spinal anesthesia in neonates is not associated with hemodynamic instability. It is theorized that neonates have less venous capacitance and an **immature sympathetic nervous system**, leading to a **lack of hypotension and bradycardia during a high spinal**. Given the lack of hemodynamic instability, **respiratory distress and apnea** are the first signs of a **high spinal**.

REFERENCE

Coté CJ, Lerman J, Todres ID, eds. *A Practice of Anesthesia for Infants and Children*. 4th ed. Philadelphia, PA: Saunders Elsevier; 2009:877–9.

64. ANSWER: A

The **Parkland formula of 4 mL/kg per percent body area** burned is used for fluid replacement in most pediatric patients. Ultimately, perfusion to peripheral organs is most important. Urine output of **1 mL/kg per hour** is often used as a surrogate for perfusion of the kidneys. Although the Parkland formula can be used, one should start with **urine output guiding further fluid replacement**. The replacement of choice is **crystalloid**, as a capillary leak may lead to increased oncotic pressure in the interstitum if colloid is utilized. Dextrose-containing solutions are used for maintenance fluids and should not be used for fluid replacement.

REFERENCE

Coté CJ, Lerman J, Todres ID, eds. *A Practice of Anesthesia for Infants and Children*. 4th ed. Philadelphia, PA: Saunders Elsevier; 2009:722.

65. ANSWER: C

Craniosynostosis is often associated with congenital syndromes (including Apert syndrome, Pfeiffer syndrome, and Crouzon syndrome). While strip craniectomy can be done endoscopically and is not usually associated with massive blood loss, calvarial reconstruction is quite prone to large blood losses. Strip craniectomy should be performed prior to 1 year of age. If done at less than 1 year of age, 50% of affected children have an IQ greater than 70; however, if done beyond 1 year of age, only 7% of children will have an IQ greater than 70. Craniosynostosis is commonly associated with midfacial abnormalities and a difficult airway.

REFERENCE

Koh JL, Gries H. Perioperative management of pediatric patients with craniosynostosis. *Anesthesiol Clin*. 2007;25(3):465–81.

66. ANSWER: B

Anatomical characteristics of the neonatal airway differ significantly from those of an adult. These anatomical differences in the neonate have important airway implications.

Typically, the **neonatal larynx is located in a higher position in the neck (C2–3) relative to the adult larynx (C4–5).** This higher location can result in the larynx being described as "anterior" during direct laryngoscopy. An anterior larynx can be more difficult to visualize and may require a form of laryngeal pressure, including cricoid pressure or the BURP maneuver (backward, upward, and rightward laryngeal pressure).

The **epiglottis** in a **neonate** is relatively **longer than in an adult**. The epiglottis in a neonate can also be U-shaped and be positioned over the laryngeal inlet. These features of the epiglottis may suggest the use of a straight laryngoscope blade in order to directly lift the epiglottis off the laryngeal opening during direct laryngoscopy.

In a neonate the **anterior attachment of the vocal cords** is more **caudad** than the posterior attachment. This results in angulation of the vocal cords with respect to the axis of the trachea. In adults this angulation does not occur and the vocal cords are perpendicular to the long axis of the trachea.

In a neonate the **tongue is relatively larger** than in an adult.

In adults the **larynx** is described as being **cylindrical with the narrowest part at the glottis opening**. Classically the larynx of a neonate has been described as "funnel shaped" with the narrowest part occurring at the cricoid ring. Recent studies suggest this may not be completely accurate. Two studies using MRI and CT suggest that in children less than 2 years of age the immediate subglottic area is the narrowest portion of the airway. In any event, compared to adults, the **widest portion of the larynx in neonates is either lower (at the cricoid ring) or at the same level (at the glottis opening).**

KEY FACTS

- Neonatal larynx is located in a higher position in the neck (C2–3) relative to the adult larynx (C4–5).
- Epiglottis in a neonate is relatively longer than in an adult.
- Anterior attachment of the vocal cords is more caudad.
- Tongue is relatively larger.
- Widest portion of the larynx in neonates is either lower (at the cricoid ring) or at the same level (at the glottis opening).

REFERENCES

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Santillanes G, Gausche-Hill M. Pediatric airway management. *Emerg Med Clin North Am*. 2008; 26:961–75.

67. ANSWER: B

A **congenital diaphragmatic hernia (CDH)** is a defect in the diaphragm causing abdominal viscera to herniate into the thorax. The defect is most commonly (~80%) found **posterolaterally, at the foramen of Bochdalek**, on the left side of the diaphragm. It occurs in approximately 1:2000 births, with an equal distribution between males and females, and is linked to genetic defects and other congenital abnormalities.

These neonates usually present with respiratory distress and a scaphoid abdomen. In addition, **hypoxemia and hypercapnia result from visceral compression of lung parenchyma and primary pulmonary hypoplasia**. The neonates may be hypotensive due to torsion of great vessels and compression of cardiac structures. Neonates with CDH may be **severely hypoxemic and/or hypercapneic** and require high-frequency oscillatory ventilation and/or ECMO prior to surgical repair. Survival rates have improved with less aggressive ventilation maneuvers and permissive hypercapnia, avoiding barotrauma and decreased venous return.

Recommended anesthetic management includes **ventilation with low peak airway pressures**. Attempts should not be made to expand the compressed lung, as this may result in a **pneumothorax of the contralateral (less hypoplastic) lung**. Likewise, bag-mask ventilation should not

occur due to the risk of abdominal distention and herniation of abdominal viscera across the midline of the thoracic cavity. Orogastric suctioning is encouraged to reduce visceral compression on the lung.

KEY FACTS

- Congenital diaphragmatic hernia (CDH) is a defect in the diaphragm causing abdominal viscera to herniate into the thorax. The defect is most commonly (~80%) found posterolaterally, at the foramen of Bochdalek.
- Hypoxemia and hypercapnia result from visceral compression of lung parenchyma and primary pulmonary hypoplasia.
- Includes ventilation with low peak airway pressures
- Pneumothorax of the contralateral (less hypoplastic) lung

REFERENCES

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Lally KP, Paranka MS, Roden J, et al. Congenital diaphragmatic hernia. Stabilization and repair on ECMO. *Ann Surg*. 1992;216:569–73.

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68. ANSWER: D

Although a small percentage of children with croup have an allergic etiology for their problem, the vast majority of cases are infectious in etiology. Viral infections are the most common cause of **croup**, which is more accurately termed **laryngotracheobronchitis**. Mucosal swelling results in airway obstruction that manifests as follows:

- Inspiratory stridor
- Tachypnea
- Suprasternal, intercostal, and/or substernal retractions
- Hoarseness
- A cough commonly described as high-pitched or "barking" in nature

Viral laryngotracheobronchitis usually has a **gradual onset** following an upper respiratory tract infection; a low-grade fever is commonly present. Compared to children with epiglottitis, a child with croup is more likely to be younger (less than 3 years of age), less likely to have a marked elevation of temperature, and more likely to be tachypneic.

Epiglottitis tends to occur in slightly older children and without any kind of viral prodrome. The child with epiglottitis commonly appears **toxic** and has **a higher temperature**. The classic presentation involves the "three D's"—**drooling, dysphagia, and distress**. Although the child may present with a **muffled voice**, a barking cough is not usually present.

A child with a foreign body in the trachea generally does not have manifestations of a viral prodrome.

Although airway problems may be exacerbated during an upper respiratory infection, it would be unlikely that the initial presentation of tracheomalacia would occur in a 9-month-old child. **Tracheomalacia** is generally initially manifested in **younger children**.

KEY FACTS

- Laryngotracheobronchitis: Mucosal swelling results in airway obstruction that manifests as inspiratory stridor, tachypnea, suprasternal, intercostal, and/or substernal retractions, hoarseness, cough commonly described as high-pitched or "barking" in nature.
- Epiglottitis child appears toxic and has a higher temperature. The classic presentation involves the "three D's"—drooling, dysphagia, and distress.

REFERENCES

Coté CJ, Lerman J, Todres ID, eds. *A Practice of Anesthesia for Infants and Children*. 4th ed. Philadelphia, PA: Saunders Elsevier; 2009:675–6.

Sobol SE, Zapata S. Epiglottitis and croup. *Otolaryngol Clin North Am*. 2008; 41:551–66.

69. ANSWER: C

Pyloric stenosis—hypertrophic muscle at the pyloric opening—occurs in about 2.4/1000 live births, more commonly in males. It usually presents as **nonbilious, projectile vomiting in 3- to 6-week-old infants**. Physical examination may reveal an olive-shaped mass in the epigastric area.

Ultrasound is the preferred method for establishing the diagnosis. Previously, radiographic contrast studies were used to demonstrate the classic "string" sign—contrast narrowly exiting the pylorus.

Protracted vomiting results in loss of gastric fluid with a consequent loss of hydrochloric acid; the resulting hypochloremia produces impaired renal excretion of sodium bicarbonate. Consequently most children with pyloric stenosis present with a **hypochloremic, hypokalemic metabolic alkalosis**. Administration of sodium bicarbonate may exacerbate the metabolic alkalosis and is therefore not proper management.

Management of pyloric stenosis is a medical **not a surgical emergency**. The patient needs to be **rehydrated**, initially with **sodium chloride**. Potassium is added once urine

output is confirmed. With rehydration and resolution of the alkalosis, the patient can proceed to the operating room for a pyloromyotomy.

Patients should be treated as having a full stomach, even if a nasogastric tube is in place. Administration of oral sodium bicitrate is not indicated in the management of pyloric stenosis.

KEY FACTS

- Nonbilious, projectile vomiting in 3- to 6-week-old infants
- Hypochloremic, hypokalemic metabolic alkalosis
- Not a surgical emergency

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14.

PAINFUL DISEASE STATES

Aykut Bilge, Jason S. Lee, and Pascal Scemama de Gialluly

1. A 2.5-year-old child is in the recovery room following a surgical procedure. Which pain scale is the most useful to assess pain in this child?

A. Visual Analogue Scale (VAS)
B. Wong-Baker FACES Pain Rating Scle (WBFS)
C. Face Legs Arms Cry Consolability Scale (FLACC)
D. OUCHER Pain Scale

2. A 3-year-old, 15 kg patient is receiving epidural analgesia with 0.1% bupivacaine and hydromorphone at 10 μg/mL via a thoracic epidural catheter. In your assessment, the patient has adequate analgesic coverage but is disturbed by severe pruritus as reported by parents. What is the initial *next* step in the management of this patient?

A. Reassure parents and continue current epidural infusion.
B. Administer a dose of diphenhydramine.
C. Start low-dose naloxone infusion.
D. Discontinue epidural infusion and start intravenous analgesia.

3. A 15-year-old African American patient with sickle cell disease is admitted for the management of vaso-occlusive pain crisis presenting as back, extremity, and chest pain. On examination, affected areas display a normal response to touch. Which of the following pain management options would be beneficial in this situation?

A. Tricyclic antidepressants
B. Thoracic epidural analgesia
C. Trigger point injections
D. Gabapentin

4. The most common presentation of pain in children and adolescents is:

A. Back pain
B. Headache
C. Abdominal pain
D. Extremity pain

5. A 14-year-old female patient with recurrent abdominal pain is admitted after initial evaluation in the emergency room for severe abdominal pain. Which one of the symptoms or signs below are red flags in the evaluation of abdominal pain in this patient?

A. Cough
B. Headache
C. Arthritis
D. Tinnitus

6. A 15-year-old female child has developed chronic pain affecting her distal limb following a traumatic injury and prolonged limb immobilization. Her condition has been diagnosed as complex regional pain syndrome (CRPS), type I. Which of the following statements is *most* accurate in the diagnosis and treatment of this patient?

A. Opioids are effective in treatment.
B. Allodynia or hyperalgesia is often present.
C. Intravenous regional block is contraindicated.
D. Presence of a documented nerve injury is essential for diagnosis.

7. A 10-year-old male patient is seen in the emergency department and brought to the operating room for repair of tibia fracture. The parents state that the patient had difficult pain management during past hospitalizations and had been found to have CYP2D6 enzyme deficiency. What would be the best postoperative pain management strategy for this patient after he tolerates PO intake?

A. Oxycodone
B. Tramadol

C. Codeine
D. Hydrocodone

8. A 12-year-old male patient with a history of severe asthma presents with a fractured distal humerus, requiring surgical repair. On examination, the patient seems distressed, has bilateral wheezing but is able to maintain oxygen saturations above 96% at room air. Which of the following is *most* likely to provide adequate postoperative analgesia while minimizing further respiratory compromise?

A. Opioid analgesia
B. Brachial plexus block, interscalene approach
C. Brachial plexus block, infraclavicular approach
D. Brachial plexus block, axillary approach, and musculocutaneous nerve block

9. A 9 month old patient is undergoing circumcision under general anesthesia. Which pain management option is *most* appropriate in the management of postoperative pain for this patient?

A. Caudal epidural analgesia with 0.125% bupivacaine with epinephrine up to 4 mL/kg single injection
B. Penile block with 0.125% bupivacaine with epinephrine up to 4 mL single injection
C. Parenteral ketorolac up to 2 mg/kg
D. Enteral acetaminophen not to exceed 75 mg/kg per day

10. A 14-year-old female patient with complex regional pain syndrome (CRPS) is being followed at a chronic pain clinic for her leg pain. During her visit, she states that her affected leg was accidentally hit during a rush at school and she felt much more intensified pain than she would expect. Which of the following terms *most* accurately describes her symptom?

A. Paresthesia
B. Allodynia
C. Hyperalgesia
D. Dysesthesia

11. A 15-year-old female patient has been followed by the chronic pain clinic for headaches and distractions at school. In the past year, her condition has been managed with tricyclic antidepressant medications and the use of biofeedback mechanisms. During her last clinic visit, she complains of worsening headaches, which awaken her from sleep at night and become more intense in the morning. What is the *most* appropriate initial management after she expressed these concerns?

A. Initiate referral and neuroimaging study (CT/MRI).
B. Optimize antidepressant treatment with increasing the nighttime dose.
C. Start physical therapy with transcutaneous electrical nerve stimulation (TENS).
D. Start acupuncture treatments.

12. A 16-year-old male patient with cancer pain and spasticity is admitted for optimization of his chronic pain regimen. He is currently on multimodal drug therapy, which includes neuropathic pain medications and antispasmodics, baclofen, ketamine, gabapentin, and methadone. Which one of his current medications exerts its effect via Γ-amino butyric acid receptors?

A. Baclofen
B. Ketamine
C. Gabapentin
D. Methadone

13. A 16-year-old male patient is receiving epidural analgesia via a T6-7 epidural catheter following a thoracotomy. His pain is well controlled at the incision and chest tube site, but he complains of ipsilateral shoulder pain. What type of neurons and fibers are involved in the transmission of the pain experienced by this patient?

A. Nociceptive specific neurons, A-δ fibers only
B. Nociceptive specific neurons, A-δ and C fibers
C. Wide dynamic range neurons, A-δ fibers only
D. Wide dynamic range neurons, A-δ and C fibers

14. A 15-year-old female patient with metastatic bone cancer is receiving treatment with chemotherapy and radiotherapy. Her multiorgan pain is managed with a combination of opioid and nonopioid analgesics. An electrocardiogram (EKG) was performed to evaluate her cardiac status following a course of chemotherapy which showed a QTc of 470 ms. Which one of the following pain medications requires dose adjustment or discontinuation to prevent serious arrhythmias?

A. Acetaminophen
B. Methadone
C. Ketorolac
D. Oxycodone

15. A 4-year-old patient with abdominal pain is being evaluated for a large but operable Wilms tumor. Imaging studies suggest the tumor is confined to the kidney and there is no evidence of local evasion or metastasis. Which type of pain is most likely to be experienced by this child?

A. Somatic pain
B. Neuropathic pain
C. Visceral pain
D. Psychogenic pain

16. A 15-year-old female patient who developed neuropathic pain following a lower-extremity trauma is being treated with a combination of oral and topical analgesics. She has recently started applying capsaicin cream topically, which improved her overall pain control. Capsaicin manifests its analgesic effect by acting on which of the following targets?

A. TRPV channels
B. Sodium channels
C. Calcium channels
D. NMDA receptors

17. A 10-year-old, 52 kg male patient is admitted to hospital with sickle cell crisis with pain in his abdomen, hip, and thighs. This patient has had several hospitalizations in the last 3 years for similar complaints. He has chronic pain and at home uses 5 mg of oxycodone on average about two times a day. You are consulted for the pain management of this child. Which of the following would constitute the best initial pain management regimen for this patient?

A. MS Contin (Morphine sulphate controlled release) PO regimen
B. Oxycodone (Oxycontin) regimen PO q4hr
C. Morphine patient controlled analgesia (PCA)
D. Non-Steroidal Anti-Inflammatory Drugs (NSAIDs)

18. Which of the following drugs acts on the same receptor as methadone?

A. Gabapentin
B. Paroxetine
C. Duloxetine
D. Ketamine

19. You are seeing a 15-year-old male status post hemipelvectomy for sarcoma with chronic phantom limb pain. You notice that the patient is on gabapentin 600 mg TID and his pain is well controlled. What is the mechanism of action of gabapentin?

A. It interacts with the GABAergic (gamma aminobutyric acid) system.
B. It blocks sodium channels.
C. It binds voltage-dependent calcium channels.
D. It binds to N-Methyl-D-aspartate (NMDA) receptors.

20. Which of the following descriptions defines allodynia?

A. Increased, exaggerated pain in response to a normally painful stimulus
B. Pain that is caused by a stimulus that normally is not painful
C. Pain that correlates to a peripheral nerve distribution
D. Abnormal sensation that can be either spontaneous or caused by some stimulus

21. At what postconceptual age do children start responding to tissue injury and inflammation?

A. 14 weeks
B. 26 weeks
C. 34 weeks
D. 40 weeks

22. You are taking care of a 7-year-old girl with cerebral palsy and severe cognitive impairment. She is scheduled for a left femoral osteotomy. What pain assessment method will be most appropriate for this patient to assess postoperative pain?

A. Look at the patient's face and match what you see to a pain Visual Analog Scale (VAS)
B. Ask the mother if she thinks her child is in pain and how severe the pain is
C. Use the r-FLACC Scale
D. Use the Wong Baker Faces Pain Scale

23. Acupuncture is a popular complementary medicine used for pain in the pediatric population with benefits including:

A. Immediate pain relief upon application
B. Opioid antagonists such as naloxone do not inhibit the analgesic properties of acupuncture
C. Continued analgesic properties despite endorphin enzyme degradation
D. The analgesic effects of acupuncture persists for several hours after application

24. An 11-year-old girl presents with chronic pain in her left foot and ankle following a motor vehicle accident, causing nerve injury to her left foot. Per review of her chart, she is noted to have allodynia, hyperalgesia, edema, and color changes in her ankle and is diagnosed with complex regional pain syndrome (CRPS) type II. She has CRPS type II versus type I because of:

A. Nerve injury related to her accident
B. Allodynia
C. Hyperalgesia
D. Edema and color changes in her foot

25. You are consulted to see a 14-year-old girl with a 1-year history of chronic abdominal pain. She has been extensively worked up by the gastroenterology service, and all studies have come back normal. This girl's life is severely impacted by her pain: she has trouble walking because of

her pain and she cannot participate in any sport activities, making her very sad. Her pain is not alleviated by acetaminophen, ibuprofen, or opioids. She describes the pain as burning, continuous, and worsened by movement. Upon physical examination, you find a specific point of maximal tenderness about 2 inches from the midline on the right side at the level of the umbilicus. This area is also allodynic. What is your most likely next step?

A. Start the patient on gabapentin.
B. Recommend a psychiatric consultation.
C. Perform a diagnostic Transversus Abdominis Plane (TAP) block.
D. Start the patient on peppermint oil.

26. A 10-year-old 50 kg boy has been on a morphine PCA for the last 2 days for postoperative pain after an appendectomy. The PCA settings have been set at a continuous rate of 0.3 mg/hr with demand dose of 0.3 mg every 10 minutes with a lockout of 2 mg/hr. The boy has used a total of 36 mg of morphine over the last 24 hours. Which of the following oral regimens is the most appropriate transition for this patient?

A. Oxycodone 5–10 mg every 4 hours as needed
B. Hydrocodone 10–15 mg every 4 hours as needed
C. Methadone 15 mg every 6 hours as needed
D. Morphine sustained release 10 mg every 8 hours as needed

CHAPTER 14 ANSWERS

1. ANSWER: C

Pain in children is assessed by using two different methods: self-report and observational-behavioral measures. Because pain is a subjective symptom, the standard for pain assessment has been self-report, in which a child is asked to quantify pain using a scale of numbers. However, the tools developed for **self-report** are only appropriate for **children older than 3 years and with normal cognitive skills.** For children **under 3 years of age** and for **cognitively impaired children**, **observational-behavior measures** are more frequently used in the assessment of pain, both by observing and quantifying behavior patterns.

Visual Analog Scale (VAS)—A self-report scale. Numbers from 0 (no pain) to 10 (maximum pain) are presented on a horizontal or vertical scale. Appropriate for **ages 6 years and older**.

Wong-Baker Faces Scale (WBFS)—A self-report scale. The child is shown a series of line diagrams of faces with **expressions of increasing distress**. It is coded as 0 (no distress) to 5 (maximum distress) or, alternatively, from 0 to 10. Its reliability and validity are confirmed in **children 3 to 18 years of age**.

Oucher Scale (OUCHER)—A self-report scale. It includes **photographic faces** of children on a 0 (no distress) to 100 (maximum distress) scale. It is appropriate for children **over 3 years of age**.

Face, Legs, Activity, Cry, Consolability Scale (FLACC)—An **observational-behavior scale**. It includes five categories of **pain behaviors**: facial expression, leg movement, activity, cry, and consolability. Each category is scored from 0 to 2 to yield a total score ranging from 0 to 10. This scale is appropriate for **children 3 years and younger**. A modified (revised) version is validated and used for older but cognitively impaired children.

KEY FACTS

- >3 years old and normal cognitive skills: self-report scales can be used
  - VAS: numbers 0 to 10; >6 years old
  - WBFS: facial expressions, 0–5 or 0–10 severity
  - OUCHER: photographic faces, 0–100 severity
- <3 years or cognitively impaired: observational-behavior scale more common
  - FLACC- five categories of pain behaviors

REFERENCE

Malviya S, Polaner DM, Berde C. Acute Pain. In: Cote CJ, Lerman J, Todres ID, eds. *A Practice of Anesthesia for Infants and Children*. 4th ed. Philadelphia, PA: Saunders Elsevier; 2009:940–6.

2. ANSWER: C

Pruritus is a **common side effect of epidural analgesia** with solutions containing opioids. Hydromorphone, fentanyl, and morphine are commonly used in epidural regimens in combination with local anesthetics such as bupivacaine, ropivacaine, and chloroprocaine.

Side effects of epidural opioids can range from pruritus, nausea and vomiting, and urinary retention to respiratory depression. Pruritus occurs in 30%–70% of cases in children receiving epidural or intrathecal opioids. The mechanism of pruritus is thought to be a **central opioid effect** rather than direct histamine degranulation from mast cells. Thus, **antihistaminics such as diphenhydramine are ineffective in treating pruritus** in this situation.

Opioid antagonists such as nalbuphine and naloxone, when used in low doses, are most effective to treat pruritus resulting from the central opioid effect from epidural/spinal opioid analgesia. Nalbuphine, at 25 μg/kg–50 μg/kg, is given intravenously every 6 hours as needed, or an infusion of naloxone is started at a rate of 0.25 μg/kg per hour.

Decreasing the opioid concentration or removal of the opioid from the epidural solution is also an effective treatment strategy in this situation.

KEY FACTS

- Pruritus is common and real, and treatment should always be considered as a side effect of epidural analgesia.
- The cause of pruritus is a central opioid effect, not histamine mediated.
- Treat with nalbuphine at 25–50 μg/kg IV every 6 hours or naloxone at 0.25 μg/kg per hour.

REFERENCE

Malviya S, Polaner DM, Berde C. Acute Pain. In: Cote CJ, Lerman J, Todres ID, eds. *A Practice of Anesthesia for Infants and Children*. 4th ed. Philadelphia, PA: Saunders Elsevier; 2009:970–2.

3. ANSWER: B

Sickle cell disease is a hereditary **disorder of hemoglobin synthesis**, in which there is abnormal production of Hemoglobin S. Hemoglobin A is normally composed of two alpha and two beta globin chains and makes up the majority of hemoglobin in adults.

Hemoglobin S is produced by a mutant beta globin gene, which causes a single amino acid substitution (valine for glutamic acid) in position 6 of the beta globulin chain. This ultimately leads to instability of the molecule. When exposed to lower oxygen tension, hemoglobin S aggregates

and polymerizes, causing sickle cell–shaped deformation of red blood cells, hemoglobin precipitation, and hemolysis. The pathophysiology in sickle cell anemia is now thought to be more complex than deformed cells occluding microcirculation. Rather, it is thought to be a **combination of inflammation, vascular adhesion abnormalities, platelet activation, and coagulation cascade activation**, which results in **a vaso-occlusive episode** and the associated **ischemic pain**.

Vaso-occlusive episodes are treated using a **multimodal approach:**

1. Medications: **Opioids, NSAIDs, and acetaminophen** are the mainstays of treatment. The presence of hyperalgesia over the affected area suggests peripheral and central sensitization. Neuropathic medications may be considered.
2. Physical therapy: **Transcutaneous electrical nerve stimulation** (TENS) for localized pain.
3. Behavior therapy: Relaxation techniques, **coping skills** development.
4. Regional analgesia: **Thoracic epidural analgesia** can provide excellent relief in acute chest syndrome and should be strongly considered.

In the case presented here, the patient exhibits a normal response to touch over affected areas; therefore, the presence of a neuropathic component is unlikely. Gabapentin is a medication used in neuropathic pain and is not suitable in the treatment of ischemic pain. Similarly, trigger point injections and antidepressant medications have no use in the treatment of ischemic pain.

KEY FACTS

- Mainstays of treatment include opioids, NSAIDs, and acetaminophen; epidural analgesia is very effective and TENS is used for localized pain.
- Abnormal response to touch (i.e., hyperalgesia) suggests nerve sensitization and indicates neuropathic medications may work.

REFERENCE

Szabova A, Goldschneider K. Chronic Pain. In: Cote CJ, Lerman J, Todres ID, eds. eds. *A Practice of Anesthesia for Infants and Children*. 4th ed. Philadelphia, PA: Saunders Elsevier; 2009:987–8.

4. ANSWER: B

The **prevalence of chronic pain** in children and adolescents at anytime is approximately **15%.** In one study, the 3-month prevalence, characteristics, consequences, and provoking factors of chronic pain in 749 children and adolescents were studied. The most common presentation of pain in this population was **headache (60.5%) followed by abdominal pain (43.3%), limb pain (33.6%), and back pain (30.2%)**. Another source cites back pain as reported in up to 50% of children by the mid-teenage years and weekly abdominal pain in up to 17%. A significant portion of children and adolescents with pain also had sleep problems, inability to pursue hobbies, eating problems, and school absence. Overall, chronic pain among children is common and is frequently associated with physical illness and disability, as in adults.

The care model for chronic pain in children is multidisciplinary, with pain physicians, psychologists, physical therapists, nurses, and consultants playing vital roles. The approach to management includes history and physical along with ancillary data (lab tests, imaging) likely already ordered by the primary or consulting physician. Of utmost importance is to identify **"red flag" symptoms (Box 14.1) for headache, abdominal pain, and back pain**.

Treatment is also multidisciplinary. For example, treatment of abdominal pain when not related to other causes includes medications, behavioral medicine, dietary management, TENS (if abdominal wall origin of pain noted), and blocks.

Box 14.1 **RED FLAGS AND SYMPTOMS FOR ABDOMINAL PAIN**

1. Persistent right upper or right lower quadrant pain
2. Dysphagia
3. Persistent or cyclic vomiting
4. Gastrointestinal blood loss
5. Family history of inflammatory bowel disease, celiac disease, or peptic ulcer disease
6. Pain that wakes the child from sleep
7. Arthritis
8. Nocturnal diarrhea
9. Involuntary weight loss
10. Decelaration of linear growth
11. Delayed puberty
12. Unexplained fever
13. Hepatosplenomegaly, intraabdominal masses, perianal lesions
14. Bilious emesis
15. Costovertebral angle tenderness

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KEY FACTS

- Prevalence of chronic pain in children and adolescents at any time is approximately 15%.
- The most common presentation of pain is headache (60.5%), followed by abdominal pain (43.3%), limb pain (33.6%), and back pain (30.2%).

REFERENCE

Szabova A, Goldschneider K. Chronic Pain. In: Cote CJ, Lerman J, Todres ID, eds. *A Practice of Anesthesia for Infants and Children*. 4th ed. Philadelphia, PA: Saunders Elsevier; 2009:982–3.

5. ANSWER: C

One of the goals in the evaluation of chronic pain is to look for and identify an underlying serious illness, if it exists. Red flags (Box 14.1) can point to a serious underlying pathology and indicate a need for referral or further laboratory and imaging studies. Additional history regarding medications, allergies, family, and a thorough review of systems is essential.

KEY FACT

- Recognize red flags that would indicate serious illness as the underlying cause of chronic pain.

REFERENCE

Szabova A, Goldschneider K. Chronic Pain. In: Cote CJ, Lerman J, Todres ID, eds. *A Practice of Anesthesia for Infants and Children*. 4th ed. Philadelphia, PA: Saunders Elsevier; 2009:981–3.

6. ANSWER: B

Complex regional pain syndrome (CRPS) is the most recent nomenclature describing two types of painful conditions, type I (formerly called reflex sympathetic dystrophy, RSD) and type II (formerly called causalgia). The hallmark of this condition is the **presence of pain, often with allodynia or hyperalgesia**. The signs and symptoms in both types of CRPS are indistinguishable. The only difference between types I and II is the presence of a **documented nerve injury in type II CRPS**. In most cases, the affected area exhibits changes in skin color and temperature, edema, motor activities such as tremor, dystonia, and weakness. The affected limb may have changes in nail and hair growth.

Traumatic injury and limb immobilization are prime predisposing factors. Also, a **genetic** predisposition is suggested by the clinical observation that CRPS is rare in the African American population. In the pediatric population, the condition is **rare under 10 years old**, though it has been reported in children as young as 5 years (type I) and 3 years of age (type II). Furthermore, in children and adolescents, CRPS is predominantly seen in **females** (female:male ratio of 5:1).

Treatment of CRPS can be challenging, with the ultimate goal being restoration of function. This is usually achieved with a **multidisciplinary approach**, including **pharmacological therapy, physical therapy, and psychological interventions**. Effective medications used in CRPS management include tricyclic antidepressants and anticonvulsant agents (gabapentin, oxcarbazepine). **Physical therapy** is the cornerstone of therapy and focuses on aggressive mobilization of the affected limb, with range of motion exercises, desensitization, strength training, and transcutaneous electrical nerve stimulation.

Sympathetic nerve blocks have also been used when more conservative therapies have not been successful in treating pain or when a child has not been able to participate in physical therapy due to severe allodynia. In the pediatric pain population, intravenous regional blocks have gained popularity as a beneficial treatment option for cases involving the distal limb, allowing the child to tolerate and proceed with physical therapy. Lumbar plexus blocks may be used for patients who have lower-extremity CRPS, and brachial plexus blocks maybe used for patients with upper-extremity involvement.

KEY FACTS

- A documented nerve injury in CRPS II distinguishes it from CRPS I.
- Predisposing factors include traumatic injury, limb immobilization, genetics, and female gender.
- Treatment is multidisciplinary, with aggressive limb mobilization being the cornerstone.
- Sympathetic nerve blocks and intravenous regional blocks have been useful in allowing the child to proceed with physical therapy when medications and conventional treatments have failed to alleviate pain.

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7. ANSWER: A

Drug elimination via the liver (and, to small extent, via the lungs and kidneys) requires biotransformation into more

polar forms. Two types of biotransformation can occur in the liver, namely, phase I and phase II reactions. **Phase I reactions transform drugs via oxidation**, reduction, or hydrolysis, whereas **phase II reactions transform drugs via conjugation** into more polar forms. **Cytochrome P-450 (CYP)** system enzymes are responsible for **phase I** elimination of lipophilic compounds in the body.

In the past two to three decades, multiple isoforms of the CYP system enzymes with different drug specificities have been identified. Among those, the **CYP2D6** enzyme is responsible for the metabolism of more than **20% of prescribed medications** as well as conversion of certain drugs to their biologically active forms.

This enzyme is low to absent in fetal life, and its activity is limited to only 20% of adult values at 1 month of age. **Adult levels of enzyme activity** are reached by age **3–5 years.** Expression of the CYP2D6 enzyme exhibits **wide polymorphism** in the population. Some individuals may have reduced metabolic activity (poor metabolizers), and the frequency of poor metabolizers varies among different ethnic groups (7% of Caucasians, 0–1% of Chinese).

Drugs that require the CYP2D6 enzyme to turn them into biologically active metabolites are **not effective in the portion of the population who are poor metabolizers**. Among the oral analgesics listed earlier, **codeine, hydrocodone,** and **tramadol** require the CYP2D enzyme to transform them into active analgesics.

Codeine is a prodrug that is metabolized to morphine. Codeine's analgesic effect is thought to come from its metabolite, codeine 6-glucuronide. Thus, in patients who are poor metabolizers, codeine will have a limited analgesic effect. Similarly, hydrocodone is metabolized into hydromophone and tramadol into O-D tramadol.

Oxycodone and hydromophone do not require CYP metabolism to become active compounds and therefore are better choices for postoperative analgesia in this patient.

KEY FACTS

- Liver metabolism phase I—oxidation; phase II—conjugation.
- CYP2D6 metabolizes more than 20% of prescribed medications, but "poor metabolizers" exhibit inadequate biotransformation of drug through this enzyme.
- Codeine, hydrocodone, and tramadol require CYP2D6 for transformation into active analgesics.
- Hydromorphone and oxycodone are active analgesics without biotransformation by CYP2D6.

REFERENCE

Cote CJ, Lerman J, Ward RM, Lugo RA, Goudsouzian N. Pharmacokinetics and Pharmacology of Drugs Used In Children. In: Cote CJ, Lerman J, Todres ID, eds. *A Practice of Anesthesia for Infants and Children*. 4th ed. Philadelphia, PA: Saunders Elsevier; 2009: 92–5, 138–9.

8. ANSWER: D

Pain management following orthopedic procedures involving upper and lower extremities can be achieved by regional and neuraxial blocks, as well as parenteral and enteral opioid administration. Intermittent or patient-controlled opioid analgesia is a proven and effective method of postoperative pain management. However, due to **respiratory depressant effects, opioids** should **be used with caution in patients** with **respiratory compromise**. If possible, alternative pain management strategies, such as regional blocks, should be employed either as the sole anesthetic or for an opioid-sparing effect.

Brachial plexus blocks are an effective means of providing anesthesia and analgesia for the upper extremity. Based on the anatomic location of the surgical area on the upper extremity, the brachial plexus can be approached at the desired level.

The **interscalene approach, infraclavicular approach, and axillary approach with musculocutaneous nerve block** are all adequate methods of providing analgesia for procedures involving the **distal humerus**. However, the complications listed below for interscalene and infraclavicular approaches makes the axillary approach with musculocutaneous nerve block the best choice to minimize further respiratory compromise.

Interscalene approach complications include **phrenic nerve block** (incidence is reported as high as 50% and, in some reports, there is some degree of phrenic nerve block in all patients; this is critical in very young children whose breathing is diaphragm dependent); **block of the recurrent laryngeal nerve** causing vocal cord paralysis and airway resistance; and **pneumothorax**.

Infraclavicular approach complications include potential for **intrapleural injection and pneumothorax**.

Axillary approach complications include **hematoma and intravascular injection**. This approach will not adequately block the musculocutaneous nerve, which provides sensation to the elbow area because this nerve exits the brachial plexus proximally in the axillary fossa. A separate block of the musculocutaneous nerve is required.

KEY FACTS

- Opioids should be avoided (or their limited use closely monitored) in patients with respiratory compromise.
- Complications of the interscalene approach include phrenic nerve block, recurrent laryngeal nerve block, and pneumothorax.
- Complications of the infraclavicular approach include intrapleural injection and pneumothorax.
- Complications of the axillary approach include hematoma and intravascular injection.
- When using the axillary approach, a separate block of musculocutaneous nerve is required as the nerve branches out proximally.

REFERENCE

Polaner DM, Suresh S, Cote C. Regional Anesthesia. In: Cote CJ, Lerman J, Todres ID, eds. *A Practice of Anesthesia for Infants and Children*. 4th ed. Philadelphia, PA: Saunders Elsevier; 2009:894–9.

9. ANSWER: D

Circumcision is a common surgical procedure performed on all age groups, including neonates, infants, children, and adults. The most common indications are phimosis and parental preference. In the pediatric age group, this procedure is commonly performed under general anesthesia. Pain management options for the postoperative period include **caudal epidural block, penile block** (dorsal nerve and subcutaneous ring), **parenteral** and **enteral opioids, and nonopioid analgesics**.

Caudal epidural block is one of the simplest and most common blocks used in pediatric postoperative pain management. **Up to 1 mL/kg (maximum 20 mL) of 0.125% or 0.25% bupivacaine with or without epinephrine** is injected into the sacral epidural space via the caudal approach. The relatively large volume of local anesthetic provides analgesia at the sacral and lumbar levels, which may last several hours. The **penile block** is also a commonly used anesthetic and analgesic technique for procedures involving the penis (circumcision, hypospadias repair, urethral dilatation), though it reliably provides analgesia for the **distal two thirds of the penis**. Penile blocks can be performed either as a dorsal nerve block or as a subcutaneous ring block or a combination of the two. It is performed by a single injection of **0.125% bupivacaine without epinephrine**. Since the dorsal artery of the penis is an end artery, its vasospasm could cause necrosis, so **epinephrine must be avoided for penile blocks**.

Parenteral and enteral nonopioid analgesics are useful adjuncts in surgical pain management. **Ketorolac** is a NSAID with very potent analgesic properties. One major concern is its effect on platelet aggregation and the potential for bleeding. Safety and efficacy have not been established in infants and children.

Acetaminophen administered orally or rectally is a commonly used nonopioid analgesic in the pediatric age group. The recommended oral dose of acetaminophen is 10–15 mg/kg every 4 hours with a maximum daily dose of 75 mg/kg for children and 3 g for adults. Due to the **risk of hepatotoxicity**, the total daily dose **should not exceed 75 mg/kg in children**, **60 mg/kg in term neonates and preterm neonates over 32 weeks postconceptual age**, and **40 mg/kg in preterm neonates under 32 weeks postconceptual age**.

KEY FACTS

- Caudal epidural block: up to 1 mL/kg (maximum 20 mL) of 0.125% or 0.25% bupivacaine with or without epinephrine
- Penile block: 1 to 4 mL of 0.125% bupivacaine *without* epinephrine
- PO acetaminophen: is an effective form of nonopioid analgesics
- Acetaminophen maximum daily doses: 40 mg/kg for preterm neonates under 32 weeks postconceptual age, 60 mg/kg for term neonates and preterm neonates over 32 weeks postconceptual age, 75 mg/kg for children, 3g for adults

REFERENCE

Cote CJ, Lerman J, Ward RM, Lugo RA, Goudsouzian N. Pharmacokinetics and Pharmacology of Drugs Used In Children; Lonnqvist P-A, Lerman J, General Abdominal and Urologic Surgery; Polaner DM, Suresh S, Cote C. Regional Anesthesia. In: Cote CJ, Lerman J, Todres ID, eds. *A Practice of Anesthesia for Infants and Children*. 4th ed. Philadelphia, PA: Saunders Elsevier; 2013:909–950.

10. ANSWER: C

Complex regional pain syndrome (CRPS) is the most recent nomenclature describing two types of painful conditions, type I (formerly reflex sympathetic dystrophy, RSD) and type II (formerly causalgia). The **hallmark** of this condition is the **presence of pain, often with allodynia or hyperalgesia**. The only difference between types I and II is the presence of **documented nerve injury in type II**. In most cases, the affected area exhibits changes in skin color and temperature, edema, motor activities such as tremor, dystonia, and weakness.

Although both allodynia and hyperalgesia can be seen in either type of CRPS, the symptom presented in this case is more likely to be explained by hyperalgesia.

Paresthesia is an **abnormal** sensation whether **spontaneous or evoked**.

Allodynia is a pain sensation due to a stimulus (such as normal touch) that **does not normally provoke pain**.

Hyperalgesia is an increased response to a **stimulus that is normally painful**.

Dysesthesia is an **unpleasant** abnormal sensation, whether **spontaneous or evoked**.

KEY FACTS

- Paresthesia (just abnormal, i.e., numbness, tingling) versus dysesthesia (unpleasant)—both can be either spontaneous or evoked
- Hyperalgesia (exaggerated pain response to stimulus normally causing pain) versus allodynia (pain in response to stimulus *not* normally causing pain)

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11. ANSWER: A

Headache is one of the most common presentations of pain in children (approximately 60% of all pain presentations). Headaches are divided into two major groups. **Primary headaches** include migraine headache, tension-type headache, cluster headache, and trigeminal neuralgia. **Secondary headaches** are usually due to a variety of causes such as head and neck traumas, muscle spasms, vascular disorders, nonvascular intracranial disorders, infection, disorders of eye, ear, nose, sinuses, teeth and cranium, homeostasis disturbances, and psychiatric conditions.

A thorough evaluation of history, symptoms, prior records, and psychosocial status is important in the management of headache in the pediatric population. **Multimodal strategies,** including pharmacological therapy, behavioral therapy, physical therapy as well as acupuncture and yoga, are useful.

However, the clinician should be cognizant of red flag symptoms and signs (Box 14.2), which can point to a serious underlying pathology. In the case presented here, the patient presents with **worsening morning headaches and pain that awakens her from sleep**, both of which can be **signs of intracranial pathology**. This warrants referral and/or an imaging study.

Box 14.2 **RED FLAGS AND SYMPTOMS FOR SECONDARY HEADACHE**

- Persistent vomiting
- Focal neurological signs
- Meningeal signs
- Unexplained fever
- Increased intracranial pressure
- Changes in behavior and mental status
- Sudden onset of severe headache
- Morning headaches
- Headaches awakening the child from sleep

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KEY FACT

- Recognize red flags that may indicate a serious underlying illness as the cause of headaches refractory to medical management.

REFERENCE

Szabova A, Goldschneider K. Chronic Pain. In: Cote CJ, Lerman J, Todres ID, eds. *A Practice of Anesthesia for Infants and Children*. 4th ed. Philadelphia, PA: Saunders Elsevier; 2009:982–4.

12. ANSWER: A

Multimodal drug therapy is one of the essential components of chronic pain management. Single drug therapy often falls short, and a rational polypharmacy is prudent. Antidepressants, anticonvulsants, muscle relaxants, opioids, and NSAIDs are commonly used medications in the treatment of chronic pain patients.

Baclofen is a centrally acting muscle relaxant medication commonly used in spastic conditions such as cerebral palsy and spinal cord injury. It interacts with Γ-amino butyric acid receptor **(GABA) b subtype**. It is most commonly administered orally, but it is also approved for intrathecal administration via implanted pumps.

Ketamine is a derivative of phencyclidine and exerts its effect on N-methyl-D-aspartate **(NMDA) receptors as an antagonist**. It is used in low doses for analgesia and in higher doses for sedation and anesthesia with a great margin of safety.

Gabapentin is an anticonvulsant agent with a molecular structure that is similar to Γ-amino butyric acid (GABA). However, it does not bind or act on GABA receptors. It exerts its effect by binding to the α2-delta subunit of the voltage-dependent **calcium channels**. It is the drug of choice in neuropathic pain management due to its good tolerability and minimal side effects.

Methadone is a **synthetic opioid** with a **very long elimination half-life (mean of 19 hours).** Methadone is administered orally (approximately 80% bioavailability) or intravenously. Supplied as a racemic mixture, the l-isomer acts as a μ opioid, whereas the d-isomer acts as an N-methyl-D-aspartate (NMDA) receptor antagonist. Due to its long-acting effect and efficacy in treating neuropathic pain, it is a very useful drug in the management of patients with cancer pain and other serious illnesses.

KEY FACTS

- Baclofen: muscle relaxant, acts at GABA-b receptors, administered PO or intrathecally

- Ketamine: PCP derivative, antagonizes NMDA receptors, used for analgesia or anesthesia
- Gabapentin: structure similar to GABA but acts at calcium channels
- Methadone: synthetic opioid, l-isomer acts at μ receptors, d-isomer acts at NMDA receptors

REFERENCE

Cote CJ, Lerman J, Ward RM, Lugo RA, Goudsouzian N. Pharmacokinetics and Pharmacology of Drugs Used In Children; Malviya S, Polaner DM, Berde C. Acute Pain; Szabova A, Goldschneider K. Chronic Pain. In: Cote CJ, Lerman J, Todres ID, eds. *A Practice of Anesthesia for Infants and Children*. 4th ed. Philadelphia, PA: Saunders Elsevier; 2009:123–4, 953–4, 988–91.

13. ANSWER: D

Pain impulses are conducted at the dorsal horn of the spinal cord by two types of sensory nerve fibers. **Myelinated A-δ fibers transmit sharp and well-localized pain rapidly**. **C fibers are unmyelinated** and therefore possess a lower conduction velocity and **transmit dull, aching, and diffusely localized pain**. **Nociceptive specific neurons** are located at **lamina I and II** areas of the dorsal horn and receive input from both A-δ and C fibers. However, they are not involved in referred pain sensory conduction.

Referred pain is a result of the **convergence of somatic and visceral nociceptive** input into **lamina V** of the dorsal horn, where **wide dynamic range neurons** are located. These neurons receive input from both A-δ and C fibers as well. There are many examples of referred pain resulting from the convergence of somatic and visceral conduction, such as left arm pain with angina, right shoulder pain with cholecystitis, and shoulder pain with pleuritic stimulation from chest tube as demonstrated in this case.

KEY FACTS

- A-δ fibers: myelinated, fast conductance, well-localized and sharp pain immediately after injury (i.e., the pain you feel immediately after pricking your thumb with a needle)
- C-fibers: unmyelinated, slower conductance, diffuse pain (i.e., the throbbing sensation in your thumb several minutes after pricking it)
- Referred pain: secondary to convergence of somatic and visceral input including A-δ and C fibers

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Fitzgerald M, Howard RF. The Neurobiologic Basis of Pediatric Pain. In: Schecter NL, Berde CB, Yaster M, eds. *Pain in Infants, Children, and Adolescents*. 2nd ed. Philadephia, PA: Lippincott, Williams & Wilkins; 2003:20–23.

14. ANSWER: B

Prolonged QT syndrome is a condition that presents as prolongation of the "corrected" QT interval on EKG. A **QTc more than 450 ms** is considered abnormal. It is associated with genetic predisposition (long QT syndrome), certain disease states (chronic liver disease, hypothyroidism), and adverse effects of certain drugs, including antiemetics (droperidol, dolasetron), analgesics (methadone), antidepressives (imipramine), antipsychotics (haloperidol), antiarrhythmics (amiodarone), and diuretics (thiazide). Prolonged **QTc is a risk factor for sudden and serious ventricular arrhythmias.**

Methadone is a synthetic opioid with a very **long elimination half-life** (**mean of 19 hours**). It is administered orally or intravenously with approximately 80% bioavailability via oral administration. Methadone is supplied as racemic mixture. The l-isomer acts as μ opioid, whereas the d-isomer acts as N-methyl-D-aspartate (NMDA) receptor antagonist. Its effect on the NMDA receptor makes it effective in the treatment of neuropathic pain and the development of tolerance as opposed to other opioids.

Due to methadone's long-acting effect and its efficacy in neuropathic pain, it is a very useful drug in the management of patients with pain secondary to cancer and other serious illnesses. Methadone has a **structural similarity to the calcium-channel blocker verapamil**. Thus, methadone in large **doses may cause arrhythmias** in predisposed individuals who may already have **prolonged QT syndrome**.

Acetaminophen, ketorolac, and oxycodone have no known effects on QT interval.

KEY FACTS

- Various factors can affect the QTc: genetic predisposition (long QT syndrome), disease states (chronic liver disease, hypothyroidism), drugs, including antiemetics (droperidol, dolasetron), analgesics (methadone), antidepressives (imipramine), antipsychotics (haloperidol), antiarrhythmics (amiodarone), and diuretics.
- Methadone may predispose to arrhythmias in individuals who exhibit prolonged QTc because it is structurally similar to verapamil.

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Apfel CC. Postoperative Nausea and Vomiting. In: Miller RD, ed. *Miller's Anesthesia*. 7th ed. Philadelphia, PA: Churchill Livingstone; 2010:2326, 2744.

15. ANSWER: C

Pain is defined as an **unpleasant sensory and emotional experience associated with actual or potential tissue damage**. Multiple classifications of pain exist, including those based on **origin**, **duration** (acute, chronic), **underlying disease** process (cancer pain), episodes, or **intensity** (recurrent, breakthrough pain).

Depending on the pathologic and emotional status of the patient, **more than one type of pain may be present.**

Somatic pain has a **musculoskeletal origin** and arises from tissues such as skin, mucosa, muscle, bones, and ligaments.

Neuropathic pain arises as a direct consequence of a **lesion or disease affecting the somatosensory system** (peripheral or central nervous system).

Visceral pain arises **from internal organs** such as bowels, kidneys, or ovaries as a result of distention, ischemia. or inflammation.

Psychogenic pain is a report of pain attributable primarily to psychological factors usually in the **absence of any objective physical pathology that could account for pain.**

KEY FACTS

- Somatic pain: musculoskeletal in origin
- Neuropathic pain: secondary to direct injury or damage to nervous system
- Visceral pain: originates from internal organs
- Psychogenic pain: psychological in nature without identifiable cause

REFERENCE

Turk DC, Okifuji A. Pain Terms and Taxonomies of Pain. In: Fishman SM, Ballantyne JC, Rathmell JP. *Bonica's Management of Pain*. 4th ed. Philadelphia, PA: Wolters Kluver/Lippincott, Williams & Wilkins; 2010:13–23.

16. ANSWER: A

Several peripheral and central nervous system receptors are responsible for pain sensory transmission. Primary nociceptive sensory neurons express multiple voltage-gated sodium channels, which are important targets in neuropathic pain disorders. For example, **familial erythromelalgia**, a genetic disorder causing severe burning pain in extremities, is result of a **mutation in voltage-gated sodium channels**.

Neuronal **calcium channels** are also important targets in pain modulation. The gabapentinoids **gabapentin and pregabalin** are commonly used in chronic and neuropathic pain management. They exert their effects by modulating intracellular calcium influx via neuronal calcium channels.

Transient receptor potential vanilloid (TRPV) channels are other peripheral nervous system targets involved in pain sensation. **Capsaicin**, a natural ingredient of hot chili pepper, exerts its analgesic effect by interacting with **TRPV channels** and **interfering with release of substance P from cutaneous C fibers**. Although capsaicin has been found to be useful in neuropathic pain conditions, its use, especially in pediatric patients, has been limited due to its untoward effects of stinging and burning at the application site.

The **NMDA receptors** of central nervous system are also involved in pain modulation. Systemically administered low-dose **ketamine**, a NMDA antagonist, is an effective analgesic in most neuropathic pain conditions.

KEY FACTS

- Pain sensation is processed through several different receptors that act via sodium and calcium channels.
- Gabapentin and pregabalin act at calcium channels.
- Capsaicin acts at TRPV channels.
- Ketamine acts at NMDA receptors.

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Krane EJ, Leong MS, Golianu B, Leong YY. Treatment of Pediatric Pain with Nonconventional Analgesics. In: Schecter NL, Berde CB, Yaster M. *Pain in Infants, Children, and Adolescents*. 2nd ed. Philadephia, PA: Lippincott, Williams & Wilkins; 2003:236–7.

17. ANSWER: C

Periods of acute pain are unfortunately a fact of life for children with sickle cell. Referred to sickle cell "crisis," these **vaso-occlusive episodes of pain** account for most hospitalizations and emergency room visits of children with sickle cell. They tend to have an abrupt and unpredictable onset. The pain is typically located in the extremities, chest, lower back, and abdomen. These crises are often triggered

by **infection, dehydration, hypoxia, and acidosis** but not always. Frequent and severe crises can lead to chronic daily and persistent pain. In a study by Platt et al., 5% patients with hemoglobinopathy reported more than 30% of all pain episodes and those with a higher frequency of pain episodes died earlier than those with less frequent pain crises.

Interestingly, **sickle cell crisis pain** is not the result of direct tissue or nerve damage but the result of **tissue hypoxia**. While the precise mediators of sickle cell pain have not been clearly identified, neurobiological studies point to an important role by Substance P in ischemic pain as well as protons via acid-sensing ion channels (ASICs) that are expressed in the dorsal root ganglia and the brain. At home, sickle cell pain is usually treated with **NSAIDs and oral opioids**. Multidisciplinary approaches to pain management, including **medications, biofeedback, hypnosis, guided imagery, and family therapy,** have been found to optimize pain control, normal functioning, and quality of life. When the pain is too severe or medications by mouth are not tolerated, hospitalization is necessary. Because of their wide fluctuations in pain levels, sickle cell crises are best initially treated with intravenous opioids delivered via patient-controlled analgesia. For that reason, **long-acting opioids such as MS Contin or shorter acting orally administrated opioids are not initially recommended**. NSAIDs have not been found to be very effective for severe sickle cell pain. An addition of a low basal rate can be considered for patients already on chronic oral opioids at home or once opioid requirements for effective analgesia are known. Such opioid basal rate, however, presents an increased risk of hypoxemia, especially at night, possibly worsening the vaso-occlusive episode. Close nursing observation with frequent pain assessments and monitoring is highly recommended for these patients.

KEY FACTS

- Sickle crises are vaso-occlusive episodes of pain that are often triggered by infection, dehydration, hypoxia, and acidosis.
- Home regimen usually includes NSAIDs and oral opioids, whereas inpatient episodes of pain usually require intravenous opioids.
- Multidisciplinary approaches to pain management include medications, biofeedback, hypnosis, guided imagery, and family therapy.

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Platt OS, Thorington BD, Brambilla DJ, et al. Pain in sickle cell disease. *N Engl J Med*. 1991;325:11–6.

Warfield C, Bajwa Z. *Principles and Practice of Pain Medicine*. 2nd ed. New York, NY: McGraw-Hill; 2004: Chapter 52.

18. ANSWER: D

In addition to being an opioid agonist, **methadone** also acts as an **antagonist to NMDA receptors** (similarly to ketamine). For this reason, methadone is useful for treating chronic pain, given that **NMDA activation is associated with hyperalgesia and opioid tolerance**. Methadone is also used in children to wean off long-term opioid use, to prevent withdrawal, and to treat pain when other opioids have failed. Of note, this synthetic opioid has a relatively **long half-life (around 19 hours)** and can present an **increased risk to sedation and respiratory depression**. Methadone may also potentially cause QT prolongation by blocking delayed rectifier potassium channels. It is less likely to trigger torsades de pointes, however, since it increases the dispersion of repolarization by usually less than 100 msec. The pediatric **IV dose of methadone** is **0.1–0.2 mg/kg** as a bolus with **0.05 mg/kg** titrated every 6–8 hours after. It may also be given **orally (0.1–0.2 mg/kg every 6–12 hours)**. Methadone has been particularly useful in pediatric patients with chronic diseases, cancers, and burns.

Ketamine has also been used to treat acute and chronic pain via **NMDA antagonism**. Using ketamine reduces the narcotic requirement, thus avoiding opioid tolerance and opioid-induced hyperalgesia. Ketamine also prevents central sensitization and allows for synergistic analgesia with other medications. Its use has been shown to improve overall function and therefore improve family interaction in the pediatric population as well. Ketamine often **preserves spontaneous ventilation and stimulates the cardiovascular system due to catecholamine release**. This medication may also sometimes cause a dissociative state for some patients given that it is a phencyclidine derivative. Ketamine may be administered via multiple routes, including orally, sublingually, intramuscularly, intravenously, and rectally.

Gabapentin acts on **voltage-dependent calcium channels** and combines the greatest efficacy with the least side effects in the treatment of **neuropathic pain, chronic abdominal pain, and migraines** in the pediatric population. **Paroxetine is a selective serotonin reuptake inhibitor (SSRI)**. SSRIs have not been shown to have analgesic effects most likely because of the lack of norepinephrine reuptake. **Duloxetine is a selective serotonin and norepinephrine reuptake inhibitor** and is used in treatment of chronic pain in children who also have depression.

KEY FACTS

- Methadone is both an opioid agonist that also acts as an antagonist to NMDA receptors.
- NMDA activation is associated with hyperalgesia and opioid tolerance.
- Methadone has a very long half-life of 19 hours and thus can present an increase risk to sedation and respiratory depression.

REFERENCES

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Davis PJ, Cladis FP, Motoyama EK, eds. *Smith's Anesthesia for Infants and Children*. 8th ed. St. Louis, MO: Elsevier Mosby; 2011:210–1, 219–20.

19. ANSWER: C

Gabapentin, an anticonvulsant, binds to **voltage-dependent calcium channels, reducing the calcium current** and **decreasing glutamate release in the dorsal horn**. The results include decreased neuronal activity, AMPA receptor activation on noradrenergic synapses, and substance P production. **Side effects** include sedation, peripheral edema, mood swings, irritability, and suicidality in teens. For **pediatric patients (<60 kg), 10–15 mg/kg/dose TID** are generally used, but this dose is reached after titration over several weeks. **Readjustment to these doses** is required for patients with **renal failure** (mode of elimination), but not hepatic failure, given that it is not metabolized by the liver. Side effects of this drug include sedation, dizziness, confusion ataxia, headaches, and confusion.

Gabapentin was created as a structural analogue of GABA, hence the name; however, it does not interact with the GABAergic system. Gabapentin does not bind to GABA or NMDA receptors. Gabapentin has been shown to be an effective first-line treatment for **neuropathic pain** such as phantom limb pain.

Neuropathic pain is chronic pain that persists via **activation of nociceptive neurons even without any inflammation or tissue injury**. The form of pain may be varied, ranging from ongoing aching pain to abnormal stimulus-evoked pain to brief lancinating pain that may be spontaneous or stimulus evoked. On exam, **allodynia (pain caused by a nonpainful stimulus) and hyperalgesia (exaggerated pain response to a normally painful stimulus)** are positive findings for neuropathic pain. Other findings may include muscle tone, bulk, and strength abnormalities indicating involvement of motor neurons in addition to nociceptive ones. Autonomic neurons may also be involved, causing color, temperature, and vascular changes in affected tissue.

Phantom limb pain is one type of neuropathic pain that consists of **perceived pain distal to the site of amputation**. The mechanism is thought to involve spontaneous activation of central sensory neurons that previously were activated by afferents from nerves in the lost limb. **Treatments** for phantom limb pain include **tricyclic antidepressants, anticonvulsants such as gabapentin, sodium channel blockers, opioids**, and more invasive procedures, including implanted neural stimulators/pumps. These treatments have been shown to be less successful for phantom limb pain versus other neuropathic pain syndromes, however.

KEY FACTS

- Gabapentin, an anticonvulsant, binds to voltage-dependent calcium channels, reducing the calcium current and decreasing glutamate release in dorsal horn neurons of the spinal cord.
- Neuropathic pain is caused by activation of nociceptive neurons even without any inflammation or tissue injury.

REFERENCES

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Cote CJ, Lerman J, Anderson BJ, eds. *A Practice of Anesthesia for Infants and Children*. 5th ed. St. Louis, MO: Mosby Elsevier; 2013:132, 959.

Warfield C, Bajwa Z. *Principles and Practice of Pain Medicine*. 2nd ed. New York, NY: McGraw-Hill; 2004:Chapter 62.

20. ANSWER: B

Allodynia is pain that is caused by a stimulus that normally is not painful (i.e., lightly rubbing the skin). This form of pain has been seen in multiple neuropathic processes, including chronic regional pain syndrome. The mechanism of allodynia includes a **reduced threshold of action at peripheral nociceptor terminals and CNS myelinated Aβ fibers**. **Hyperalgesia** describes increased, **exaggerated pain response to a normally painful stimulus**. Neuralgia describes pain that correlates to a peripheral nerve; usually the sensation is electric and sharp. **Paresthesia** is not a form of pain; it is **an abnormal sensation** (i.e., pinprick) that can be either spontaneous or caused by some stimulus, while **dysesthesia** is a **painful, unpleasant sensation that can be either spontaneous or evoked by a stimulus**.

KEY FACT

- Allodynia is pain that is caused by a stimulus that normally is not painful; it is caused by reduced threshold of action at peripheral nociceptor terminals and CNS myelinated Aβ fibers.

REFERENCE

Warfield C, Bajwa Z. *Principles and Practice of Pain Medicine*. 2nd ed. New York, NY: McGraw-Hill; 2004:Chapter 4.

21. ANSWER: B

The **nature of pain in neonates**, as a conscious experience, remains unclear. There is, however, unquestionable evidence that neonates respond to pain and that untreated pain results in harmful neuroendocrine responses, disrupted eating

and sleeping cycles, and sensitization to pain, as evidenced by increased response to pain during later painful events. Despite these findings, pain in neonates is often undertreated because of difficult pain assessments, insufficient knowledge of clinicians, and concern for addiction to narcotics.

Pain pathways develop during the second and third trimester and at **26 weeks postconceptual age**, **the peripheral and spinal afferent transmission is matured enough to respond to tissue injury and inflammation with withdrawal reflexes, autonomic arousal, and hormonal-metabolic stress responses**. Withdrawal thresholds to noxious stimuli are lower in preterm neonates than older neonates, infants, and children.

KEY FACTS

- Pain pathways develop during the second and third trimester of gestation.
- By 26 weeks postconceptual age, the peripheral and spinal afferent transmission are matured enough to respond to tissue injury and inflammation with withdrawal reflexes, autonomic arousal, and hormonal-metabolic stress responses.

REFERENCE

Cote CJ, Lerman J, Anderson BJ, eds. *A Practice of Anesthesia for Infants and Children*. 5th ed. St. Louis, MO: Mosby Elsevier; 2013:939.

22. ANSWER: C

Pain assessment in children unable to communicate or verbalize their pain such as this patient constitutes a significant challenge for clinicians. At the same time, such patients often experience more pain because of associated conditions such as muscle spasms, spasticity, and often many surgical procedures. Studies have shown that **pain in cognitively impaired children** is **vastly undertreated** because of challenging pain assessment and concerns for side effects of narcotics administration. As a result, several behavior scales have been developed to attempt to better assess pain in these patients. Examples of these scales include the **University of Wisconsin Pain Scale for Preverbal and Nonverbal Children, the Non-communicating Children's Pain Checklist Postoperative Version (NCCPC-PV), and the revised Face Legs, Activity, Cry, Consolability Observational Tool (r-FLACC**). Because of greater simplicity, easier implementation, and good interrater reliability, the **r-FLACC** is most often used in clinical settings and provides with an overall pain score from 0 to 10 (see Table 14.1). The **Wong Baker Faces Pain Scale** is a pain self-assessment visual tool that has been extensively validated in children aged 3 to 18 years. This scale is not appropriate for a child with severe cognitive impairment. The **Visual Analog Scale** is also a pain self-assessment tool that is not appropriate for this patient (Table 14.1).

KEY FACT

- R-FLACC is most often used to assess pain in cognitively impaired children because of simplicity, easier implementation, and good interrater reliability.

REFERENCE

Cote CJ, Lerman J, Anderson BJ, eds. *A Practice of Anesthesia for Infants and Children*. 5th ed. Mosby Elsevier; 2013:940–6.

Table 14.1 **REVISED FLACC FOR PAIN ASSESSMENT IN THE COGNITIVELY IMPAIRED**

	0	1	2
Face	No particular expression or smile	Occasional grimace/frown; withdrawn or disinterested [Appears sad or worried]	Consistent grimace or frown Frequent/ constant quivering chin, clenched jaw [Distressed-looking face; expression of fright or panic]
Legs	Normal position or relaxed	Uneasy, restless, tense [Occasional tremors]	Kicking, or legs drawn up [Marked increase in spasticity, constant tremors or jerking]
Activity	Lying quietly, normal position, moves easily	Squirming, shifting back and forth, tense [Mildly agitated (e.g., head back and forth, aggression); shallow, splinting respirations, intermittent sighs]	Arched, rigid, or jerking [Severe agitation head banging; shivering (not rigors); breath holding, gasping or sharp intake of breath; severe splinting]
Cry	No cry (awake or asleep)	Moans or whimpers, occasional complaint [Occasional verbal outburst or grunt]	Crying steadily, screams or sobs, frequent complaints [Repeated outbursts, constant grunting]
Consolability	Content, relaxed	Reassured by occasional touching, hugging or "talking to," distractible	Difficult to console or comfort [Pushing away caregiver, resisting care or comfort measures]

Note: Revised descriptors for children with disabilities shown in brackets.

23. ANSWER: D

Acupuncture has become more popular and widely excepted in the United States. One of its benefits is that the **analgesic effects of acupuncture may persist for several hours after application**; however, the effects are not immediate and may take 20–30 minutes to act. This complementary therapy originated in China and incorporates the **idea of qi (life force/energy) via various pathways called meridians**. Acupuncture uses specific points along these meridians to correct any imbalances in these meridians that cause pain. Depending on the specific form of acupuncture, there are hundreds to thousands (2000) of different points in the body. Other popular forms have evolved that include Korean hand acupuncture, Japanese acupuncture, French energetics system, electroacupuncture, and percutaneous electrical nerve stimulation.

Many studies investigating the efficacy of acupuncture have varied results in large part to the variability of skills of the acupuncturists. It is thought that needling of nerve fibers in the muscle sends impulses to the spinal cord, midbrain, and hypothalamus-pituitary system. **Enkephalin, dynorphin, beta-endorphins, GABA, serotonin, norepinephrine, and nitric oxide** are all thought to be involved in these systems. Endorphin enzyme degradation and opioid antagonists may both hinder the analgesic properties of acupuncture. Animal studies have shown that deficiency in opioid receptors and endorphins limits the analgesic effects of acupuncture. The World Health Organization has determined in 2002 (based on a review of multiple clinical trials) that acupuncture is effective in treating allergies, biliary colic, depression, dysentery, dysmenorrheal, epigastritis, facial pain, headache, hypertension, hypotension, induction of labor, knee pain, leucopenia, low back pain, malposition of fetus, morning sickness, nausea, vomiting, neck pain, dental pain, shoulder arthritis, postoperative pain, renal colic, rheumatoid arthritis, sciatica, sprains, stroke, and tennis elbow. Further studies are constantly being conducted to increase the acceptance of acupuncture as an effective means for pain control.

KEY FACTS

- Analgesic effects of acupuncture may persist for several hours after application.
- Acupuncture can be effective in treating a variety of conditions, including allergies, biliary colic, depression, dysentery, dysmenorrheal, epigastritis, facial pain, headache, hypertension, hypotension, induction of labor, knee pain, leucopenia, low back pain, malposition of fetus, morning sickness, nausea, vomiting, neck pain, dental pain, shoulder arthritis, postoperative pain, renal colic, rheumatoid arthritis, sciatica, sprains, stroke, and tennis elbow.

REFERENCE

Ballantyne JC. *The Massachusetts General Hospital Handbook of Pain Management*. 3rd ed. Philadelphia, PA: Lippincott, Williams & Wilkins 2006:248–55.

24. ANSWER: A

The main difference between types I and II CRPS is the evidence of major nerve injury; in fact, CRPS type II was previously known as causalgia. Both CRPS types involve **allodynia, hyperalgesia, and edema and color changes to the affected site**. Allodynia is pain caused by a stimulus that is not normally painful. Hyperalgesia is an exaggerated pain response to a normally painful stimulus. Other symptoms include weakness, tremors, dystonia, immobility, and changes in hair/nail growth.

In the pediatric population, CRPS is **more common in females**, **Caucasians**, and **after the age of 10 years old**. Many times, patients are active and high achievers; it has been suggested that there is also a **genetic predisposition** for this syndrome.

CRPS diagnostic criteria include the following:

- Continuing pain disproportionate to inciting event
- At least one sign and one symptom in three or more categories:
  - Sensory (allodynia, hyperalgesia)
  - Vasomotor (temperature, skin color changes and/or asymmetry)
  - Sudomotor (edema, sweating changes and/or asymmetry)
  - Motor/trophic (decreased range of motion, motor dysfunction, hair/nail/skin changes
- No other diagnosis can better explain the signs and symptoms.
- CRPS Type I: no evidence of significant nerve injury
- CRPS Type II: evidence of significant nerve injury

Evaluation of this syndrome is multifactorial and includes a detailed, physical exam, including a full neurological exam, behavioral assessment, psychosocial assessment, physical therapy assessment, and a careful review of previous medical records.

The treatment of CRPS is focused on functional restoration of the affected region via rapid initiation of multidisciplinary therapy. The likelihood of cure is much higher if treatment is started in the initial phase of the disease. The **treatment** of CRPS includes the following:

- Physical therapy: stress loading, desensitization, active range of motion

- Regional and sympathetic blocks (no neurolysis)
- Medications: NSAIDs, opioids, anticonvulsants, TCAs, alpha-blockers, bisphosphonates
- Behavioral medicine and psychological intervention

KEY FACTS

- CRPS is defined continuing pain disproportionate to inciting event and one sign and one symptom in three or more categories: sensory, vasomotor, sudomotor, and motor/trophic.
- CRPS Type I: no evidence of significant nerve injury.
- CRPS Type II: evidence of significant nerve injury.

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Cote CJ, Lerman J, Anderson BJ, eds. *A Practice of Anesthesia for Infants and Children*. 5th ed. St. Louis, MO: Mosby Elsevier; 2013:955–6.

Harden RN, Bruehl S, Stanton-Hicks M, Wilson PR. Proposed new diagnostic criteria for complex regional pain syndrome. *Pain Med*. 2007;8:326–31.

25. ANSWER: C

This patient has most likely **chronic abdominal wall pain** secondary to an **anterior cutaneous nerve entrapment syndrome (ACNES)**. Chronic abdominal wall pain is often missed and misdiagnosed. A study of referral patients by gastroenterologists found that almost **8% of patients with chronic abdominal pain had in fact chronic abdominal wall pain**. Chronic abdominal wall pain originates in the abdominal wall and **does not involve the abdominal viscera**. The most common cause of chronic abdominal wall pain is ACNES. In ACNES, there is an **entrapment of one of the intercostal nerve branches** (T7-T12) as it courses through the abdominal muscle wall in the TAP plane and then through the rectus abdominis muscle. One common area of entrapment is when the nerve makes a **90-degree turn from the posterior sheath of the rectus abdominis** muscle to innervate the anterior cutaneous area of the abdominal wall. It is thought that the pain from ACNES results from **compression or stretching of the nerve** in this area. The nerve can also be pushed or stretched by intraabdominal or extraabdominal processes. The **typical history and physical exam findings** of ACNES include a very **localized point of maximum pain** and tenderness often situated at the edge of the rectus abdominis muscle; burning, sharp, and continuous pain exacerbated by tension of abdominal muscles; or increased abdominal pressure and presence of surgical scars. The area around the point of maximum pain is often allodynic. One important aspect of the physical examination for suspected ACNES is a **positive Carnett's test**. This test is best performed with the patient prone and relaxed. If the patient has increased tenderness in the tender region when asked to elevate the head and shoulders, then the test is considered positive. When the pain arises from the abdominal wall, the muscle contraction accentuates the pain, whereas when the pain arises from an intraabdominal process, the tensed muscles guard the underlying viscera, thereby reducing pain. It is important, however, to recognize that there are false positives with the Carnett's sign and that the presence of ACNES does not rule out an intraabdominal process as both entities can coexist.

The most definitive way to diagnose ACNES is to perform a **diagnostic TAP block**. Patient with ACNES will experience temporary complete or almost complete relief with such block. When patients experience more than 50% in pain relief, the diagnostic test is considered positive. The **treatment** of ACNES depends on its severity. For mild ACNES, conservative measures such as abdominal binder, heat, and minimizing aggravating activities are often enough. The symptoms usually resolve over several weeks. For moderate to severe ACNES, treatment includes targeted TAP or rectus sheath block using steroids, radiofrequency ablation, neurolysis, and surgical interventions.

KEY FACTS

- A study of referral patients by gastroenterologists found that almost 8% of patients with chronic abdominal pain had in fact chronic abdominal wall pain.
- Chronic abdominal wall pain originates in the abdominal wall and does not involve the abdominal viscera.
- The most common cause of chronic abdominal wall pain is ACNES, where there is an entrapment of one of the intercostal nerve branches (T7-T12) as it courses through the abdominal muscle wall in the TAP plane and then through the rectus abdominis muscle.
- One common area of entrapment is when the nerve makes a 90-degree turn from the posterior sheath of the rectus abdominis muscle to innervate the anterior cutaneous area of the abdominal wall.
- It is thought that the pain from ACNES results from compression or stretching of the nerve in this area.
- The most definitive way to diagnose ACNES is to perform a diagnostic TAP block.

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26. ANSWER: A

This patient's opioid requirement for IV narcotics is roughly morphine 0.03 mg/kg/hr given the patient's weight (50 kg) and total amount (36 mg) in 24 hours.

36 mg/50 kg/24 hr = 0.03 mg/kg/hr

Based on Table 14.2 this correlates best with Answer A, oxycodone 5–10 mg every 4 to 6 hours as needed. IV morphine 0.03 mg/kg per hour correlates with oral oxycodone 0.1–0.2 mg/kg every 4–6 hours. For a 50 kg patient, this would translate to:

50 kg × 0.1 mg/kg = 5 mg

to

50 kg × 0.2 mg/kg = 10 mg of oxycodone every 4 to 6 hours

In clinical practice, the **converted oral opioid dose would also be reduced another 20%–30%** to provide a margin of safety to avoid side effects and toxicity ranging from nausea, vomiting, and oversedation to respiratory depression/apnea. In general, **morphine PO to IV is 1:3 to 1:6** (for opioid-naïve patients). The rest of the ratios are listed in Table 14.2 by Cote et al.

Answers B, C, and D are higher than the recommended dose. For a 50 kg pediatric patient, the correct oral regimens would be:

- Hydrocodone 5–10 mg every 4 hours (IV morphine 0.03 mg/kg/hr correlates with oral hydrocodone 0.1–0.2 mg/kg every 4–6 hours, which would be 5–10 mg for a 50 kg patient)
- Methadone 5–10 mg every 6 hours (IV morphine 0.03 mg/kg/hr correlates with oral methadone 0.1–0.2 mg/kg every 4–6 hours, which would be 5–10 mg for a 50 kg patient)
- Morphine sustained release 15–30 mg every 8 hours (IV morphine 0.03 mg/kg/hr correlates with SR morphine 15–30 mg for patients 35–50 kg)

Table 14.3 outlines the general setup for IV narcotics via PCA (patient-controlled analgesia) in the pediatric population.

KEY FACTS

- In clinical practice, the converted oral opioid dose would also be reduced another 20%–30% to provide a

Table 14.2 **OPIOID ANALGESICS: RELATIVE POTENCY AND INITIAL DOSING GUIDELINES**

DRUG	POTENCY RELATIVE TO MORPHINE	ORAL DOSE	INTRAVENOUS DOSE	PO:IV DOSE RATIO
Morphine	1	0.3 mg/kg q3–4hr Sustained release: 20–35 kg: 10–15 mg q8–12hr 35–50 kg: 15–30 mg q8–12hr	Bolus: 0.1 mg/kg q2–4hr Infusion: 0.03 mg/kg/hr	1:3 1:6 for opioid-naive child
Hydromorphone	5–7	0.04–0.08 mg/kg every 3–4hr	Bolus: 0.2 mg/kg q2–4hr Infusion: 0.006 mg/kg/hr	
Fentanyl	80–100	NA	Bolus: 0.5–1 μg/kg q30 minutes to 2 hours infusion: 0.5–2 μg/kg/hr	NA
Codeine	0.1	0.5–1 mg/kg q4–6hr	NR	NA
Oxycodone	1–1.5	0.1–0.2 mg/kg q4–6hr	NA	NA
Hydrocodone	1–1.5	0.1–0.2 mg/kg q4–6hr	NA	NA
Methadone	1	0.1–0.2 mg/kg q6–12hr	0.1 mg/kg q6–12hr	1:2
Oxymorphone	1	0.03 mg/kg q4–6hr	NA	NA
Nalbuphine	0.8–1	0.3 mg/kg q2–4hr	50–100 μg/kg q2–4hr	4–5:1

NA, Not applicable; NR, not recommended.

SOURCE: From Cote CJ, Lerman J, Todres ID, eds. *A Practice of Anesthesia for Infants and Children*. 4th ed. Philadelphia, PA: Saunders Elsevier; 2009. Adapted from Berde CB, Sethna NF. Analgesics for the treatment of pain in children. *N Engl J Med*. 2002;347:1094.

Table 14.3 PATIENT-CONTROLLED ANALGESIA DOSING GUIDELINES

DRUG	DEMAND DOSE (MG/KG)	LOCKOUT INTERVAL (MIN)	CONTINUOUS BASAL INFUSION (MG/KG/HR)	4-HOUR LIMIT (MG/KG)
Morphine	10–20	6–15	0–20	250–400
Hydromorphone	2–4	6–15	0–4	50–80
Fentanyl	0.5	6–10	0–0.5	7–10

margin of safety to avoid side effects and toxicity ranging from nausea, vomiting, and oversedation to respiratory depression/apnea.

- In general, morphine PO to IV is 1:3 to 1:6 (for opioid-naïve patients).

REFERENCE

Cote CJ, Lerman J, Anderson BJ, eds. *A Practice of Anesthesia for Infants and Children*. 5th ed. St. Louis, MO: Mosby Elsevier; 2013:923–33.

15.

OTOLARYNGOLOGY

Daniel K. Broderick and Pacifico Tuason

1. A 2-year-old boy has a witnessed choking episode on a peanut. He now has frequent coughing and an inspiratory stridor. Oxygen saturation is 96% on room air. Chest X-ray showed no radio-opaque objects. The surgeon wants to perform a rigid bronchoscopy and possible foreign body removal. What information is most appropriate when proceeding with the anesthetic management for this patient?

A. A normal chest X-ray is the most common radiographic finding in acute foreign body aspiration.
B. IV induction with rapid sequence intubation is the most appropriate choice for this patient.
C. Maintenance of light to moderate IV anesthesia is most often used to prevent respiratory complications.
D. Severe laryngeal edema and bronchospasm are the most common major nonfatal complications.

2. A 12-year-old girl with Trisomy 21 will undergo tonsillectomy for a history of obstructive sleep apnea. The patient is followed closely by her pediatrician and has had extensive presurgical testing prior to today's procedure. Which of the following statements is *most* accurate when considering an anesthetic plan for this patient?

A. The incidence of atlantoaxial instability in Trisomy 21 is 12%–32% and can be ruled out with review of prior cervical spine radiograph or computed tomography (CT).
B. McGill oximetry score of 2 correlates with a significantly higher risk of major postoperative respiratory complications and the need for preemptive pediatric intensive care unit (PICU) admission.
C. Equianalgesic doses in children with OSA with preoperative saturation nadir of less than 85% is one-half that of children whose nadir was greater than 85%.
D. Posttonsillectomy bleeding is uncommon and typically occurs 5–10 days after surgery when the eschar covering the tonsillar bed retracts.

3. A 10-year-old boy with a tracheostomy tube becomes dyspneic and is unable to ventilate. He requires emergency tracheostomy evaluation and possible revision. You quickly stop by the anesthesia supply room and, aside from a variety of endotracheal tubes, what is the *most* appropriate type of extra tracheostomy tube to bring to the operating room?

A. Inner diameter (ID): 5.5 mm; outer diameter (OD): 7.9 mm; uncuffed, fenestrated
B. Inner diameter (ID): 5.5 mm; outer diameter (OD): 7.9 mm; cuffed, nonfenestrated
C. Inner diameter (ID): 6.5 mm; outer diameter (OD): 9.0 mm; uncuffed, fenestrated
D. Inner diameter (ID): 6.5 mm, outer diameter (OD): 9.0 mm; cuffed, nonfenestrated

4. A newborn infant girl has cyanosis and an inspiratory stridor. She is intubated by the pediatric team shortly after delivery. In the neonatal intensive care unit (NICU), a small suction catheter is introduced into the nose and is not visible in the pharynx. She is stable and the surgeon wants to take the patient to the operating room for definitive surgical procedure. Which of the following is an appropriate next step in management of this infant?

A. Blind trans-nasal puncture with trochar
B. Bypass imaging for immediate repair
C. Flexible nasal endoscopy by surgeon
D. Obtain an urgent echocardiogram

5. A 5-day-old term infant boy with Type C tracheoesophageal fistula is undergoing primary repair. IV

induction was uneventful and the tube was advanced to the right mainstem and withdrawn until breath sounds were present. Tube placement was verified with a bronchoscope. During surgical exposure, the patient desaturates to 70% and abdomen becomes distended. What is the *most* likely cause?

A. Hyperextension of the neck during repositioning
B. Occlusion of the proximal suction catheter
C. Lung and mediastinal retraction by the surgeon
D. Shunting of blood from a left-to-right ventricular septic defect (VSD)

6. An ex-28-week premature baby boy is currently 2 months old. He was intubated right after birth for low Apgar scores. Four weeks later, after multiple reintubations for different reasons, he was extubated and was doing relatively well. He is still in the NICU but is now noted to have progressive respiratory stridor, dyspnea, air hunger, and retractions. Continuous positive airway pressure (CPAP) was initiated with minimal improvement. The best next step is to:

A. Take soft tissue radiographs of the neck and computed axial tomography.
B. Obtain a gastrointestinal (GI) consult for possible gastroesophageal reflux disease and pH probe placement.
C. Do a flexible and rigid endoscopy of the airway and esophagus to evaluate for acquired stenosis, then intubate.
D. Wait and observe.

7. When performing tympanoplasty and mastoidectomy procedures, which of the following should be avoided when the patient is under anesthesia:

A. Neuromuscular blockade is essential for proper positioning and lateral rotation of the head for middle ear visualization during surgery.
B. In patients with Down syndrome and achondroplasia there is a 15%–31% chance of having atlantoaxial instability; hence, extreme caution should be taken when positioning the head.
C. Relative hypotension (i.e., mean arterial pressure 10% to 25% less than baseline) may help to reduce bleeding.
D. The omission of nitrous oxide does not significantly increase the requirements (minimal alveolar concentration) for less soluble inhaled anesthetics.

8. An otherwise healthy 2-year-old child has a recurrent history of otitis media and is scheduled for myringotomy tube placement under general anesthesia. When seen in the holding area, you noted rhinorrhea and an occasional cough. The parents claim that this has been going on and off for the last several months with no fever. His O_2 saturation on room air was 94%. Which of the following most likely applies regarding care of patients with recurrent history of otitis media for myringotomy tube placement?

A. Serous otitis media can be recurrent but is treatable and does not lead to hearing loss.
B. Complications in children with mild upper respiratory infections (URIs) is similar to those without URIs perioperatively and thus surgery can proceed.
C. Controlled respirations with potent inhaled anesthetics delivered via face mask and no IV access is the usual standard practice.
D. Rectal acetamenophen is rapidly absorbed, achieving therapeutic blood levels in minutes compared to oral acetaminophen.

9. An 8-year-old Chinese girl is scheduled for adenotonsillectomy. She has been diagnosed with obstructive sleep apnea (OSA) and tolerates the use of CPAP at night. Which of the following mediations used for adenotonsillectomy applies?

A. A single dose of dexamethasone (1 mg/kg) is associated with reduced parental and physician rated pain scores after adenotonsillectomy.
B. The Cochrane Collaboration assessed the effect of NSAIDs on bleeding after pediatric tonsillectomy and found an increase in bleeding.
C. Dexmedetomidine use, especially in obese children, is not well tolerated.
D. Codeine, a "low-risk" oral opioid commonly used in the ambulatory setting, is a good analgesic of choice for patients with OSA.

10. A 4-year-old, 18 kg girl is scheduled to undergo treatment for laryngeal papillomatosis with a CO_2 laser. Which of the following techniques is most likely to *harm* the patient in the event of airway fire?

A. Minimal oxygen (21%) with sevoflurane and nitrous oxide
B. Placement of a wet towel over the head and chest
C. Aluminized plastic endotracheal tube with saline-filled cuff
D. Immediate extubation if smoke is detected in the surgical field

11. A 3-year-old boy is scheduled to undergo typanostomy tube placement. He has had a runny nose and wet

cough for 3 days. His temperature is 38.3°C, lungs are clear, and he has green nasal discharge. The parents say that their son gets 6–8 colds a year and that it was difficult to get time off. What single component of the patient's history puts him at highest risk for laryngospasm during the procedure?

A. Surgical procedure
B. Fever >38°C
C. Green nasal discharge
D. Productive cough

12. A 38 kg, 13-year-old girl is to undergo sinus abscess drainage. The ENT requests a topical anesthetic to the nasal mucosa. In the preoperative area, you soak cotton swabs with 4% cocaine and place the bottle on the counter. Her mother asks about the safety of cocaine as a topical anesthetic. Which of the following can be part of an appropriate response?

A. It is an amide-type local anesthetic and metabolized by liver enzymes.
B. The maximum safe dose is 3.5 mg/kg to avoid systemic effects.
C. 40% of the cocaine is absorbed during application by nasal swab.
D. Peak systemic concentrations occur 30 minutes after intranasal application.

13. An uncooperative 3-year-old boy with seizure disorder on phenytoin is premedicated with oral midazolam prior to rigid bronchoscopy for foreign body removal. Following induction, the surgeon uses the jet ventilator attached to a sidearm of the rigid bronchoscope to assist in ventilation. You administer 0.5 mg/kg of dexamethasone to reduce inflammation and airway edema. The foreign body is successfully removed. Which of the following is a correct statement about this case?

A. Phenytoin suppress CYP3A4 activity, resulting in slower metabolism of midazolam.
B. Peak concentrations of oral midazolam occur 30–40 minutes after administration.
C. High-frequency jet ventilation uses tidal volumes of 1–3 cc/kg.
D. This dexamethasone dose is similar to the minimal effective dose for PONV.

14. A 2-month-old, full-term baby is scheduled for hernia repair. Other than a few breath-holding spells when she was younger, the baby is noted to be doing well. On examination you noted that she is on the "chunky" side. Which of the following is most likely to describe airway mechanics happening during anesthesia:

A. During inhalational induction, airway obstruction occurs because the pharynx is particularly prone to collapse from the negative pressure during inspiration on an infant's large tongue.
B. The principal muscle that dilates the pharynx is the hyoglossus muscle.
C. Hyperoxia and hypocarbia will increase the dilating activity of the upper airway muscles.
D. The larynx of the infant is located in the neck at C2-3 level as opposed to adults where it is located at C4-5.

15. A 7-year-old boy is emergently being brought to the operating room for posttonsillectomy bleeding. His primary surgery was done 6 days ago and was noted to be uneventful. This morning he started noticing blood after drinking a glass of milk. The mother claims that 2 hours prior the bleeding was profuse and that is why they decided to rush to the emergency department. Which of the following describes the course of a posttonsillectomy bleed?

A. Bleeding post tonsillectomy is more common 5 to 10 days after surgery when the eschar covering the tonsillar bed retracts.
B. The most common site for postoperative tonsillar bleed originates in the tonsillar fossa.
C. Posttonsillectomy bleeding is not a surgical emergency.
D. Coagulation studies are not indicated for patients who bleed post tonsillectomy.

16. A 6-year-old child is scheduled for bronchoscopy for recurrent pneumonia. You noticed that he has been coughing quite often at the holding area, and you are worried that he will do the same once the bronchoscope is inserted. You decided that you will give a paralytic for the procedure and allow apneic oxygenation through side port of the bronchoscope as tolerated. If no ventilation occurs, the rate of rise of arterial carbon dioxide per minute is:

A. 1–5 mm Hg
B. 6–10 mm Hg
C. 11–15 mm Hg
D. 16–20 mm Hg

17. An 8-year-old boy is undergoing laser surgery for laryngeal polyps with an endotracheal tube. The patient is paralyzed and you have dropped your FiO_2 setting 50%. Several minutes into the case while the surgeon

was using the laser machine you noticed smoke coming out of the surgical field. Even before you can say something to the surgeon and to the operating room team, you noticed fire on the surgical site. According to the American Society of Anesthesiologist Practice Advisory for the Prevention and Management of Operating Room Fires, the first step you should do for airway fire is:

A. Turn all airway gases down to zero.
B. Pour saline over the surgical site.
C. Immediately remove the endotracheal tube.
D. Remove any flammable material from the surgical site.

18. A 5-month-old infant diagnosed with Trisomy 21 is coming in for bilateral cleft lip repair. Her workup came out negative for any other associated congenital anomalies. On physical exam you noted that her tongue is slightly enlarged and protruding. You are worried she might obstruct her airway after extubation so you decided to eliminate any long-acting narcotic for the case. What nerves can you block to reduce the need for narcotics?

A. External nasal nerve and buccal nerve
B. External nasal nerve and zygomaticofacial nerve
C. External nasal nerve and infraorbital nerve
D. External nasal nerve and infratrochelear nerve

19. A 5-year-old, otherwise healthy child is undergoing tonsillectomy for recurrent strep infections. The parents claim that this child is known to have motion sickness, which he gets from the mother's side of the family. What is the incidence of PONV after adenotonsillectomy?

A. 20%
B. 45%
C. 70%
D. 90%

20. A 10-year-old boy with Duchenne muscular dystrophy (DMD) has a 3 cm peritonsillar abscess that tracks several centimeters in the cephalad and caudad direction. Computed tomography (CT) shows severe mediastinitis. Temperature is 39.1°C and the O_2 saturation is 95%. He has facial swelling and his mouth opening is <1 cm. His last meal was a frozen milkshake 2 hours ago. The surgeons want to proceed emergently for abscess drainage and VATS. Which of the following is the best choice when considering the anesthetic plan for this patient?

A. Proceed with RSI with rocuronium and propofol because the patient is a full stomach.
B. Routine insertion of a nasogastric tube after induction is relatively contraindicated.
C. Succinycholine and volatile anesthetics should be avoided in this patient with DMD.
D. 20% benzocaine is the drug of choice for oropharyngeal topicalization in this case.

21. A 1-day-old infant girl born at 38 weeks has severe microagnathia and upper airway obstruction due to Pierre Robin sequence. She has failed conservative measures and the decision is made to proceed with tracheostomy for respiratory distress, with the eventual goal of mandibular distraction osteogenesis. Which of the following statements is *most* appropriate when considering an anesthetic plan for this patient?

A. Cranial (not caudal) displacement of the tongue is a hallmark of Pierre Robin sequence.
B. Hypercalcemia is associated with DiGeorge syndrome with Pierre Robin sequence.
C. Direct laryngoscopy or fiberoptic intubation can be used to secure an endotracheal tube.
D. If electrocautery is required, oxygen should be minimized and nitrous oxide maximized.

22. A mature 10-year-old girl with hearing impairment is to undergo surgery for bilateral cochlear implants. She developed hearing loss after having two bouts of meningitis at ages 4 and 7. She knows sign language and can read lips. Which of the following measures would *most* likely lead to a successful anesthetic in her case?

A. Maintenance of deep anesthesia with inhalational gases
B. Allow for induction of anesthesia without the parents present
C. Maintenance of muscle relaxation during delicate microsurgery
D. Masks kept off the anesthesiologist's face during preinduction

23. A 3-year-old boy with a history of six to eight upper respiratory infections a year has expiratory stridor following aspiration of a peanut fragment. He is stable and will undergo rigid bronchoscopy for foreign body retrieval. What is the *most* likely cause of the chest radiograph shown in Figure 15.1 (see next page)?

A. Situs inversus with dextrocardia
B. Fragment in the left mainstem bronchus
C. Right-sided pneumothorax
D. Right phrenic nerve paralysis

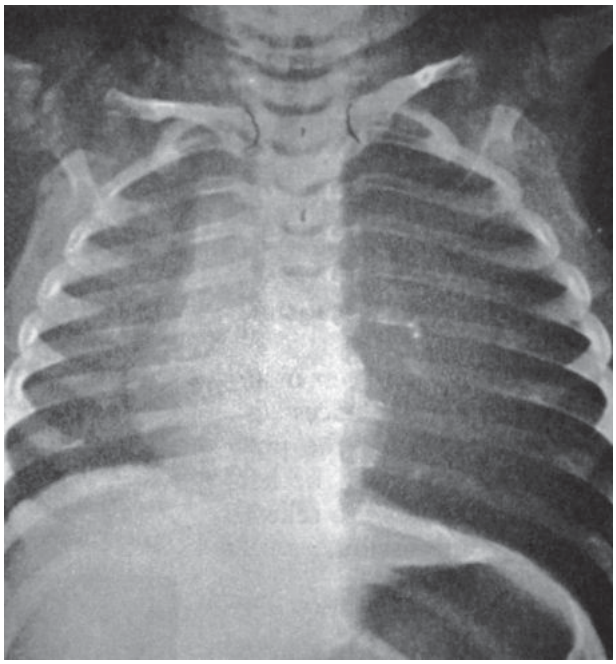

Figure 15.1 (From Kliegman RM, Behrman RE, Jenson HB, Stanton BF, eds. *Nelson Textbook of Pediatrics*. 18th ed. Philadelphia, PA: Saunders Elsevier; 2007:1770.)

24. A 3-year-old is scheduled to undergo tympanoplasty and mastoidectomy for a history of recurrent acute otitis media with extension to the mastoid process. Which of the following drugs would *most* likely lead to poor tympanic graft placement following surgery?

A. Succinylcholine
B. Nitrous oxide
C. Dexamethasone
D. Propofol

25. A 1700 g premature male neonate is born at 32 weeks to an eclamptic mother. He is found to have a tracheoesophageal fistula requiring urgent repair. When evaluating lab values and considering the anesthetic plan, which of the following would be considered normal in this neonate?

A. Hg concentration of 16–18
B. Blood volume of 100 mL/kg
C. Insensible loss of 0.5 mL/kg per hour
D. Maintenance of core temp of 36°C

CHAPTER 15 ANSWERS

1. ANSWER: D

Foreign body aspiration is a commonly encountered management issue in pediatric anesthesia. The **mean and median age** of children with this problem is 1–2 years and 2–4 years, respectively. **Nuts and seeds** are the most commonly aspirated foreign bodies. Witnessed choking is highly suggestive of aspiration and has a positive predictive value of approximately 90%. The **most common symptoms** include coughing, shortness of breath, wheezing, cyanosis, and stridor. **Surgical management** includes either rigid or flexible bronchoscopy.

Answer A is incorrect. **Workup of a stable patient** should include a chest X-ray. Radiolucent objects easily allow X-rays to pass and consequently appear black on chest films. Conversely, radio-opaque objects are white. While only **11% of foreign bodies are radio-opaque**, the vast **majority (83%) of X-rays** in patients with confirmed aspirated foreign bodies are *not* normal. The **most common X-ray findings** include localized emphysema/air trapping, atelectasis, infiltrate, and mediastinal shift. Chest CT is more sensitive in the identification of aspirated foreign bodies in the bronchial tree; however, radiation exposure, patient cooperation, and cost typically limit its usefulness in this clinical situation.

Answer B in incorrect. This patient has **inspiratory stridor, suggestive of an upper airway obstruction**. A primary consideration when choosing an anesthetic induction plan for patients with foreign body aspiration is the possibility of dislodging an unstable proximal foreign body and converting it to complete obstruction. In a review of approximately 10,000 cases of pediatric foreign body aspiration, **the most common cause of mortality** was respiratory arrest and associated cardiovascular collapse with a portion of these cases attributed to unstable progression of the body to a more occlusive position. Conversely there are no case reports of aspiration of gastric contents. The primary worry of rapid IV inductions is **abolishing spontaneous negative pressure breathing for positive pressure breathing**, theoretically making progression of the body more likely. Furthermore, inserting an endotracheal tube would also increase the risk of dislodgement and would be counterproductive in a case where rigid bronchoscopy was preferred, as the bronchoscope is used not only for intervention by the surgeon but also for ventilation by the anesthesiologist. Therefore, a majority of pediatric **anesthesiologists prefer inhalation induction** when foreign bodies are suspected.

Answer C is incorrect. A significant risk of rigid bronchoscopy compared to flexible bronchoscopy is airway trauma and rupture of the tracheo-bronchial tree leading to pneumothorax, pneumomediastinum, and potentially respiratory and cardiovascular collapse. **Coughing and bucking during instrumentation** due to stimulation from the rigid bronchoscope increases the risk for these complications. Furthermore, once the foreign object is retrieved, a dropped object can relodge and cause additional or more severe airway obstruction. Therefore, most pediatric anesthesiologists recommend either deep maintenance anesthesia and, at times, neuromuscular blocking agents in conjunction with assisted ventilation to prevent movement during instrumentation. Topicalization of the airway by the surgeon may also assist in preventing these complications.

Answer D is correct. In a meta-analysis of approximately 9400 cases, the most common, major nonfatal complications were severe laryngeal edema or bronchospasm requiring tracheotomy or reintubation. Pneumothorax or pneumomediastinum was next most common, followed by cardiac arrest, hypoxic brain damage, and tracheal/bronchial laceration requiring repair.

KEY FACTS

- The mean and median age of children who aspirate foreign bodies is 1–2 years and 2–4 years respectively, and nuts and seeds are the most commonly aspirated foreign bodies.
- The most common symptoms include coughing, shortness of breath, wheezing, cyanosis, and stridor.
- While only 11% of foreign bodies are radio-opaque, the vast majority (83%) of X-rays in patients with confirmed aspirated foreign bodies are *not* normal.
- The most common X-ray findings include localized emphysema/air trapping, atelectasis, infiltrate, and mediastinal shift.
- A majority of pediatric anesthesiologists prefer inhalation induction when foreign bodies are suspected.
- The most common cause of mortality in a patient with foreign body aspiration is respiratory arrest and associated cardiovascular collapse often due to unstable progression of the body to a more occlusive position.
- In patients with foreign body aspiration, the most common major nonfatal complications were severe laryngeal edema or bronchospasm requiring tracheotomy or reintubation; pneumothorax and pneumomediastinum was next most common, followed by cardiac arrest, hypoxic brain damage, and tracheal/bronchial laceration requiring repair.

REFERENCE

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2. ANSWER: C

Answer A is incorrect. Children with Trisomy 21 are also at risk of atlantoaxial instability. Atlantoaxial subluxation can occur during tonsilar surgery, which can manifest as neck pain, torticollis, and cervical adenitis. While the **incidence of** atlantoaxial instability is 12%–32% in Trisomy 21, it is not completely ruled out by imaging studies. A history of **neurologic signs and symptoms** is more important in ruling out a spine that is at risk for instability. These **signs include** abnormal gait, clumsiness, numbness/tingling in the extremities, and failure to reach development milestones in younger children. Children who do not show signs of instability by history or exam are at less risk of dislocation even if their imaging indicates atlantoaxial instability.

Answer B is incorrect. Tonsillar and/or adenoidal hyperplasia, leading to airway obstruction, sleep disturbance, and daytime drowsiness, is a common indication **for adenotonsillectomy**. While mortality is rare (about 1/16,000 to 1/35,000 procedures), children with increased risk for perioperative morbidity, including respiratory and cardiac complications, need to be identified. Evaluation of a child with history of obstructive sleep apnea should include a complete airway exam. Children with larger tonsils, covering greater than 50% of the pharyngeal space, are at increased risk for developing airway obstruction during anesthetic induction. Trisomy 21 is associated with the development of **obstructive sleep apnea (OSA)** due to the increase in size of soft tissues of the oral and nasopharyngeal cavity. The sleep study may contain a large amount of information, including the **apnea hypopnea index (AHI), the respiratory disturbance index (RDI), and the McGill oximetry score**. The **AHI** is a summation of the number of obstructive apnea and hypopnea events during the sleep period that are greater than 10 seconds. **RDI** is similar to AHI, except that it also accounts for respiratory-effort-related arousals that disrupt sleep. RDI greater than 20 per hour is associated with breath holding during induction. RDI greater than 30 is associated with laryngospasm and desaturation during emergence from anesthesia. The **McGill oximetry score** corresponds to increasing severity of the desaturation nadir during sleep. A score of 1 is normal and a desturation of 92% is the cutoff for normal children. Scores of 2, 3, and 4 correspond to desaturation nadirs of <90%, <85%, and <80%, respectively. A significant fraction (about 25%) of children with McGill oximetry scores of 4 will experience major postoperative respiratory complications.

Answer C is correct. **Children with OSA, especially severe disease, are more sensitive to exogenously administered opioids.** The molecular mechanism of this phenomenon is not clear, but animal models indicate it may be an increase in the density of mu-opioid receptors in the respiratory centers of the brain that are responsible for the increased sensitivity to the respiratory effects of opiods. A study by Brown et al. demonstrated that children with nighttime desaturation nadirs of <85% are twice as sensitive to opiods, such that they require half the dose of opioid to achieve equianalgesia, as compared to children with less severe OSA (>85% desaturation nadir).

Answer D is incorrect. **Posttonsillectomy bleeding is uncommon**, and occurs in 1%–2% of patients. However, 75% of cases of posttonsillar bleeding occur in the first 6 hours after surgery. The origin of bleeding is most often the tonsillar fossa. Management includes volume evaluation and rescucitation, usually with crystalloid or colloid. If the bleed is significant and the child is taken back to the operating room, a rapid sequence approach to intubation is often indicated as the patient is considered full stomach due to swallowed blood.

KEY FACTS

- Children with Trisomy 21 are at risk of atlantoaxial instability with an incidence of 12%–32%.
- Neurologic signs and symptoms of atlantoaxial instability include abnormal gait, clumsiness, numbness/tingling in the extremities, and failure to reach development milestones in younger children.
- Children who do not show signs of instability by history or exam are at less risk of dislocation even if their imaging indicates atlantoaxial instability.
- Tonsillar and/or adenoidal hyperplasia, leading to airway obstruction, sleep disturbance, and daytime drowsiness, is a common indication for adenotonsillectomy.
- Trisomy 21 is associated with the development of OSA due to the increase in size of soft tissues of the oral and nasopharyngeal cavity.

REFERENCE

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3. ANSWER: D

It is within the scope of the practice of pediatric anesthesia to understand the types and uses of tracheostomy tubes. The **size of the tracheostomy tube** is generally named by the inner diameter of the cannula. For example, a size "6" tube would indicate a 6 mm inner diameter (ID). **The outer diameter (OD)** varies by manufacturer, but it is generally about 2 mm larger than the inner diameter. The **outer diameter should fit at most within three quarters of the diameter of the trachea**, which can be measured during bronchoscopy or by using imaging, or estimated

Table 15.1 GUIDELINES FOR INFANT, PEDIATRIC, AND ADULT TRACHEOSTOMY TUBE SIZES

WEIGHT	INNER DIAMETER IN MM (ID)
Premature <2 kg	2.5 cuffless neonatal
Newborn 3–5 kg	**3.0–3.5 cuffless neonatal**
Infant 6–9 kg	**3.5–4.0 neonatal**
Child 10–11 kg	**4.0 pediatric**
Child 12–14 kg	**4.5 pediatric**
Child 15–18 kg	**5.0 pediatric**
Child 19–22 kg	**5.5 pediatric**
Older child 24–28 kg	**6.0 cuffed**
Child/preteen 30–36 kg	**6.5 cuffed**
Adults	**7.0–9.0**

SOURCE: Courtesy of Dr. Robert Kacmarek. Adapted from Wilkins RL, Stoller JK, Kacmarek RM, eds. *Egan's Fundamentals of Respiratory Care*. 9th ed. Philadelphia, PA: Mosby Elsevier; 2009:Chapter 33.

based on weight and age of the patient. Sizing of the tracheostomy tube can also be done by age or weight, both of which have both been found to correlate with an appopriate tracheostomy tube size. The weight-based table (Table 15.1) can be used to approximate the most appropriate size tube.

Alternatively, two formulas can be used to estimate the ID tube size:

$$\text{ID} = (\text{age} \times 0.3) + 3.5$$

$$\text{ID} = (\text{weight} \times 0.08) + 3.1$$

These two formulas were derived from studying a cohort of pediatric patients who sustained spinal cord injuries, requiring periodic resizing of tracheostomy tubes as they grew older. Using the sizing chart or the formulas, a 6.5 mm ID tracheostomy tube is most appropriate for a 10-year-old child. The choice of outer diameter, while important in some cases, is a distractor in these choices. The choice of cuffed versus uncuffed relies on the intended use of the tracheostomy tube. **Cuffed tubes** are preferred in the case of controlled or mechanical ventilation where positive-pressure ventilation is required. Without a cuff, a large leak may occur during mechanical ventilation. Cuffed tubes are also optimal in patients who are prone to aspiration. Uncuffed tubes are preferred when the patient is able to ventilate without positive-pressure assistance, as cuffs can exert pressure on the tracheal wall. In the patient scenario, reestablishment of a controlled airway and ensuring you are able to ventilate properly are the goals. Therefore, a cuffed tube is preferred over an uncuffed tube. Similarly, fenestrated tubes are used in patients where flow of air proximal to the tracheostomy and through the oropharynx is desired, such as in patients nearing decannulation. In this scenario, choosing and inserting a fenestrated tube may cloud the picture if ventilation with positive pressure cannot be accomplished with the new tube. Therefore, a nonfenestrated tube is the best choice.

KEY FACTS

- The size of the tracheostomy tube is generally named by the inner diameter of the cannula.
- The outer diameter varies by manufacturer, but it is generally about 2 mm larger than the inner diameter.
- The outer diameter should fit at most within three quarters of the diameter of the trachea, which can be measured during bronchoscopy or using imaging, or estimated based on weight and age of the patient.

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4. ANSWER: D

Answer A is incorrect. **Congenital narrowing of the posterior choanae of the nose** occurs with a frequency of 1 in 5000 to 1 in 9000 live births. There is a female predominance in most studies. The **narrowing is caused by** a mix of bony or membranous obstruction as well as medialization of the lateral wall of the nose. A unilateral obstruction is more common than bilateral, and those with bilateral choanal atresia are likely overrepresented in the literature. Because **neonates are obligate nose breathers**, bilateral choanal atresia presents with asphyxia neonatorum, which is a medical emergency at birth. **Signs and symptoms** include airway obstruction, stridor and paradoxical cyanosis (infants usually turn pink at birth as they cry; however, infants with bilateral choanal atresia will become cyanotic). An oral airway or intubation is often required at birth to stabilize the patient. A fine catheter (such as a suction catheter) introduced into the nose which fails to pass into the oropharynx is one method of diagnosing unilateral or bilateral choanal atresia. **Modern surgical treatment** includes endoscopic transnasal repair, which includes decongestion of the nose, passing an endoscope into the nose and then using dilators to perforate the atretic plate under direct vision. **Blind transnasal puncture with a trochar is not a standard approach** to treatment of the atresia as passage should be accomplished under endoscopic guidance. Some infants with choanal atresia have craniofacial abnormalities, and instruments blindly passed into the nose may travel intracranially.

Answer B is incorrect. Following stabilization and during the planning phase of management, a CT scan can be

performed to identify the nature and severity of the anatomic defect. CT can also differentiate **other causes of the bilateral nasal obstruction**, such as pyriform aperture stenosis or bilateral nasolacrimal duct cysts. Unilateral causes of nasal obstruction, such as foreign body, turbinate hypertrophy, septal deviation, or nasal tumor can also be investigated with CT.

Answer C is incorrect. While flexible nasal endoscopy and then repair is a common surgical modality in these patients, it is prudent to obtain imaging and echocardiogram prior to proceeding with immediate surgery. See A, B, and D.

Answer D is correct. About 50% of infants with choanal atresia **have other associated anomalies** such as CHARGE (Coloboma of the eye, Heart defects such as Tetrology of Fallot, Atresia of the nasal choanae, Retardation of growth/development, Genital abnormalities, and Ear abrnormalities). An echocardiogram would be an appropriate study for the patient after stabilization to evaluate for presence of heart defects.

KEY FACTS

- Congenital narrowing of the posterior choanae of the nose occurs with a frequency of 1 in 5000 to 1 in 9000 live births with a female predominance.
- Because neonates are obligate nose breathers, bilateral choanal atresia presents with asphyxia neonatorum, which is a medical emergency at birth.
- Signs and symptoms include airway obstruction, stridor, and paradoxical cyanosis (infants usually turn pink at birth as they cry; however, infants with bilateral choanal atresia will become cyanotic).
- Modern surgical treatment includes endoscopic transnasal repair, which includes decongestion of the nose, passing an endoscope into the nose, and then using dilators to perforate the atretic plate under direct vision.
- About 50% of infants with choanal atresia have other associated anomalies such as CHARGE (Coloboma of the eye, Heart defects such as Tetrology of Fallot, Atresia of the nasal choanae, Retardation of growth/development, Genital abnormalities, and Ear abrnormalities).

REFERENCE

Ramsden JD, Campisi P, Forte V. Choanal atresia and choanal stenosis. *Otolaryngol Clin North Am*. 2009;42(2):339–52.

5. ANSWER: A

The **most common tracheoesophageal fistula (TEF) is Type C**, where the esophagus is atretic and fistula communicates with the stomach. The **diagnosis is made** with gastric distention from gas and a nasogastric tube cannot be advanced past 8–13 cm in the esophagus, indicating atresia. The **primary complication of TEF** is aspiration of gastric contents from the fistula into the trachea as well as GI distension that compromises respiration. During **surgical repair**, which is accomplished usually by left thoracotomy, **common complications** include hypo- or hyperventilation, aspiration, atelectasis, mucus plug, and pneumothorax. In this case, hyperextension of the neck during repositioning of the patient would cause the endotracheal tube (ETT) to retract proximally into the trachea, making it more likely to come in contact with the fistula, whereby ventilation occurs with the path of least resistance into the stomach and not the lungs. Thus, neck hyperextension may cause iatrogenic hypoventilation, desaturation, and abdominal distension.

Answer B is incorrect. **Proper positioning of the endotracheal tube** is essential in carrying out successful anesthetic management of the TEF patient. Atropine (0.02 mg/kg IV) is usually given prior to induction to ablate the vagal response to laryngoscopy. Induction can be done in a variety of ways, with the primary objective to minimize positive-pressure ventilation and inflation of the stomach. Therefore, using bag-mask ventilation would be the least appropriate technique during induction. A **common technique for intubation of a neonate with TEF** is to intubate the right mainstem and then withdraw the tube until bilateral breath sounds are heard. Alternatively, a fiberoptic technique can be employed primarily to guide initial placement of the tube. It would be secured distal to the fistula and the tube should be rotated so that the bevel (pointed end) faces posteriorly. This prevents accidental intubation of the fistula, on the anterior aspect of the trachea. A **suction catheter is often placed in the proximal pouch of the blind esophagus in order to empty ongoing secretions**. An acute occlusion of this suction catheter is unlikely to cause desaturation as there is no direct communication with the trachea or stomach. In type B and D TEF, the fistula communicates with the proximal esophagus and therefore it is possible for secretions to pass to the trachea if they are not suctioned properly.

Answer C is incorrect. As the surgical approach is often through left thoracotomy, retraction of the mediastinum and lung is a **common cause of desaturation**. In some cases, the anesthesia team must request relaxation of retraction at regular periods when saturations descend to critical levels. However, both desaturation and abdominal distension are unlikely to occur due to retraction.

Answer D is incorrect. Up to **50% of infants with TEF have associated anomalies in the VACTERL spectrum**, which are Vertebral, Anal, Cardiac, TEF, Renal, and Limb anomalies. Approximately 20%–35% will have existing cardiac anomalies, the most common of which is a VSD. With a VSD, any cause of pulmonary artery hypertension, such as hypoxia and hypercapnia, may precipitate a right-to-left shunt (not a left-to-right shunt), the primary manifestation

of which is oxygen desaturation. Abdominal distention would also not be caused by a left-to-right shunt.

KEY FACTS

- The most common TEF is Type C, where the esophagus is atretic and the fistula communicates with the stomach.
- The diagnosis is made with gastric distention from gas and a nasogastric tube cannot be advanced past 8–13 cm in the esophagus, indicating atresia.
- The primary complication of TEF is aspiration of gastric contents from the fistula into the trachea as well as GI distension that compromises respiration.
- During surgical repair, which is accomplished usually by left thoracotomy, common complications include hypo- or hyperventilation, aspiration, atelectasis, mucus plug, and pneumothorax.
- A suction catheter is often placed in the proximal pouch of the blind esophagus in order to empty ongoing secretions.
- Common techniques for intubation of a neonate with TEF is to intubate the right mainstem and then withdraw the tube until bilateral breath sounds are heard or the use of a fiberoptic technique to guide initial placement of the tube.
- Up to 50% of infants with TEF have associated anomalies in the VACTERL spectrum.

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6. ANSWER: C

Acquired subglottic stenosis is usually the result of prolonged tracheal intubation for respiratory support of infants born prematurely. **In older children**, it is a result of laryngeal trauma from different causes. The subglottis is the narrowest portion of the neonate's airway. Presentation varies from asymptomatic to complete airway obstruction. If a patient has stridor and fails extubation multiple times, subglottic stenosis is likely. Severe, prolonged, repeated **croup episodes** make this a likely diagnosis. A tracheostomy may be necessary with surgical correction ultimately. **Characteristic findings** of subglottic stenosis include inspiratory stridor, retraction of the intercostal muscles, inspiratory thrill over the larynx, and wheezing from the trachea only. Observation alone is not appropriate in a patient with impending respiratory failure (Answer D).

While Answers A and B are necessary for workup of this patient, the patient has impending respiratory failure likely from laryngotracheal stenosis and requires an endotracheal tube or tracheostomy in order to allow oxygenation and ventilation. Soft tissue radiographs and CT scans will show the exact location and degree of the stenotic segment. **Gastroesophageal and gastrolaryngoesophageal reflux** are thought to contribute to the development and exacerbation of subglottic stenosis and need to be excluded. With regard to this case the best approach is direct endoscopic visualization of the larynx and espophagus. It is ultimately required to fully evaluate the suspected stenotic segment. A rigid rod-lens telescope and/or a flexible bronchoscope are used to directly visualize the larynx and trachea all the way beyond the obstruction. A leak test can also be performed after direct visualization to evaluate the degree of stenosis once the trachea is intubated. An esophagogastroduedenoscopy is usually performed at the same time to evaluate for reflux disease. If indeed there is evidence of reflux disease proper, treatment can be initiated.

KEY FACTS

- Acquired subglottic stenosis is usually the result of prolonged tracheal intubation for respiratory support of infants born prematurely.
- In older children, it is a result of laryngeal trauma from different causes.
- Gastroesophageal and gastrolaryngoesophageal reflux are thought to contribute to the development and exacerbation of subglottic stenosis.
- Characteristic findings of subglottic stenosis include inspiratory stridor, retraction of the intercostal muscles, inspiratory thrill over the larynx, and wheezing from the trachea only.

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7. ANSWER: A

It is **important that the facial nerve be identified** during these procedures because of its proximity to the surgical field. **Neuromuscular blockade is then contraindicated** if nerve stimulation is to be done to identify structures

during dissection. In patients with suspected **atlantoaxial instability** (as in patients with Down syndrome and achondroplasia) extra care is required when positioning. Tilting the table left or right (airplaning) helps in exposure more than extreme head rotation. Working on small structures of the ear can be difficult if there is increased bleeding on the field. **Relative hypotension** (mean arterial pressure 10%–25% less than baseline) is acceptable and may help to reduce bleeding. Concentrated epinephrine 1:8000 is frequently applied to the tympanic membrane to induce vasoconstriction. The maximum topical dose for epinephrine is 10 μg/kg, which may be repeated every 30 minutes.

The use of nitrous oxide is of special mention aside from its known PONV side effect. Nitrous oxide diffuses along a concentration gradient into air-filled middle ear spaces more rapidly than nitrogen moves out because nitrous oxide is 34 times more soluble in blood than nitrogen. The middle ear is vented passively through the opening of the Eustachian tube at 20–30 cm of H_2O pressure. **Nitrous oxide increases the pressures within the middle ear** such that they exceed the ability of the Eustachian tube to vent the middle ear and leads to a pressure buildup. If the function of the Eustachian tube is compromised during surgery, the pressure in the middle ear builds up further. This can lead to graft displacement when doing a tympanoplasty. In addition, **once nitrous oxide is discontinued**, it is quickly reabsorbed, creating a void in the middle ear with resulting negative pressure. This negative pressure may result in serous otitis, disarticulation of the ossicles in the middle ear (especially the stapes), and hearing impairment, which may last up to 6 weeks postoperatively. The omission of nitrous oxide does not significantly increase the requirements (minimal alveolar concentration) for the less soluble inhaled anesthetics (sevoflurane or desflurane) in children.

KEY FACTS

- It is important that the facial nerve be identified during tympanoplasty and mastoidectomy procedures because of its proximity to the surgical field.
- Neuromuscular blockade is then contraindicated if nerve stimulation is to be done to identify structures during dissection.
- In patients with suspected atlantoaxial instability (as in patients with Down syndrome and achondroplasia) extra care is required when positioning.
- Relative hypotension (mean arterial pressure 10%–25% less than baseline) is acceptable and may help to reduce bleeding.
- Nitrous oxide increases the pressures within the middle ear such that they exceed the ability of the Eustachian tube to vent the middle ear and leads to a pressure buildup.
- In addition, once nitrous oxide is discontinued, it is quickly reabsorbed, creating a void in the middle ear with resulting negative pressure, which may result in serous otitis, disarticulation of the ossicles in the middle ear (especially the stapes), and hearing impairment, which may last up to 6 weeks postoperatively.

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Cote CJ, Lerman J, Todres ID, eds. *A Practice of Anesthesia for Infants and Children*. Kindle ed. Philadelphia, PA: Saunders Elsevier; 2012:64757–8.

8. ANSWER: B

Chronic serous otitis media is common in young children and, if poorly managed, can lead to hearing loss and formation of cholesteatoma. **Myringotomy tube placement** is a very brief operation and can be performed as an ambulatory surgery using a potent inhalational agent and nitrous oxide via face mask with spontaneous respirations. Occasionally a laryngeal mask (LMA) may be used for prolonged cases (e.g., children with narrow ear canals). Although reasonable to have an intravenous setup, **IV access can often be deferred**. Children with **chronic otitis frequently have persistent rhinorrhea and suffer recurrent upper respiratory tract infection (URI).** Eradication of middle ear congestion and improved fluid drainage often resolves the concomitant symptoms. Of note, it has been shown that complications from mild URIs in children are similar to those who are asymptomatic. In general, **morbidity is not increased in children who present for minor surgery with an acute uncomplicated mild URI, provided tracheal intubation can be avoided**. However, an early study showed that children with URIs are at a 2- to 7-fold increased risk of respiratory complications and an 11-fold increase if they are intubated. Other complications associated with URI include laryngospasm, bronchospasm, and arterial desaturation.

Most of the pediatric anesthesia and surgery literature is in agreement that **a pediatric patient with purulent rhinitis, fever, productive cough, and/or evidence of lower respiratory tract infection should have an elective case postponed.** However, pediatric patients with minor symptoms are probably not at significantly greater risk for complications than an otherwise healthy child, especially if intubation can be avoided.

If given orally, acetaminophen is rapidly absorbed. Oral acetaminophen achieves therapeutic blood levels in minutes. If given rectally, absorption is slow. Onset of action is 60 to 90 minutes with peak effect of 1 to 3 hours.

KEY FACTS

- Chronic serous otitis media is common in young children and, if poorly managed, can lead to hearing loss and formation of cholesteatoma.

- Myringotomy tube placement is a very brief operation and can be performed as an ambulatory surgery using a potent inhalational agent and nitrous oxide via face mask with spontaneous respirations.
- Although reasonable to have an intravenous setup, IV access can often be deferred.
- Children with chronic otitis frequently have persistent rhinorrhea and suffer recurrent URIs, and eradication of middle ear congestion and improved fluid drainage often resolves the concomitant symptoms.
- In general, morbidity is not increased in children who present for minor surgery with an acute uncomplicated mild URI, provided tracheal intubation can be avoided.
- A pediatric patient with purulent rhinitis, fever, productive cough, and/or evidence of lower respiratory tract infection should have an elective case postponed.

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9. ANSWER: A

A single **dose of dexamethasone** reduces postadenotonsillectomy pain and edema when electrocautery has been used. If given at 1 mg/kg, it has been shown to reduce pain scores. Single-dose dexamethasone has also shown to have a narcotic sparing effect and has not been shown to be associated with aseptic necrosis of the hip or infection. The Cochrane Collaboration assessed the effect of NSAIDs on bleeding after pediatric tonsillectomy in 13 trials (955 children) and **did not find any increase in bleeding** that required reoperation for hemostasis. **Dexmedetomidine infusion** at 2 μg/kg over 10 min followed by 0.7 μg/kg per hour combined with inhalation agent can provide satisfactory intraoperative conditions for adenotonsillectomy without adverse effects.

In children with OSA syndrome, use of dexmedetomidine reduces postoperative opioid requirements significantly, and the incidence and severity of severe emergence agitation are reduced, with few children desaturating. **After larger doses of dexmedetomidine (2 and 4 μg/kg),** the opioid-free interval increases and the postoperative opioid requirements decrease. However, **duration of stay in the PACU** is prolonged. The use of **codeine,** although considered a "low-risk" oral opioid, may be problematic in children with OSA. Codeine is metabolized by the cytochrome P450 debrisoquine 4-hydroxylase (CYP2D6) to its active analgesic metabolites. The CYP2D6 gene displays polymorphism, including gene duplication (ultra-rapid metabolizers) and inactive genes. Gene duplication may lead to ultra-rapid metabolism, which for prodrugs, such as codeine, might yield a 50% greater fraction of morphine and its glucuronides compared with extensive metabolizers. **Respiratory arrest after codeine** has been reported in both adults and children who demonstrate ultra-rapid metabolism of codeine.

KEY FACTS

- A single dose of dexamethasone reduces postadenotonsillectomy pain and edema when electrocautery has been used, and if given at 1 mg/kg, it has been shown to reduce pain scores.
- Single-dose dexamethasone has also shown to have a narcotic sparing effect and have not been shown to be associated with aseptic necrosis of the hip or infection.
- In children with OSA syndrome, use of dexmedetomidine reduces postoperative opioid requirements significantly, and the incidence and severity of severe emergence agitation are reduced, with few children desaturating.
- After larger doses of dexmedetomidine (2 and 4 μg/kg), the opioid-free interval increases and the postoperative opioid requirements decreases, but the PACU LOS is prolonged.
- The use of codeine, although considered a "low risk" oral opioid, may be problematic in children with OSA, and respiratory arrest may occur in patients who demonstrate ultra-rapid metabolism of codeine.

REFERENCE

Cote CJ, Lerman J, Todres ID, eds. *A Practice of Anesthesia for Infants and Children*. Kindle ed. Philadelphia, PA: Saunders Elsevier; 2012:65165–9.

10. ANSWER: A

Laryngeal papillomatosis is the most common tumor of the larynx in children. The incidence is 1 in 400 and is caused by infection with the human papilloma virus. **Primary symptoms** include hoarseness, stridor, aphonia, and respiratory distress if the lesions grow large enough to significantly obstruct air flow. **Treatment modalities** include debulking with CO_2 laser or nonsurgical treatment with interferon alfa-n1. Laser (light amplified by stimulated emission of radiation) energy is absorbed by any tissue containing water, which rapidly increases the temperature and vaporizes the target tissue as well as assists in hemostasis by cauterizing capillaries. Because of the rapidly increasing temperatures, **one of the primary risks** of their use is ignition of materials in the airway or nearby materials ignited

by an errantly deflected laser. The mixture of airway gases can impact the amount of fuel available to the fire for propagation of the fire once ignited. Both oxygen and nitrous oxide are combustible and their use should be minimized as much as possible. Volatile anesthetics are safe to use with lasers. Therefore, Answer A is the least likely to protect the patient, as the addition of **nitrous oxide**, depending on its concentration, may add fuel for propagation of airway fires ignited by the laser.

Answer B is incorrect. Another potential hazard of laser treatment for airway surgery is the risk of an errantly deflected or misdirected laser beam. **Deflected or misdirected beams** can hit the endotracheal tube; the skin of the face, neck, or chest; or operating room personnel. The use of nonflammable drapes as well as the application of wet towels to the skin of the chest, neck, and face can reduce the risk of fire ignition and protect the patient by acting as a shield.

Answer C is incorrect. **Standard endotracheal tubes are made of polyvinylchloride, can be ignited by the laser beam, and thus are flammable**. **Metal-wrapped endotracheal tubes** are available for use in laser surgeries with the primary purpose to deflect the beam and prevent vaporization of the tube or ignition. Some of these specialized ETTs are **double cuffed**, in case one cuff is damaged by the laser beam. The cuffs are often filled with saline, which offers better protection from airway fires, as compared to air-filled cuffs. Saline-filled cuffs often have **methylene blue** as an additive so that if the cuff is damaged, it becomes evident to the surgeon in the operating field. It is important to note that metal-wrapped endotracheal tubes tend to be approximately 1 mm larger in their outer diameter, as compared to standard ETTs, which may impact sizing especially in children.

Answer D is incorrect. If an airway fire is detected by visualization of flames or smoke, **the proper treatment includes** halting ventilation and flow of air into the larynx (removing O_2 source as fuel), extubation of the trachea to decrease inhalation of toxic products, dousing the fire with saline/water, suctioning debris, and using mask ventilation and/or reintubating. Bronchoscopy and steroids can be considered prior to the end of surgery.

KEY FACTS

- Laryngeal papillomatosis is the most common tumor of the larynx in children.
- Primary symptoms of laryngeal papillomatosis include hoarseness, stridor, aphonia, and respiratory distress if the lesions grow large enough to significantly obstruct air flow.
- Treatment modalities include debulking with CO_2 laser or nonsurgical treatment with interferon alfa-n1.
- One of the primary risks of laser use is ignition of materials in the airway or nearby materials ignited by an errantly deflected laser.
- Deflected or misdirected beams can hit the endotracheal tube; the skin of the face, neck, or chest; or operating room personnel.
- Standard endotracheal tubes are made of polyvinylchloride, can be ignited by the laser beam, and thus are flammable.
- The proper treatment of an airway fire includes halting ventilation and flow of air into the larynx (removing O_2 source as fuel), extubation of the trachea to decrease inhalation of toxic products, dousing the fire with saline/water, suctioning debris, and using mask ventilation and/or reintubating.

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11. ANSWER: A

Typanostomy tubes are placed in patients with chronic otitis media or recurrent acute otitis media. The **procedure involves** inserting an ear speculum in the canal, making a small incision on the tympanic membrane, and insertion of a typanostomy tube that straddles the tympanic membrane. The procedure is usually bilateral, takes approximately 10 minutes, and is performed under general inhalation anesthesia with mask ventilation. **In children with URI**, the decision to either postpone surgery or proceed can be made through evaluation of the overall health of the child, severity of symptoms, and the experience and comfort of the practitioner. **Most large-scale studies** show that children with a recent URI (last 2 weeks) are at greater risk of respiratory events, such as significant desaturation, apnea, bronchospasm, and laryngospasm. **Airway reactivity** is thought to peak at day 3 following appearance of symptoms and to last for 4–6 weeks after the start of a URI. The **incidence of laryngospasm** ranges from 1/1000 to 1/5 in high-risk surgeries, such as otolaryngologic procedures. Several patient-specific risk factors have been identified that predispose a patient to laryngospasm. A 2010 study showed that an increased risk for laryngospasm was associated with URI symptoms that were present on the day of surgery or had occurred in the last 2 weeks. The same study looked at the risk of laryngospasm according to the presence of cold symptoms, including fever, nasal discharge, and moist cough, finding that when looking at cold symptoms alone, **green nasal discharge is associated with the highest relative risk of laryngospasm**.

A fever of higher than 38°C in a child with upper respiratory tract infection presenting for surgery carries a relative risk of 2.3, about twice the risk of laryngospasm than if fever is not present.

Green nasal discharge in a child with URI carries a relative risk of 4.4, or about 4 times the risk of laryngospasm than if it is not present.

Productive or moist cough carries a relative risk of 3.8, or about 4 times the risk of laryngospasm than if not present.

KEY FACTS

- Typanostomy tubes are placed in patients with chronic otitis media or recurrent acute otitis media, and this entails inserting an ear speculum in the canal, making a small incision on the tympanic membrane, and insertion of a typanostomy tube that straddles the tympanic membrane.
- Airway reactivity in a patient with a URI is thought to peak at day 3 following appearance of symptoms and to last for 4–6 weeks after the start of a URI.
- Green nasal discharge is associated with the highest relative risk of laryngospasm.
- Fever of higher than 38°C in a child with upper respiratory tract infection presenting for surgery carries a relative risk of 2.3, about twice the risk of laryngospasm than if fever is not present.
- Productive or moist cough carries a relative risk of 3.8, or about 4 times the risk of laryngospasm than if not present.

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12. ANSWER: C

Answer A is incorrect. There is some confusion in the literature in the classification of cocaine due to its tertiary amine group; however, **cocaine is an ester-type local anesthetic** by virtue of its two ester linkage groups that are cleaved by pseudocholinesterase (otherwise known as plasma cholinesterase) as well as a variety of other nonspecific, liver-derived esterases. Pseudocholinesterase is the same enzyme that cleaves the ester leakage on succinylcholine. Though **pseudocholinesterase deficiency and the risk of cocaine toxicity** is a theoretical concern, no documented cases have been found in the literature of cocaine toxicity caused by genetic deficiency. A small study in 1989 documented a statistically nonsignificant decrease in overall pseudocholinesterase levels in patients with symptoms or complications from cocaine abuse. However, it is likely that the levels of cocaine used in intranasal topicalization are not high enough to achieve a clinically signiciant effect, even if a deficiency in the enzyme exists.

Answer B is incorrect. The **maximum safe dose** (to prevent systemic effects) is 1.5 mg/kg (not 3.5 mg/kg). Because the application of cocaine is often made through swabs or cotton pledgets, regulating the exact dose is difficult. Nevertheless, one study looked at the **average amount of cocaine aborbed from a cotton pledget**, which was found to be approximately 40%. A **survey of several thousand ENT surgeons who regularly use cocaine** as a topical anesthetic showed that complications are rare in doses below 200 mg (for the average adult).

Answer C is correct. Nasal application results, on average, in 40% absorption of the cocaine to the mucosa, leaving 60% on the cotton swab.

Answer D is incorrect. Peak concentrations after intranasal application occur in about 1 hour.

KEY FACTS

- Cocaine is an ester-type local anesthetic by virtue of its two ester linkage groups that are cleaved by pseudocholinesterase (otherwise known as plasma cholinesterase) as well as other nonspecific, liver-derived esterases.
- Though pseudocholinesterase deficiency and the risk of cocaine toxicity is a theoretical concern, no documnted cases have been found in the literature of cocaine toxicity caused by genetic deficiency.
- The maximum safe dose (to prevent systemic effects) of cocaine is 1.5 mg/kg.
- A survey of several thousand ENT surgeons who regularly use cocaine as a topical anesthetic showed that complications are rare in doses below 200 mg (for the average adult).
- The average amount of cocaine absorbed from a cotton pledget was found to be approximately 40%.

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Harper SJ, Jones NS. Cocaine: what role does it have in current ENT practice? A review of the current literature. *J Laryngol Otol*. 2006;120:808–11.

13. ANSWER: C

Answer A is incorrect. The typical dose of **midazolam for premedication** in children is 0.25–0.75 mg/kg orally

or 0.1–0.150 mg/kg IM. **Several types of medications depress the activity of CYP3A4**, most notably, erythromycin, protease inhibitors, calcium channel blockers, and grapefruit juice. Depression of CYP3A4 will cause greater than expected levels of midazolam and prolong the sedative effect. Phenytoin and carbamazepine, along with rifampin, barbiturates, glucocorticoids, and St. John's wort all **induce the CYP3A4 enzyme**, which will lead to faster than expected metabolism and shorter duration of action.

Answer B is incorrect. It is important to consider that peak plasma concentrations differ markedly according to the route of administration of midazolam. **Peak concentrations after intravenous or intranasal administration** of midazolam occur in about 10 minutes. For **rectal administration**, peak concentrations occur in 16 minutes; 20 minutes for **IM,** and approximately 53 minutes for **oral** administration. Data support the observation that **the dose of midazolam needed increases as age decreases in children**, similar to the MAC of inhaled agents. Therefore, greater doses may be required to achieve the same degree of sedation in very young children.

Answer C is correct. Ventilation of the child during rigid bronchoscopy can be achieved by hand ventilation with a circuit attachement to the bronchoscope. High resistance may be met as a result of partial occlusion of the lumen, which is more likely to occur when smaller, 2.5–3.5 mm internal diameter, rigid bronchoscopes are used. Either large inspired volatile gas concentrations or TIVA technique is required to maintain general anesthesia. An alternative is the use of high-frequency jet ventilation (HFJV) during rigid brochoscopy. **HFJV utilizes the Venturi effect** by entraining room air into the bronchoscope by a burst ("jet") of oxygen delivered under pressure. Typical tidal volumes are 1–3 cc/kg and frequencies range from 60 to 1500. **Barotrauma** is one complication of HFJV that can result in pneumothorax and/or pneumomediastinum. Blood or infectious particles may be forced distally into the airways by the jet of oxygen under high pressure.

Answer D is incorrect. Two studies have looked at the minimal dose of **dexamethasone** in preventing PONV in children undergoing ENT procedures. One study found 0.15 mg/kg, while the other was inconclusive, showing no statistical difference between 0.0625 and 1.0 mg/kg. Therefore, Answer D is not currently supported by evidence in the literature.

KEY POINTS

- The typical dose of midazolam for premedication in children is 0.25–0.75 mg/kg orally or 0.1–0.150 mg/kg IM.
- Several types of medications depress the activity of CYP3A4, most notably, erythromycin, protease inhibitors, calcium channel blockers, and grapefruit juice.
- Phenytoin and carbamazepine, along with rifampin, barbiturates, glucocorticoids, and St. John's wort, all induce the CYP3A4 enzyme.
- The dose of midazolam needed increases as age decreases in children, similar to the MAC of inhaled agents.
- HFJV utilizes the Venturi effect by entraining room air into the bronchoscope by a burst ("jet") of oxygen delivered under pressure; typical tidal volumes are 1–3 cc/kg and frequencies range from 60 to 1500.

REFERENCE

Cote CJ, Lerman J, Todres ID, eds. *A Practice of Anesthesia for Infants and Children*. 4th ed. Philadelphia, PA: Saunders Elsevier; 2009:44–6, 666, 673–4.

14. ANSWER: A

There are several anatomic and mechanical aspects of the upper airway that differ between the pediatric airway and the adult. These differences often dictate differences in anesthetic management technique. **During the inspiration phase of an inhalational induction**, the upper airway is potentially prone to upper airway obstruction (collapse) due to the negative pull on the infant's large tongue. **The effect of negative pressure** is to pull the tongue against the pharynx, thus collapsing the soft tissues of the oropharynx. In the past, it was a long-held belief that the infant's tongue is relatively large in relation to the rest of the oral cavity; however, recent MRI studies have shown that **the pediatric tongue** (between ages 1 and 11 years) is in fact proportional to other soft tissues and bony structures of the oral cavity. Nevertheless, the tongue may be a significant source of obstruction for patients of any age. **Other anatomic differences between the infant and adult** are the position and the shape of the epiglottis. The **infant's epiglottis** is narrow, "omega shaped," and angled away from the tracheal axis, whereas the adult epiglottis is flat, broad, and parallel to the trachea. **The narrowest part of the pediatric airway** is the cricoid cartilage, in contrast to the adult, where the narrowest portion is the rima glottidis (the opening between the true vocal cords and the arytenoid cartilages).

Answer B is incorrect. The **airway is kept patent** by the upper airway muscles, particularly the genioglossus and not the hyoglossus muscle. The genioglossus muscle is the principal muscle that dilates the pharynx.

Answer C is incorrect. Hypoxia and hypercarbia (not hyperoxia and hypocarbia) increase the **dilating activity of the upper airway via the genioglossus muscle**. Under general anesthesia the activity of the genioglossus muscle is depressed through the effects on the central nervous system, which commonly results in oropharyngeal obstruction.

Answer D is incorrect. The **infant larynx** is located more cephalad in the neck C3-C4 (not C2-C3) as compared to the adult, which is located at C4-C5. The consequence of this anatomic difference is that the distances between the tongue, epiglottis, and larynx are smaller than they are in an adult, making visualization more difficult due to a more acute angle during standard laryngoscopy.

KEY FACTS

- During the inspiration phase of an inhalational induction of an infant, the upper airway is potentially prone to upper airway obstruction (collapse) due to the negative pull on the infant's large tongue; the effect of negative pressure is to pull the tongue against the pharynx, thus collapsing the soft tissues of the oropharynx.
- The pediatric tongue (between ages 1 and 11 years) is in fact proportional to other soft tissues and bony structures of the oral cavity.
- The infant's epiglottis is narrow, "omega shaped," and angled away from the tracheal axis, whereas the adult epiglottis is flat, broad, and parallel to the trachea.
- The narrowest part of the pediatric airway is the cricoid cartilage, in contrast to the adult, where the narrowest portion is the rima glottidis (the opening between the true vocal cords and the arytenoid cartilages).
- The airway is kept patent by the upper airway muscles, particularly the genioglossus and not the hyoglossus muscle.
- The infant larynx is located more cephalad in the neck C3-C4 (not C2-C3) as compared to the adult, which is located at C4-C5.

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Cote CJ, Lerman J, Anderson BJ, eds. *A Practice of Anesthesia for Infants and Children*. 5th ed. Philadelphia, PA: Saunders Elsevier; 2013:237–8.

Gregory GA, ed. *Pediatric Anesthesia*. 4th Ed. New York, NY: Churchill Livingstone; 2002:663–4.

15. ANSWER: B

Answer A is incorrect. **Posttonsillectomy bleeding is considered a surgical emergency**. A potentially open blood vessel can continually ooze blood causing anemia and hypovolemia. There are two periods with the highest risk of posttonsillectomy bleeding: an acute (primary) phase that happens within 24 hours and a latent (secondary) phase that occurs 5 to 10 days after surgery. **Approximately 75% of the postoperative tonsillar bleeding occurs within 6 hours of surgery** (primary phase). This phase of postoperative bleeding is often brisk and profuse. **Primary bleeding** is one of the reasons why prolonged recovery is required for these patients before sending them home. Some institutions will admit these patients overnight for observation; in fact, posttonsillectomy bleeding is responsible for conversion of ambulatory surgery to inpatient admission in 1%–2% of cases. **The latent (secondary) phase** typically occurs 5–10 days after surgery and is due to retraction of the eschar covering the tonsillar bed. The anesthetic approach to a take-back in this case includes quick but thorough evaluation by the anesthesiologist, including review of the original anesthetic record and a careful estimate of volume status. **A history of dizziness or orthostatic hypotension** is suggestive of a greater than 20% loss of circulating blood volume. Vigorous volume resuscitation with crystalloid prior to induction is often the most prudent course of action to ensure maintenance of hemodynamic stability. Blood transfusion is rarely required in these cases.

Answer B is correct. The most common site of bleeding is in the tonsillar fossa (67%), 27% in the nasopharynx, and 7% in both.

Answer C is incorrect. Posttonsillectomy bleeding is considered a surgical emergency.

Answer D is incorrect. In cases when the bleeding blood vessel has not been identified during exploration of the surgical site, it is not a bad practice to send for a coagulation study to rule out a bleeding diathesis.

KEY FACTS

- Posttonsillectomy bleeding is considered a surgical emergency.
- With posttonsillectomy bleeding there are two phases: an acute (primary) phase that happens within 24 hours and a latent (secondary) phase that occurs 5 to 10 days after surgery.
- Approximately 75% of the postoperative tonsillar bleeding occurs within 6 hours of surgery (primary phase).
- A history of dizziness or orthostatic hypotension is suggestive of a greater than 20% loss of circulating blood volume.

REFERENCE

Cote CJ, Lerman J, Todres ID, eds. *A Practice of Anesthesia for Infants and Children*. Kindle ed. Philadelphia, PA: Saunders Elsevier; 2012:665–6.

16. ANSWER: A

During bronchoscopic procedures, oxygen can be delivered through the side port of the bronchoscope (apneic

oxygenation) during apneic periods. Often ventilation is possible through this port. **It may be necessary to intermittently ventilate the patient (either through the bronchoscope or via bag-mask ventilation) to prevent acidosis**.

If **apneic oxygenation** is done, $PaCO_2$ increases by an average of 3 mm Hg per minute (a range of 1 to 6 mm Hg). A review of the alveolar gas equation highlights the relationship between the important physiologic variables during apnea:

$$pAO_2 = FiO_2\left(pATM - pH_2O\right) - \left(paCO_2 / RQ\right)$$

Remember that breathing (in a nonparalyzed patient) is controlled by a complex set of inputs from chemoreceptors and the central nervous system, and it is ultimately output to effector muscles. The **peripheral arterial chemoreceptors**, located in the carotid and aortic bodies, are thought to play a role in sensing arterial PaO_2 and pH, whereas **central chemoreceptors**, located on the ventral surface of the medulla, are responsive to $PaCO_2$ and pH.

The relationship between PaCO_2 and cerebral blood flow (CBF) is linear where a 1 mm Hg increase in $PaCO_2$ leads to an increase in CBF by approximately 2 mL/100 g per minute (these studies were done in adults, not children). Increases in $PaCO_2$ also increase pulmonary vascular resistance (PVR), independent of the blood pH. Other factors that increase PVR include a decrease in PaO_2, decrease in blood pH, and stimulation and release of circulating catecholamines.

KEY FACTS

- If apneic oxygenation is done, $PaCO_2$ increases by an average of 3 mm Hg per minute (a range of 1 to 6 mm Hg).
- It may be necessary to intermittently ventilate the patient (either through the bronchoscope or via bag-mask ventilation) to prevent acidosis.
- The peripheral arterial chemoreceptors, located in the carotid and aortic bodies, are thought to play a role in sensing arterial PaO_2 and pH, whereas central chemoreceptors, located on the ventral surface of the medulla, are responsive to $PaCO_2$ and pH.
- The relationship between $PaCO_2$ and CBF is linear where a 1 mm Hg increase in $PaCO_2$ leads to an increase in CBF by approximately 2 mL/100 g/min (these studies were done in adults, not children).

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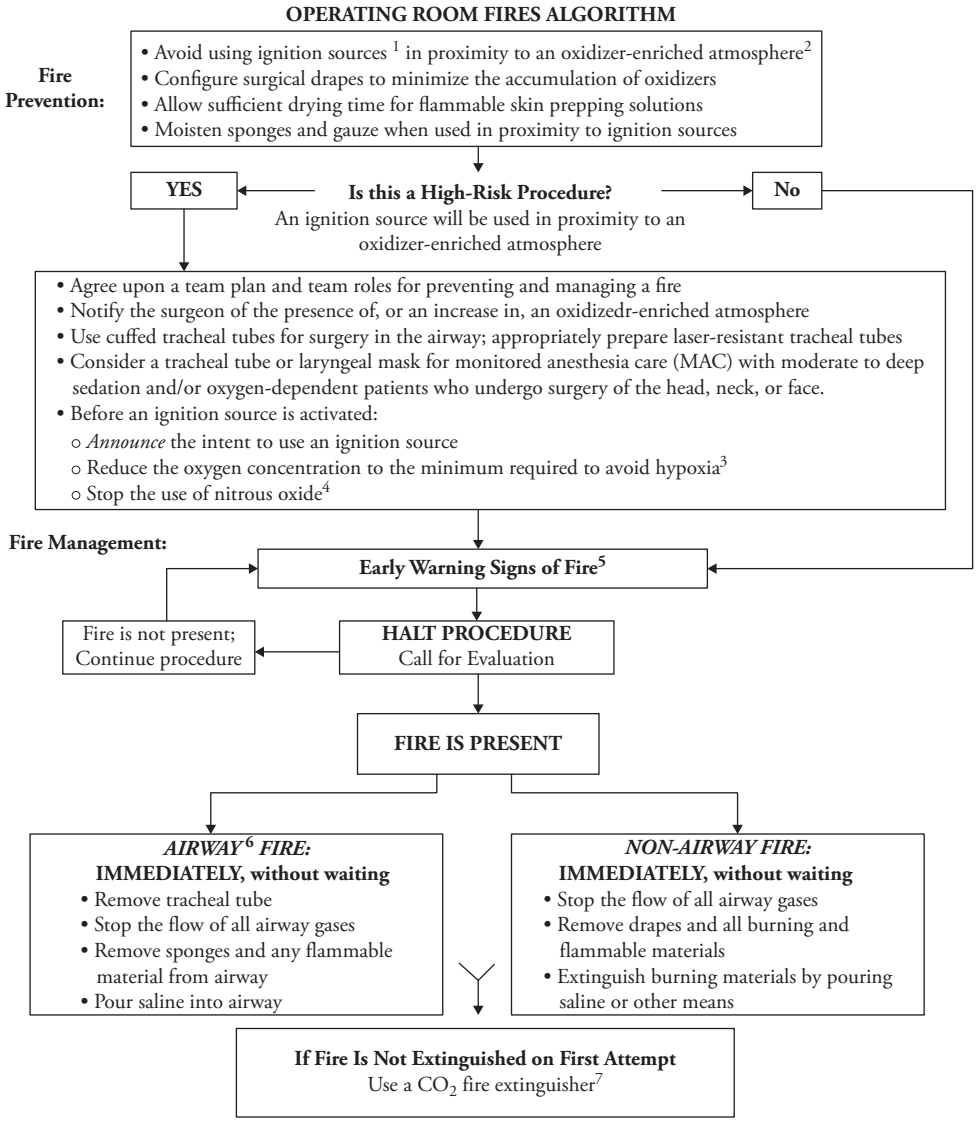
Chapter 212. Anesthesia for Bronchoscopy. Barry A. Harrison, Gurinder Vasdev. Faust RJ. *Anesthesiology Review*. 3rd ed. Anesthesia for Bronchoscopy. p. 515

17. ANSWER: C

Answer A is incorrect. The **first step during an airway fire** is halting the procedure and immediate extubation. Practice advisory for the prevention and management of operating room fires: an updated report by the American Society of Anesthesiologists Task Force on Operating Room Fires. Apfelbaum JL, Caplan RA, Barker SJ, Connis RT, Cowles C, Ehrenwerth J, Nickinovich DG, Pritchard D, Roberson DW, Caplan RA, Barker SJ, Connis RT, Cowles C, de Richemond AL, Ehrenwerth J, Nickinovich DG, Pritchard D, Roberson DW, Wolf GL; American Society of Anesthesiologists Task Force on Operating Room Fires. *Anesthesiology*. 2013 Feb;118(2):271–290. doi: 10.1097/ALN.0b013e31827773d2.



is the Practice Advisory for Prevention and Management of Operating Room Fires. The algorithm shows the different steps The American Society of Anesthesiologists recommends for when faced with cases that have a potential for airway fire. From the answer choices, the first step to take during a known airway fire is to halt the procedure and remove the endotracheal tube. In cases of both airway or no airway fire, it is still recommended that you turn off all airway gases. **Subsequent steps include** removal of all flammable substances from the airway or near the patient, including sponges or non-flame-resistant clothing or drapes. **Finally**, it is recommended to extinguish the fire with saline or water. If the fire is not extinguished by these initially maneuvers, then it is recommended that a **CO_2 extinguisher** be used to put out the fire. **CO_2** extinguishers are not the most common type of fire extinguisher. **CO_2** extinguishers use **CO_2** as an agent that displaces oxygen, removes heat from combustion zones, and because no extinguishing agent is used, they are labeled as "clean agents" and do not leave a residue after discharge. In contrast, ordinary "kitchen" fire extinguishers that use dry agents like monoammonium phosphate or sodium bicarbonate leave a residue after use. **Final steps include** re-establishing an airway and examination of the oropharynx and/or trachea and bronchial tree with bronchoscopy.

Answer B is incorrect. While pouring saline into the field is an important part of the algorithm and fundamental in extinguishing an airway fire, it is not the first step in management.

Answer C is correct. Halting the procedure and immediately removing the endotracheal tube is the best first step in management of a suspected airway fire.

Answer D is incorrect. Removing flammable substances from the surgical site and patient is important; however, extubating the endotracheal tube should be the first step.

KEY FACTS

- The first step during an airway fire is halting the procedure and immediate extubation.
- Subsequent steps include removal of all flammable substances from the airway or near the patient, including sponges or non-flame-resistant clothing or drapes.
- Finally, it is recommended to extinguish the fire with saline or water.
- If the fire is not extinguished by these initial maneuvers, then it is recommended that a CO_2 extinguisher be used to put out the fire.
- Final steps include re-establishing an airway and examination of the oropharynx and/or trachea and bronchial tree with bronchoscopy.

REFERENCE

American Society of Anesthesiologists Task Force on Operating Room Fires, Caplan RA, Barker SJ, et al. Practice advisory for the prevention and management of operating room fires. *Anesthesiology*. 2008;108:786–801.

18. ANSWER: C

Patients with associated congenital anomalies need special attention and vigilance. The anesthetic goal is to have a patient emerge from anesthesia comfortable and maintaining airway patency. The use of **narcotics** can provide postoperative analgesia but also cause respiratory depression and relax airway musculature. Salloum et al. describe how to block the **external nasal nerve and the infraorbital nerve** resulting in a dense block in the maxillary area and upper lip. The nerve blocks combined with a field block will enable cleft lip cases to be done without general anesthesia.

Cleft lip and/or cleft palate are the most common head and neck congenital anomalies. Cleft palate results from failure of the two palatal processes to fuse. Most infants with cleft palate present with feeding difficulties; breast-feeding may not be possible. Severe feeding problems, breathing problems, and aspiration occur in patients with the **Pierre Robin sequence**. In the Pierre Robin sequence, cleft palate is associated with a receding lower jaw as well as posterior and cephalic displacement of the tongue, resulting in obstruction of the naso-oropharyngeal airway. This is a **medical emergency and is a cause of sudden infant death syndrome (SIDS)**. The etiology of isolated palate clefts is multifactorial and likely to be associated with other anomalies. Approximately 8% to 10% of isolated cleft palates are associated with the velocardiofacial syndrome and a 22q deletion. The primary goal of surgery to repair a cleft palate is to help the patient attain normal speech.

Surgical repair of a patient with a **cleft lip is not an emergency**. The best age for operation can be described as the widely accepted **"rule of 10."** This includes body weight of 10 lb (4.5 kg) or more, hemoglobin of 10 g/dL or more, and after the 10th week of life. Rarely, there is marked distortion of the alveolus after cleft lip repair, **and preliminary maxillary orthodontic treatment may be needed**. This often involves the use of appliances or simple constant pressure by use of an elastic band.

KEY FACTS

- Cleft lip and/or cleft palate are the most common head and neck congenital anomalies.
- The use of narcotics can provide postoperative analgesia but also cause respiratory depression and relax airway musculature.
- Peripheral nerve blockade of the external nasal nerve and the infraorbital nerve combined with a field block will enable cleft lip surgery to be completed without general anesthesia.
- Surgical repair of a patient with a cleft lip is not an emergency.
- The best age for operation can be described as the widely accepted "rule of 10": weight of 10 lb (4.5 kg) or more, hemoglobin of 10 g/dL or more, and after the 10th week of life.
- Approximately 8% to 10% of isolated cleft palates are associated with the velocardiofacial syndrome and a 22q deletion.
- The primary goal of surgery to repair a cleft palate is to help the patient attain normal speech.

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Vasconez HC, Habash A. Plastic and reconstructive surgery. In: Doherty GM, ed. *Current Diagnosis and Treatment: Surgery*. 13th ed. New York, NY: McGraw-Hill; 2010:xx–xx.

19. ANSWER: C

In children, **the incidence of PONV is inversely related to age**, increasing throughout childhood, and reaches a peak during adolescence, a time in which the incidence of PONV is greater than that of adults. During childhood, girls and boys experience the same incidence of PONV; **after puberty** girls experience more. The type of surgery

also influences the likelihood of PONV, with tonsillectomies **reporting the highest incidence**. Studies have shown that up to 70% of children undergoing this procedure will develop PONV. **Eye surgery, hernia repairs, orchiopexy, and middle-ear procedures** all are associated with higher incidences of PONV.

A **multimodal approach is indicated to lessen the occurrence of PONV**. There are multiple neuronal pathways thought to be involved in nausea. Stimulation of the chemoreceptor trigger zone, located in the area postrema of the 4th ventricle, is a primary pathway leading to the vomiting reflex. **Drugs that modulate (inhibit) both the efferent and afferent inputs include 5-HT3, histamine, muscarinic, and dopaminergic antagonists**. 5-HT3 antagonists (**ondansetron**) are the drugs of first choice for prophylaxis of vomiting. Pharmacologist doses of 0.1–0.2 mg/kg are usually recommended. Administration of **dexamethasone** is also effective in decreasing the incidence of PONV and can extend the period of effective treatment by up to 24 hours. The recommended doses for dexamethasone are 0.1–0.5 mg/kg. Studies have demonstrated that children given a single dose of dexamethasone were two times less likely to vomit after tonsillectomy than children who did not receive it.

Other maneuvers that are used to prevent PONV include avoiding the use of N_2O, using propofol for its antiemetic effect (it has also been given as a low-dose infusion as part of the anesthetic), avoiding unnecessary prolonged NPO periods preoperatively, and proper hydration during the case. All are essential and should not be taken for granted.

KEY FACTS

- In children, the incidence of PONV is inversely related to age, increasing throughout childhood, and reaches a peak during adolescents, a time in which the incidence of PONV is greater than that of adults.
- During childhood, girls and boys experience the same incidence of PONV; after puberty girls experience more.
- The type of surgery also influences the likelihood of PONV, with tonsillectomies reporting the highest incidence; eye surgery, hernia repairs, orchiopexy, and middle-ear procedures are all associated with higher incidences of PONV as well.
- Drugs that modulate (inhibit) both the efferent and afferent inputs that trigger the emesis reflex include 5-HT3, histamine, and muscarinic and dopaminergic antagonists.

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20. ANSWER: B

Answer A is incorrect. **Peritonsillar abscesses** occur more frequently in older children, adolescents, and young adults and are the most common deep tissue infection treated by ENT surgeons. The infection usually originates in the tonsil itself due to gram positives like *Strep. pyogenes*, gram negatives like *H. influenzae*, and some anaerobes like *Fusobacterium*. The **infection can then spread to the peritonsillar space and compress the mandibular branch of the trigeminal nerve**, which innervates the muscles that control mastication, causing trismus or pterygoid spasm and inflammation. Assessment for degree of trismus is part of a careful assessment of the airway in this patient. **Cephalad spread of the infection** can cause facial swelling and poor mask fit, which is a consideration in this patient. **Caudad spread** can lead to upper airway obstruction due to glottic edema and, in some case reports, mediastinitis, which can be a significant cause of hypoxemia. If trismus is not present and mouth opening is adequate, direct laryngoscopy may be accomplished with special care given to avoid aggravating the abscess with the laryngoscope or endotracheal tube. **When trismus is present,** as in this case, an inhalational induction using sevoflurane can be accomplished; usually the trismus resolves once an adequate depth of anesthesia is established. Fiberoptic intubation is performed nasally or orally, which can be facilitated with propofol. Having the equipment and surgeon present capable of emergency tracheostomy or cricothyrotomy is an important consideration. RSI would be contraindicated in this patient with trismus and a potentially difficult airway.

Answer B is correct. Though insertion of a nasogastric tube is a routine procedure, especially in the case of a known full stomach, it is not without complications. **Esophageal rupture and resulting hemorrhage** are rare but known complications. **In mediastinitis with esophageal involvement,** the increased friability of tissues makes the esophagus more prone to rupture. Therefore, routine placement of a nasogastric tube in this case would be relatively contraindicated.

Answer C is incorrect. **Succinycholine is generally contraindicated in cases of known DMD** due to the risk of hyperkalemia and cardiac arrest; therefore, avoiding succinylcholine in this patient would indeed be correct. The routine use of volatile anesthetics in such cases has also come into question due to several case reports of postoperative rhabdomyolosis and hyperkalemia, and it is theorized that both the presence of dystrophin and volatile anesthetic agents destabilizes the muscle membrane, making it prone to injury. Nevertheless, this risk is weighed against the risk associated

with a known difficult airway, as in this patient, and sevoflurane should *not* be categorically avoided in such situations.

Answer D is incorrect. **Benzocaine carries the risk of methemoglobinemia**, and would be relatively contraindicated in a patient who is already hypoxemic due to mediastinitis and oropharyngeal compromise.

KEY FACTS

- Peritonsillar abscesses occur more frequently in older children, adolescents, and young adults, and they are the most common deep tissue infection treated by ENT surgeons.
- The infection usually originates in the tonsil itself due to gram positives like *Strep. pyogenes*, gram negatives like *H. influenzae*, and some anaerobes like *Fusobacterium*.
- The infection can spread to the peritonsillar space and compress mandibular branch of the trigeminal nerve, which innervates the muscles that control mastication, causing trismus or pterygoid spasm and inflammation.
- Cephalad spread of the infection can cause facial swelling and poor mask fit, which is a consideration in this patient.
- Caudad spread can lead to upper airway obstruction due to glottic edema and, in some case reports, mediastinitis, which can be a significant cause of hypoxemia.
- When trismus is present, as in this case, an inhalational induction using sevoflurane can be accomplished; usually the trismus resolves once an adequate depth of anesthesia is established.
- Succinycholine is generally contraindicated in cases of known DMD due to the risk of hyperkalemia and cardiac arrest.
- Benzocaine carries the risk of methemoglobinemia.

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21. ANSWER: C

Answer A is incorrect. **Pierre Robin sequence (PRS)** occurs in approximately 1 in 8500 births—40% are isolated and the remaining cases are associated with a coexisting syndrome, the most common of which is Stickler syndrome, a genetic disorder affecting collagen. **The hallmarks of PRS** include microagnathia, cleft palate and glossoptosis, or a caudal (downward)—not cranial—displacement of the tongue that can result in feeding or respiratory difficulties. Noninvasive airway maneuvers to improve respiration include prone positioning and placement of nasopharyngeal airways. In the case of respiratory distress, which often presents in the first week of life, tracheostomy may be indicated. **Mandibular distraction osteogenesis (MDO) is the most common surgical treatment for PRS, which involves an intial osteotomy and then gradual lengthening of the mandible as bone remodels.** The surgery expedites the growth of the mandibule, gradually relieves the airway obstruction, and optimizes respiratory mechanics. Prior to the more widespread use of MDO, approximately 39% of infants required tracheostomy, versus now only 8%. In addition to tracheostomies and MDO surgery, **children with PRS may require general anesthesia for G-tubes and cleft lip/cleft palate repair**.

Answer B is incorrect. **DiGeorge syndrome (velocardiofacial syndrome)** is associated with Pierre Robin sequence in approximately 15% of cases. CATCH-22 is a mnemonic for DiGeorge syndrome: Cardiac defect, Abnormal facies, Thymic hypoplasia, Cleft palate, HYPOcalcemia, and 22q11 chromosome microdeletion.

Answer C is correct. A 2012 case series and retrospective review examined 33 Pierre Robin sequence (PRS) newborns requiring intubation for various reasons, including mandibular distraction osteogenesis (MDO), g-tube, tracheostomy, and for respiratory distress. In all cases, mask ventilation was established, typically by inhalational induction. Two thirds were intubated with a fiberoptic bronchoscope and one third were intubated by direct laryngoscopy. No major complications were reported. It is important to note, however, that intubation is not absolutely required to proceed with tracheostomy. **Children who cannot be intubated** by bronchoscope due to subglottic stenosis or by direct laryngoscopy because of difficulty with visualization can undergo tracheostomy by mask as long as spontaneous ventilation is adequate or an LMA is employed. **Tracheostomy under sedation** with ketamine or other medications that minimally depress the respiratory drive and local anesthetic infiltration is a third option. However, an antisiolagogue should be administered to reduce secretions.

Answer D is incorrect. Electrocautery use near the airway presents a risk for fire. Both oxygen and nitrous oxide are flammable and should be minimized or turned off (in the case of N_2O) if the bovie is used. Wet towels on the chest and face as well as flame-resistant operating room drapes can be employed. In the case of fire or smoke in the airway, the first maneuvers are immediate extubation, dousing the field with water or saline, and then switching to mask ventilation or reintubation.

KEY FACTS

- PRS occurs in approximately 1 in 8500 births—40% are isolated and the remaining cases are associated with

a coexisting syndrome, the most common of which is Stickler syndrome, a genetic disorder affecting collagen.
- The hallmarks of PRS include microagnathia, cleft palate and glossoptosis, or a caudal (downward)—not cranial—displacement of the tongue that can result in feeding or respiratory difficulties.
- Noninvasive airway maneuvers to improve respiration include prone positioning and placement of nasopharyngeal airways.
- In the case of respiratory distress, which often presents in the first week of life, tracheostomy may be indicated.
- MDO is the most common surgical treatment for PRS.
- In addition to tracheostomies and MDO surgery, children with PRS may require general anesthesia for G-tube placement and cleft lip/cleft palate repair.
- DiGeorge syndrome (velocardiofacial syndrome) is associated with Pierre Robin sequence in approximately 15% of cases.

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22. ANSWER: D

Answer A is incorrect. **Hearing loss is broadly divided into** conductive hearing loss (CHL) and sensorineural hearing loss (SNHL). **CHL** is the most common and occurs because of physical disruption of the transmission and/or transduction of sound. It is **caused by** ear canal atresia/stenosis, cerumen, cholesteatoma, perforated tympanic membranes, or discontinuity of the ossicular chain (malleus, incus, stapes). **SNHL** is caused by damage or maldevelopment of the hair cells, cochlea, or 8th cranial nerve. These can be caused **by genetic, anatomic, traumatic, autoimmune, or infectious etiologies**. The most common congenital infection is cytomegalovirus, while the most common postnatal infection to cause SNHL is bacterial meningitis from *Streptococcus pneumoniae*. **During surgery for cochlear implants**, a retroauricular incision and mastoidectomy are performed to provide a pathway for the device placement in the inner ear. Postoperatively, the patient is fitted for an externally worn speech processor. **Stapedius reflex thresholds** are often obtained intraoperatively to be used for speech processor fitting. More reliable stapedius reflex threshold values can be achieved during **lighter levels of hypnosis**. In most children, increasing the depth of inhalational anesthetic will increased the stapedius reflex threshold.

Answer B is incorrect. **Preoperative anxiety** is common in children, and it is estimated that 40%–60% of children develop significant fear and anxiety before surgery. **Children between the ages of 1 and 5 years** are at greatest risk for developing extreme anxiety and distress. While many mature, independent older children can successfully undergo induction of anesthesia without their parents present, this is less likely to be the case in children who have had repeat surgeries or hospitalizations (as in this case). Furthermore, it is often helpful to have a parent or sign language specialist accompany the child to the operating room to facilitate communication and a smooth transition to induction.

Answer C is incorrect. A common theme to otologic procedures is the need to identify and preserve the facial nerve. **The 7th cranial nerve passes through the middle ear and is at risk during almost all otologic procedures.** Many surgeons use EMG-based neural monitoring that will not function if paralytics are in use during the maintenance phase of anesthesia. Communication with the surgeon about his or her plans for neuromonitoring is imperative during surgery for cochlear implants and many other otologic procedures.

Answer D is correct. To maximize the ability for the child to understand and be able to communicate during the anxiety-prone phase of preinduction and induction, if the child reads lips, it is helpful for the masks of the anesthesiologist and other operating room personnel to be kept down until after induction of anesthesia.

KEY FACTS

- Hearing loss is broadly divided into CHL and SNHL.
- CHL is the most common and occurs because of physical disruption of the transmission and/or transduction of sound, and it is caused by ear canal atresia/stenosis, cerumen, cholesteatoma, perforated tympanic membranes, or discontinuity of the ossicular chain (malleus, incus, stapes).
- SNHL is caused by damage or maldevelopment of the hair cells, cochlea, or 8th cranial nerve secondary to genetic, anatomic, traumatic, autoimmune, or infectious etiologies.
- Stapedius reflex thresholds are often obtained intraoperatively to be used for speech processor fitting, and more reliable stapedius reflex threshold values can be achieved during lighter levels of hypnosis.
- Preoperative anxiety is common in children, and it is estimated that 40%–60% of children develop signficant fear and anxiety before surgery.
- The 7th cranial nerve passes through the middle ear and is at risk during almost all otologic procedures, and monitoring the function of this nerve requires lack of muscle paralysis.

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23. ANSWER: B

Answer A is incorrect. **Situs inversus** is a rare mirror-image arrangement of heart, lungs, and abdominal organs, where the left atrium and stomach are on the right and the right atrium and liver are on the left. Determination of visceratrial situs can be made by chest X-ray or ultrasound of the heart and abdominal organs. Situs inversus falls into a larger group of syndromes called **heterotaxia syndromes** that are often associated with severe congenital heart defects, such as ASD, VSD, AV septal defect, pulmonary stenosis/atresia, and anomalous systemic venous or pulmonary venous return. **Dextrocardia** simply refers to the heart present on the right side of the chest (as in situs inversus), in contrast to the normal levocardia. Other issues in these children include lung, diaphragm, or thoracic cage abnormalities and asplenia, which increases the risk of serious infections such as bacterial sepsis. A total of 6–8 respiratory infections a year is within the normal range and would not necessarily represent a child with decreased immunity. In the radiograph (Fig. 16.1), the heart is in its normal configuration, with the left ventricle pointing left, the aortic arch and great vessels on the right and stomach (with gastric air bubble) on the left. Therefore, the chest X-ray does not represent situs inversus.

Answer B is correct. This patient has an **expiratory stridor**, which is suggestive—but not pathopneumonic—of lower airway obstruction. While most **aspirated foreign bodies will preferentially lodge in the right bronchial tree**, this is an example of a left mainstem bronchus foreign body that is causing an expiratory-phase obstruction (ball-valve effect), leading to breath-stacking and left-sided hyperinflation (otherwise known as localized emphysema). As a result, the heart and trachea are pushed to the right. The same phenomenon may occur if the peanut fragment happened to lodge in the right mainstem. The presence of emphysema on chest X-ray, depending on the degree, may make maintenance of controlled but spontaneous ventilation a more desirable choice. Institution of positive-pressure ventilation through an endotracheal tube or LMA may worsen the emphysema and can risk more serious complications, such as barotrauma, tension pneumothorax, and cardiovascular collapse. See question 1 for a more complete discussion of the anesthetic management of foreign body aspiration.

Answer C is incorrect. **Pneumothorax** can occur following aspirated foreign body, either from pathologic air-trapping (as in B) or as a complication of the procedure to retrieve the object. A right-sided pneumothorax would typically not cause bowing of the trachea and heart to the right side. Furthermore, subtle lung markings can be seen on the right. Nevertheless, this film could theoretically represent a left-sided pneumothorax with significant air filling the thoracic cavity from a traumatic rupture of the bronchial tree and consequent one-way valve effect.

Answer D is incorrect. **Unilateral phrenic nerve paralysis** in children is uncommon, and it usually results from iatrogenic injury following intrathoracic surgery for congenital heart defects. A more marked elevation of the hemidiaphragm would typically occur, as compared to the radiograph.

KEY FACTS

- Situs inversus is a rare mirror-image arrangement of heart, lungs, and abdominal organs, where the left atrium and stomach are on the right and the right atrium and liver are on the left.
- Situs inversus falls into a larger group of syndromes called heterotaxia syndromes that are often associated with severe congenital heart defects.
- Dextrocardia simply refers to the heart present on the right side of the chest (as in situs inversus), in contrast to the normal levocardia.
- Most aspirated foreign bodies will preferentially lodge in the right bronchial tree.
- Expiratory stridor is suggestive of, but not pathopneumonic for, lower airway obstruction.
- Pneumothorax can occur following aspirated foreign body, either from pathologic air-trapping or as a complication of the procedure to retrieve the object.
- Unilateral phrenic nerve paralysis in children is uncommon, and usually results from iatrogenic injury following intrathoracic surgery for congenital heart defects, and a marked elevation of the hemidiaphragm results on chest radiograph.

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24. ANSWER: B

Answer A is incorrect. Almost all cases of **acute otitis media are accompanied by mastoiditis** due to inflammation of the mastoid air cells. **Usually, antibiotic treatment prevents the spread** of bacterial growth and inflammation. However, if the infection continues and involves destruction of the bony trabeculae of the mastoid, then the infection is termed **acute mastoid osteitis or coalescent mastoiditis**. Though it is rare due to the prevalence of improved management of otitis media, ongoing infection can involve the petrous portion of the temporal bone, causing eye pain and facial nerve palsy. The most common bacterial cause is *Streptococcus pneumoniae*. These children require intravenous antibiotics and mastoidectomy. **Mastoidectomy** involves surgical exposure and removal of the mastoid air cells. Tympanoplasty is sometimes done in conjuction with mastoidectomy. The aim of **tympanoplasty** is to reconstruct the tympanic membrane that is chronically perforated from infection. Various materials may be grafted at the site of reconstruction, including fat, fascia, and perichondrium. Anesthetic management is similar to other inner-ear surgeries. The patient is induced inhalationally or intravenously. The head is carefully rotate to the side of surgery. Maintenance of anesthesia should not include a long-acting paralytic because of the frequent need for EMG-based facial nerve monitoring, due to the fact that the facial nerve courses through the mastoid process. Succinycholine would be an acceptable alternative if muscle relaxation is required during endotracheal intubation.

Answer B is correct. The use of nitrous oxide is relatively contraindicated during placement of the tympanic graft. **Because nitrous oxide is 30 times more soluble than the nitrogen in air**, it diffuses much faster into closed gas spaces, such as the inner ear. Some surgeons believe that the tympanic membrane graft tends to lift away from the site of implantation with the use of nitrous oxide.

Answers C and D are incorrect. The most common complication from surgeries of the inner ear is **postoperative nausea and vomiting (PONV)** due to surgical stimulation of the vestibular labyrinth and the anesthetic technique. Both dexamethasone and propofol have been shown to decrease the incidence of PONV after middle ear surgeries.

KEY FACTS

- Almost all cases of acute otitis media are accompanied by mastoiditis due to inflammation of the mastoid air cells.
- If the infection involves destruction of the bony trabeculae of the mastoid, then the infection is termed "acute mastoid osteitis" or "coalescent mastoiditis."
- Ongoing otitis media can involve the petrous portion of the temporal bone, causing eye pain and facial nerve palsy, most commonly by *Streptococcus pneumoniae*.
- The use of nitrous oxide is relatively contraindicated during placement of the tympanic graft as it is 30 times more soluble than the nitrogen in air and it diffuses much faster into closed gas spaces, such as the inner ear, than the nitrogen can diffuse out.
- The most common complication from surgeries of the inner ear is PONV due to surgical stimulation of the vestibular labryinth and the anesthetic technique.

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25. ANSWER: B

Answer A is incorrect. The hemoglobin concentration in neonates is a function of gestational age. The mean hemoglobin concentration of a neonate born at less than 30 weeks gestation is 13. A **term infant would be expected to have an Hg concentration** of 16 to 18. Therefore, 16–18 would be too high in this infant and would not be a normal lab value.

Answer B is correct. Blood volume is also considered to be a function of gestational age. **Term infants have an average blood volume** of approximately 85 mL/kg, whereas **the blood volume of preterm infants** can be as high as 90 to 105 mL/kg. Therefore, a blood volume of 100 mL/kg would be expected in this neonate.

Answer C is incorrect. **Insensible losses are considerably higher in the preterm neonate**. In those weighing less than 1000 g, insensible losses of 2–3 mL/kg per hour can be expected due to lack of mature skin and subcutaneous tissue, and large exposed surface area-to-mass ratio. Larger premature infants (2000–2500 g) can be expected to have an insensible loss of 0.5–1 mL/kg per hour. Therefore, a loss of 0.5 mL/kg per hour would be unreasonable in this case.

Answer D is incorrect. The optimal environmental (ambient) temperature for minimal heat loss and oxygen consumption for an unclothed infant is one that maintains core temperature at 36.5°C–37°C. A core ambient temperature to maintain a core of 36°C is too low for this infant and would require adjustment.

KEY FACTS

- The mean hemoglobin concentration of a neonate born at less than 30 weeks gestation is 13.

- A term infant would be expected to have an Hg concentration of 16 to 18.
- Term infants have an average blood volume of approximately 85 mL/kg, whereas the blood volume of preterm infants can be as high as 90 to 105 mL/kg.
- Insensible losses are considerably higher in the immature preterm infants.

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16.

PLASTIC AND ORAL-MAXILLARY FACIAL SURGERY

Dusica Bajic

1. Which of the following is a true statement about Charcot-Marie-Tooth disease?

A. It is an autosomal dominant disease.
B. Onset of symptoms occurs most often at birth.
C. It is a rare inherited neurological disorder, affecting approximately 1 in 2 million people in the United States.
D. The neuropathy of Charcot-Marie-Tooth disease affects only motor nerves.

2. A 13-year-old girl with history of Charcot-Marie-Tooth disease presents for removal of a large nevus located on the skin of the right hip. She has severe needle phobia. Which drug should be avoided during her perioperative care?

A. Midazolam
B. Ketamine
C. Sevoflurane
D. Nitrous oxide

3. Which of the listed syndromes can present with a potential difficult intubation due to a short, webbed neck and micrognathia?

A. Angelman syndrome
B. Beckwith-Wiedemann syndrome
C. Ehler-Danlos syndrome
D. Noonan syndrome

4. A 10-year-old boy presents for the surgical intervention involving fronto-orbital and midfacial advancement. As an infant, he underwent craniosynostosis repair due to a brachycephalic shaped skull. He also has a history of conductive hearing loss due to atresia of the external auditory canal. Review of systems is otherwise negative. Which of the listed diagnoses for this child is correct?

A. Angelman syndrome
B. Beckwith-Wiedemann syndrome
C. Crouzon syndrome
D. Ehler-Danlos syndrome

5. Which cranial suture is prematurely fused in a child with Apert syndrome?

A. Metotopic suture
B. Coronal suture
C. Sagittal suture
D. Lambdoid suture

6. Which of the listed syndromes is associated with either simple or complex syndactyly?

A. Crouzon syndrome
B. Apert syndrome
C. Goldenhar syndrome
D. Klippel Feil syndrome

7. A 6-month-old child presents to the preoperative clinic for evaluation prior to scheduled repair of the complex thumb/index finger syndactyly. Which of the following preoperative tests should be considered?

A. Transthoracic ECHO
B. CBC
C. ECG
D. Brain MRI

8. A 10-year-old boy with Treacher-Collins syndrome presents for surgical repair of acute appendicitis. Which of the following statements regarding anesthesia management is correct?

A. Treacher-Collins syndrome is not associated with cardiac abnormalities and therefore does not require a cardiac workup.

B. Direct laryngoscopy becomes less difficult with increasing age.
C. Treacher-Collins syndrome is an autosomal dominant inherited disorder.
D. Patients with Treacher-Collins syndrome are difficult to intubate but do not present with difficult mask ventilation.

9. A newborn presents with respiratory distress immediately after birth that is intermittent and relieved whenever the infant cries. He is diagnosed with choanal atresia. Which of the following statements is true regarding choanal atresia?

A. Complete obstruction of posterior nares is found only in 10% of cases.
B. Adequate ventilation requires continuous use of an oropharyngeal airway.
C. Transpalatal repair is usually performed at 2 months of age in otherwise healthy, full-term infants.
D. It is an isolated anomaly that is never associated with other congenital abnormalities.

10. Physical exam in the newborn child with choanal atresia is also significant for coloboma of the eye, ear abnormalities, and genital hypoplasia. The surgeon decides to perform endoscopic transnasal puncture instead of transpalatal repair. Preoperative workup for this child should also include:

A. EEG
B. ECHO
C. X-ray of the hips
D. No further workup is necessary.

11. A newborn with CHARGE association is scheduled for endoscopic transnasal puncture instead of transpalatal repair of choanal atresia. Anesthesia management for this child includes one of the following:

A. Easy mask ventilation and easy intubation.
B. Difficult ventilation due to congenital lung disease.
C. Hemodynamic instability due to heart defects.
D. Increased risk of bleeding due to coagulation factor deficiencies.

12. A 6-year-old girl with hemifacial microsomia characterized by distinct unilateral mandibular hypoplasia is scheduled for ORIF of the right elbow fracture. Which of the following statements regarding anesthesia concerns is true?

A. Despite unilateral mandibular hypoplasia, this patient is unlikely to present with a difficult intubation.
B. Coexistent urinary anomalies are associated with this condition.
C. Intubation becomes more difficult with increasing age.
D. A preoperative echocardiogram is not required.

13. An active 5-year-old boy who presented to the emergency room complaining of headaches and projectile vomiting for the last 7–10 days is now scheduled for frontal craniotomy. Which of the following statements regarding anesthesia induction is correct?

A. Inhalational induction in this child is the most appropriate approach.
B. Placement of an IV for induction is the most appropriate in this child.
C. Intravenous barbiturates should not be used in this setting.
D. Intravenous ketamine would be an appropriate induction agent.

14. Which of the following statements is true regarding the induction of anesthesia in a child with increased intracranial pressure?

A. Heavy premedication with midazolam should always precede intravenous induction.
B. Ketamine is a drug of choice for intravenous induction.
C. Thiopental is an ideal induction agent in neurosurgery.
D. Succinylcholine should always be avoided.

15. A 12-year-old boy presented with facial asymmetry, proptosis, progressive visual failure, and partial progressive oculomotor palsy. MRI revealed paranasal tumor that extended into the cavernous sinus. You are evaluating him for the scheduled biopsy of the mass. Which statement regarding childhood tumors in the nasopharynx is true?

A. Most childhood tumors in the nasopharynx are malignant.
B. Skull base tumors in children do not present a therapeutic challenge because they are always superficial and easy to remove surgically.
C. The juvenile nasal angiofibroma is the most aggressive benign tumor of the skull base.
D. Risk of bleeding is minimal.

16. Which of the following syndromes is associated with obstructive sleep apnea in children?

A. Ehler-Danlos syndrome
B. Angelman syndrome

C. Prader-Willi syndrome
D. DiGeorge syndrome

17. Which of the following statements is true regarding the obstructive sleep apnea in children?

A. Affected children are commonly overweight or obese.
B. An apnea/hypopnea index less than 1 should be an indication for admission after tonsillectomy.
C. Lymphoid hyperplasia is the most common etiology factor for obstructive sleep apnea.
D. Oral premedication is contraindicated in patients with OSA.

18. Which of the following statements regarding cleft lip and palate is true?

A. Despite presence of cleft lip/palate, infants do not have any problems with feeding and are well nourished.
B. In addition to cleft lip/palate, these patients never have any other airway abnormalities.
C. Congenital heart defects are not specifically associated with isolated cleft palate, but they may be present as part of a syndrome or association.
D. Cleft repair is always undertaken under one procedure to minimize anesthesia exposure.

19. What is the most appropriate pre-operative assessment prior to cleft lip/palate repair?

A. Additional workup is not required since other systems are not affected.
B. A chest X-ray for possible pneumonia that is found frequently in this patient population.
C. Check out for bleeding tendency.
D. Cardiac workup is necessary in every patient with isolated cleft palate.

20. Which of the following peripheral nerve blocks could be indicated for cleft lip surgery in a 10-month-old infant scheduled for day surgery?

A. Superficial cervical plexus block
B. Infraorbital nerve block
C. Only local infiltration by surgeon should be done.
D. No regional anesthesia can be performed safely for this procedure.

21. Which of the following syndromes is characterized by a triad of symptoms that consist of: micrognatia, cleft palate, and glossoptosis?

A. Hurler syndrome
B. Hunter syndrome
C. Pierre Robin syndrome
D. Treacher-Collins syndrome

22. During the extensive craniofacial hypoplasia repairs, which of the listed anesthesia concerns is true?

A. Airway management is usually difficult.
B. Surgical repair is usually short.
C. There is no increased risk of perioperative bleeding requiring blood transfusion.
D. A deep extubation at the end of surgery is indicated.

23. Which of the following statements is correct regarding the use of tissue expanders?

A. Tissue expansion technique with expanders is only limited to skin.
B. It is applied only to adult size patients.
C. Use of skin tissue expanders leads to minimal tissue morbidity and scarring with a near-perfect match in color and texture of the skin.
D. This technique is not very popular since expanded flaps are less resistant to bacterial invasion than random cutaneous flaps.

24. A 6-month-old child is diagnosed with a vascular ring. Symptoms of stridor and difficulty with feeding were present soon after birth. History of slow breast and bottle feeding, fatigue with feeding, symptoms of dyspnea with feeding ("dying spells"), frequent regurgitation, and aspiration pneumonias were all noted. The workup etiology was initiated when solid foods were introduced, since it was associated with more pronounced dysphagia. Which of the following statements is correct regarding the vascular rings?

A. Vascular rings commonly present in early infancy.
B. Surgery should be delayed until 6 months of age due to the risk of cardiac arrest in early infancy.
C. Vascular compression may result in emphysema of one or more lung lobes, compressing other lung tissue.
D. The use of esophageal stethoscope in infants with vascular rings is recommended.

25. An 8-month old baby who was born with a port-wine stain on the forehead and upper eyelid of one side of the face presents for a repeat laser therapy under general anesthesia. The pre-op evaluation includes results of the CT scan that revealed abnormal blood vessels in the pia mater overlying the brain on the same side of the head as the birthmark. The child is taking anti-seizure medication. Mother reports that convulsions when occur are limited to the body opposite the birthmark

and vary in severity. Which of the following statements is correct?

A. This syndrome is also associated with congenital heart malformations.
B. Despite presence of a seizure disorder, these children rarely have mental retardation.
C. This cavernous angioma over trigeminal nerve distribution may be associated with possible laryngeal and tracheal involvement.
D. Glaucoma is present in only 50% of cases.

26. An 8-year-old boy presents for repair of fractured mandible. The injury occurred 5 hours ago, just after he finished eating lunch. Review of all the other systems is negative in this otherwise healthy child. Which of the following statements regarding the mandibular fracture repair is correct?

A. Potential surgery might include either interdental wiring or mandibular open reduction and wiring.
B. Intubation is usually easy in this otherwise healthy child with normal facial anatomy and absence of any craniofacial syndromes.
C. Patient should not be intubated through the nose.
D. After the procedure, potential postoperative vomiting can be managed despite mouth being wired closed.

CHAPTER 16 ANSWERS

1. ANSWER: A

Charcot-Marie-Tooth (CMT) disease is one of the most common inherited neurological disorders, affecting approximately 1 in 2500 people in the United States. The disease is named for the three physicians who first identified it in 1886—Jean-Martin **Charcot** and Pierre **Marie** in Paris, France, and Howard Henry **Tooth** in Cambridge, England.

Symptoms. **Onset** of symptoms is most often in **adolescence or early adulthood**, but some individuals develop symptoms in mid-adulthood. The **neuropathy** of CMT affects **both *motor and sensory nerves***. A typical feature includes weakness of the foot and lower leg muscles, which may result in **foot drop** and a **high-stepped gait** with frequent tripping or falls. Later in the disease, weakness and muscle atrophy may occur in the hands, resulting in difficulty with carrying out fine motor skills (the coordination of small movements usually in the fingers, hands, wrists, feet, and tongue).

Etiology. CMT is caused by mutations in genes that produce proteins involved in the structure and function of either the peripheral nerve axon or the myelin sheath. It is an **autosomal dominant disease**. Although different proteins are abnormal in different forms of CMT disease, all of the mutations affect the normal function of the peripheral nerves. Consequently, these nerves slowly degenerate and lose the ability to communicate with their distant targets. The degeneration of motor nerves results in muscle weakness and atrophy in the extremities (arms, legs, hands, or feet), and in some cases the degeneration of sensory nerves results in a reduced ability to feel heat, cold, and pain.

KEY FACT

- Charcot-Marie-Tooth disease is an autosomal dominant disease with degeneration of motor nerves resulting in muscle weakness and atrophy in the extremities (arms, legs, hands, or feet), and in some cases the degeneration of sensory nerves results in a reduced ability to feel heat, cold, and pain.

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National Institute of Neurological Disorders and Stroke. NINDS Charcot-Marie-Tooth disease information page. Available at: http://www.ninds.nih.gov/disorders/charcot_marie_tooth/charcot_marie_tooth.htm. Accessed June 16, 2014.

2. ANSWER: D

Drugs to Avoid in Charcot-Marie-Tooth disease. The Charcot-Marie-Tooth Association (http://www.cmtausa.org) has long maintained the "Medical Alert" list of potentially neurotoxic medications. **Nitrous oxide** (N_2O), an inhalational anesthetic agent, is listed in a group of drugs with moderate to significant risk and should therefore be avoided during administration of anesthesia. The November/December 1995 NAMI Advocate warned of a potentially *fatal* drug interaction. The latter involves **selective serotonin reuptake inhibitor antidepressants** such as Prozac, Zoloft, Paxil, and Luvox. There are no contraindications for administration of midazolam, ketamine, or sevoflurane.

KEY FACT

- **Nitrous oxide** is listed in a group of drugs with moderate to significant risk in patients with Charcot-Marie-Tooth disease.

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3. ANSWER: C

Ehler-Danlos syndrome is an autosomal dominant disease of connective tissue. Though patients may have dislocation of the temporomandibular joint, they are usually not characterized as being a difficult to intubate.

Angelman syndrome, an autosomal dominant disease, presents as microcephaly and prognathia with a protruding tongue, and may potentially present as a difficult airway management.

Beckwith-Wiedemann syndrome is either a sporadic or autosomal dominant genetic disorder associated with known difficult airway management due to macroglossia and prognathism. It is classified as an overgrowth syndrome (macrosomia) that affects many parts of the body, including the airway. Of note, hyperinsulinism can be associated with hypoglycemia. Neonates are especially at risk for hypoglycemia and perioperative serum glucose monitoring is warranted.

Noonan syndrome is an autosomal dominant disease of a single gene defect (12q22; 12q24). In addition to short

stature with vertebral and skeletal abnormalities, as well as factor XI deficiency, Noonan syndrome can also present with a potentially difficult intubation, due to a short, webbed neck, micrognathia, and dental malocclusion.

KEY FACT

- Angelman syndrome, Beckwith-Wiedemann syndrome, and Noonan syndrome can all potentially present with difficult airway management.

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Nargozian C. The airway in patients with craniofacial abnormalities. *Paediatr Anaesth*. 2004;14:53–9.

4. ANSWER: C

Crouzon syndrome is a rare genetic disease. The incidence is estimated to be 16.5 cases per 1 million persons.

Etiology. Crouzon syndrome is inherited as an **autosomal dominant** trait with complete penetrance and variable expressivity. Increased paternal age is a factor in sporadic cases. Mutations have been described in the *FGFR2* gene.

Symptoms. Crouzon syndrome is also described as **craniofacial dysostosis**. It is characterized by cranial deformity due to premature craniosynostosis, hypoplastic midface, exophthalmos, hypertelorism, and mandibular prognathism. In Crouzon syndrome, craniosynostosis of the coronal, sagittal, and lambdoid sutures may occur, giving the skull a **brachycephalic shape**. Occasionally, scaphocephaly or cloverleaf deformity may occur. Crouzon syndrome accounts for approximately 4.8% of general craniosynostosis cases. Ocular findings include proptosis, megalocornea, nystagmus, keratoconus, ectopia lentis, or colobomas of the iris. Frequent headaches, seizures, and mental deficiency may also occur. An estimated 30%–55% of patients with Crouzon syndrome experience hearing loss (usually conductive). The external auditory canals may be atretic. Finally, anomalies of the cervical vertebrae mostly involve C2 and C3.

KEY FACTS

- Crouzon syndrome (craniofacial dysostosis) is an autosomal dominant inherited disease associated with premature craniosynostosis.
- The cranial deformity results from premature craniosynostosis with the features of a hypoplastic midface, exophthalmos, hypertelorism, and mandibular prognathism.
- In Crouzon syndrome, craniosynostosis of the coronal, sagittal, and lambdoid sutures may occur, giving the skull a brachycephalic shape.
- Associated cervical vertebral anomalies at C2 and C3 in Crouzon syndrome may limit neck mobility.

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Trainor PA, Adrews BT. Facial dysostoses: etiology, pathogenesis and management. *Am J Med Genet C Semin Med Genet*. 2013;163(4):283–94.

5. ANSWER: B

Apert syndrome is also known as acrocephalosyndactyly type 1. It is inherited as an autosomal dominant trait. The incidence of Apert syndrome is estimated to be 15.5 cases per 1 million persons. The major diagnostic criteria for Apert syndrome are craniosynostosis and syndactyly of the hands and the feet. It represents 4.5% of all cases of craniosynostosis. The skull is acrocephalic with a shortened anteroposterior diameter and a flat occiput. The craniosynostosis involves the coronal suture, making the forehead prominent. Other associated anomalies include abnormalities of the cervical vertebrae (single fusion, 37%; multiple fusion, 31%) with C5 and C6 often involved.

Otolaryngological Manifestations. The nasal bridge is depressed, and the midface is typically hypoplastic associated with common visual impairment (e.g., amblyopia). The palate is narrow and is described as Byzantine arch shaped (i.e., Byzantine arch palate). These patients usually undergo midface advancement. Cleft palate may also occur (30%). Associated anomalies include those of the ears and airway, as well as tracheal stenosis.

KEY FACTS

- Apert syndrome, also known as acrocephalosyndactyly type 1, is an autosomal dominant inherited disease.
- Patients with Apert syndrome have craniosynostosis and syndactyly of the hands and the feet.
- The skull is acrocephalic with a shortened anteroposterior diameter and a flat occiput.
- The craniosynostosis involves the coronal suture, making the forehead prominent.

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Weber B, Schwabegger AH, Vodopiutz J, Janecke AR, Forstner R, Steiner H. Prenatal diagnosis of Apert syndrome with cloverleaf skull deformity using ultrasound, fetal magnetic resonance imaging and genetic analysis. *Fetal Diagn Ther*. 2010;27(1):51–6.

6. ANSWER: B

Syndactyly is one of the most common hereditary limb malformations depicting the fusion of certain fingers and/or toes. It is also considered one of the most heterogeneous developmental deformities known in the medical literature. Apert syndrome is listed as being associated with syndactyly. In addition, Apert syndrome is associated with coronal craniosynostosis (shortened anteroposterior diameter of the scull and a flat occiput), hypoplasia of the midface, visual impairment, Byzantine arch palate, and abnormalities of the cervical vertebrae such as single or multiple fusions of the cervical vertebrae with C5 and C6 vertebrae most commonly involved.

The rest of the listed syndromes are summarized as follows:

- **Crouzon syndrome:** As craniofacial dysostosis, Crouzon syndrome is characterized by cranial deformity due to premature craniosynostosis, hypoplastic midface, exophthalmos, hypertelorism, and mandibular prognathism. It is inherited as an autosomal dominant trait.
- **Goldenhar syndrome**: It is an eponym for hemifacial microsomia (facial asymmetry), including hypoplasia of the mandible as well as small pharynx. Patients with more severe forms present as very difficult intubations due to limited jaw mobility, as well as compromised natural breathing through a narrow pharynx. One of the differential diagnoses for Goldenhar syndrome is the Treacher-Collins syndrome, which also has the same presentation but is a bilateral abnormality.
- **Klippel-Feil syndrome**: A rare disease that presents with a short neck due to congenital fusion of any two of the seven cervical vertebrae. The most common signs associated with Klippel-Feil syndrome are short neck, low hairline at the back of the head, and restricted mobility of the upper spine. Other symptoms may include scoliosis, short statue, spinal bifida, cleft palate, and/or heart malformations.

KEY FACT

- Syndactyly can be associated with Apert syndrome, also known as acrocephalosyndactyly type 1.

REFERENCE

Malik S. Syndactyly: phenotypes, genetics and current classification. *Eur J Hum Genet*. 2012;20:817–24.

7. ANSWER: C

Syndactyly of the border digits (thumb/index finger or ring/small fingers) is treated at an early age to prevent the larger digit from curving toward the smaller digit with growth. Typically, syndactyly of these digits is treated at 6 months of age. The treatment of syndactyly of the other digits is elective and is more commonly performed when the digits have grown, at 18–24 months of age. The workup is more complex in cases when syndactyly is part of a syndrome (e.g., *Apert syndrome* or *Potter syndrome*). To rule out **possible congenital long QT syndrome**, which might be present in children with syndactyly, an electrocardiogram (ECG) should be considered as part of preoperative evaluation. Patients with long QT syndrome are at risk of developing life-threatening arrhythmias after exposure to anesthesia.

KEY FACT

- Patients with syndactyly should be considered for a preoperative ECG to rule out congenital long QT syndrome.

REFERENCE

Mandal B, Kaur G, Batra YK, Mahajan S. Manifestation of long QT syndrome with normal QTc interval under anesthesia: a case report. *Pediatr Anesth*. 2011;21:1265–7.

8. ANSWER: C

Treacher-Collins syndrome, described as mandibulofacial dysostosis, is a rare (1:50,000 incidence) genetic abnormality inherited in the autosomal dominant fashion. Their typical physical features include (1) downward slanting eyes; (2) micrognathia (a small lower jaw) and microstomia (a small mouth); (3) underdeveloped, aplastic zygoma; and (4) conductive hearing loss, as well as malformed or absent ears. Some features related to Treacher-Collins syndrome are seen less frequently: cleft palate, coloboma of the upper lid, choanal atresia, and cardiac anomalies.

Anesthesia implications are several. Preoperatively, both cardiac function and airway should be assessed in detail. These patients **can be difficult to mask ventilate and are commonly very difficult to intubate**. Intubation of patients with Treacher-Collins syndrome frequently becomes more difficult with increasing age. LMA can be useful in facilitating fiberoptic intubation. Some children may even require tracheotomy. In addition, they should be monitored for airway compromise in the postoperative period.

KEY FACTS

- Patients with Treacher-Collins syndrome can be difficult to mask ventilate and are commonly very difficult to intubate.
- Intubation of patients with Treacher-Collins syndrome frequently becomes more difficult with increasing age.

REFERENCES

Inada T, Fujise K, Tachibana K, et al. Orotracheal intubation through the laryngeal mask airway in paediatric patients with Treacher-Collins syndrome. *Paediatr Anaesth*. 1995;5(2):129–32.

Nargozian C. The airway in patients with craniofacial abnormalities. *Paediatr Anaesth*. 2004;14:53–9.

9. ANSWER: B

Choanal atresia is a complete membranous or body occlusion of the posterior nares in 90% of cases. The diagnosis can be easily confirmed by listening for air exchange over each nostril with a stethoscope. Once diagnosis is established, the airway obstruction should be relieved with an oropharyngeal airway until completion of surgery. Unlike transpalatal repair in otherwise healthy, full-term infants, endoscopic transnasal puncture may be preferred in preterm infants or in those with associated significant abnormalities such as the **CHARGE association**. Surgical interventions are performed immediately at 1-2 days of life.

Preoperatively, adequate ventilation requires continuous use of the oropharyngeal airway. Special anesthesia consideration primarily includes the maintenance of the airway until completion of surgery. At the end of the procedure, pharynx should be suctioned with care to ensure that stents are clean and patent. Patients should be extubated only when fully awake. Postoperatively, airway observation should continue, since aspiration during feeding commonly occurs after the repair of choanal atresia.

KEY FACT

- Adequate ventilation in a newborn with choanal atresia requires continuous use of an oropharyngeal airway until surgical repair: **transpalatal repair** in healthy newborns or **transnasal puncture** in preterm infants or those with associated anomalies.

REFERENCES

Pagon RA, Graham JM, Zonana J, Yong SL. Coloboma, congenital heart disease, and choanal atresia with multiple anomalies: CHARGE association. *J Pediatr.* 1981;99(2):223–7.

Stack CG, Wyse RK. Incidence and management of airway problems in the CHARGE association. *Anesthesia*. 1991;46(7):582–5.

10. ANSWER: B

Choanal atresia could be associated with **CHARGE syndrome** (formerly known as CHARGE association), caused by a genetic disorder that is inherited in an autosomal dominant pattern. The term CHARGE came into use as an acronym for the set of unusual congenital features seen in some newborn children.

CHARGE is an acronym for:

Coloboma of the eye

Heart defects

Atresia of the nasal choanae

Retardation of growth and/or development

Genital and/or urinary abnormalities

Ear abnormalities and deafness

The pattern of malformations varies among individuals with this disorder, and infants often have multiple life-threatening medical conditions. The diagnosis of CHARGE syndrome is based on a combination of major and minor characteristics. ***Major characteristics*** include coloboma of the eye, microphthalmia, choanal stenosis/choanal atresia, cranial nerve abnormalities associated with difficulty swallowing, facial paralysis, a sense of smell that is diminished (hyposmia) or completely absent (anosmia), and mild to profound hearing loss. In addition, ***minor characteristics*** include heart defects, slow growth starting in late infancy, developmental delay, and cleft lip/palate. Patients frequently have hypogonadotropic hypogonadism, which affects the production of hormones that direct sexual development. Males are often born with micropenis and undescended testes (cryptorchidism). Being that congenital heart defects could be present at the same time as the choanal atresia as part of the CHARGE association, ECHO of the heart should be performed as part of the preoperative evaluation.

KEY FACTS

- CHARGE syndrome includes **C**oloboma of the eye, **H**eart defects, **A**tresia of the nasal choanae, **R**etardation of growth and/or development, **G**enital and/or urinary abnormalities, and **E**ar abnormalities and deafness.
- In patients with CHARGE syndrome, a preoperative echocardiogram should be performed to exclude cardiac abnormalities.

REFERENCES

Lerman J, Cote CJ, Steward JS, eds. *Manual of Pediatric Anesthesia with an Index of Pediatric Syndromes*. 6th ed. Philadelphia, PA: Churchill Livingstone; 2010; 278–80.

Thevasagayam M. El-Hakin H. Diagnosis choanal atresia—a simple approach. *Acta Paediatrica*. 2007;96:1238–44.

11. ANSWER: C

Significant concerns in a child with CHARGE syndrome include the following: (1) possible difficult ventilation and difficult intubation, (2) possible impaired renal function due to urinary abnormalities, as well as (3) hemodynamic instability due to heart defects. Increased risk of bleeding due to coagulation factor deficiencies is unlikely. Congenital lung disease is not the part of CHARGE syndrome description.

KEY FACTS

- CHARGE syndrome includes **C**oloboma of the eye, **H**eart defects, **A**tresia of the nasal choanae, **R**etardation of growth and/or development, **G**enital and/or urinary abnormalities, and **E**ar abnormalities and deafness.
- In patients with CHARGE syndrome, significant perioperative concern includes hemodynamic instability due to heart defects.

REFERENCES

Lerman J, Cote CJ, Steward JS, eds. *Manual of Pediatric Anesthesia with an Index of Pediatric Syndromes*. 6th ed. Philadelphia, PA: Churchill Livingstone; 2010; 552t.

Stack CG, Wyse RK. Incidence and management of airway problems in the CHARGE association. *Anesthesia*. 1991;46(7):582–5.

12. ANSWER: C

Goldenhar syndrome is also described as hemifacial microsomia, as well as oculo-auriculo-vertebral syndrome. It is a rare congenital defect of unclear etiology characterized by incomplete hemifacial development of the ear, nose, soft palate, lip, and mandible. Common clinical manifestations include dermoids, preauricular skin tags, and strabismus. Furthermore, **20% of cases may be associated with congenital cardiac abnormalities** (i.e., atrial septal defect/ventricular septal defect, Tetralogy of Fallot, or coarctation of the aorta). Finally, presence of vertebral abnormalities may **significantly limit neck extension**. As with Treacher-Collins syndrome, **intubation frequently becomes more challenging with increasing age**.

Anesthesia implications are several and include the following:

1. Airway problems. Mask ventilation might be difficult due to inability to hold a facemask in place and maintain an airway once anesthesia is induced.
2. Tracheal intubation might be very difficult if deformities are present bilaterally. LMA should be kept readily available in addition to difficult airway supplies. Intubation might be easier if unilateral or left-sided malformations are present.
3. Potential hemodynamic changes due to presence of congenital heart disease.

Treatment is usually confined to surgical intervention necessary to help the child develop appropriately (e.g., jaw distraction/bone grafts, ocular dermoid debulking, repairing cleft palate/lip, repairing heart malformations or spinal surgery). Some patients with Goldenhar syndrome will require hearing aids or glasses.

KEY FACTS

- Goldenhar syndrome is also known as hemifacial microsomia (unilateral mandibular hypoplasia).
- Airway in Goldenhar syndrome is potentially very difficult. Similar to Treacher-Collins syndrome, intubation frequently becomes more challenging with increasing age.
- Patients with Goldenhar syndrome may present with cardiac anomalies in 20% of cases.

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Altintas F, Cakmakkaya OS. General anesthesia for a child with Goldenhar syndrome. *Pediatr Anesth.* 2005;15(6):529–30.

Holzman SR, Mancuso TJ, Sethna NF, DiNardo JA, eds. *Pediatric Anesthesiology Review: Clinical Cases for Self-Assessment*. New York, NY: Springer; 2010:222–3.

Nargozian C, Ririe DG, Bennun RD, Mulliken JB. Hemifacial microstomia: anatomical prediction of difficult intubation. *Pediatr Anesth*. 1999;9:393–8.

13. ANSWER: B

Craniopharyngiomas are the most common childhood tumor that occurs in the sella-chiasmatic region. They are histologically benign neuroepithelial tumors of the central nervous system. Evidence suggests that adult craniopharyngiomas occurring at age 65–74 years are histologically and biologically different from pediatric craniopharyngiomas that are predominately observed in children aged 5–10 years (bimodal distribution incidence). Typically, the tumors arise within the sella turcica or adjacent suprasellar space.

Clinical Presentation. Symptoms of craniopharyngiomas are caused by mass effects on adjacent normal intracranial structures. They can become quite large, obstructing cerebral spinal fluid pathways and causing **hydrocephalus with increased intracranial pressure** that leads to **headaches, nausea, and projectile vomiting**. Additional symptoms might include vision loss, growth hormone deficiency (e.g., short statue), hypothyroidism, adrenal insufficiency, and diancephalic syndrome. Diancephalic syndrome is present in emaciated hyperactive children who occasionally

present with unusual eye movements and even blindness; these symptoms result from extrinsic compression of the hypothalamus. Conversely, damage to or invasion of the ventromedial hypothalamus can result in a dysregulation of energy balance and resultant obesity upon presentation.

Anesthetic Management. Increased intracranial pressure should always be considered when planning anesthesia induction in children with intracranial lesions.

An inhalational induction is appropriate unless the patient has intracranial hypertension. Inhalational agents increase cerebral blood flow.

Certainly, placement of an IV for anesthesia induction is the most appropriate approach. It should be done with topical local anesthetic to facilitate pain-free PIV insertion. One should also consider oral premedication that should be used judiciously. Intravenous anesthesia induction would allow for a more rapid induction without the possibility of airway compromise that sometimes may occur during an inhalational induction. Difficulty in ventilation would be associated with increased CO_2 and subsequent increased blood flow to the brain, worsening intracranial pressure.

Barbiturates (e.g., thiopental) have some advantages in neurosurgical patients, since this class of drugs does lower both cerebral blood flow and the cerebral metabolic rate for oxygen ($CMRO_2$). Although not commonly used, one could consider rectal administration of **methohexital** in a dose of 25–30 mg/kg. This approach will induce a light sleep in most children. However, in some children a given dose might lead to airway obstruction.

Intravenous anesthetic agents, with the exception of ketamine, either have no effect on cerebral blood flow or decrease it in the absence of hypercarbia. **Ketamine** is a potent cerebral vasodilator leading to increase in cerebral blood flow. Together with its effect on increased $CMRO_2$, it can cause sudden increases in intracranial pressure. When considering intramuscular instead of oral premedication, intramuscular midazolam, instead of ketamine should be considered for a particularly anxious, uncooperative child who refuses oral premedication.

KEY FACTS

- An intravenous rapid sequence induction is most appropriate for patients with increased intracranial pressure presenting as headaches, nausea, and projectile vomiting.
- Ketamine is a potent cerebral vasodilator leading to increased cerebral blood flow, increased $CMRO_2$, and sudden increases in intracranial pressure.

REFERENCES

Holzman RS, Mancuso TJ, Sethn NF, DiNardo JA. *Pediatric Anesthesiology Review: Clinical Cases for Self-Assessment*. New York, NY: Springer; 2010:173–83.

Karavitaki N, Wass JA. Craniopharyngiomas. *Endocrinol Metab Clin North Am*. 2008;37(1):173–93, ix–x.

Lerman J, Cote CJ, Steward JS, eds. *Manual of Pediatric Anesthesia with an Index of Pediatric Syndromes*. 6th ed. Philadelphia, PA: Churchill Livingstone; 2010:235–65.

14. ANSWER: C

Management during induction of anesthesia in a child with increased intracranial pressure should aim to minimize changes in intracranial pressure and fluctuations in arterial and venous pressures. One should remember that the cerebral blood flow (CBF) in infants and children (90–100 mL/100 g/min) is greater than in adults (50–60 mL/100 g/min). It varies directly with changes in $PaCO_2$ between 20 and 80 mm Hg. Specifically, CBF increases 4% per each mm Hg increase in $PaCO_2$.

Midazolam decreases CBF, cerebral metabolic rate for oxygen ($CMRO_2$), and intracranial pressure (ICP). However, heavy premedication should always be avoided in patients undergoing craniotomy for fear of hypoventilation. Some children may benefit from a small dose of midazolam to calm them before surgery, but they should be closely observed until the airway is secured. A $PaCO_2$ of approximately 30–35 mm Hg is preferred during controlled ventilation in neurosurgical patients.

Ketamine should not be used in neurosurgical patients with raised intracranial pressure. This drug increases both the CBF and $CMRO_2$ leading to increase of ICP.

Thiopental reduces ICP and is considered an ideal induction agent in neurosurgery. It does not prevent an increase in blood pressure or ICP during laryngoscopy and intubation. These may be attenuated by prior administration of intravenous lidocaine (1 mg/kg) and an opioid (e.g., fentanyl 5 μg/kg) at anesthesia induction.

Succinylcholine may transiently and very slightly increase CBF and ICP in children with space-occupying lesions; this response may be attenuated by prior administration of a small dose of a nondepolarizing muscle relaxant. Some children undergoing emergency craniotomy have a full stomach and should have a rapid sequence induction with either succinylcholine of high-dose rocuronium (1.2 mg/kg). Finally, one should keep in mind that hyperkalemia was reported after succinylcholine was given to children with cerebral trauma and other central nervous system diseases (e.g., paraplegia, encephalitis, subarachnoid hemorrhage).

KEY FACTS

- Thiopental reduces ICP and is considered an ideal induction agent in neurosurgery.
- Succinylcholine may transiently and very slightly increase CBF and ICP in children with space-occupying lesions; this response may be attenuated by prior administration of a small dose of a nondepolarizing muscle relaxant.

- For a rapid sequence induction, either succinylcholine or high-dose rocuronium (1.2 mg/kg) may be used.

REFERENCE

Lerman J, Cote CJ, Steward JS, eds. *Manual of Pediatric Anesthesia with an Index of Pediatric Syndromes*. 6th ed. Philadelphia, PA: Churchill Livingstone; 2010:235–65.

15. ANSWER: C

Most childhood tumors in the nasopharynx are benign, but they can have significant consequences due to its mass effect on the surrounding tissue. Pediatric skull base lesions include pediatric tumors such as encepahalocele, fibrous dysplasia, neuroblastoma, craniopharyngioma, juvenile nasopharyngeal angiofibroma, cholesteatoma, chordoma, chondrosarcoma, and Ewing sarcoma. Encepahaloceles, dermoids, and benign teratomas can occur as congenital remnants, in which case they present at an early age with airway obstruction.

Skull base tumors in children present a therapeutic challenge because of their unique pathological composition, the constraints of the maturing skull and brain, and the small size of the patients.

Juvenile nasopharyngeal angiofibromas are rare, histologically benign, locally invasive tumors or vascular malformations of the nasopharynx that are found primarily in the pubescent males. These lesions are considered the most aggressive of all the other benign tumors of the nasopharynx. They extend locally into the surrounding nasopharyngeal tissue and cranially through the skull base. They are usually evaluated radiologically (e.g., CT and/or MRI with angiogram) and managed by embolization to reduce vascularity prior to subsequent surgical resection.

Anesthesia management consideration for placement of embolization device is as follows:

1. Maintain slightly higher intravascular volume.
2. Maintain normal to slightly higher than normal systemic blood pressure.
3. Establish moderate controlled hypercarbia to facilitate coil placement.

For the surgical removal of the tumor, physiological parameters should be reversed since there is a high risk of bleeding. Specifically, juvenile nasal angiofibroma is a rare benign but very vascular tumor that may involve the nose. Even biopsy of these tumors may result in extensive bleeding that is very difficult to control. An operation to remove the tumor may result in massive blood loss and one should be prepared for it accordingly. Regarding the anesthesia management, one should consider (1) invasive hemodynamic monitoring (arterial line), (2) controlled hypotension, (3) volume reduction, and (4) positive pressure-controlled hyperventilation during anesthesia maintenance for surgical resection of the vascular lesion.

KEY FACTS

- Juvenile nasopharyngeal angiofibromas are rare, histologically benign, locally invasive tumors or vascular malformations of the nasopharynx that are found primarily in the pubescent males.
- These lesions are considered the most aggressive of all benign tumors of the nasopharynx.

REFERENCES

Beham A, Beham-Schmid C, Regauer S, et al. Nasopharyngeal angiofibroma: true neoplasm or vascular malformation? *Adv Anat Pathol*. 2000;7:36–46.

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Tsai EC, Santoreneous S, Rutka JT. Tumors of the skull base in children: review of tumor types and management strategies. *Neurosurg Focus*. 2002;12(5):e1.

16. ANSWER: C

Prader-Willi syndrome is described as a sporadic mutation or cytogenetic deletion at chromosome inherited from father (same genetic defect in Angelman syndrome is inherited from mother). Neonates with Prader Willi syndrome present with hypotonia, poor feeding, and absent reflexes. As the children grow, second phase of the disease is characterized by hyperactivity, uncontrollable polyphagia, disturbed thermoregulation, and mental retardation. Resulting obesity leads to cardiorespiratory failure. Anesthetic considerations for Prader-Willi syndrome management are several:

1. Anticipate difficult PIV access due to obesity.
2. To avoid danger of intraoperative hypoglycemia one should monitor blood glucose carefully. Intravenous glucose solution should be infused before, during, and after surgery/anesthesia.
3. Be aware that both low-grade pyrexia (e.g., in cases of scoliosis, strabismus, and hernia surgery) and hypothermia may occur intraoperatively.
4. Obstructive sleep apnea is common.
5. Postoperatively, these patients should be closely monitored for apnea and airway obstruction. Nasal CPAP may improve ventilation in selected candidates.

In addition to Prader-Willi syndrome, obstructive sleep apnea in children is also found in children with **Crouzon** and **Apert** syndromes.

Ehler-Danlos syndrome, an autosomal dominant disease of the connective tissue might be associated with dislocation of the temporo-mandibular joint, but it should not be associated with obstructive sleep apnea in children.

Angelman syndrome, an autosomal dominant disease, presents as microcephaly and prognathia with protruding tongue and may potentially present as a difficult airway management. It is not associated with obstructive sleep apnea.

DiGeorge syndrome / velocardiofacial syndrome is a relatively common human disorder (1:5000 newborns) caused by a defect in chromosome 22. It is associated with several abnormalities: craniofacial anomalies (micrognatia, short trachea, laryngo-/tracheomalatia), heart defects (i.g. truncus arteriosus, tetralogy of Fallot), poor immune system function (immune deficiencies), a cleft palate, complications related to low levels of calcium in the blood (i.g hypoparathyroidism), and behavioral disorders (cognitive and motor delay). It is however, not associated with obstructive sleep apnea. Special anesthesia considerations for DiGeorge syndrome include the following: (1) preoperative detailed evaluation of cardiac and immune status; (2) preoperative check of electrolytes, especially Ca^{2+}; (3) anticipation of possible difficult airway; and (4) caution with transfusion (irradiate blood prior to transfusing).

KEY FACTS

- Obstructive sleep apnea is found in children with (1) Prader-Willi, (2) Crouzon, and (3) Apert syndromes.

REFERENCES

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Dearlove OR, Dobson A, Super M. Anesthesia and Prader-Willi syndrome. *Paediatr Anaesth*. 1998;8(3):267–71.

17. ANSWER: C

Chronic obstruction due to lymphoid hyperplasia is the most common etiology factor for obstructive sleep apnea (OSA). It is also associated with obesity and several syndromes (e.g., Apert syndrome, Crouzon syndrome, and Prader Willi syndrome). Affected children may be **obese or asthenic**, show difficulty arousing in the morning and have daytime somnolence, nocturnal enuresis and behavior problems (attention-deficit disorder and limited attention span), nocturnal apnea, and profuse sweating. Consequences of untreated OSA include failure to thrive, poor academic performance, and cardiopulmonary disease.

The American Academy of Pediatrics guideline contains the following recommendations for the diagnosis of OSA: (1) all children should be screened for snoring; (2) complex high-risk patients should be referred to a specialist; (3) patients with cardiorespiratory failure cannot await elective evaluation; (4) diagnostic evaluation is useful in discriminating between primary snoring and OSA, **the gold standard being polysomnography**; (5) **adenotonsillectomy** is the first line of treatment for most children, and continuous positive airway pressure is an option for those who are not candidates for surgery or do not respond to surgery; (6) high-risk patients should be monitored as inpatients postoperatively; and (7) patients should be reevaluated postoperatively to determine whether additional treatment is required.

Polysomnographic indications for admission after tonsillectomy for the T&A with a history of OSA include the following:

1. A baseline value for partial pressure of CO_2 ($PaCO_2$) ≥ 50 mm Hg
2. A baseline awake O_2 saturation ≤ 92%
3. Episodes of O_2 desaturation ≤ 80%
4. Apnea/hypopnea index greater than 1

In cases when polysomnography is unavailable, overnight O_2 saturation monitors have been suggested as a valuable screening tool. Although the positive predictive value of overnight SpO_2 monitors is very high, a negative test is less helpful and should be interpreted cautiously.

Anesthesia Concerns. Children with OSA should be closely monitored before and after surgery. Supervised mild sedation (oral midazolam) is safe preoperatively but is often omitted. Note that the small incremental doses of opioid should be administered while the child is breathing spontaneously during the surgery (e.g., IV fentanyl 0.5 μg/kg or morphine IV 0.025 mg/kg). **Children with OSA have abnormal (upregulated/increased) opioid sensitivity** and may develop apnea even after administered reduced opioid doses despite the surgical postoperative pain.

KEY FACTS

- Children with chronic OSA have increased opioid sensitivity and require judicious administration of opioids.
- Affected children may be overweight but often have a normal BMI.
- Polysomnographic indications for admission after tonsillectomy for the T&A with a history of OSA include a baseline value for partial pressure of CO_2 ($PaCO_2$) ≥ 50 mm Hg, a baseline awake O_2 saturation ≤ 92%, episodes of O_2 desaturation ≤ 80%, and apnea/hypopnea index greater than 1.

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Lerman J, Cote CJ, Steward JS, eds. *Manual of Pediatric Anesthesia with an Index of Pediatric Syndromes*. 6th ed. Philadelphia, PA: Churchill Livingstone; 2010:283–85.

18. ANSWER: C

Cleft lip and palate is present in various combinations in as many as 1:1000 live births. Defects may be isolated or they can occur as part of a syndrome or association of defects (e.g., Pierre-Robin syndrome).

Infants with these lesions may be both malnourished and anemic as a result of feeding difficulties and may have a history of repeated respiratory infections.

Isolated cleft palate appears to be a separate entity from cleft lip with or without cleft palate. Isolated cleft palate has an incidence of 1:2500 live births. Other anomalies are seen in up to 25% of all patients with cleft lip, palate, or both, and more often in children with bilateral cleft lip. Airway anomalies (e.g., Pierre Robin or Treacher Collins syndrome) may make intubation extremely difficult.

It is true that congenital heart defects are not specifically associated with isolated cleft palate but may be present as part of a syndrome or association. Up to 20% of patients with the Pierre Robin syndrome have cardiac anomalies such as atrial or ventral septal defect, or patent ductus arteriosus.

The surgical care of a patient with cleft lip/palate may be done in many possible stages. These include the following:

1. Application of orthodontic splints or devices to the palate
2. Cleft lip repair—usually done at 10–12 months of age
3. Cleft palate repair—usually done at 12–18 months of age
4. Alveolar bone graft
5. Pharyngoplasty for velopharyngeal incompetence—usually performed at 5–15 years
6. Maxillary advancement (Le Fort procedure) required for some adolescent patients

KEY FACTS

- Isolated cleft palate is not specifically associated with congenital heart defects.
- 20% of patients with the Pierre Robin syndrome have cardiac anomalies such as atrial or ventral septal defect, or patent ductus arteriosus.

REFERENCES

Holzman SR, Mancuso TJ, Sethna NF, DiNardo JA. *Pediatric Anesthesiology Review: Clinical Cases for Self-Assessment*. New York, NY: Springer; 2010:74–6.

Robin NH, Baty H, Franklin J, et al. The multidisciplinary evaluation and management of cleft lip and palate. *South Med J*. 2006;99(10):1111–20.

19. ANSWER: C

Very careful and detail preoperative assessment should be performed in children with cleft lip/palate presenting for surgery.

Patient with cleft lip/plate present with frequent upper respiratory infections, not pneumonias. In case of the upper respiratory tract infection, surgery should be postponed. Special attention to the airway, lungs and other systems should be done that might be affected in congenital syndrome (e.g., Pierre Robin or Treacher Collins syndrome).

History of bleeding tendency should be inquired. In addition, history of medication use should be reviewed with emphasis on salicylates, NSAIDs, gingko, garlic, or ginseng. If possible, determine the bleeding time; if it is prolonged, surgery should be deferred until complete hematology evaluation is done. Blood is usually rarely needed for cleft palate surgery when there is no bleeding tendency present.

It is true that congenital heart defects are not specifically associated with isolated cleft palate, but may be present as part of a syndrome or association. Up to 20 % of patients with the Pierre Robin Syndrome have cardiac anomalies such as atrial or ventral septal defect, or patent ductus arteriosus.

KEY FACTS

- History of bleeding tendency should be inquired in all patients with cleft/lip palate.
- 20% of patients with the Pierre Robin syndrome have cardiac anomalies such as atrial or ventral septal defect, or patent ductus arteriosus.

REFERENCE

Lerman J, Cote CJ, Steward JS, eds. *Manual of Pediatric Anesthesia with an Index of Pediatric Syndromes*. 6th ed. Philadelphia, PA: Churchill Livingstone; 2010:322.

20. ANSWER: B

Cleft lip surgery is often performed in the day surgery unit because the surgery is superficial and postoperative problems are rare. The use of an infraorbital nerve block provides good postoperative analgesia for this type of surgery and should be routinely used.

Infraorbital nerve block is simple to perform and provides good analgesia for infants undergoing cleft lip repair but also for children undergoing endoscopic sinus procedures. Although in older children, the site of the infraorbital foramen can be palpated 1–1.5 cm below the infraorbital rim in the line with the supraorbital notch and the pupil, in infants it cannot be palpated. Instead, position of the infraorbital foramen should be estimated by using the following landmarks: the infraorbital nerve lies approximately under the midpoint of a line drawn between the middle of the palpebral fissure and the angle of the mouth.

In contrast to cleft lip surgery, children undergoing cleft palate surgery are admitted for 24-hour observation. This is because both airway and bleeding problems may occur in the postoperative period. Considering that an upper respiratory obstruction is a particular risk in the postoperative period, opioid analgesics should be used with caution.

KEY FACT

- An infraorbital nerve block is an appropriate regional anesthetic option for infants undergoing cleft lip repair.

REFERENCE

Lerman J, Cote CJ, Steward JS, eds. *Manual of Pediatric Anesthesia with an Index of Pediatric Syndromes*. 6th ed. Philadelphia, PA: Churchill Livingstone; 2010:317–25.

21. ANSWER: C

Pierre Robin syndrome (also described as sequence) is a congenital condition of facial abnormalities. The three main features include the following:

1. **Micrognathia** (small mandible) + retrognathia
2. **Cleft palate** that is U-shaped and wider
3. **Glossoptosis** (tongue displacement backwards)

The syndrome is generally diagnosed clinically shortly after birth. The infant usually has respiratory difficulty, especially when supine. Patients with Pierre Robin Syndrome have difficult airway, as well as postoperative ventilatory obstruction. Preoperative work up for children with Pierre Robin syndrome should also include detailed heart evaluation. Up to 20% of patients with this syndrome have cardiac abnormalities such as atrial/ventral septal defect or patent ductus arteriosus.

Hurler syndrome (mucopolysaccharidosis **type I**) is autosomal recessive genetic disorder (1:100,000 incidence) that is characterized by the buildup of glycosaminoglycans (formerly known as mucopolysaccharides) due to specific enzyme deficiency (alpha-L iduronidase) responsible for degradation of mucopolysaccharides in lysosomes. As a result, it is usually classified as **lysosomal storage disease**. Clinically, patients with Hurler syndrome present with several features:

1. Coarse facial features, macrocephaly, macroglossia, as well as limited neck mobility that predisposes them to the difficult airway management. One should note that in contrast to e.g. Pierre Robin and Goldenhar syndromes, airway management becomes more difficult with advance age of children with Hurler syndrome.
2. Their cardiovascular system is also affected by this systemic disease and is associated with coronary artery disease, thickened valves and myocardium. It all predisposes children with Hurler syndrome to develop congestive heart failure with time.
3. From the neuromuscular standpoint, Hurler syndrome children develop cognitive delay and possible hydrocephalus.
4. Miscellaneous features also include: short stature and kyphoscoliosis.

Anesthesia concerns in children with **Hurler syndrome** include detailed preoperative cardiovascular evaluation (including the heart ECHO), intraoperative preparedness for extremely difficult airway management, as well as postoperative monitoring for airway compromise.

Hunter syndrome (mucopolysaccharidosis **type II**) has X-linked recessive inheritance. It is also classified as lysosomal storage disease that is caused by a deficient (or absent) enzyme, iduronate-2-sulfatase leading to accumulation of heparan sulfate and dermatan sulfate in tissues. Clinical features and anesthesia concerns are similar to those described for **Hurler syndrome**.

Treacher-Collins syndrome, described as **mandibulofacial dysostosis**, is a rare (1:50,000 incidence) genetic abnormality inherited in the **autosomal dominant** fashion. Their typical physical features include (1) downward slanting eyes; (2) micrognathia (a small lower jaw) and microstomia (a small mouth); (3) underdeveloped aplastic zygoma; (4) conductive hearing loss as well as malformed or absent ears. Some features related to Treacher-Collins syndrome are seen less frequently: cleft palate, coloboma of the upper lid, choanal atresia, and cardiac anomalies.

KEY FACT

- Pierre Robin syndrome is characterized by a triad of symptoms that include: micrognatia, cleft palate, and glossoptosis.

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Holzman SR, Mancuso TJ, Sethna NF, DiNardo JA. *Pediatric Anesthesiology Review: Clinical Cases for Self-Assessment*. New York, NY: Springer; 2010:75.

Holzman SR, Mancuso TJ, Sethna NF, DiNardo JA. *Pediatric Anesthesiology Review: Clinical Cases for Self-Assessment*. New York, NY: Springer; 2010:377–86.

Lerman J, Cote CJ, Steward JS,e ds. *Manual of Pediatric Anesthesia with an Index of Pediatric Syndromes*. 6th ed. Philadelphia, PA: Churchill Livingstone; 2010:317–573t.

Nargozian C. The airway in patients with craniofacial abnormalities. *Paediatr Anaesth*. 2004;14:53–9.

22. ANSWER: A

Anesthesia concerns during craniofacial hypoplasia repair surgeries are several and include the following:

- Difficult airway management in case of significant deformities sometimes requires tracheostomy under local anesthesia.
- In the light of difficult airway, patients should always be extubated awake.
- Potentially extensive perioperative blood loss requires blood transfusion in small children.
- Long surgeries might be associated with potential problems related to prolonged anesthetics (e.g., pressure sores, nerve compression, eye damage).
- Anesthetic should be carefully managed to allow for relatively rapid wakeup at the end of the procedure so that the surgeon may check the cranial nerve function.
- Due to potentially extensive swelling of the adjacent tissue to the airway, parents should be informed that there is a high chance that the patient will remain intubated after the procedure.

KEY FACTS

- Patients with craniofacial hypoplasia may present with difficult airway management and advanced airway equipment should be readily available.
- Following craniofacial hypoplasia repair, patients should be extubated awake at the end of the surgery.

REFERENCES

Lerman J, Cote CJ, Steward JS, eds. *Manual of Pediatric Anesthesia with an Index of Pediatric Syndromes*. 6th ed. Philadelphia, PA: Churchill Livingstone; 2010:329–30.

Nargozian C. The airway in patients with craniofacial abnormalities. *Paediatr Anaesth*. 2004;14:53–9.

23. ANSWER: C

Tissue expansion has become a major reconstructive modality over the past 30 years. It has become more and more widespread, particularly in the fields of breast reconstruction, burn surgery, and pediatric plastic surgery. In many cases, tissue expansion can be said to have revolutionized plastic surgery.

Tissue expansion has numerous advantages. While it provides skin with a near-perfect match in color and texture, minimal donor site morbidity and scarring occur. It also can be used in various parts of the body to provide tissue with specialized sensory function or adnexal characteristics. Examples include the superior sensation of the skin flaps in breast reconstruction and the hair-bearing flaps designed in the treatment of male pattern baldness developed with expanders. In addition, expanded flaps are more resistant to bacterial invasion than random cutaneous flaps. This technique has been extended to other types of tissue, including bladder reconstruction, vascular elongation, and nerve lengthening.

Disadvantages include temporary cosmetic deformity during the expansion phase, prolonged period of expansion, the need for multiple procedures, and complications associated with the implant and placement.

KEY FACTS

- Tissue expanders have been used in reconstructive surgery for the past 30 years; they revolutionized plastic surgery.
- They are applied not only to skin but other tissue as well.
- Expanded flaps are more resistant to bacterial invasion than random cutaneous flaps.

REFERENCE

Yesilada AK, Akçal A, Dagdelen D, Sucu DÖ, Kilinç L, Tatlidede HS. The feasibility of tissue expansion in reconstruction of congenital and acquired deformities of pediatric patients. *Int J Burns Trauma*. 2013;3(3):144–50.

24. ANSWER: C

Vascular rings are unusual congenital anomalies that occur early in the development of the aortic arch and great vessels. The primary symptomatology associated with vascular rings is described in this case scenario and relates to the structures that are encircled by the ring, chiefly the trachea, and esophagus. Prompt diagnosis and treatment of these congenital abnormalities can be lifesaving. Surgery should not be delayed until child is older since they are prone to sudden cardiorespiratory arrest.

The **double aortic arch** is the anomaly that usually produces the most severe airway compression in the youngest patients. The second most common configuration, right aortic arch and left ligamentum arteriosum with retroesophageal left subclavian artery, displays a spectrum of severity. Some individuals present in infancy or very early in childhood while others do not present until adulthood.

Special anesthesia concerns include the following:

1. Presence of respiratory failure is due to chronic or recurrent respiratory infections.
2. Vascular compression may result in emphysema of one or more lung lobes, compressing other lung tissue.
3. Airway compression may be at the level of the carina or main bronchi, which means that normally situated endotracheal tube might not prevent airway obstruction.
4. Patient may remain intubated postoperatively to prevent serious complications.
5. Use of esophageal stethoscope in infants with vascular rings has been reported to cause acute airway obstruction (secondary to esophageal dilation and compression of the airway).

KEY FACTS

- Vascular rings are unusual congenital anomalies that occur early in the development of the aortic arch and great vessels.
- Some individuals present in infancy or very early in childhood while others do not present until adulthood.
- Surgery should not be delayed until child is older because they are prone to sudden cardiorespiratory arrest.
- Vascular compression may result in emphysema of one or more lung lobes, compressing other lung tissue.
- Use of esophageal stethoscope in infants with vascular rings has been reported to cause acute airway obstruction (secondary to esophageal dilation and compression of the airway).

REFERENCES

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25. ANSWER: D

Sturge-Weber syndrome is usually manifested at birth by a port-wine stain on the forehead and upper eyelid of one side of the face. The birthmark can vary in color from light pink to deep purple and is caused by an overabundance of capillaries around the ophthalmic branch of the trigeminal nerve, just under the surface of the face. There is also malformation of blood vessels in the pia mater overlying the brain on the same side of the head as the birthmark. This causes calcifications of tissue and loss of nerve cells in the cerebral cortex.

Neurological symptoms include seizures that begin in infancy and may worsen with age. Convulsions usually happen on the side of the body opposite the birthmark and vary in severity. There may also be muscle weakness on the side of the body opposite the birthmark. Some children will have developmental delays and mental retardation; about 50% will have glaucoma (and optic neuropathy often associated with increased intraocular pressure), which can be present at birth or develop later. Increased pressure within the eye can cause the eyeball to enlarge and bulge out of its socket (buphthalmos). Care should be done to prevent hypertension or raised intraocular pressure during anesthesia management (e.g., intubation and extubation). Sturge–Weber syndrome rarely affects other body organs.

Children with Sturge-Weber syndrome present for repeated laser therapy of their port-wine stain.

KEY FACTS

- Patients with Sturge-Weber syndrome present with typical port-wine stain on the forehead and upper eyelid of the one side of the face.
- They also may have glaucoma, intracranial calcifications, seizure disorder and mental retardation.
- They present for repeated laser therapy of their port-wine stain.

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26. ANSWER: A

There are numerous special anesthesia problems related to management of a patient that presents with fracture mandible. These include the following:

Although children are otherwise healthy with normal facial anatomy, **airway management following mandibular fracture frequently represents a challenge**. Intubation may be difficult because of tissue damage, trismus, and distortion of normal airway anatomy. Furthermore, foreign bodies (e.g., teeth) might be present in the airway that can further compromise laryngoscopy and intubation. Note that radio-opaque debris such as teeth may be visible on X-ray. Therefore, consulting radiographs before induction of anesthesia should be done. For children with full stomach that will otherwise warrant rapid sequence intubation, surgery should be delayed as long

as possible. Intravenous metoclopramide should also be administered.

Patients should be intubated through the nose. One should determine the more patent nostril prior to intubation. For emergency surgery, orotracheal endotracheal tube should be used initially, followed by placement of orogastric tube and emptying the stomach before it can be changed to a nasotracheal tube.

Intraoperative anesthesia technique should be directed toward decreasing a risk of postoperative nausea/vomiting. This is because postoperative vomiting is a potential life-threatening event in cases of mouth being wired closed. Suction as well as wire cutters should be readily available at all times near the bedside for children whose jaws are wired closed.

KEY FACTS

- Patients with a mandibular fracture frequently present with difficult airway management due to tissue damage, trismus, and distortion of normal airway anatomy.
- Patients should be nasally intubated for a surgical repair of the mandible.
- Postoperative vomiting is a potential life-threatening event if the mouth is wired closed.

REFERENCE

Lerman J, Cote CJ, Steward JS, eds. *Manual of Pediatric Anesthesia with an Index of Pediatric Syndromes*. 6th ed. Philadelphia, PA: Churchill Livingstone; 2010:325–7.

17.

OPHTHALMOLOGY

Aman Kalra, Tasneem T. Dohadwala, and Najma Mehter

1. A 9-year-old girl with a history of postoperative nausea and vomiting (PONV) is scheduled for strabismus repair of her left eye. You plan a general anesthetic with a LMA. Which one of the following factors puts this patient at greatest risk of PONV?

A. A propofol-based anesthetic
B. Gender of this patient
C. Combination prophylactic therapy
D. The type of surgery

2. A 14-year-old adolescent girl reports severe history of PONV after her last strabismus repair. During the interview she mentions blurry vision and dry mouth, which lasted for several days after her last anesthetic. You plan prophylactic antiemetic therapy along with a propofol-based general anesthetic. Which of the following prophylactic drug or combination will be the most appropriate for this patient?

A. A 5-HT_3 receptor antagonist as your primary prophylactic agent
B. A 5-HT_3 receptor antagonist in combination with dexamethasone
C. A combination of a scopolamine transdermal patch, a 5-HT_3 antagonist, and dexamethasone
D. Scopolamine transdermal patch in combination with a 5-HT_3 antagonist

3. Cervical spine instability is *most* likely to be associated with which one of the following syndromes?

A. Marfan syndrome
B. Hurler syndrome
C. Down syndrome
D. Alport syndrome

4. A 3-year-old girl with Down syndrome and known first-degree AV block is scheduled for strabismus surgery on her right eye. Which of the following measures is most likely to be effective in preventing oculocardiac reflex (OCR)?

A. Choosing regional over general anesthesia
B. Pretreatment with intravenous atropine or glycopyrrolate
C. Choosing a retrobulbar over peribulbar block
D. A propofol-based anesthetic over a sevoflurane-based general anesthetic

5. The choice of anesthetic agent used for maintenance of anesthesia has shown to have an effect on the intensity and severity of bradycardia and associated hemodynamics during an OCR. Which among the following anesthetics results in the highest heart rate during an OCR?

A. Propofol
B. Thiopental sodium
C. Ketamine
D. Sevoflurane

6. A 7-year-old girl received a penetrating injury to her eye. Which among the following will cause the greatest increase in intraocular pressure (IOP)?

A. Decreased $PaCO_2$
B. Elevated PaO_2
C. Elevated central venous pressures
D. Low arterial blood pressure

7. A 5-year-old child presents with penetrating trauma to her right eye. Parents report that the child had a bowl of cereal an hour ago. The child has a working IV from the emergency room. Which one of the following statements is the *most* appropriate anesthetic management of this patient?

A. A rapid sequence induction with Propofol 2–4 mg/kg and succinylcholine 1–2 mg/kg.

B. A rapid sequence induction with Propofol 2–4 mg/kg and Rocuronium 1.2 mg/kg.
C. Deliberate hypercapnia and relative hypoxemia to decrease IOP.
D. If the laceration is small (<2 mm), IOP should be kept below 35 mm Hg.

8. A 10-day old, 1000 g premature infant is scheduled for an exploratory laparotomy for bowel perforation. Which of the following risk factors is most important with regard to the development of retinopathy of prematurity (ROP) in this patient?

A. Extremely low birth weight
B. Exposure to high concentrations of oxygen in the operating room during surgery
C. Hypothermia and acidosis
D. Exposure to bright light in the operating room

9. A 6-month-old infant is scheduled for bilateral inguinal hernia repair. The infant was born at 26 weeks gestation. The patient's chart review reveals a history of mild stable ROP. Which of the following statement is most accurate with respect to your anesthetic plan for this patient?

A. It is important to keep this patient's saturations between 90% and 94%.
B. No ROP precautions are necessary in this patient at this time.
C. Administration of dexamethasone is preventive against ROP.
D. The risk of ROP significantly decreases after 55 weeks post conceptual age.

10. A 2 kg preterm male is diagnosed with glaucoma. The ophthalmologist would like to start him on a topical ophthalmic regimen. Administration of which one of the following topical glaucoma agents is associated with apnea in neonates?

A. Latanoprost
B. Timolol
C. Pilocarpine
D. Acetazolamide

11. Which of the following ophthalmic topical medications is known to inhibit plasma cholinesterase for up to 6 weeks after discontinuation?

A. Echothiophate
B. Latanoprost
C. Trophicamide
D. Dorzolamide

12. Stimulation of which receptor results in mydriasis (pupillary dilatation)?

A. Alpha-1 sympathetic receptors
B. Beta-agonist receptors
C. Beta-antagonist receptors
D. Cholinergic receptors

13. A 3-year-old boy emergently comes to the operating room with a penetrating eye injury with concern for elevated IOP. Which of the following condition would further increase the IOP?

A. Respiratory alkalosis
B. Metabolic acidosis
C. Respiratory acidosis
D. Hyperoxia

14. A 15-month-old boy with Down syndrome is undergoing cataract surgery under general anesthesia with a LMA and spontaneous ventilation. Intraoperatively, an "eye" block is performed by the surgeon, after which the patient suddenly becomes profoundly hypotensive and apneic. Which type of "eye" block is most likely to have resulted in this complication?

A. Retrobulbar block
B. Peribulbar block
C. Sub-Tenon's block
D. Infraorbital block

15. A full-term baby girl is diagnosed with nasolacrimal duct obstruction at birth. Which of the following statements is most accurate with regard to her clinical course and management?

A. Spontaneous resolution is likely by 1 year of age; tear duct probing will most likely not be necessary for treatment.
B. Congenital nasolacrimal duct obstructions are not associated with other syndromes and craniofacial defects.
C. Analgesic requirements after nasolacrimal probing and irrigation are substantial.
D. Irrigating the lacrimal system with saline or fluorescin after the procedure to demonstrate patency does not increase the risk of laryngospasm.

16. A 3-year-old child presents to the operating room for repair of a ruptured globe. He weighs 16 kg and is clinging to his mother and seems extremely irritable. An IV placed in the emergency room is no longer functional. Which of the following approaches to anesthetic induction would be the most appropriate in this patient?

A. Attempt premedication with PO midazolam followed by inhalation induction with sevoflurane.
B. Insist on placing an IV, and then proceed with a modified rapid sequence induction with propofol and rocuronium.
C. Induction of general anesthesia with intramuscular ketamine, followed by IV placement.
D. Insist on placing an IV, since a rapid sequence induction with succinylcholine is highly recommended in order to prevent aspiration of gastric contents.

17. A 5-year-old suddenly goes into severe laryngospasm during inhalation induction with sevoflurane. He starts to desaturate rapidly and he is administered 4 mg/kg of IM succinylcholine. After intubation, the surgeon proceeds with the planned strabismus repair. He plans to perform a forced duction test (FDT) at the start of the surgery. Which of the following statement is most accurate with regard to the effect of anesthetics on the accuracy of this test?

A. Volatile agents like sevoflurane may interfere with the accuracy of a FDT.
B. Rocuronium has no effect the accuracy of FDT.
C. Succinylcholine produces sustained contraction of extraocular muscles and a FDT should not be performed for at least 10 minutes.
D. Fentanyl may attenuate FDT.

CHAPTER 17 ANSWERS

1. ANSWER: D

PONV in the Pediatric Population: Among children, PONV is inversely related to age. The incidence of PONV is low in infants and toddlers and reaches its peak in adolescents, for whom the incidence exceeds that for adults.

Before puberty, there are *no gender-related differences* in PONV; after puberty, girls experience much more PONV than boys.

The type of surgery influences the incidence of PONV. The incidence of **PONV** in children is greatest after **tonsillectomy/adenoidectomy, strabismus repair, hernia repair, orchidopexy, microtia repair, and middle ear procedures**.

The choice of the anesthetic technique can influence the incidence of PONV in children. **Propofol**-based anesthetics are associated with a lower incidence of PONV compared to volatile agent–based anesthetics. Elimination of **nitrous oxide** has also shown to decrease the incidence of PONV.

Multimodal combination therapy for PONV is more effective than a single-treatment strategy. Combining 5-HT_3 receptor antagonists like ondansetron with dexamethasone and using a propofol-based anesthetic have shown to be collectively more effective in curbing PONV.

Adequate fluid resuscitation also plays in important role in PONV prevention. In a study by Goodarzi et al., postoperative vomiting (POV) was reported in 54% of the control group, who received 10 mL/kg per hour of lactated Ringer's solution, versus only 22% of the "superhydration group," who received 30 mL/kg per hour of lactated Ringer's solution.

KEY FACTS

- Before puberty, there are no gender-related differences in PONV. The incidence of PONV is low in infants and toddlers.
- The type of surgery greatly influences the severity and intensity of PONV.
- The choice of anesthetic influences the incidence and severity of PONV. Propofol-based techniques decrease PONV.
- Multimodal combination therapy for PONV prophylaxis is better than a single treatment strategy.
- Adequate fluid resuscitation plays an important role in prevention of PONV.

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Goodarzi M, Matar MM, Shafa M, Townsend JE, Gonzalez I. A prospective randomized blinded study of the effect of intravenous fluid therapy on postoperative nausea and vomiting in children undergoing strabismus surgery. *Paediatr Anaesth*. 2006;16:49–53.

2. ANSWER: B

PONV Prophylaxis: The most effective prophylaxis strategy in children at higher risk for PONV and/or those who have a history of severe PONV is to use combination therapy that includes fluid hydration, a 5-HT_3 receptor antagonist, and a second drug such as dexamethasone.

Ondansetron is a serotonin 5-HT3 receptor antagonist commonly used as a first-line drug for antiemetic prophylaxis and rescue therapy. Its half-life in children is slightly shorter than it is in adults (2.5 vs. 3.8 hours), and side effects are unusual in all populations.

Dexamethasone is an effective antiemetic that exerts its effect through central inhibition of the nucleus tractus solitarii and not via the area postrema. Dexamethasone has a slow onset of action, which is why it appears to be more effective if administered at the beginning of the case rather than toward the end. Administration of dexamethasone alone or in combination with other antiemetics can extend the period of effective treatment up to 24 hours. A 4 mg prophylactic dose is as effective as 8 mg based on a recent meta-analysis.

Scopolamine is an anticholinergic agent that is effective in the prevention of motion sickness and PONV. Unlike glycopyrrolate, scopolamine DOES cross the blood–brain barrier and can cause significant adverse effects. Its side effect profile includes tachycardia, dry mouth, skin erythema, agitation, confusion, drowsiness, and blurred vision. To minimize the relatively high incidence of side effects, a transdermal 1.5 mg dosage form was developed specifically for use in the prevention of motion sickness and PONV. In this patient, however, it will be wise to avoid scopolamine since she suffered from prolonged effects after her last anesthetic.

KEY FACTS

- Dexamethasone is a well-documented and effective antiemetic as a single agent and in combination with other antiemetics. It has a slow onset but has a long period of effectiveness (up to 24 hr).

- Ondansetron, a serotonin 5-HT3 receptor antagonist remains the first-line drug in antiemetic prophylaxis and rescue management.
- Scopolamine is an anticholinergic agent that is effective in the prophylaxis of PONV. Since it crosses the blood–brain barrier, it does have a significant side effect profile, most prominently drowsiness, blurry vision, dry mouth, and tachycardia.
- Multimodal combination antiemetic therapy is more effective than single therapy.

REFERENCES

Apfel CC, Korttila K, Abdalla M, et al. An international multicenter protocol to assess the single and combined benefits of antiemetic interventions in a controlled clinical trial of a 2×2×2×2×2×2 factorial design (IMPACT). *Control Clin Trials*. 2003;24:736–51.

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3. ANSWER: B

Marfan syndrome is an inherited disorder that affects connective tissue. It is caused by a defect in the fibrillin 1 gene (FBN1), which affects elastic and nonelastic connective tissues. Marfan syndrome can also seriously affect the eyes and vision. These children have an increased risk of retinal detachment, lens dislocation, glaucoma, and cataract formation.

Hurler syndrome, also known as **Mucopolysaccharidosis Type 1,** is a genetic disorder that results from the abnormal buildup of glycosaminoglycans. Glycosaminoglycans are long chains of sugar carbohydrates in each of our cells that help build bone, cartilage, tendons, corneas, skin, and connective tissue. These children have various degrees of cognitive dysfunction, macroglossia, airway obstruction, and **cervical spine instability**. Deposition of mucopolysaccharide material results in systemic dysfunction—cardiac and respiratory dysfunction, corneal opacities, and glaucoma. Cataracts have *not* been described with this disorder.

Down syndrome (Trisomy 21) is the most common chromosomal abnormality in humans. It also remains the most common genetic cause of learning disabilities in children. Congenital cardiac lesions such as ventricular septal defects, patent ductus arteriosus, and Tetralogy of Fallot are common in these patients. Other abnormalities frequently seen in these patients include macroglossia, subglottic stenosis, atlantoaxial instability, and hypothyroidism. Children with Down syndrome frequently present with ophthalmic disease such as neonatal cataracts, significant refractive errors (e.g., hypermetropia, astigmatism), strabismus, glaucoma, keratoconus, nasolacrimal duct obstruction, and nystagmus.

Alport syndrome (progressive hereditary nephritis) is one of the disorders in a group of familial oculorenal syndromes. Signs and symptoms include sensorineural hearing loss, progressive renal disease, multiple ophthalmologic disorders (including cataracts, retinal detachment, and keratoconus), and myopathy.

REFERENCE

Cote CJ, Lerman J, Anderson B, eds. *A Practice of Anesthesia for Infants and Children*. 5th ed. Philadelphia, PA: Saunders Elsevier; 2013:686–8.

4. ANSWER: B

Oculocardiac reflex is a trigeminovagal reflex that was first described by Aschner and Dagnini in 1908. The reflex is fairly common during pediatric ophthalmologic surgery (particularly strabismus surgery). Traction on extraocular muscles (particularly the medial rectus) and/or pressure on the eyeball triggers this reflex, which manifests as sinus bradycardia, and occasionally even ominous rhythms such as atrioventricular block, ventricular ectopy, and even asystole. The afferent impulses are carried via the long and short ciliary nerves (via the ciliary ganglion) to the ophthalmic division of the trigeminal nerve (cranial nerve V), and further to the sensory nucleus of the trigeminal nerve near the fourth ventricle. The efferent impulses initiate at the vasomotor center in the brainstem and travel via the vagus nerve (cranial nerve X) to the heart (Fig. 17.1).

Pretreatment with intravenous atropine or glycopyrrolate has been shown to be effective in preventing bradycardia. Pretreatment may be especially indicated in patients with a history of conduction block, vasovagal responses, or β-blocker therapy.

The reflex may occur during regional and general anesthesia, and the depth of anesthesia has been thought to be irrelevant. **A retrobulbar block is not uniformly effective at preventing the reflex, and orbital injections can in fact trigger the response.** The response is exacerbated by hypercapnia and/or hypoxemia.

The type of anesthetic has shown to influence the incidence and severity of the OCR. A propofol-based maintenance technique was associated with the greatest decrease in heart rate, while ketamine had the least

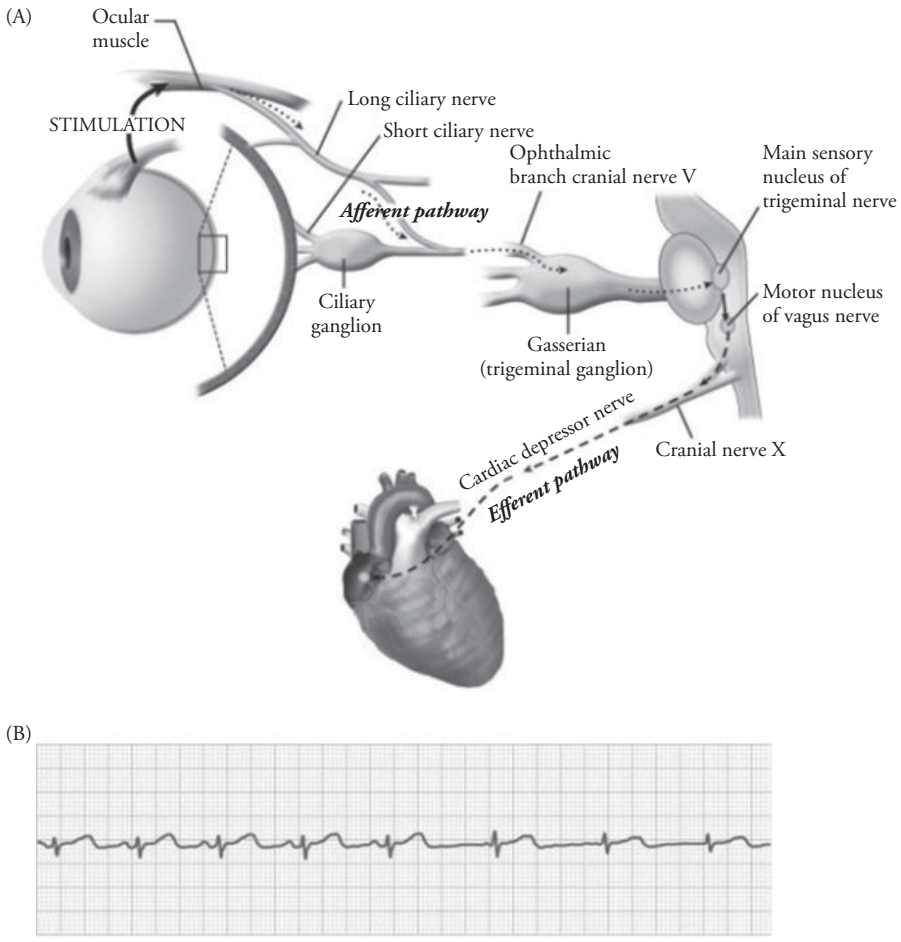

Figure 17.1 Neural pathways of the oculocardiac reflex. (Reprinted with permission from Cote CJ, Lerman J, Todres ID, eds. *A Practice of Anesthesia for Infants and Children*. 5th ed. Philadelphia, PA: Saunders Elsevier; 2013:32.)

decrease. Halothane and sevoflurane have been shown to have intermediate effects, although the effect is more pronounced during halothane anesthesia. Remifentanil also has shown to exacerbate the decrease in heart rate.

When the reflex occurs, **the anesthesiologist should first ask the surgeon to stop manipulations**. Most of the time, the heart rhythm returns to normal with cessation of manipulation alone. The response also tends to fatigue with repeated stimulation. If significant bradycardia persists or recurs, intravenous atropine is administered. Rarely, in the event of severe bradycardia or asystole, chest compressions may be required to allow the atropine to circulate. It is generally safe to proceed with surgery once normal sinus rhythm is restored.

KEY FACTS

- OCR is a trigeminovagal phenomenon. The afferent signals are carried by the ophthalmic division of the trigeminal nerve, while the efferent signal is carried by the vagus nerve to the heart.
- Pretreatment with atropine or glycopyrrolate has been shown to be effective in attenuating the reflex.
- The OCR can occur irrespective of the depth of anesthesia.
- A propofol-based maintenance technique is associated with the greatest decrease in heart rate, while ketamine with the least decrease. Sevoflurane has been shown to have an intermediate effect.
- When the reflex occurs, releasing of the stimulus is usually effective in ablating the dysrhythmias within 10 to 20 seconds.

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5. ANSWER: C

The choice of anesthetic has shown to influence the incidence and severity of the OCR. A **propofol**-based maintenance technique has been shown to be associated with the greatest decrease in heart rate, while **ketamine** is associated with the least decrease during strabismus surgery in children. **Halothane and sevoflurane** have been shown to have intermediate effects, although the effect is more pronounced during halothane anesthesia. **Remifentanil** also has shown to exacerbate the decrease in heart rate.

The **depth of anesthesia** does not appear to either decrease or increase the incidence of OCR.

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Hahnenkamp K, Honemann CW, Fischer LG, Durieux ME, Muehlendyck H, Braun U. Effect of different anaesthetic regimens on the oculocardiac reflex during paediatric strabismus surgery. *Paediatr Anaesth*. 2000;10:601.

6. ANSWER: C

Succinylcholine-induced increased IOP: The effect of succinylcholine on IOP is well documented. *Succinylcholine increases IOP by* 6–10 *mm Hg.* This effect begins within a minute after injection, peaks at 2–4 minutes, and subsides by 6–10 minutes. The mechanisms by which succinylcholine increases IOP have not been clearly defined. The following mechanisms have been postulated.

1. Cycloplegia (paralysis of the ciliary muscles of the eye) induced mydriasis obstructs the outflow of aqueous humor into the canal of schlemm, thus increasing IOP.
2. Tonic contraction of extraocular muscles exerts pressure on the globe, thus increasing IOP.
3. Transient dilatation of choroidal blood vessels increases choroidal blood volume, which increases IOP.

IOP: Normal IOP is around 12 to 15 mm Hg. An IOP greater than 20 mm Hg is considered abnormal. If the IOP remains elevated for long periods of time, blood flow to the retina gets impaired, possibly leading to loss of vision.

The globe is a relatively noncompliant compartment. IOP maintains the shape and optical properties of the eye. The volume of internal structures is fixed except for **aqueous fluid and choroidal blood volume**. The quantity of these two factors regulates IOP. Other factors that indirectly affect these two factors include **vitreous volume, extra ocular muscle tone, central venous pressure, arterial blood pressure, PaO_2, and $PaCO_2$**. IOP increases in situations when arterial blood pressure and/or the central venous pressure are high. Hypoxemia and hypercarbia cause vasodilation and increase IOP.

KEY FACTS

- Normal IOP is 12–15 mm Hg. Elevated IOP can have extremely deleterious effects on vision.
- Succinylcholine increases IOP by 6–10 mm Hg. The effect is immediate within a minute of injection and peaks in 4–6 minutes. The effect is gone by 10 minutes.
- The quantity of aqueous humor and choroidal blood volume are the two primary factors that regulate IOP.
- Several other factors also govern IOP. These include vitreous volume, extra ocular muscle tone, central venous pressure, arterial blood pressure, PaO_2, and $PaCO_2$.

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Kelly RE, Dinner M, Turner LS, Haik B, Abramson DH, Daines P. Succinylcholine increases intraocular pressure in the human eye with the extra ocular muscles detached. Anesthesiology. 1993;79:948–52.

7. ANSWER: B

Ocular trauma in childhood is common and may cause transient or permanent visual impairment. A ruptured globe from blunt or penetrating injury risks the potential loss of vitreous humor, which may cause permanent blindness if severe. Any increases in IOP during induction of anesthesia have a potential to exacerbate the loss of the vitreous and extrude globe contents. A ruptured globe is a surgical emergency.

The goal of management of a patient with an **open globe injury** and full stomach is to prevent increases in IOP and to prevent aspiration.

The importance of maintaining a quiet environment in the preoperative period cannot be overemphasized. Judicious premedication is warranted to reduce crying, coughing, and anxiety-induced vomiting.

Anesthetic induction is accomplished using a rapid sequence technique using high doses of **nondepolarizing muscle relaxant**, thus avoiding succinylcholine. An

acceptable recipe is propofol 3–5 mg/kg and rocuronium 1.2 mg/kg. Intravenous fentanyl 1–3 μg/kg and IV lidocaine 1 mg/kg will help prevent acute increases in IOP from pain secondary to laryngoscopy and tracheal intubation. The decision on whether to use succinylcholine in open globe surgeries remains controversial and should be based on the potential for a difficult airway and the viability of the eye. In a study by Libonati et al., no loss of globe contents occurred in a series of 63 patients who received succinycholine for induction of anesthesia. If the risk of aspiration is considered high, succinylcholine may be used. It is better to avoid aspiration by using succinylcholine than to have aspiration occur and have subsequent increases in IOP from hypoxia and hypercarbia. Several investigators have found that **pretreatment with a nondepolarizing agent** (one-tenth the usual intubating dose) attenuates the increase in IOP from succinylcholine.

During emergence, it will be important to avoid increases in IOP that may be caused by acute hypertension or coughing on the endotracheal tube. Strategies to avoid this include administration of IV lidocaine 1.5 mg/kg or deep extubation. In addition, antiemetic prophylaxis is indicated (ondansetron 0.05 mg/kg plus dexamethasone 0.5 mg/kg) to avoid emesis-induced increases in IOP postoperatively.

KEY FACTS

- The overall goal of anesthetic management in a patient with an open globe injury is to minimize increases in IOP and prevent aspiration.
- Judicious premedication is warranted to reduce crying, coughing, and anxiety-induced vomiting.
- A rapid sequence induction technique utilizing a high-dose nondepolarizing agent and propofol is preferable in order to minimize increases in IOP. Succinylcholine may be used if risk of aspiration is deemed high or difficult intubation is suspected.
- Studies have not shown loss of globe contents with succinylcholine, although this remains a valid theoretical concern.

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8. ANSWER: A

Retinopathy of prematurity (ROP) is an important cause of blindness and other visual disabilities in preterm infants. ROP is a postnatal disorder of the retinal vessels that develops only in the incompletely vascularized retinas of premature infants. Extreme prematurity and low birth weight are the strongest predictors of ROP. Retinal vessel growth begins from the optic disc at 14 to 18 weeks gestation, proceeding outward as the retina differentiates. Retinopathy of prematurity (ROP) occurs in approximately over 60% of extremely low birth weight (ELBW) infants (birth weight less than 1000 g), with the incidence being inversely proportional to birth weight and gestational age.

The **pathogenesis of ROP** appears to be multifactorial in origin, and hyperoxia is just one of many contributory factors. Other etiological factors include **hypoxia, shock, asphyxia, hypothermia, acidosis, vitamin E deficiency, and exposure to bright light**.

The initial vaso-occlusive/vaso-obilitrative phase (**Phase 1**) of early ROP has been attributed to suppression of vascular endothelial growth factor (VEGF), and possibly erythropoietin, by hyperoxia. **Phase 2** of ROP is characterized by hypoxia- induced pathologic vascular proliferation due to rising levels of VEGF, erythropoietin, and IGF-1. Progressive severe ROP can result in severe irreversible visual impairment secondary to scarring and retinal detachment.

A recent Cochrane review concluded and confirmed (the now historical assumption) that **liberal unrestricted oxygen delivery to a preterm infant is more harmful to the retina than restrictive oxygen delivery**, although the data reviewed failed to specify the optimum blood oxygen concentrations that should be delivered.

A recent randomized trial by the SUPPORT Study group compared two lower-oxygen saturation target ranges (85% to 89%, compared to 91% to 95%), in extremely preterm infants with moderately severe retinopathy. This trial showed that rates of severe retinopathy did not differ significantly between the lower-oxygen-saturation group and the slightly higher-oxygen-saturation group (28.3% and 32.1%). However, there was one additional death for approximately every two cases of severe retinopathy that were prevented in the 85%–89% group.

As has been previously documented in the STOP-ROP study from 2000, the evidence implicating hyperoxia as contributing to the development of ROP must be recognized but placed in perspective. In this study, the use of supplemental oxygen at pulse oximetry saturations of 96% to 99% did not cause additional progression of prethreshold ROP but also did not significantly reduce the number of infants requiring peripheral ablative surgery. The conclusion reached by this group stated, "Although the relative risk–benefit of supplemental oxygen for each infant must be individually considered, clinicians need no longer be

concerned that supplemental oxygen, as used in this study, will exacerbate active prethreshold ROP."

In summary, anesthesiologists should take practical precautions to protect an infant's retinas from hyperoxia without unnecessarily endangering the infant. No comprehensive epidemiologic studies have yet examined anesthetic risk factors, but, given the many cofactors that are associated with this entity, it appears that anesthesia management, although very important, is a small piece of this puzzle. **During anesthesia, the goal should be to deliver the minimum inspired oxygen concentration that provides oxygen saturations between 90% and 94% and avoid significant fluctuations in oxygen saturations.**

KEY FACTS

- ROP is a postnatal disorder of the retinal vessels that develops only in the incompletely vascularized retinas of premature infants.
- Extreme prematurity and low birth weight are the strongest predictors of ROP. ROP occurs in 60% of ELBW infants.
- ROP is a multifactorial disease, and hyperoxia is just one of the several other etiological factors.
- Anesthesiologists should take practical precautions to protect an infant's retinas from hyperoxia without unnecessarily endangering the infant. Saturations should be maintained between 90% and 94% at the minimum.

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9. ANSWER: B

ROP is a postnatal disorder of the retinal vessels that develops only in the incompletely vascularized retinas of premature infants. Extreme prematurity and low birth weight are the strongest predictors of ROP. The immature retina responds to elevated oxygen tension (or another insult) by arrest of normal vasculogenesis and later by neovascularization and fibrous-tissue formation in the retina and vitreous humor. Retinal tears and detachment may occur secondary to contraction of the vitreous humor. Normal vasculogenesis takes place between 16 and 44 weeks. The risk of developing ROP in *infants older than 44 weeks* post conceptual age is negligible. Therefore, there is no need to limit oxygen saturation in the 90%–94% range in this patient.

Dexamethasone is an effective antiemetic that exerts its effect through central inhibition of the nucleus tractus solitarii and not via the area postrema. Dexamathasone has potent anti-inflammatory and immunosuppressant effects. Dexamethasone has *no role* in the treatment or prevention of ROP.

KEY FACTS

- Normal vasculogenesis takes place between 16 and 44 weeks.
- The risk of developing ROP in infants older than 44 weeks post conceptual age is negligible.
- Dexamethasone has no role in the treatment or prevention of ROP.

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10. ANSWER: B

Latanoprost is a prostaglandin F2 analogue that increases aqueous humor outflow and decreases IOP. Side effects are minimal and usually limited to ocular side effects.

Timolol is a nonselective beta-antagonist that reduces IOP by decreasing aqueous humor production through blockage of beta receptors on the ciliary epithelium. Side effects include bronchospasm, bradycardia, hypotension, and **apnea in neonates**.

Pilocarpine is a parasympathomimetic agent that is used for the treatment of open-angle glaucoma. It acts on muscarinic receptors on the iris sphincter muscle, causing the muscle to contract and engage in miosis. Pilocarpine also stimulates the ciliary muscle to contract, which opens the trabecular meshwork. A combination of miosis and loss of accommodation facilitates drainage of aqueous humor,

Table 17.1 PHARMACOLOGY: GLAUCOMA MEDICATIONS

MECHANISM	DRUG	SIDE EFFECTS
Cholinergic agonist	Pilocarpine	Gastrointestinal disturbance, diaphoresis, and brow pain
Cholinesterase inhibitor	Echothiophate	Bradycardia, hypotension, nausea, vomiting, diarrhea, weakness, inhibition of plasmacholinesterase
Sympathomimetic agents	Apraclonidine (α2) Brimonidine (β2)	Does not cross blood-brain barrier (BBB) Crosses BBB—apnea, bradycardia, hypotension, hypothermia, somnolence
α- and β-adrenergic antagonists	Betaxolol (β1-selective), Carteolol (β), Levobunolol (β), Metoprolol (β), Timolol (β)	Bradycardia, hypotension *Nonselective β-antagonists*—may cause bronchospasm, apnea in neonates
Prostaglandin F2 analogues	Latanoprost, Bimatoprost, Travoprost	Minimal, limited to ocular side effects usually
Competitive inhibitors of carbonic anhydrase	Acetazolamide—systemic Dorzolamide, Brinzolamide	Acidosis, hypokalemia, hyponatremia, nausea, vomiting and taste alterations Ocular stinging, burning, itching and bitter taste
Inert sugar	Mannitol	Transient hypervolemia, followed by hypovolemia and potential hypotension

hence decreasing IOP. Side effects include gastrointestinal disturbance, diaphoresis, and brow pain.

Acetazolamide is a carbonic anhydrase inhibitor that reduces formation of aqueous humor. Side effects include acidosis, hypokalemia, hyponatremia, and allergic reactions. See Table 17.1.

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11. ANSWER: A

Echothiophate is a long-acting anticholinesterase agent (cholinesterase inhibitor) used for the treatment of open-angle glaucoma. It enhances activity of endogenous acetylcholine, which leads to continuous stimulation of the iris sphincter producing miosis. It also stimulates the ciliary muscle to continuously contract, which opens the trabecular meshwork at the irido-corneal angle and facilitates outflow of aqueous humor. Miosis along with improved drainage of aqueous humor helps reduce IOP. The drug invariably gets absorbed systemically and irreversibly binds with plasma cholinesterase. Low levels of cholinesterase can result in **systemic parasympathomimetic side effects** such as bradycardia, bronchospasm, diarrhea, and flushing. Drugs like succinylcholine, mivacurium, and ester local anesthetics may have prolonged effects due to the deficiency of cholinesterase in the system. Cholinesterase activity may remain inhibited for up to 6 weeks after discontinuation of ophthalmic echothiophate. Toxicity from echothiophate may be antagonized by administration of pralidoxime (2-PAM), 25 mg/kg intravenously.

Latanoprost is a prostaglandin F2 analogue that increases aqueous humor outflow, whereby decreasing IOP. Side effects are minimal and usually limited to ocular side effects. Latanoprost does not affect plasma cholinesterase.

Tropicamide is a short-acting muscarinic antagonist used to dilate the pupil. It rarely produces atropine-like systemic effects and does not affect plasma cholinesterase.

Dorzolamide is a topical carbonic anhydrase inhibitor that reduces the production of aqueous humor. Dorzalolamide has no effect on plasma cholinesterase activity.

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Davis PJ, Cladis FP, Motoyama EK, eds. *Smith's Anesthesia for Infants and Children*. 8th ed. Saunders Elsevier; 2011:872–6.

12. ANSWER: A

Stimulation of alpha-1 sympathetic receptors on the iris leads to contraction of the radial muscle, which results in **mydriasis**. The most commonly used topical mydriatic agent in clinical practice is phenylephrine. Phenylephrine is an alpha-1 receptor agonist that rapidly produces vasoconstriction and mydriasis when topically applied to the eye. System side effects are uncommon, but if absorbed in

Table 17.2 AUTONOMIC OCULAR PHYSIOLOGY

RECEPTOR	EFFECT
α1-stimulation	Mydriasis
β-stimulation (largely of beta-2 subtype)	No effect on papillary diameter
Cholinergic stimulation	Miosis

sufficient quantities, it may lead to systemic alpha adrenergic effects, such as hypertension and reflex atropine-sensitive bradycardia.

Beta receptors in the eye are largely of beta-2 subtype. They are present in the ciliary muscle but absent in the iris. Beta stimulation has no effect on pupillary diameter. Blocking the beta receptors on the ciliary epithelium with drugs such as timolol results in a decrease in the production of aqueous humor and hence IOP. How beta blockade leads to decreased aqueous production and reduced IOP is uncertain.

Parasympathetic cholinergic receptors are present on the iris sphincter and the ciliary muscle. Stimulation of these cholinergic receptors results in miosis and contraction of the ciliary muscle. Contraction of the ciliary muscle opens the trabecular meshwork and facilitates drainage of the aqueous humor, hence decreasing IOP. See Table 17.2.

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13. ANSWER: C

With the relatively noncompliant globe, any pharmacologic or metabolic process that increases choroidal blood volume (CBV) will increase IOP. **Hypercarbia, coughing, and increase in central venous pressures all lead to choroidal congestion and resultant increase in IOP**. Although well tolerated in the healthy eye, this congestion may lead to extrusion of contents if the globe is ruptured. The anesthesiologist should carefully control the child's physiology during induction and maintenance of anesthesia in order to minimize changes in IOP.

The arterial circulation of the eye is autoregulated. **Only marked deviations in systemic arterial pressures affect IOP**. **Elevated venous pressures**, on the other hand, **can dramatically increase IOP**, primarily by augmenting the choroidal blood volume and tension of the orbit.

Table 17.3 EFFECT OF ACID-BASE IMBALANCE ON INTRAOCULAR PRESSURE (IOP)

INCREASED IOP	DECREASED IOP
Increased central venous pressure (Trendelenburg position, coughing, valsalva maneuver, straining, increased intrathoracic pressure)	
Respiratory acidosis	Respiratory alkalosis
Metabolic alkalosis	Metabolic acidosis
Hypoxia	Hyperoxia

A **linear relationship exists between IOP and increasing CO_2 partial pressures**. **Hypocarbia decreases IOP** through vasoconstriction of the choroidal blood vessels and decreases formation of aqueous humor through reduced carbonic anhydrase activity. The increased IOP associated with hypoventilation and hypercarbia can increase IOP by its vasodilatory effect of choroidal blood vessels. **Metabolic acidosis** will result in a compensatory respiratory alkalosis and decrease IOP. Metabolic alkalosis will theoretically have an opposite effect.

Hyperoxia is associated with profound choroidal vasoconstriction and a reduction in IOP, whereas hypoxia is capable of increasing IOP by dilating intraocular vessels. See Table 17.3.

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Davis PJ, Cladis FP, Motoyama EK, eds. *Smith's Anesthesia for Infants and Children*. 8th ed. Saunders Elsevier; 2011:877–8.

14. ANSWER: A

The **retrobulbar** or **intraconal block** was first described in 1884. The block involves injection of local anesthetic into the posterior cone of the extraocular muscles and is effective in producing anesthesia and akinesia by blocking the ciliary ganglion and the oculomotor and abducens nerves. The retrobulbar technique is infrequently used in the pediatric population. Complications of the retrobulbar block include oculocardiac reflex (OCR), retrobulbar hemorrhage, penetration of the optic nerve, intravascular injection, and **brainstem anesthesia**.

Table 17.4 LOCAL AND REGIONAL ANESTHESIA FOR OCULAR SURGERY

REGIONAL BLOCK	SIDE EFFECTS
Retrobulbar	OCR, retrobulbar hemorrhage, penetration of the optic nerve, intravascular injection, and brainstem anesthesia
Peribulbar	Large local anesthetic volume requirements can increase forward pressure on the globe. Higher failure rate (up to 10%)
Sub-Tenon's	Chemosis and subconjunctival hemorrhage

The **peribulbar** or **periconal block** has been used increasingly since it was first described in 1986. Because the cone of the extraocular muscles is not entered, the potential for intraocular and intradural injection is minimized, and the risk of retrobulbar hemorrhage and direct nerve injury is virtually eliminated. Disadvantages of the peribulbar block include a slightly higher failure rate (10% incidence) and an increased forward pressure on the globe secondary to the larger volumes of local anesthetic required.

The **sub-Tenon's block** was first reported in adults in 1992 as a blunt-needle alternative to the sharp needle peribulbar or retrobulbar blocks. Tenon's capsule is a fascial sheath that envelops the eyeball and separates it from the orbital fat. The inner surface is separated from the outer surface of the sclera by a potential space called the episcleral or sub-Tenon's space. The advantages include relatively painless insertion of the block and the ability to use a blunt needle with less opportunity to inject into the unwanted areas of the eye. This block is associated with a higher incidence of chemosis and subconjunctival hemorrhage.

The **infraorbital block** provides regional anesthesia to the lower eyelid, upper lip, and part of the nasal vestibule. It can be used for analgesia for cleft lip repair and facial lacerations. See Table 17.4.

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Davis PJ, Cladis FP, Motoyama EK, eds. *Smith's Anesthesia for Infants and Children*. 8th ed. Saunders Elsevier; 2011:897.

15. ANSWER: A

Congenital nasolacrimal duct obstruction is present in 60% to 70% of all infants at birth; spontaneous resolution is observed in 96% of these infants by 1 year of age.

Congenital obstructions are most often isolated findings, but they may be **associated with a variety of syndromes and craniofacial defects** (e.g., Goldenhar syndrome).

The initial **surgical management** of congenital obstruction usually requires only simple probing to establish patency. A small Bowman probe is inserted through one or both of the puncti, through the lacrimal sac, and subsequently into the nasolacrimal duct to pierce the valve of Hasner beneath the inferior turbinate. The procedure is often atraumatic, requires no more than 5 to 10 minutes, and has been performed successfully in the office setting in children younger than 6 months of age. In the operating room, the procedure is usually performed under general anesthesia. **Analgesic requirements** after nasolacrimal probing and irrigation are minimal; thus, large doses of opioids should be avoided.

Irrigation of the lacrimal system may result in excessive pooling and possible laryngospasm, and aspiration. Techniques to prevent such possible risks include head-down positioning, careful suctioning through the ipsilateral naris or oropharynx, and considering a laryngeal mask airway or intubation for optimal protection of the airway.

KEY FACTS

- Congenital nasolacrimal duct obstruction is present in 60% to 70% of all infants at birth; spontaneous resolution is observed in over 96% of these infants by 1 year of age. No treatment is necessary in the majority of cases.
- Congenital nasolacrimal duct obstructions are most often isolated findings but may be associated with a variety of syndromes and craniofacial defects.
- Tear duct probing is often atraumatic; it usually requires no more than 5 to 10 minutes. Analgesic requirements after nasolacrimal probing and irrigation are negligible.
- Irrigation of the lacrimal system may result in excessive pooling, possible laryngospasm, and aspiration. Consider laryngeal mask airway placement or intubation for optimal airway protection.

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Davis PJ, Cladis FP, Motoyama EK, eds. *Smith's Anesthesia for Infants and Children*. 8th ed. Saunders Elsevier; 2011:885–6.

16. ANSWER: A

Ocular trauma in childhood is common and may cause transient or permanent visual impairment. A ruptured globe from blunt or penetrating injury risks the potential loss of vitreous humor, which may cause permanent

blindness. Any **increases in IOP** during induction of anesthesia have a potential to exacerbate the loss of the vitreous and extrude globe contents.

The goal of management of a patient with an open globe injury and full stomach is **to prevent increases in IOP and to prevent aspiration**.

The importance of maintaining a quiet environment in the preoperative period cannot be overemphasized. Judicious premedication is warranted to **reduce crying, coughing, and anxiety-induced vomiting.**

A modified rapid sequence induction technique with **propofol and rocuronium** would have been the method of choice if this patient had a working IV. The decision on whether to use succinylcholine in open globe surgeries remains controversial. **Succinylcholine increases IOP by 6–10 mm Hg**. The effect is immediate within a minute of injection and peaks in 4–6 minutes. The effect is gone by 10 minutes. In a study by Libonati et al., no loss of globe contents occurred in a series of 63 patients who received succinylcholine. If the risk of aspiration is considered high, succinylcholine may be used. It is better to avoid aspiration by using succinylcholine than to have aspiration occur and have subsequent increases in IOP from hypoxia and hypercarbia. Several investigators have found that **pretreatment with a nondepolarizing agent** (one tenth the usual intubating dose) attenuates the increase in IOP from succinylcholine.

In this patient, **inhalation induction with sevoflurane** is a reasonable approach. Attempting peripheral IV placement in an irritable child will only result in more crying and straining and consequent acute increase in IOP to 30–40 mm Hg. This can be dangerous and result in vitreous contents being extruded. Obviously inhalation induction is not completely safe and aspiration remains a risk.

Ketamine is a phencyclidine derivative and NMDA receptor antagonist that results in a dissociative state of anesthesia. It is very lipid soluble and shows excellent bioavailability after intravenous and intramuscular injection. In patients with ruptured globe, ketamine is not a preferred agent since it has a potential to increase the IOP by as much as 30%.

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17. ANSWER: B

Strabismus repair is the most commonly performed eye surgery in children.

The Forced Duction Test (FDT) is routinely performed at the beginning of strabismus surgery to determine if there is evidence of mechanical restriction to ocular mobility. It helps the surgeon to differentiate a paretic muscle from a mechanical restriction that may be limiting motility. The eyes should be immobile during FDT. If succinylcholine was used as in this patient, **at least 20 minutes** should have passed before performing duction testing. **Succinylcholine produces sustained contraction of extraocular muscles** that interferes with an accurate interpretation of the forced duction test. The extraocular muscles are the group of six muscles that control movement of the eyeball.

Nondepolarizing muscle relaxants like rocuronium and vecuronium do not interfere with the interpretation and accuracy of forced duction testing. Similarly volatile inhalation agents and opioids have no effect on FDT.

KEY FACTS

- FDT is performed at the start of strabismus surgery to determine whether the restriction to ocular mobility is due to muscle paresis or mechanical restriction.
- The surgeon should be notified if succinylcholine was used during induction. It is advisable to wait for **at least 20 minutes** before a FDT is performed. Succinylcholine produces sustained contraction of the extraocular muscles and may interfere with the accuracy of the test results.
- Volatile agents, nondepolarizing muscle relaxants, and opioids have no effect on FDT.

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18.

ORTHOPEDIC SURGERY

Solmaz P. Manuel, Christine L. Mai, and Robert Brustowicz

1. A 4-year-old boy with a family history suspicious for Duchenne muscular dystrophy is scheduled for emergent femur fracture repair. He arrives to the operating room with a respiratory rate of 22 breaths/min and is crying in pain. His mother reports a normal neonatal course, no known medical issues since birth, and no known drug allergies. His last full meal was 3 hours ago. The *most* appropriate anesthetic management would be:

A. Induction with IM ketamine, glycopyrrolate, and succinylcholine with cricoid pressure followed by immediate intubation
B. Inhalation induction with sevoflurane and cricoid pressure
C. Awake IV catheter placement, followed by rapid sequence intravenous induction with propofol and remifentanil
D. Awake fiberoptic intubation

2. A 5-year-old boy with osteogenesis imperfecta presents for an open reduction and internal fixation (ORIF) of his radius. Which of the following is a commonly seen clinical feature of osteogenesis imperfecta?

A. Pectus excavatum
B. Conductive hearing loss
C. Flat feet
D. Cleft palate

3. A 6-year-old girl with neurofibromatosis type 1 (NF1) is scheduled for closed reduction and percutaneous pinning of an elbow fracture. She appears anxious and is treated with oral midazolam. She has a history of a viral illness with a cough 4 weeks before surgery that has resolved. During induction with sevoflurane, nitrous oxide, and oxygen she develops hypertension with systolic blood pressure of 220 mm Hg. The *most* likely explanation for this finding is:

A. Laryngospasm
B. Paradoxical reaction to midazolam
C. Pheochromocytoma
D. Inappropriately large blood pressure cuff

4. A 14-year-old boy with Klippel-Feil syndrome presents for posterior spinal fusion due to scoliosis. Preoperative assessment of Klippel-Feil patients should include screening for:

A. AV malformations
B. Hepatic anomalies
C. Congenital heart abnormalities
D. Reactive airway disease

5. A tall, thin 10-year-old boy presents for an anterior-posterior spinal fusion from T4-L2 levels. You detect a murmur on physical exam. Preoperative testing for this patient should include which of the following?

A. Chemistry panel
B. Coagulation studies
C. Echocardiogram
D. Exercise stress test

6. An 8-year-old child with spastic cerebral palsy is scheduled to undergo muscle contracture release under general anesthesia. An appropriate anesthetic plan would include:

A. Premedication with oral midazolam
B. Use of half normal dose of neuromuscular blocking drug
C. Avoidance of succinylcholine
D. Increased dose propofol

The next three questions refer to treatment or management of a single patient.

7. You see a 14-year-old boy in preoperative clinic who was recently diagnosed with osteosarcoma following the workup of a nonhealing basketball injury. The primary tumor is believed to originate in the right femur with metastatic disease discovered in the ipsilateral pelvis. He complains of significant pain and inability to bear weight on his right lower extremity. A chemotherapy regimen of doxorubicin, cisplatin, and methotrexate has been initiated, and he is scheduled for right radical en bloc resection of the tumor. Which of the following interventions would be *most* effective for pain control management in this patient?

A. Discontinuing the use of any opioids during the preoperative period
B. The addition of methadone preoperatively
C. High-dose ketamine intraoperatively
D. A postoperative regimen that should be strictly controlled and titrated by the anesthesia team

8. In regard to the patient in question 7, which of the following possible adverse effects are correctly paired with the culprit chemotherapeutic agent?

A. Cisplatin—nephrotoxicity, Doxorubicin—cardiomyopathy, Methotrexate—myelosuppression
B. Cisplatin—hemorrhagic cystitis, Doxorubicin—cardiomyopathy, Methotrexate—myelosuppression
C. Cisplatin—nephrotoxicity, Doxorubicin—pulmonary fibrosis, Methotrexate—myelosuppression
D. Cisplatin—hemorrhagic cystitis, Doxorubicin—pulmonary fibrosis, Methotrexate—diarrhea

9. In regard to the patient in question 7, which of the following strategies will most effectively minimize intraoperative blood loss?

A. Tumor embolization 2 weeks prior to surgery
B. Preoperative autologous blood donation 2 weeks prior to surgery
C. Cell salvage available intraoperatively
D. Tranexamic acid infusion intraoperatively

10. A 5-year-old boy with dystrophic epidermolysis bullosa (EB) presents for contracture release of hands bilaterally. Anesthetic considerations in patients with EB should include:

A. Consider preoperative treatment with corticosteroids.
B. Securely tape peripheral intravenous catheter (PIV) in place.
C. Esophageal stethoscope may replace electrocardiogram (ECG) monitoring.
D. Insert nasogastric (NG) tube to reduce risk of aspiration.

11. A 5-year-old child with a history of a myelomeningocele defect corrected at birth, hydrocephalus with a ventriculoperitoneal shunt, and neurogenic bladder requiring regular home catheterization is scheduled to undergo orthopedic correction of clubfeet. Anesthetic considerations should include:

A. Maintenance of a strict latex-free operating room
B. Use of ketorolac for multimodal pain management
C. Avoidance of succinylcholine
D. Fast-track postanesthesia care unit (PACU) stay

12. Spinal surgery is associated with a small incidence of neurological impairment. Which of the following groups has the greatest potential for neurologic complications?

A. Thoracic scoliosis
B. Mesenchymal scoliosis
C. Congenital scoliosis
D. Infantile scoliosis

13. During a long spinal fusion the somatosensory evoked potentials (SSEPs) and motor evoked potentials were questionable, and the orthopedic surgeon is anxious to further assess her patient's neurologic function. You suggest that she consider the ankle-clonus test. Which of the following is true about the ankle-clonus test?

A. This is a type of real-time monitoring.
B. It can be performed at any point during the anesthetic.
C. It has a reported sensitivity of 100%.
D. The usefulness of the test is limited to children of an appropriate developmental age.

14. You are taking care of a 17-year-old patient with idiopathic scoliosis and a 70-degree thoracic curve presenting for a posterior spinal fusion. The surgeon is concerned about how the surgery will affect the patient's pulmonary functions, specifically the FVC and FEV1. You advise him that these values will:

A. Decrease with a nadir on POD 1 and will be about 80% of preoperative values 7 to 10 days after surgery
B. Decrease with a nadir on POD 3 and will be about 60% of preoperative values 7 to 10 days after surgery
C. Decrease but only with an anterior approach and will be about 80% of preoperative values 7 to 10 days after surgery

D. Decrease with a nadir on POD 1 and will be around 60% of preoperative values 7 to 10 days after surgery

15. Following a bilateral clubfoot repair done with tourniquets, both tourniquets are released at the same time. Which of the physiologic changes are you most likely to see?

A. A decrease in heart rate
B. An increase in blood pressure
C. Ventilatory minute volume that remains unchanged in spontaneously breathing patients
D. A decrease in the core body temperature

16. You are supervising a CRNA anesthetize a 12-year-old male for a radial fracture. The tourniquet has been up for 2 hours, and the surgeon says she needs 30 more minutes to complete the surgery. The CRNA calls you into the room because the surgeon wants to keep the tourniquet up during this time and the CRNA wants it deflated for 10 minutes before reinflating to complete the procedure. What do you tell the surgeon?

A. Keep on closing since the tourniquet pain will go away when the tourniquet goes down.
B. Deflate the tourniquet for 10 minutes as recommended because of concern about vascular damage to the limb.
C. Deflate the tourniquet for 10 minutes as recommended because of concern about nerve damage from direct compression.
D. Keep on closing since short periods of ischemia followed by reperfusion make the muscle tissue more susceptible to injury.

17. A Jehovah's Witness patient is being successfully managed using a normovolemic hemodilution techniquefor a femur fracture repair. Which of the following physiologic conditions contributes to the continued adequate oxygen delivery during this procedure?

A. Improved blood rheology
B. Increased heart rate resulting in an increased cardiac output
C. Shift to the left of the oxygen-hemoglobin dissociation curve
D. Normothermia

18. A 10-year-old girl with Down syndrome is scheduled to receive general anesthesia for cervical spine fusion. Which of the following is *most* likely to complicate the airway management of this patient?

A. High-arched palate
B. Protruding upper incisors
C. Atlanto-axial instability
D. Increased muscle rigidity

19. A 5-month-old girl with Down syndrome is scheduled for a spica cast placement under anesthesia. Echocardiographic examinations in infants with Down syndrome *most commonly* show:

A. Atrioventricular septal defect
B. Patent ductus arteriosus
C. Aortic stenosis
D. Ventricular septal defect

CHAPTER 18 ANSWERS

1. ANSWER: C

Duchenne muscular dystrophy (DMD) is an X-linked recessive myopathy associated with mutation of the dystrophin gene, resulting in nonfunctional dystrophin protein. This disorder is the **most common of the progressive muscular dystrophies** with an incidence of 3:10,000 births. Muscle fiber degeneration is the primary pathologic process in this disease. Children with DMD are often undiagnosed until initial symptoms of **symmetric proximal skeletal muscle weakness** show up at the age of 3 to 5 years. Patients often present with hip girdle weakness, waddling gait, distal calf muscle hypertrophy, and lumbar lordosis.

As the disease progresses, **scoliosis** may develop and skeletal muscle atrophy predisposes to **long bone fractures**. Scoliosis, in combination with progressive pulmonary weakness, can lead to impaired respiratory function. **Difficulty swallowing** due to pharyngeal involvement can make patients susceptible to frequent **pneumonia**. In advance stages, **cardiomyopathy** and **arrhythmias** may occur. Perioperative cardiac evaluation is highly recommended.

Patients with DMD and other muscular dystrophies often require surgery for diagnostic muscle biopsy, scoliosis correction, and release of contractures. Choice of anesthetic agents is important for DMD patients. **Succinylcholine** is contraindicated because of increased risk of rhabdomyolysis, hyperkalemia, arrhythmias, and cardiac arrest. There is no clear link between DMD and malignant hyperthermia; however, it is highly recommended to **avoid potent inhalational agents** in young children with DMD because it can trigger rhabdomyolysis and hyperkalemia.

Propofol has been used successfully, but **higher than expected doses** may be required for induction. Narcotics are also relatively safe to use; however, consider avoiding long-acting opioids to optimize postoperative ventilation.

Nondepolarizing muscle blockade agents can be used, but they often have a slow onset and prolonged duration of action in muscular dystrophy patients. Postoperative pulmonary complications have been associated with the use of long-acting neuromuscular blockers, requiring postoperative mechanical ventilation. Monitoring with a peripheral nerve stimulator is recommended with the use of nondepolarizing agents.

Awake fiberoptic intubation would unnecessarily cause distress and increase risk for aspiration in this child.

KEY FACTS

- Children with DMD are often undiagnosed until initial symptoms of symmetric proximal skeletal muscle weakness show up at the age of 3 to 5 years.
- In advance stages of the disease, scoliosis can lead to respiratory impairments, muscle atrophy can lead to fractures and difficulty swallowing, and cardiomyopathy and arrhythmias may occur.
- Succinylcholine is contraindicated and inhalational agents should be avoided.

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2. ANSWER: B

Osteogenesis imperfecta (OI) is genotypical and phenotypical heterogenous group of rare inherited connective tissue disorders involving defective type I collagen production. The disorder manifests in weakness and defective growth of tissues dependent on **type I collagen** for structure, mainly bone, dentin, sclerae, and ligaments. Classification (types I–IV) is based on the nature of the fractures and clinical, genetic, and radiologic findings. Type I is the most common (1:30,000 live births), and along with Type IV are autosomal dominant inheritance patterns. Type II and III forms have autosomal recessive inheritance patterns. These patients have the classic triad of **blue sclerae**, **multiple fractures,** and **conductive hearing loss**. Severely affected OI patients suffer multiple fractures with minimal trauma, and infants with Type IV osteogenesis imperfect tend to die in the perinatal period. Very mild forms of Type IV osteogenesis imperfecta may be manifested by only premature osteoporosis. Type I osteogenesis imperfecta may have **aortic root dilation, aortic insufficiency, and mitral valve prolapse**. Rarely, **cor pulmonale** from severe kyphoscoliosis can occur.

Bone fragility is the hallmark clinical feature of OI. There are risks of fracture from **malpositioning, tourniquet application, and airway handling**. Spinal deformity, most often kyphoscoliosis, develops with age due to decreased ligamentous stability, compression fractures, osteoporosis, and spondylolisthesis. The teeth are malformed and fracture easily. OI is not associated with increased incidence of cleft palate.

KEY FACTS

- OI is a rare inherited connective tissue disorder involving defective type I collagen production. The disorder manifests in weakness and defective growth of bone, dentin, sclerae, and ligaments.

- These patients have the classic triad of blue sclerae, multiple fractures, and conductive hearing loss.
- These patients may have aortic root dilation, aortic insufficiency, mitral valve prolapse, and core pulmonale.

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3. ANSWER: C

Neurofibromatoses are genetic disorders of the nervous system primarily affecting the development and growth of neural tissues, resulting in subsequent growth of neural tumors. The neurofibromatoses are divided into type I (peripheral or von Recklinghausen) and type II (central or bilateral acoustic neurofibromatosis). **NF1 is much more common** and accounts for 90% of all neurofibromatoses.

The clinical features of NF1 are diverse and the severity of clinical manifestations varies greatly between patients and over time. There are many important anesthetic issues to consider. All NF1 patients should be screened for **hypertension** before surgery. Common causes include renal artery stenosis, catecholamine-secreting nodular plexiform neurofibroma, or **pheochromocytoma** (found in up to 1% of NF1 patients). All patients with NF1 should be questioned for the presence of intermittent headaches, anxiety attacks, palpitations, and night sweats, which are common for pheochromocytoma. If pheochromocytomas go unrecognized, **severe hypertension** can occur during anesthesia.

Intracranial tumors occur in 5% to 10% of NF1 patients and signs and symptoms of intracranial hypertension may develop. Therefore, all patients must be evaluated for **undiagnosed central nervous system (CNS) tumors** and **increased intracranial pressure**. Patients should also be assessed for the presence of epilepsy.

A thorough airway exam is highly recommended. Intraoral, laryngeal, and pharyngeal neurofibromas may lead to **airway distortion, obstruction, or dyspnea**. Involvement of the recurrent laryngeal nerve can result in unilateral vocal cord paralysis. Cranial nerve involvement from the large intracranial tumors found in neurofibromatosis can lead to impairment and **loss of effective gag reflex and swallowing mechanisms**. Patients with neurofibromas involving the cervical spine should be evaluated for **cervical instability**.

Pulmonary function should be evaluated for the presence of restrictive lung disease, which can be caused by **kyphoscoliosis**, intrapulmonary neurofibromas, and progressive pulmonary fibrosis associated with NF1. An echocardiogram and cardiac evaluation are recommended to assess for **cardiac neurofibromas**. Aside from pheochromocytoma, NF1 is associated with other tumors such as neuroblastomas, leukemia, sarcomas, and Wilms tumor. Neurofibromas can be highly vascular and patients can have **extensive bleeding** from removal of these tumors.

KEY FACTS

- Neurofibromatoses are divided into type I (peripheral or von Recklinghausen) and type II (central or bilateral acoustic neurofibromatosis). NF1 is much more common and accounts for 90% of all neurofibromatoses.
- All NF1 patients should be screened for hypertension before surgery, because it is often caused by renal artery stenosis, catecholamine-secreting nodular plexiform neurofibroma, or pheochromocytoma (found in up to 1% of NF1 patients).
- All patients should be evaluated for possible increased intracranial pressure and cranial nerve involvement from CNS tumors; airway issues from intraoral, laryngeal, and pharyngeal neurofibromas; and cervical instability, cardiac neurofibromas, and restrictive lung disease from kyphoscoliosis.

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4. ANSWER: C

Klippel-Feil syndrome is a rare disease characterized by the congenital fusion of two or more cervical vertebrae. Those with the syndrome have a short neck with limited mobility of the cervical spine. It is very common for these patients to have an **anatomically difficult airway,** and they have increased susceptibility to cervical spine injury and subsequent neurologic deficit. Klippel-Feil syndrome has a very heterogenous presentation with numerous associated abnormalities. It is unclear whether Klippel-Feil syndrome is a single unique disease with common genetic etiology, or if it is a phenotypic presentation of a heterogeneous group of congenital spinal deformities. Associated abnormalities may also include **congenital scoliosis** (55%), **renal anomalies** (33%), **spina bifida**, cleft palate, **cardiac malformations** (most often ventricular septal defect), short stature, **restrictive respiratory disease**, congenital

elevation of scapula, hearing impairment, and posterior fossa dermoid cysts.

Preoperative assessment in Klippel-Feil patients should include a thorough evaluation of degree of cervical instability present, any preexisting neurologic impairment, and airway evaluation. These patients can have a **difficult airway** with **micrognathia**. Cervical fusion and anatomic abnormalities become worse with time; therefore, a **previous uneventful anesthetic history does not guarantee an uncomplicated airway**. Lateral and anteroposterior flexion-extension cervical spine radiographs are recommended. Cervical magnetic resonance imaging (MRI) is indicated to assess the degree of neurologic involvement, such as cord compression and myelopathy.

Preoperatively the anesthesiology team should also consider presence of **congenital heart defects** and cardiac conduction abnormalities. Preoperative ECG and echocardiography are indicated. **Pulmonary function** should be assessed, which could be severely compromised in patients with chest deformities and advanced scoliosis. Consider chest radiography and pulmonary function tests. Patients with Klippel-Feil syndrome should also be screened for **kidney anomalies** and renal failure.

KEY FACTS

- Klippel-Feil syndrome is characterized by the congenital fusion of two or more cervical vertebrae, causing limited mobility of the cervical spine.
- Preoperative assessment should include a thorough evaluation of degree of cervical instability present, preexisting neurologic impairment, congenital heart defects, pulmonary function, and renal anomalies.

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5. ANSWER: C

Marfan syndrome is an autosomal dominant connective tissue disorder caused by mutations in the FBN1 gene, which encodes the connective protein fibrillin-1. Connective tissue in Marfan patients has **decreased tensile strength and elasticity**. The range of expression can be from mild to severe, with defects of the skeletal system, ocular system, and cardiovascular system posing the most significant threats.

Patients with Marfan syndrome are tall, with long, thin extremities and fingers (arachnodactyly). Joint ligaments are loose, resulting in frequent **dislocations**. **Kyphoscoliosis** and **pectus excavatum** can lead to **restrictive pulmonary disease**. These patients tend to also develop **pneumothoraces**, especially under anesthesia if they are subjected to **positive-pressure ventilation**. Ocular manifestations of Marfan's syndrome include **severe myopia**, **spontaneous retinal detachments**, displaced lenses, and glaucoma.

Aortic root disease, leading to aneurysmal dilatation, aortic regurgitation, and dissection, is the main cause of morbidity and mortality in Marfan patients. Dilatation of the aorta is found in approximately **50% of children** with Marfan syndrome.

Young patients you suspect for having Marfan syndrome should have a **chest radiograph** as well as an **ECG** before surgery. The 2010 American College of Cardiology/American Heart Association/American Association for Thoracic Surgery (ACC/AHA/AATS) thoracic aorta guidelines recommend **echocardiography** at initial diagnosis, at 6 months, and then at least annually. Marfan patients tend to have restrictive lung disease, particularly those with scoliosis. Therefore, a **pulmonary function test** is warranted prior to surgery. Besides a complete blood count and a type and cross for this type of surgery, a chemistry panel adds limited value to the preoperative evaluation of this patient. Coagulation studies are not routinely indicated.

KEY FACTS

- Patients with Marfan syndrome are tall, with long, thin extremities and fingers (arachnodactyly), due to a connective tissue disorder caused by mutations in the FBN1 gene.
- Disease manifestations include frequent joint dislocations, rib cage abnormalities leading to restrictive pulmonary disease, spontaneous pneumothoraces with positive-pressure ventilation, aortic root dilation/dissection, and ocular issues such as severe myopia and retinal detachment.
- Preoperative workup should include an ECG and echocardiogram as well as pulmonary function tests.

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6. ANSWER: A

Cerebral palsy (CP) describes a heterogeneous group of nonprogressive motor impairment syndromes. These conditions range in severity and are due to brain development abnormalities due to static encephalopathy as a result of in utero or perinatal insults. Clinical features of CP include cognitive impairment, vision loss, hearing loss, seizures, and communication and behavioral disturbances.

In the operating room, communication difficulties and hearing loss may mask true intellect and heighten anxiousness. CP patients tend to do well with **oral benzodiazepine premedication** and having their **parents present for induction** of anesthesia.

Concurrent medications may interact with anesthetics used. Specifically, **antiepileptics** are known to **increase resistance** to NMBDs.

Succinylcholine use is not associated with hyperkalemia in CP because the muscles of these patients have not been denervated.

Noncommunicative patients with CP require *less* propofol to obtain the same bispectral index (BIS) as healthy pediatric patients.

KEY FACTS

- CP describes a heterogeneous group of nonprogressive motor impairment syndromes.
- Patients may benefit from an oral premedication and a parent present during induction.
- Succinylcholine use is not associated with hyperkalemia in CP because the muscles of these patients have not been denervated.

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7. ANSWER: B

Osteosarcoma, the most common primary bone cancer of childhood, has an estimated incidence of 4.6 per million people in the United States. The majority of these tumors occur during the adolescent growth spurt in patients between 10 and 19 years of age.

Osteosarcoma is an aggressive neoplasm that exhibits osteoblastic differentiation and forms malignant osteoid and bone. It originates most frequently in the metaphyseal region of **tubular long bones**, typically involving the femur, tibia, or humerus. Initial complaints of pain and swelling are often attributed to athletic injuries. Clinical findings may include limited range of motion, joint effusions, tenderness to palpation, and warmth. **Elevated alkaline phosphatase or lactic dehydrogenase** with otherwise normal complete blood cell count and chemistry panel are found. Radiographs demonstrate a characteristic **sunburst lesion.**

Complete surgical resection is the treatment of choice for osteosarcoma, and pain control in the perioperative period may be particularly challenging and require a **multimodal approach**.

Patients with osteosarcoma often have **significant preoperative pain** and are already receiving significant amounts of opioids to help control it. Opioids should not be discontinued, but rather preoperative evaluation should include an assessment of the patient's opioid requirements so that an intraoperative and postoperative pain plan appropriately considers the increased requirements that will be necessary.

The addition of **methadone**, which possesses both opioid mu and NMDA receptor activity, may be helpful. Low-dose preoperative methadone (5 mg to 10 mg) followed by doses every 8 hours postoperatively has been shown to be safe and effective for pain control. Sustained-release opioids such as oxycodone SR or a fentanyl patch may be helpful but should not be used in opioid-naïve patients.

Opioids alone rarely provide adequate analgesia; the addition of agents from other pharmacologic classes is frequently beneficial. Useful agents include **gabapentin** and **nonsteroidal anti-inflammatory drugs** (NSAIDs). Ketamine, an NMDA antagonist, in subanesthetic doses has been shown to significantly decrease postoperative pain, specifically in opioid-tolerant patients. Additionally, surgical procedures of the upper and lower extremities lend themselves well to **neuraxial** or **regional anesthetic** procedures.

Osteosarcoma patients can benefit from a multidisciplinary approach to their pain management. Anesthesiology, surgery, pain specialists, and psychiatry may work together to devise a plan that minimizes postoperative discomfort and maximizes the patient's ability to participate in physical therapy.

KEY FACTS

- Osteosarcoma is an aggressive neoplasm that originates most frequently in the metaphyseal region of tubular long bones, typically involving the femur, tibia, or humerus.
- Complete surgical resection is the treatment of choice for osteosarcoma, and pain control in the perioperative period may be particularly challenging and require a multimodal approach.
- Treatment options include methadone, gabapentin, NSAIDs, ketamine, and neuraxial/regional nerve catheters.

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8. ANSWER: A

Osteosarcoma, the most common primary bone cancer of childhood, has an estimated incidence of 4.6 per million people in the United States. The majority of these tumors occur during the adolescent growth spurt in patients between 10 and 19 years of age.

Osteosarcoma is an aggressive neoplasm that exhibits osteoblastic differentiation and forms malignant osteoid and bone. It originates most frequently in the metaphyseal region of tubular long bones, typically involving the femur, tibia, or humerus. Initial complaints of pain and swelling are often attributed to athletic injuries. Clinical findings may include limited range of motion, joint effusions, tenderness to palpation, and warmth. Elevated alkaline phosphatase or lactic dehydrogenase with otherwise normal complete blood cell count and chemistry panel are found. Radiographs demonstrate a characteristic sunburst lesion.

Complete surgical resection is the treatment of choice for osteosarcoma. Currently patients are pretreated with chemotherapy in an attempt to reduce micrometastatic disease and facilitate limb salvage surgery. Agents currently used in chemotherapy regimens for osteosarcoma include doxorubicin, cisplatin, methotrexate, and ifosfamide (see Table 18.1). Although almost 90% of patients are able to initially have limb-salvage surgery, frequent complications (infection, prosthetic loosening, and nonunion, local tumor recurrence) may necessitate further surgery or amputation.

Preoperative evaluation may reveal significant comorbidities or adverse effects caused by chemotherapy agents, which may have important implications for anesthetic management.

Adriamycin (doxorubicin) is associated with cardiotoxicity and cardiomyopathy. Acute toxicity can arise early in treatment (prolonged QT, dysrhythmias, cardiomyopathy) and often reverses with cessation of therapy. Chronic toxicity appears as early as the first year of therapy to years or decades after therapy has been completed. Risks are increased in children versus adults, with larger cumulative doses, and in patients who undergo concomitant radiation therapy. Preoperative echocardiography may be beneficial even in asymptomatic patients.

Cisplatin, high-dose **methotrexate**, and **ifosfamide** may all cause nephrotoxicity. Leucovorin therapy may be helpful with methotrexate-related renal failure.

Bone marrow suppression can occur with all cytotoxic drugs.

Table 18.1 CHEMOTHERAPEUTIC AGENTS AND THEIR POSSIBLE ADVERSE EFFECTS

CHEMOTHERAPEUTIC AGENT	SIDE EFFECTS
DNA-Altering Drugs	
Cyclophosphamide	Hemorrhagic cystitis
	Myelosuppression
Cisplatin	Myelosuppression
	Nephrotoxicity
Mechlorethamine	Myelosuppression
	Dermatitis
Carboplatin	Myelosuppression
	Peripheral neuropathy
	Immune hypersensitivity reaction
Antitumor Antibiotics	
Doxorubicin	Myelosuppression
	Cardiomyopathy
	Arrhythmias
Bleomycin	Pulmonary fibrosis
Idarubicin	Myelosuppression
	Hepatotoxicity
Antimetabolites	
Gemcitabine	Myelosuppression
Methotrexate	Hepatotoxicity
	Ulcerative stomatitis
	Myelosuppression
Cytarabine	Myelosuppression
	Hyperuricemia
Etopiside	Myelosuppression
	Hypotension
Antimitotic Drugs	
Vincristine	Motor weakness
	Peripheral neuropathy
	Hyponatremia
Vinblastine	Myelosuppression
	Ulcer/blister formation
Paclitaxel	Myelosuppression
	Paresthesia
Docetaxel	Myelosuppression
Monoclonal Antibody	
Cetuximab	Skin changes
	Electrolyte disturbances
Other	
Gefitinib	Diarrhea
	Interstitial lung disease
Imatinib	Edema

SOURCE: Reprinted with permission from Anderson MR, Jeng CL, Wittig JC, Rosenblatt MA. Anesthesia for patients undergoing orthopedic oncologic surgeries. *J Clin Anesth*. 2010;22(7):565–72.

Pulmonary fibrosis or pneumonitis may occur in patients who receive **bleomycin** chemotherapy. This pulmonary toxicity may be worsened with high inspired

oxygen concentrations and excessive fluid administration; therefore, it is very important to consider in the anesthetic evaluation.

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9. ANSWER: D

Osteosarcoma, the most common primary bone cancer of childhood, has an estimated incidence of 4.6 per million people in the United States. The majority of these tumors occur during the adolescent growth spurt in patients between 10 and 19 years of age.

Osteosarcoma is an aggressive neoplasm that exhibits osteoblastic differentiation and forms malignant osteoid and bone. It originates most frequently in the metaphyseal region of tubular long bones, typically involving the femur, tibia, or humerus. Initial complaints of pain and swelling are often attributed to athletic injuries. Clinical findings may include limited range of motion, joint effusions, tenderness to palpation, and warmth. Elevated alkaline phosphatase or lactic dehydrogenase with otherwise normal complete blood cell count and chemistry panel are found. Radiographs demonstrate a characteristic sunburst lesion.

Complete surgical resection is the treatment of choice for osteosarcoma. When planning an anesthetic for patients undergoing orthopedic oncologic surgeries, advanced planning should be done to minimize intraoperative blood loss. All tumors are relatively vascular structures and prone to bleeding. Because this patient has pelvic metastasis, there are particularly at high risk for significant intraoperative hemorrhage.

It is reasonable to consider preoperative embolization to minimize intraoperative bleeding. The embolization, however, would best be performed within 24 hours prior to surgery because **collateral flow is rapidly reestablished**.

Preoperative autologous blood donation (PAD) and intraoperative transfusion **does not improve long-term outcomes** over allogenic donor red blood cell transfusions. PAD often **exacerbates perioperative anemia** and increases incidence of intraoperative transfusion. Furthermore, autologous transfusions have also been implicated in transfusion-related immunomodulation along with allogenic transfusions, and both are associated with decreased disease-free survival in cancer patients.

Cell salvage technology should not be used in cancer surgery because of the increased risk of spreading malignant cells systemically.

Acute normovolemic hemodilution (ANH) is another technique sometimes used to decrease the need for perioperative transfusions. At the beginning of a procedure the patient is phlebotamized while replacing the removed intravascular volume with crystalloid or colloid. The withdrawn blood is returned to the patient later in the procedure, no longer than 8 hours after collection. ANH has been shown to reduce need for transfusion in some cardiac procedures, but not in orthopedic surgeries. **ANH may also be associated with higher intraoperative fluid and vasopressor requirements**.

Intraoperative use of **antifibrinolytics** such as tranexamic acid or aminocaproic acid has been shown to decrease intraoperative transfusion and blood loss in orthopedic oncologic surgeries. A Cochrane Database meta-analysis showed a decrease in blood loss without any increase in risk of thrombus formation with the use of antifibrinolytics such as aprotinin, epsilon-aminocaproic acid (EACA), or tranexamic acid.

Of course, placement of an **arterial catheter** for intraoperative blood pressure monitoring and blood sampling, ensuring the availability of **cross-matched blood products**, and having **adequate IV access** are crucial prior to surgical incision. Having rapid-infusion devices available is also helpful.

KEY FACTS

- Preoperative embolization to minimize intraoperative bleeding should be performed within 24 hours prior to surgery because collateral flow is rapidly reestablished.
- Cell salvage technology should not be used in cancer surgery because of the increased risk of spreading malignant cells systemically.
- Intraoperative use of antifibrinolytics such as tranexamic acid or aminocaproic acid has been shown to decrease intraoperative transfusion and blood loss in orthopedic oncologic surgeries.

REFERENCES

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10. ANSWER: A

Epidermolysis bullosa (EB) is a group of inherited **connective tissue diseases** with defective anchoring between

the dermis and epidermis, which leads to **bulla formation** (blistering) in the skin and mucous membranes following trivial trauma. Bulla most often occur when **lateral shearing forces** are applied to the skin and mucous membranes. **Perpendicular pressure is not as great a hazard**. The **oropharynx and esophagus are particularly affected**.

EB treatment is symptomatic and supportive, often including **corticosteroids**.

There are multiple anesthesia considerations in patients with epidermolysis bullosa. Preoperative initiation or stress dosing of corticosteroids should be considered.

A **careful airway evaluation** should be performed because EB patients often have **scarring and contractures of the oropharynx, mouth opening, and neck**. Dentition may also be poor with loose teeth present. Often planned fiberoptic intubation is safer than direct laryngoscopy. **Smaller endotracheal tubes** can be used to avoid unnecessary trauma to the airway. If a laryngoscope blade is used, it should be **well lubricated**. It is recommended to avoid esophageal stethoscopes and oropharyngeal suctioning as well.

Great care should be taken to avoid trauma to the skin as well. All adhesive tape should be avoided. Peripheral IVs can be secured with **gauze wrap**, a nonadhesive pulse oximeter should be used, ECG pads can be secured with petroleum jelly gauze, and gel pads should be placed under the patient. After the procedure, generous **petroleum jelly-based ointment** and nonadhesive dressings will be placed on the hands with a padded cast.

Postoperatively O_2 masks rubbing against the face should be avoided. **Adequate analgesia and antiemetic therapy** should be provided. **Parental presence** in the PACU may also help prevent excessive struggling and trauma during emergence and recovery. **Pruritus**, if present, should be treated promptly.

KEY FACTS

- EB is a group of inherited connective tissue diseases with defective anchoring between the dermis and epidermis, which leads to blistering in the skin and mucous membranes with lateral shearing forces.
- EB treatment is symptomatic and supportive, often including corticosteroids.
- Because the oropharynx and esophagus are particularly affected, airway management can be challenging, and manipulation of these tissues (with monitoring devices and suctioning) should be avoided or minimized.

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11. ANSWER: A

Spina bifida is a congenital developmental abnormality characterized by **incomplete fusion of the vertebral arches**. If the defect is large enough, a portion of the spinal cord may protrude through the opening in the bones. Spina bifida occulta refers to a spina bifida defect covered by soft tissues and skin. Spina bifida aperta refers to lesions with exposed meningoceles or myelomeningoceles. The most common location of these malformations is the lumbar and sacral areas. **Myelomeningocele** is the most severe and common form, with an incidence of about 1 in every 1,000 births.

Spina bifida defects should be surgically closed shortly after birth to reduce risk of serious infection; this, however, does not restore normal function to the affected part of the spinal cord. N**erve root dysfunction typically occurs below the level of the lesion.**

Clinical features of spina bifida may include the following:

- Lower-extremity weakness and paralysis
- Orthopedic abnormalities such as clubfeet, hip subluxation, and scoliosis
- Neurogenic bladder and bowel, resulting in incontinence, frequent urinary tract infections, and impaired renal function
- Arnold Chiari II malformation causing hydrocephalus
- Epilepsy and learning disabilities

Preoperative evaluation should include assessment of neurologic deficits, range of motion restrictions, and renal impairment. If **contractures** are present, extra pillows and padding may be needed to support limbs. If renal impairment exists, NSAIDs should be avoided. Of note, **succinylcholine may be used** and has not been shown to cause severe hyperkalemia in spina bifida patients.

Ventriculoperitoneal shunts should be functioning properly. **Short trachea and endobronchial intubation** are common in spina bifida patients; therefore, care should be taken to ensure bilateral and equal breath sounds. Furthermore, kyphoscoliosis may distort tracheal anatomy, making intubation more difficult.

Due to a reduced hypercapnic ventilator response, **extended PACU stays** may be necessary to ensure full postoperative recovery.

Frequent surgical procedures and need for urinary catheterization also lead to a **high rate of latex allergy** among children with spina bifida. Primary prevention by maintaining a strict, latex-free operating room is recommended.

KEY FACTS

- Spina bifida is a congenital developmental abnormality characterized by incomplete fusion of the vertebral arches.
- Patients with spina bifida should not be exposed to latex due to a high rate of latex allergy.
- Short trachea and endobronchial intubation are common in a spina bifida patient.

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12. ANSWER: C

The incidence of neurologic complications following scoliosis surgery is extremely low: 0.3%. Those children with curves greater than **100 degrees, with congenital scoliosis, kyphosis, or postradiation scoliosis** all have a greater likelihood of incurring some sort of neurologic injury.

Thoracic scoliosis would be a correct choice if the curve was over 100 degrees. However, thoracic scoliosis in and of itself is not a risk factor.

Mesenchymal scoliosis includes patients with Marfan syndrome, mucopolysaccharidises, arthrogryposis, and osteogenesis imperfecta. **Cardiac, airway, vascular access, and extreme fragility** are all issues encountered with these patients.

Infantile scoliosis is a type of idiopathic scoliosis. There are three types of idiopathic scoliosis: infantile (<3 years of age), juvenile (3–9 years of age), and adolescent (9–18 years of age).

Congenital scoliosis consists of those patients born with **bony abnormalities** leading to an acute angle deformity and those patients with neural tube defects (meningomyelocele, spina bifida, and syringomyelia).

KEY FACTS

- Children with curves greater than 100 degrees, with congenital scoliosis, kyphosis, or postradiation scoliosis all have a greater likelihood of incurring some sort of neurologic injury.
- Patients with mesenchymal scoliosis have cardiac, airway, and vascular access issues.
- Congenital scoliosis consists of those patients born with bony abnormalities leading to an acute angle deformity and those patients with neural tube defects (meningomyelocele, spina bifida, and syringomyelia).

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13. ANSWER: C

The ankle-clonus test is surprisingly accurate. In one series of slightly over 1,000 patients undergoing spinal arthrodesis and instrumentation, the ankle-clonus test correctly identified all six of the patients that had developed a neurologic deficit during the procedure. However, it also misidentified three patients as having a neurologic deficit who were normal. This meant the test had a sensitivity of 100% and a specificity of 99.7%.

Because the test is administered at the conclusion of the procedure, it is considered a **post hoc test** rather than real-time monitoring. In this instance it is similar to the **wake-up test**. Unlike the wake-up test, the ankle-clonus test is performed as the patient is emerging from anesthesia but before the patient fully regains consciousness. It is thought that at this juncture the patient's spinal reflexes have returned while the higher centers are still inhibited by the residual anesthesia still present. The surgeon briskly dorsiflexes the patient's foot and assesses the patient for clonus. If the surgeon can elicit clonus, then **it is assumed that the spinal cord is intact**. If the surgeon cannot elicit clonus, then there is a high likelihood that there is some neurologic damage and the patient should not be extubated until he or she can demonstrate voluntarily movement of the lower extremities.

Unlike the wake-up test, **patient cooperation is not required** to successfully assess patient's neurologic integrity using the ankle-clonus test.

KEY FACTS

- The ankle-clonus test has a sensitivity of 100% and specificity of 99.7%.
- The ankle-clonus test is performed at the end of the procedure (similar to a wake-up test) but does not need patient cooperation and can be done while a patient is emerging from anesthesia.

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Wilton NC, Anderson BJ. "Orthopedic and spinal surgery." Cote CJ, Lerman J, Todres ID, eds. *A Practice of Anesthesia for Infants and Children*. 4th ed. Philadelphia, PA: Saunders Elsevier; 2009:640.

14. ANSWER: B

The patient's pulmonary function will not approach baseline values until 1 to 2 months have elapsed. These changes are fairly consistent for patients having a **posterior spinal fusion** alone or a **combined anterior release and posterior**

spinal fusion. They can be seen in patients with both idiopathic scoliosis and neuromuscular scoliosis.

Because of the concurrent muscle weakness, those patients with neuromuscular scoliosis are more likely to require postoperative ventilation than those with idiopathic scoliosis. Similarly, those patients with nonidiopathic scoliosis as a group are five times more likely to have some type of postoperative respiratory complication. Their risk increases as the degree of thoracic curvature increases. Also, while anterior procedures do not contribute to a greater reduction in a patient's postoperative pulmonary function, anterior procedures do contribute to increased rate of respiratory complications with **atelectasis**, **infiltrates**, **hemo/pneumothoraces, pleural effusions, and prolonged intubation** being the most common.

The marked decrease in a patient's pulmonary function during the postoperative period undoubtedly contributes to the observation that patients with neuromuscular disease have less morbidity with same-day anterior/posterior procedures than a staged approach.

KEY FACTS

- Pulmonary function tests following a spinal fusion will decrease with a nadir on POD 3 and will be about 60% of preoperative values 7 to 10 days after the surgery.
- They will not approach baseline values until 1 to 2 months following the surgery.

REFERENCE

Wilton NC, Anderson BJ. "Orthopedic and spinal surgery." Cote CJ, Lerman J, Todres ID, eds. *A Practice of Anesthesia for Infants and Children*. 4th ed. Philadelphia, PA: Saunders Elsevier; 2009:638–9.

15. ANSWER: D

When the tourniquets are deflated, the ischemic limbs are reperfused. This results in a relative increase in the intravascular space being perfused by the same blood volume. Physiologically the body responds as if it were **hypovolemic** with a transient **increase in heart rate and decrease in blood pressure**. The reperfusion of the ischemic limb results in a washout of lactic acid, creatine phosphokinase, and carbon dioxide. The **increase in CO_2** causes an increase in the ventilation minute volume in spontaneously breathing patients, vasodilation, and an increase in cerebral blood volume.

During tourniquet inflation the ischemic limbs will be significantly cooler than the core body temperature. With reperfusion the blood circulation through the formally ischemic limbs will cause the **central core temperature to decrease**.

KEY FACTS

- The physiological reaction to a deflation of a tourniquet is a hypovolemic state with a transient increase in heart rate and decrease in blood pressure.
- The reperfusion of the ischemic limb leads to washout of lactic acid, creatine phosphokinase, and carbon dioxide. The increase in CO_2 causes an increase in the ventilation minute volume in spontaneously breathing patients, vasodilation, and an increase in cerebral blood volume.
- Following the deflation, the central core temperature is decreased.

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16. ANSWER: C

Histological changes occur in the muscle beneath the tourniquet **after 2 hours of tourniquet time**. Similar changes are noted in distal tissue after 4 hours of ischemic time. **Direct pressure and compression of tissue** contribute to the tissue injury. Nerves running under the tourniquet are susceptible to this type of injury, especially at the **proximal and distal edges of the cuff**.

Vascular damage is not common in children.

Tourniquet pain begins to intensify minutes after the tourniquet is inflated and is unbearable after **approximately 30 minutes**. It results in an **increase in blood pressure and heart rate** that is not responsive to analgesics. Avoiding nerve injuries outweighs concerns for getting the vital signs back to baseline.

Short periods of ischemia followed by reperfusion actually make muscle more resistant to subsequent ischemia.

KEY FACTS

- Histological changes occur in the muscle beneath the tourniquet after 2 hours of tourniquet time.
- Direct pressure and compression of tissue (especially for nerves at the proximal and distal edges of the cuff) contribute to the tissue injury.

REFERENCE

Wilton NC, Anderson BJ. "Orthopedic and spinal surgery." Cote CJ, Lerman J, Todres ID, eds. *A Practice of Anesthesia for Infants and Children*. 4th ed. Philadelphia, PA: Saunders Elsevier; 2009:648–50.

17. ANSWER: A

Blood is a non-Newtonian fluid comprised of fluid and particulate matter. When the red cell mass decreases as

in normovolemic hemodilution, the **blood viscosity decreases**. This improves its flow characteristics such that it results in improved perfusion of the capillary beds.

With normovolemic hemodilution there is an **increase in the venous return to the heart**. It has been reported that this results in an increase in cardiac output. However, if the patient remains normovolemic, this increase in cardiac output is due to an increase in the stroke volume, not heart rate. Some observers have reported little or no changes in cardiac output if the degree of hemodilution remains moderate.

There is usually **no change in the oxygen-hemoglobin dissociation curve** associated with the acute anemia introduced with normovolemic hemodilution. However, in cases of chronic anemia there is a shift of the curve, but this shift is to the right to improve oxygen delivery to the peripheral tissue. Additionally 2,3-DPG levels will increase in red cells in patients with a chronic anemia.

A slight degree of hypothermia, between 33°C and 34°C, is recommended to **reduce the child's metabolic rate** during normovolemic hemodilution. This must be carefully monitored so that the child does not begin to shiver since this will result in a marked increase in the oxygen consumption. Shivering is best controlled by not allowing the child to get too cold and with the judicious use of muscle relaxants. Interestingly, many muscle relaxants have demonstrated an increased potency and have a prolonged duration of action in children who have been hemodiluted. The exact mechanism of action has not yet been clearly defined.

KEY FACTS

- In normovolemic hemodilution, the blood viscosity decreases, which improves its flow characteristics such that it results in improved perfusion of the capillary beds.
- With normovolemic hemodilution, there is an increase in the venous return to the heart with an increase in cardiac output secondary to an increase in stroke volume.
- There is usually no change in the oxygen-hemoglobin dissociation curve associated with the acute anemia introduced with normovolemic hemodilution.

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18. ANSWER: C

Down syndrome is the most common chromosome abnormality in humans, occurring in approximately 1 in 800 live births. It is associated with advanced maternal age and is a genetic disorder most commonly a result of **Trisomy 21**, but it can also be due to balanced or unbalanced translocation of chromosome 21 or mosaicism. The syndrome is associated with physical growth delays and distinct craniofacial characteristics (microbrachycephaly, small low-set ears, oblique palpebral fissures). Specific syndromic features that may affect airway management include **short neck, small mouth opening, mandibular hypoplasia, macroglossia, narrow nasopharynx, hypertrophic lymphatic tissue (tonsils, adenoids), subglottic stenosis, and cervical spine instability**.

Generalized hypotonia, not increased muscle rigidity, is commonly associated with Down syndrome and results in higher likelihood of upper airway collapse, which can lead to **obstructive sleep apnea**. Airway concerns include frequent upper airway obstruction, postextubation stridor, and increased risk of cervical spine injury.

Other conditions that affect children with Down syndrome include **mental retardation, thyroid disease, leukemia, obesity, subglottic stenosis, gastrointestinal problems, and congenital heart defects**.

Associated findings with Down syndrome include the following:

- Physical stature: low birth weight, short stature
- Airway findings: macroglossia, micrognathia, subglottic stenosis, postextubation stridor, microdontia with fused teeth, increased tendency for upper airway obstruction
- Cardiovascular findings: congenital heart disease, atropine sensitivity, increased susceptibility to pulmonary hypertension
- Respiratory findings: increased susceptibility to respiratory infections, increased susceptibility to obstructive sleep apnea
- Gastrointestinal findings: duodenal obstruction, gastroesophageal reflux, Hirshsprung syndrome
- Nervous system findings: mental retardation, epilepsy, strabismus
- Musculoskeletal findings: hypotonia, dysplastic pelvis, atlantoaxial subluxation
- Immune system findings: immunosuppression, leukemia
- Hematologic findings: neonatal polycythemia
- Endocrine findings: hypothyroidism, low catecholamine

KEY FACT

- The airway management of patients with Down syndrome may be affected by a short neck, small mouth opening, mandibular hypoplasia, macroglossia, narrow nasopharynx, hypertrophic lymphatic tissue (tonsils, adenoids), subglottic stenosis, and cervical spine instability.

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19. ANSWER: A

Down syndrome, a genetic disorder frequently resulting from Trisomy 21, is the most common chromosome abnormality in humans, occurring in approximately 1 in 800 live births. The syndrome is associated with physical growth delays, craniofacial abnormalities, and mental retardation.

Congenital heart defects (CHDs) are associated in **40%–50% of Down syndrome children**. The most common lesions are **atrioventricular septal defects** (about one half) and **ventricular septal defects** (about one fourth). Other lesions that are less common include patent ductus arteriosus, atrial septal defects, and Tetralogy of Fallot. Therefore, it is recommended that all children with Down syndrome are screened early in infancy for CHDs. **Bradycardia** under anesthesia occurs commonly, particularly upon inhalation induction. These children are highly susceptible to **pulmonary hypertension** either due to cardiovascular pathology or from chronic hypoxia secondary to upper airway obstruction.

KEY FACT

- The most common cardiac lesions in patients with Down syndrome are **atrioventricular septal defects** (about one half) and **ventricular septal defects** (about one forth).

REFERENCES

Maxwell L, Goodwin SR, Mancuso TJ, et al. "Systemic disorders in infants and children." Motoyama EK, Davis P, eds. Smith's Anesthesia for Infants and Children. 7th ed. Philadelphia, PA: Mosby Elsevier; 2006:1091.

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19.

TRAUMA AND BURNS

Cathie Jones

1. Which of the following is the most common cause of death from injury in children?

A. Pericardial tamponade
B. Exsanguination
C. Traumatic brain injury
D. Sepsis

2. Which of the following injuries would be suggestive of nonaccidental trauma (i.e., child abuse)?

A. Rib fracture
B. Forearm fracture
C. Shin bruises
D. Lump on forehead

3. Which of the following would be representative of the amount of blood loss when you would first expect to see hypotension in a child following a traumatic injury?

A. 5 mL/kg
B. 10 mL/kg
C. 20 mL/kg
D. 40 mL/kg

4. Significant traumatic injury may lead to large volumes of blood loss and transfusion. Coagulopathy associated with massive transfusion after an injury is most likely due to which of the following:

A. Thrombocytopenia
B. Hypothermia
C. Disseminated intravascular coagulation
D. Citrate toxicity

5. Incidence of injury is highest in which age group?

A. 1–4 years of age
B. 5–9 years of age
C. 10–14 years of age
D. 15–19 years of age

6. Which of the following is true regarding traumatic injury in children in comparison to adults:

A. Thoracic trauma is more common than abdominal trauma.
B. Penetrating trauma is more common than blunt trauma.
C. Tension pneumothorax is more likely to occur.
D. Rib fractures are common in children and need aggressive pain treatment.

7. All of the following contribute to the difficulty of assessing cervical spine injuries in children except:

A. Pseudosubluxation
B. Communication difficulties related to age
C. Caudad location of injury
D. Pain

8. A 3-year-old male is brought in via ambulance after a motor vehicle crash. He was noted to be an unrestrained passenger, ejected from the vehicle, and has an open radius fracture. Upon exam, he is noted to open his eyes when a painful stimulus is applied. He withdraws when an IV is attempted to be placed, but he does not make any verbal sounds regardless of the stimulus. His heart rate is 100, blood pressure is 90/40, respiratory rate is 20, and O_2 saturation is 96%. Which of the following represents the best next step in his management?

A. Proceed to the computed tomography (CT) scan to evaluate additional injuries.
B. Transfuse 10 mL/kg of PRBCs.
C. Give pain medication.
D. Intubate due to neurologic status.

9. A patient presents after being involved in a house fire. The patient is brought directly to the emergency department by EMS. Which of the following signs on presentation would lead you to consider intubation in this patient early in the hospital course?

A. Elevated heart rate
B. Body surface burns of 20%
C. Carbonaceous sputum
D. Circumferential burns of the abdomen

10. A 6-year-old, 20 kg child is involved in a scald burn from the kitchen sink. The burns on the legs affect approximately 20% of the child's body surface area. Which of the following fluid regimens represents appropriate resuscitation for this patient following a burn?

A. 120 mL/hr of NS or LR for the next 12 hours
B. 800 mL of NS or LR over the next 8 hours
C. 1200 mL of NS or LR over the next 8 hours
D. 1600 mL of NS or LR over the next 8 hours

11. Which of the following would be most helpful in determining whether a patient has carbon monoxide in his or her blood following a house fire?

A. Venous blood gas
B. Co-oximeter
C. Pulse oximeter
D. Mixed venous oxygen saturation

12. A 3-year-old male presents with scald burns to his bilateral lower extremities, up to his thighs. The parents report that he climbed into the kitchen sink and turned the hot water on. Which of the following represents the likely total body surface area burned?

A. 10%
B. 20%
C. 30%
D. 40%

13. A patient presents for scar revision approximately 3 years after a 45% total body surface area (TBSA) burn during a chemical fire at their workplace. In planning for this patient's anesthetic, which of following is true regarding neuromuscular blockade?

A. Succinylcholine should be avoided due to upregulation of receptors.
B. Burn patients should be dosed similarly to patients with myasthenia gravis.
C. Dosing of neuromuscular blockers changes immediately after the burn injury occurs.
D. This far out from the burn injury, is it unlikely that dosing should be adjusted.

14. A patient presents after a house fire, with circumferential burns. Due to the exposure to smoke inhalation, the patient was intubated upon hospital arrival. It has been approximately 8 hours since the burn injury and the patient is requiring increasing inspiratory pressures to maintain his tidal volumes. Which of the following is likely indicated to help improve the respiratory management of this patient?

A. Changing of endotracheal tube (ETT) due to likely mucous plugging
B. Escharotomies to improve the chest excursion and assist with ventilation
C. Additional pain medication as likely ventilator dis-synchrony due to pain
D. Bronchoalveolar lavage

15. A patient presents for burn debridement and split thickness skin grafting after 45% TBSA burns. Which of the following would be most helpful to maintain the patient's temperature?

A. Warming the IV fluids
B. Convective warming
C. Warming up the operating room
D. Nothing special needs to be done to maintain normothermia

16. A 4-year-old girl presents with blunt abdominal trauma following a motor vehicle accident. The patient is suspected to have a splenic injury and has a positive FAST exam. She is being prepared to go to the operating room for an exploratory laparotomy and splenectomy. The EMTs and several other staff members have attempted to get IV access in this patient without success. The surgeon wants to move to the operating as expeditiously as possible, as the patient's vital signs are suggestive of acute blood loss. Which of the following sites is the most appropriate site to obtain vascular access at this time?

A. Femoral cut down
B. Right internal jugular central line placement
C. Additional attempts at a peripheral intravenous line
D. Intraosseous needle placed in the patient's tibia

17. A 5-year-old male is found submerged in his family's backyard pool. Which of the following is the most important next step in his resuscitation after the patient is removed from the pool?

A. Removing wet clothing to prevent hypothermia
B. Calling EMS prior to removing him from the pool
C. Instituting effective CPR as rapidly as possible
D. Instituting warming procedures as rapidly as possible

18. Which of the following agents may be beneficial in minimizing the hyperalgesia encountered in burn patients?

A. Fentanyl
B. Morphine
C. Hydromorphone
D. Methadone

19. Which of the following does not increase caloric demands in the burn patients?

A. Early burn excision and grafting
B. Sepsis
C. Cold stress
D. Anxiety

20. A child is seen falling through the ice into a cold and partially frozen pond. After removing the child from the ice and water, he is noted to be apneic and pulseless. Resuscitative efforts are begun. After CPR has started and EMS arrives, he is noted to have a core temperature of 31°C. Which of the following is appropriate in this setting as part of the resuscitation?

A. Limit shocks until core temperature is >34°C if VF/VT is present.
B. Initiate active internal rewarming.
C. Space vasoactive medications out over a longer period of time.
D. Maintain the patient in a hypothermic state for good neurologic outcomes.

21. Which of the following is not characteristic of a high-voltage electrical burn?

A. It can cause extensive skeletal muscle and neurovascular tissue damage.
B. It typically has entrance and exit wounds that show the path of injury.
C. It is usually over 1000 volts.
D. Cardiac conduction anomalies are of immediate importance.

22. A bomb goes off at an elementary school and children are brought to the emergency room for evaluation. Due to this event, you are sent to the emergency room to help evaluate and treat patients. Which of the following injuries is most common after a primary blast injury?

A. Bowel perforation
B. Lung injury
C. Limb fracture/shrapnel
D. Tympanic membrane perforation

23. All of the following may be indicated to help prevent renal dysfunction or failure from myoglobin following a burn *except*:

A. Maintaining the urine output at 1 to 1.5 mL/kg per hour
B. Maintain glucose under 180
C. Sodium bicarbonate
D. Furosemide

24. A child has suffered a head injury after falling from his bike. He was not wearing a helmet. He had no signs of losing consciousness immediately following the accident. His parents brought him to the emergency room initially because of open forearm fracture due to obvious deformity. Since arriving in the emergency room, he has become less responsive. Which of the following would be the best choice in this setting to help acutely decrease the intracranial pressure (ICP) while not interfering with his other injuries?

A. Hypertonic saline
B. Hypercarbia
C. Fentanyl
D. Mannitol

25. A 3-year-old child comes in after a motor vehicle accident where he, in his car seat, was ejected from the vehicle while restrained in his car seat. Which of the following is not part of his primary evaluation?

A. Assessment of circulation
B. FAST exam
C. Glasgow Coma Score
D. Expose the patient for occult injury

CHAPTER 19 ANSWERS

1. ANSWER: C

Traumatic brain injury is the most common cause of death from injury for all ages—children and adults. Traumatic brain injury is the **leading cause of death** (60%–70%) and the leading cause of **long-term disability**. This is a serious public health concern. It is essential that the central nervous system is considered when acutely treating and resuscitating the pediatric trauma victim. **Maintenance of systemic blood pressure (SBP)** is also important to help maintain cerebral perfusion pressure. Children presenting with an SBP less than 90 mm Hg have a three times greater mortality than those victims who present with an SBP greater than 90; however, more than 90% of children present with an SBP over 90.

KEY FACTS

- Traumatic brain injury is the leading cause of death from injury for people of all ages.
- Maintenance of systemic blood pressure is essential to improving outcomes.

REFERENCE

Young DA, Wesson DA. "Trauma" in Cote CJ, Lerman J, Anderson BJ, eds. *A Practice of Anesthesia for Infants and Children/* 5th ed. Philadelphia, PA: Saunders Elsevier; 2013:789–90.

2. ANSWER: A

Child abuse is a widespread concern. Over 3 million reports of child abuse are filed annually in the United States, but it likely does not reflect the actual number of cases. When seeing a trauma victim, it is important to evaluate whether the trauma was an accident or intentional for the protection of the child. Some patterns of injury reflect normal childhood falls: such as from learning to walk or playground accidents. Examples of these are forearm fractures (falling on an outstretched hand) and elbow fractures from falling off a jungle gym or playset. Shin bruises and bumps on forehead are frequently seen in toddlers and young children learning to walk or run, and typically are not a reason to be concerned. Bruises in areas that are not typically bumped when walking/running (e.g., thigh bruises) should raise concern in a health care provider. Fractures of large bones (e.g., femur) that require large forces to break should also raise concern. Due to the more cartilaginous components of a child's chest, **it takes tremendous force to break a rib**. In accidental trauma, a child is more likely to have a pulmonary contusion without an overly rib fracture. The following injuries should raise concerns for child abuse: **rib fracture, fracture of base or vault of skull, contusion of eye, intracranial bleeding, multiple burns, and injuries in those younger than 1 year of age**. The majority of fatalities from child abuse in the United States are in children 3 years of age and younger, with the majority of those children under 1 year of age.

KEY FACTS

- Accidental trauma can occur from normal childhood falls, and it includes forearm or elbow fractures, shin bruises, and bumps of the forehead.
- These injuries should raise concerns for child abuse: rib fractures, fracture of the base or vault of the skull, contusions of the eye, intracranial bleeding, multiple burns, and injuries in those younger than 1 year of age.
- The majority of fatalities from child abuse in the United States are in children 3 years of age and younger, with the majority of those children under 1 year of age.

REFERENCE

Young DA, Wesson DA. "Trauma" in Cote CJ, Lerman J, Anderson BJ, eds. *A Practice of Anesthesia for Infants and Children*. 5th ed. Philadelphia, PA: Saunders Elsevier; 2013:789–93.

3. ANSWER: C

The presence of hypotension due to hypovolemia is a concerning sign in children and may signal impending cardiovascular collapse. Children will typically maintain their blood pressure for a **longer period** than adults following blood loss. The first sign of blood loss in a child may be **tachycardia**, which may appear when **10%** of the patient's blood volume is lost. Hypotension typically does not present **until 25%** of the patient's blood volume has been lost. As the typical blood volume for a child is 80 mL/kg, 20 mL/kg represents a loss of 25% of the patient's blood volume.

REFERENCE

Reynolds P, Scattoloni JA, Ehrlich P, Cladis FP, Davis PJ, "Anesthesia for the Pediatric Trauma Patient" in Davis P, Cladis F, Motoyama EK, eds. *Smith's Anesthesia for Infants and Children*. 8th ed. Philadelphia, PA: Elsevier Health Sciences; 2011:980–1.

4. ANSWER: A

While the primary goal of resuscitation is maintaining intravascular volume, massive transfusion after traumatic injury may result in a coagulopathy. The most likely causes are the dilution of clotting factors, decreased platelets (thrombocytopenia), or both. **Hypothermia** can contribute toward **difficulty clotting** and is a common problem

in victims of major trauma. As such, every effort should be made to avoid hypothermia during resuscitation, to prevent contributing to a coagulopathy. Fibrinolysis or disseminated intravascular coagulation (DIC) may also occur after a traumatic injury, but like hypothermia, neither is the most likely cause of coagulopathy.

Massive blood loss in pediatric trauma victims is typically the result of **injury to solid viscera or major vascular structures**. Massive exsanguination is thankfully uncommon in the pediatric population. If they sustain injuries that cause exsanguination, they typically die at the scene of the accident. In both adults and children, approximately 25% of trauma patients receive blood transfusions, and far fewer of civilian trauma patients are massively transfused.

There is no fixed formula for when to transfuse platelets and factors in pediatric patients. Most of the studies have been done in the adult population and extrapolated into pediatrics. Adult trauma literature suggests that transfusing plasma and platelets early can help prevent some of the acute coagulopathy that comes from trauma. Many adult centers use a 6:6:1 transfusion strategy (6 units PRBCs:6 units FFP:1 unit of pooled platelets) for trauma patients expected to receive a large volume of blood. There is currently no controlled trial in pediatrics to validate the results from the adult literature. Transfusing exclusively packed red blood cells (PRBCs) is known to **lead to dilution of clotting factors and platelets**, and more studies need to be done to assess the efficacy of various transfusion strategies in the pediatric population.

Sodium citrate and citric acid are used as anticoagulants in banked blood for transfusion. When large volumes of blood are transfused, especially rapidly, the patient receives a citrate load, and **hypocalcemia** (from decreased ionized calcium) and a **metabolic alkalosis** can result. This can be treated by giving the patient calcium chloride or calcium gluconate to replenish the calcium.

Two other potential problems with massive transfusion are **hypothermia** and **hyperkalemia**. Hypothermia can be alleviated by warming the blood products prior to or while transfusing them to the patient, as well as warming the patient. Hyperkalemia is more common with older blood products due to lysed RBCs. The potassium load can be diminished by transfusing the freshest blood possible. Another option to help with lowering the potassium is **washing** the blood cells, to remove excess calcium, prior to transfusion. As the RBCs need time to be washed, this is typically not something that can be done in the setting of massive transfusion of a trauma patient.

KEY FACTS

- Coagulapathy associated with massive transfusion is typically caused by dilution of clotting factors and/or decreased platelets (thrombocytopenia).
- Complications from massive transfusion include hypocalcemia, hyperkalemia, hypothermia, and a metabolic alkalosis.
- There have not been any pediatric studies to validate the 6:6:1 transfusion strategy used in adults.

REFERENCES

Cote CJ, Grabowski EF, Stowel CP, "Strategies for Blood Product Management and Reducing Transfusions" in Cote CJ, Lerman J, Anderson BJ, eds. *A Practice of Anesthesia for Infants and Children*. 5th ed. Philadelphia, PA: Saunders Elsevier; 2013:205–20.

Young DA, Wesson DA. "Trauma" in Cote CJ, Lerman J, Anderson BJ, eds. *A Practice of Anesthesia for Infants and Children*. 5th ed. Philadelphia, PA: Saunders Elsevier; 2013:796–803.

Dehmer JJ, Adamson WT. Massive transfusion and blood product use in the pediatric trauma patient. *Semin Pediatr Surg*. 2010;19:286–91.

Holcomb JB, Jenkins D, Rhee P, et al. Damage control resuscitation: directly addressing the early coagulopathy of trauma. *J Trauma*. 2007;62:307–10.

5. ANSWER: D

Children ages 15–19 years have the highest incidence of unintentional injury, assault, and self-harm. While older children have the highest incidence of injury, overall, they have the lowest incidence of mortality. Trauma is the leading cause of mortality for all children over 1 year of age. Most of the mortality is the result of motor vehicle accidents. Other causes of traumatic mortality in children over 1 year are falls, nonaccidental trauma (child abuse), drowning, and extremes of temperature. Under 1 year of age, the leading cause of traumatic death is due to child abuse. There are approximately 20,000 deaths in children annually due to traumatic injuries.

REFERENCE

Young DA, Wesson DA. "Trauma" in Cote CJ, Lerman J, Anderson BJ, eds. *A Practice of Anesthesia for Infants and Children*. 5th ed. Philadelphia, PA: Saunders Elsevier; 2013:789–93.

6. ANSWER: C

The mechanisms of injury are different in children than adults. The majority of trauma in children is **blunt trauma**. This is typically due to injuries such as motor vehicle accidents and falls. Adults are more likely to suffer penetrating trauma. Abdominal trauma is also more common in children, again due to the mechanisms of injury that children tend to suffer. While **thoracic trauma** is not as common as abdominal trauma, **it is the second leading cause of death due to trauma in children**, second only to traumatic brain injury. Internal injuries may be masked due to the **lack of fractures secondary to the cartilaginous**

nature of a child's thorax. Many blunt injuries are managed nonoperatively.

Tension pneumothorax secondary to trauma is more likely to occur in a child than an adult. It is also more likely to cause hemodynamic instability. The **mediastinum in children is more mobile**. If a pneumothorax occurs, it is more likely to cause shifting of the structures within the chest. The movement of the trachea and great vessels in the chest are more likely to cause instability. Needle decompression should be considered before instituting positive-pressure ventilation in a child with a tension pneumothorax to prevent worsening of the vital signs.

As a child's chest is more cartilaginous than an adult's, **it is very uncommon to sustain a rib fracture**. While rib fractures may need aggressive pain treatment if they occur, a rib fracture in a child should raise the suspicion for child abuse.

KEY FACTS

- Thoracic trauma is the second leading case of death due to trauma in children.
- Internal injuries can be masked due to lack of fractures.
- Tension pneumothorax secondary to trauma is more likely to occur in a child than an adult.

REFERENCE

Young DA, Wesson DA. "Trauma" in Cote CJ, Lerman J, Anderson BJ, eds. *A Practice of Anesthesia for Infants and Children*. 5th ed. Philadelphia, PA: Saunders Elsevier; 2013:791–7.

7. ANSWER: C

Cervical spine injuries are less common in children than adults. Fractures are less likely because of the more cartilaginous nature of their spine and the incomplete ossification of the vertebrae. When children obtain a cervical spine injury, **the injury typically occurs at a more cephalad location, C3 or above**. The cervical spine in children is at risk whenever there are substantial forces that occur during the method of injury, such as from a fall or a motor vehicle accident. Until a spinal cord injury is ruled out, spinal precautions should be followed, including during airway manipulation.

Pseudosubluxation of the cervical spine is a common finding in children. It appears as an anterior displacement of C2 on C3. Because of this radiologic finding, the person examining the child will need to determine whether it is a true injury or only benign pseudosubluxation. The appearance of pseudosubluxation can be reduced on X-ray by placing the child's head in a sniffing position. This should only be done after consultation with the surgeon due to the risk of spinal cord injury. Older children who can cooperate can have an odontoid/open mouth film taken to evaluate the more cephalad vertebrae and help rule out a fracture and account for the potential pseudosubluxation.

The **age** of the child and **pain** can be **confounding factors** when examining the child for cervical spine injury. If the child is unable to verbally express himself or herself due to age, the examiner has to rely on facial expression, guarding, and other less reliable inputs. Additionally, children may arrive in the emergency room without a parent present. This is especially common after a motor vehicle accident, which is a situation where there are often forces significant enough to cause a spinal cord injury. Due to fear, pain, and stranger anxiety, it may be difficult to get a "good exam" of the child's cervical spine, where actual pain may be elicited from palpation, without a parent present. Due to these difficulties, if a cervical spine injury is suspected, and if mental status is decreased or altered, **the cervical spine should be immobilized until further studies can be done**.

It can be difficult to rule out cervical spine injury in children based on X-rays alone due to spinal cord injury without radiographic abnormality (SCIWORA). This phenomenon may occur in 25%–50% of children with spinal cord injuries. According to ATLS guidelines, a CT scan of the neck to evaluate for fracture may replace X-rays. While this has increased the number of fractures found, not all injuries, especially ligamentous, can be found on X-ray or CT. If there is concern for a ligamentous injury or SCIWORA, a magnetic resonance imaging (MRI) should be obtained.

KEY FACTS

- Cervical spine fractures and injuries are less likely in children because of the more cartilaginous nature of their spine and the incomplete ossification of the vertebrae.
- The age of the child and pain can be confounding factors when examining the child for cervical spine injury.
- Approximately 25%–50% of children with spinal cord injuries may not have a radiographic abnormality (SCIWORA).

REFERENCE

Young DA, Wesson DA. "Trauma" in Cote CJ, Lerman J, Anderson BJ, eds. *A Practice of Anesthesia for Infants and Children*. 5th ed. Philadelphia, PA: Saunders Elsevier; 2013:791–7.

8. ANSWER: D

This patient has a Glasgow Coma Score of 7 (Eyes = 2, Motor = 4, Verbal = 1) and should be intubated due to his poor neurologic status (see Table 19.1). While all of the other choices may need to happen prior to going to the

Table 19.1 MODIFICATION OF THE GLASGOW COMA SCALE FOR PEDIATRIC PATIENTS

TYPE OF RESPONSE	SCORE*	AGE-RELATED RESPONSES		
		>1 YEAR	<1 YEAR	
Eye-opening response	4	Spontaneous	Spontaneous	
	3	To verbal command	To shouting	
	2	To pain	To pain	
	1	None	None	
		>1 Year	<1 Year	
Motor response	6	Obeys commands	Spontaneous	
	5	Localizes pain	Localizes pain	
	4	Withdraws to pain	Withdraws to pain	
	3	Abnormal flexion to pain (decorticate)	Abnormal flexion to pain (decorticate)	
	2	Abnormal extension to pain (decorticate)	Abnormal extension to pain (decorticate)	
	1	None	None	
		>5 Years	2–5 Years	0–2 Years
Verbal response	5	Oriented and converses	Appropriate words, phrases	Babbles, coos appropriately
	4	Confused conversation	Inappropriate words	Cries but is consolable
	3	Inappropriate words	Persistent crying or screaming to pain	Persistent crying or screaming to pain
	2	Incomprehensive sounds	Grunts or moans to pain	Grunts or moans to pain
	1	None	None	None

* Scoring: severe, <9; moderate, 9–12; mild, 13–15.

SOURCE: Modified from James HE, Trauner DA. The Glasgow Coma Scale. In: James HE, Anas NG, Perkin RM, eds. *Brain Insults in Infants and Children*. Orlando, FL: Grune & Stratton; 1985:179–82.

operating room for fracture repair, his airway management should take precedence. Per ATLS, with a **GCS of less than 8**, **intubation** is in order. Because many EMTs do not have extensive experience taking care of children, it would not be unusual for this child to show up at the emergency department with a low GCS without a breathing tube placed by the EMTs. The lack of intubation upon arrival at the hospital does not mean that the patient should remain with a natural airway.

The patient likely needs some pain treatment and, if he continues to be **hemodynamically stable**, **he should get a CT scan to evaluate for other injuries prior to going to the operating room to have his open fracture fixed**. The CT scan may be especially important due to his poor neurologic status, which may be representative of traumatic brain injury. However, if the patient were not hemodynamically stable, it would be better to take the patient for definitive care to maintain his hemodynamic status.

Because this patient is currently hemodynamically stable, there is not evidence to suggest he needs immediate transfusion. If there were clearly signs of massive hemorrhage, consideration should be given to transfusion as part of volume replacement in this patient.

KEY FACTS

- Patients who present with a GCS score of 8 and lower should be intubated.
- Patients that are hemodynamically stable should have a CT scan to evaluate for other injuries.

REFERENCE

Young DA, Wesson DA. "Trauma" in Cote CJ, Lerman J, Anderson BJ, eds. *A Practice of Anesthesia for Infants and Children*. 5th ed. Philadelphia, PA: Saunders Elsevier; 2013:789–803.

9. ANSWER: C

Smoke inhalational injury to the tracheobronchial tree is a concern when burn patients present. This is especially true for fires that occur in enclosed spaces (e.g., house fires). Although the number of patients with true inhalational injury is small, when it does occur there is a **high risk of morbidity and mortality**. External signs of inhalational injury include facial burns, blistering/edema of the oropharynx, mucosal lesions, scorched nasal hairs, carbonaceous

sputum/sooty secretions, singed eyebrows, hoarseness, and stridor.

Thermal damage, asphyxiation, and pulmonary irritation are the main mechanisms that lead to injury in patients exposed to smoke inhalation. Thermal damage is typically **limited to the oropharynx** because heat typically dissipates by the time the air reaches the trachea. Combustion of materials in a closed space can consume significant amounts of oxygen, leaving the patient in a hypoxic environment. In patients who have a high likelihood of inhalational injury, **early intubation should be considered**. If a patient needs to be transferred to a higher echelon of care, consideration should be given to securing their airway prior to transport.

Elevated heart rate is common after burns for a variety of issues and does not mean there is reason to consider intubation. Pain, fluid status, and inflammation are all reasons that the heart rate could be elevated.

Intubation should be strongly considered when the **total body surface area (TBSA) burned is 30%–40% or greater**. Along with swelling that may come from fluid resuscitation, **the incidence of inhalational injury increases as the TBSA percentage increases**. In burns that exceed 30% of the TBSA, if they also have bronchopulmonary injury, the mortality increases to 70%. Even without inhalational injury, with a large surface area burn, these patients often develop progressive upper airway edema in the first 48 hours. This can make delayed intubation difficult and even impossible.

While circumferential burns of the abdomen will likely require treatment with escharotomy and may impede the respiratory status if not treated, they are not typically a reason to consider intubation shortly after the patient presents to the hospital.

KEY FACTS

- True inhalational injury carries a high risk of morbidity and mortality. External signs of inhalational injury include facial burns, blistering/edema of the oropharynx, mucosal lesions, scorched nasal hairs, carbonaceous sputum/sooty secretions, singed eyebrows, hoarseness, and stridor.
- Intubation should be strongly considered when the TBSA burned is 30%–40% or greater.
- Large surface area burns often develop progressive upper airway edema in the first 48 hours.

REFERENCE

Shank ES, Cote CJ, Jeevendra Martyn JA, "Burn Injuries" in Cote CJ, Lerman J, Anderson BJ, eds. *A Practice of Anesthesia for Infants and Children*. 5th ed. Philadelphia, PA: Saunders Elsevier; 2013:715–27.

10. ANSWER: B

The Parkland formula represents the approximate crystalloid fluid needs over the next 24 hours. The formula is **4 mL/kg x patient's weight in kg x TBSA% burned**. In this patient that is 4 mL/kg × 20 kg × 20% burned = 1600 mL over the next 24 hours. A total of 800 mL of crystalloid should be given over the next 8 hours, with the following 800 mL over the following 16 hours. This is meant to guide fluid resuscitation so patients are more likely to receive enough fluid. Urine output (UO), which acts as a marker of organ perfusion, needs to be maintained and should be kept at 1 mL/kg per hour. If the UO falls, more fluid should be given.

The Parkland formula is not the only formula used for a burn victim's fluid resuscitation but is the most commonly used. Another formula, the Brooke formula, uses less fluid overall. Originally the Brooke formula employed the use of colloids. The modified Brooke formula uses **2 mL/kg × patient's weight in kg × TBSA% burned** and also titrates fluid administration to urine output. Because children have relatively higher daily fluid requirements than adults, the Parkland formula is used more commonly.

There is still debate about the use of colloids in burn patients. Some centers will use colloids when the patient's albumin levels fall, and others will employ it after 24 hours of resuscitation. As **capillary leakage will occur in burned tissue**, some feel colloids are not of significant benefit. There is currently no consensus on when, or if at all, colloids should be given.

Dextrose-containing solutions should not be used for fluid replacement for burn patients, though they can be used for maintenance solutions.

There is a **risk of over resuscitating** a patient with burn injuries, so the patient's hemodynamic status should also be used in guiding the resuscitation.

KEY FACTS

- The Parkland formula is 4 mL/kg x patient's weight in kg × TBSA% burned.
- Fluid administration should be titrated to urine output and should be maintained at 1 mL/kg per hour.
- There is ongoing debate about the appropriateness of colloid use given capillary leakage occurs in burned tissue.

REFERENCES

Shank ES, Cote CJ, Jeevendra Martyn JA, "Burn Injuries" in Cote CJ, Lerman J, Anderson BJ, eds. *A Practice of Anesthesia for Infants and Children*. 5th ed. Philadelphia, PA: Saunders Elsevier; 2013:718–27.

Renz EM, Cancio LC. "Acute Burn Care" in Savitsky E, Eastridge B, eds. *Combat Casualty Care: Lessons Learned from OEF and OIF*. Fort Detrick, MD: Borden Institute; 2012:607–11.

11. ANSWER: B

Any burn in an enclosed space also places the patient at risk for carbon monoxide poisoning. **Carbon monoxide binds to hemoglobin with a greater affinity than oxygen**. Carbon monoxide also absorbs the same amount of 660 nM light as oxyhemoglobin does. For this reason the pulse oximetry will be falsely elevated, as the carboxyhemoglobin can be misread as oxyhemoglobin. In this setting a pulse oximeter reading of 96% saturation should not be reassuring to the clinician.

Carbon monoxide is an odorless, colorless gas and is a major component of smoke in open fires. It causes tissue hypoxia by binding to hemoglobin and it also causes a **left shift of a oxyhemoglobin dissociation curve**, which reduces the ability of the blood to off-load oxygen. Carbon monoxide can also bind to heme molecules in myoglobin and decrease oxygen diffusion into muscle, including in the heart. The **amount of carbon monoxide in the blood is likely best detected by co-oximetry**. Co-oximeters measure absorption at several wavelengths of light and can distinguish carboxy- from oxy-hemoglobin. Most patients may be treated with 100% oxygen and time, but if they are more severely affected and have carbon monoxide encephalopathy, they may require hyperbaric oxygen treatment.

Cyanide (CN) poisoning can also occur after a fire due to incomplete combustion of nitrogen-containing materials. It is a colorless gas with a bitter almond odor. It is produced by the combustion of plastic, polyurethane, wool, silk, nitriles, rubber, and paper products, to name a few. **CN stimulates the chemoreceptors in the carotid and aortic bodies, which can lead to hyperpnea**. It interferes with metabolism on the cellular level by inhibiting cytochrome c oxidase and affecting the mitochrondria. This converts the cell to anaerobic metabolism and **lactic acidosis** ensues. High mixed venous oxygen saturation is often diagnostic for CN poisoning. CN toxicity can be treated by sodium thiosulfate or hydroxocobalamin.

While a venous blood gas may help you determine the patient's acid-base status and help with some other lab values, it will not help you determine whether the patient was exposed to carbon monoxide poisoning.

KEY FACTS

- Carbon monoxide has a greater affinity to hemoglobin than oxygen. Carboxyhemoglobin can be misread as oxyhemoglobin; therefore, pulse oximetry can give falsely reassuring readings.
- The amount of carbon monoxide in the blood is best detected by co-oximetry.
- Cyanide poisoning causes anaerobic metabolism and lactic acidosis, and it is characterized by high mixed venous oxygen saturation.

REFERENCE

Shank ES, Cote CJ, Jeevendra Martyn JA, "Burn Injuries" in Cote CJ, Lerman J, Anderson BJ, eds. *A Practice of Anesthesia for Infants and Children*. 5th ed. Philadelphia, PA: Saunders Elsevier; 2013:712–31.

12. ANSWER: C

The rule of nines is the typical way body surface area burns are estimated (see Fig. 19.1). The patient's palm represents approximately 1% of total body surface area. Because the head represents a larger TBSA in small children, they

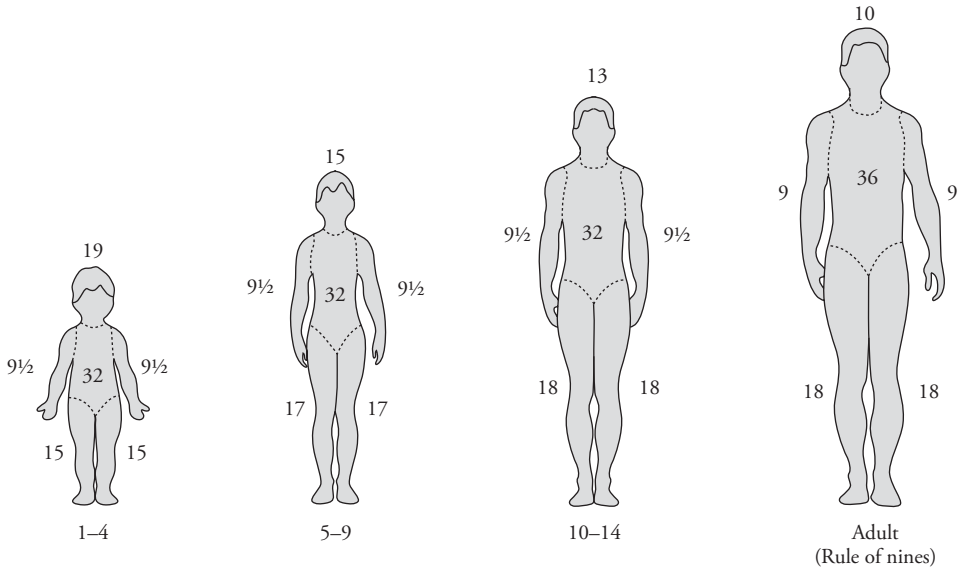

Figure 19.1 Rule of nines. (From Cote CJ, Lerman J, Todres ID, eds. *A Practice of Anesthesia for Infants and Children*. 4 ed. Philadelphia, PA: Saunders Elsevier; 2009.)

do not have the same "rule of nines" as adults (see Fig. 19.1), though the overall process of estimation is the same.

Scalds account for a larger portion of burns in children, up to 60%–70% of burns. Contact burns are the next most common and make up 20% of burns. Burns due to open flames are not very common.

While scald injuries are common, they can be representative of nonaccidental burns/trauma to the child. Things that are suggestive of **nonaccidental scald burns** are **a story inconsistent with injury, lack of splash marks, and clearly demarcated edges**—as if the patient had been dipped/submerged in the hot water. Scald burns often occur at ages that children are being **toilet trained** and are used by some as a punishment for accidents.

All scald burns are an opportunity to educate the families about safety measures that can be taken, such as turning pan handles in on the stove and turning the water heater to a lower temperature so scalding water does not leave the faucet.

KEY FACTS

- The rule of nines can be used to estimate the percentage of body surface area affected by burns, although it is adjusted by age given that the head represents a larger percentage of area in children.
- Scalds account for up to 60%–70% of burns.
- Nonaccidental scald burns might be suspected in cases where the story is inconsistent with injury, there is a lack of splash marks, or there are clearly demarcated edges.

REFERENCE

Shank ES, Cote CJ, Jeevendra Martyn JA, "Burn Injuries" in Cote CJ, Lerman J, Anderson BJ, eds. *A Practice of Anesthesia for Infants and Children*. 5th ed. Philadelphia, PA: Saunders Elsevier; 2013:712–31.

13. ANSWER: D

Burn injury can lead to the upregulation of fetal and mature acetylcholine receptors. This usually leads to a resistance to nondepolarizing muscle relaxants and an increased sensitivity to succinylcholine. This is noted to occur between 24 and 72 hours after injury. This is also noted to occur after stroke, spinal cord injury, prolonged immobility, prolonged exposure to neuromuscular blockers, multiple sclerosis, and Guillain-Barré syndrome. While burn injury upregulates the receptors, they are downregulated in myasthenia gravis, anticholinesterase poisoning, and organophosphate poisoning.

Resistance to nondepolarizers is typically seen in patients with at least 25% burns. It may take **months to years** for the receptors to return to normal. Potassium has been noted to markedly increase in burn patients following succinylcholine use. **Succinylcholine has been safely administered within 24 hours of a burn injury.** After this period, the muscle receptors are likely already altered, and succinylcholine should be avoided. Over time, as normal skin regrows, normal acetylcholine receptors return. While it is not known exactly how long to avoid succinylcholine, a conservative estimate avoids the use from 24–48 hours after injury to the next 1–2 years. Normal responses to succinylcholine have been demonstrated 3 years from the burn injury.

KEY FACTS

- Burn injuries cause an upregulation of acetylcholine receptors, leading to a resistance to nondepolarizing muscle relaxants and increased sensitivity to succinylcholine.
- Succinylcholine has been safely administered within 24 hours of a burn injury.
- Succinylcholine should be avoided between 24–48 hours after a burn up to the next 1–2 years.

REFERENCE

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14. ANSWER: B

This patient presented with circumferential burns. **Eschars often form over burned tissue and form quickly**. Eschars over full-thickness or deep-partial thickness burns may result in **vascular compromise** as the patient is resuscitated and develops edema. As the patient will likely have received a significant resuscitation by this time, this is a real concern for eschars in any location on the body. If the patient has thoracic-wall involvement, this can contribute to **respiratory issues** and appear similar to **restrictive lung disease**. It can also present as **abdominal compartment syndrome, with decreased cardiac output, venous return, and urinary output.** A beside escharotomy with electrocautery can help treat this quickly. The patient may need to progress to the operating room for full escharotomy if he or she is stabilized.

Extremities should be monitored for signs of ischemia from circumferential eschars as well. Signs showing an escharotomy is needed are the **five P's: pain, pallor, paresthesia, paralysis and pulselessness**. An emergent escharotomy may be needed if any of the aforementioned symptoms present to prevent limb loss.

While the ETT may eventually need to be changed due to mucous plugging, or potential sloughing of the mucosal

lining from inhalational injury, it is unusual to need to change a tube this early in the time course of the patient's hospitalization.

Bronchoalveolar lavage is not indicated in this scenario and would not acutely improve this patient's respiratory status.

While adequate pain management is very important in burn victims, inadequate sedation and analgesia are unlikely to cause the inspiratory pressures to increase.

KEY FACTS

- Eschars form quickly over burns and can result in vascular compromise, respiratory issues similar to restrictive lung disease, and abdominal compartment syndrome.
- An escharotomy is needed if the five P's are present: pain, pallor, paresthesia, paralysis, and pulselessness.

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15. ANSWER: C

When patients are burned, it disrupts their integumentary system. The patient's ability to regulate and maintain temperature is decreased due to large raw surfaces as well as **denervated areas that can no longer vasoconstrict** in response to cold. General anesthesia, which will be required to do the split-thickness skin grafting (STSG), also blocks thermoregulation.

While all surgical patients remain warmest when the operating room is also warm, it is especially important in burn patients. If their temperature is not maintained, it adds to their already **high metabolic demands** to facilitate heat production. Anesthesia leads to thermoregulatory vasodilation, which causes a **core to peripheral redistributation of body heat**. It is also easiest to maintain normothermia in the operating room when patients are vasodilated than to try to warm them postoperatively when they are vasoconstricted.

Cutaneous heat loss is proportional to the body surface area. In turn, the larger amount of area burned, the larger amount of area that will need to be exposed in burn debridement and grafting. The larger the TBSA burned, the warmer the operating room will need to be to maintain normothermia and prevent the problems of hypothermia.

Operating room temperature is the most important factor influencing heat loss in all surgical patients. The average adult surgical patient will maintain a core temperature if the room is 23°C, or 26°C for infants. **Core temperatures are higher in burn patients (38°C–39°C). Burn patients do best with an ambient temperature of 30°C–31°C.** This helps prevent heat loss due to **radiation**.

Convective warming, though very effective in most patients, **is often difficult to use in burn patients**. Due to the large amount of skin exposed to debride the wound, harvest skin, and place the skin grafts, it can be difficult to keep convective warming devices on the patient to help warm them.

Warming IV fluids helps prevent heat loss but is not an effective way to warm patients. Patients cannot be effectively warmed this way because you cannot substantially increase the fluid temperature above a patient's body temperature. Warming the intravenous fluids helps prevent heat loss but is not very effective. For each 1 L of fluid not warmed, the body temperature decreases 0.25°C.

KEY FACTS

- Burn patients have a decreased ability to regulate and maintain their temperature given that denervated areas can no longer vasoconstrict in response to cold.
- Anesthesia causes vasodilation, leading to redistribution of body heat from the core to the periphery.
- Burn patients do best with an ambient room temperature of **30**°C **–31**°C to help prevent heat loss from radiation.

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16. ANSWER: D

In the acute trauma setting, getting large-bore intravenous access is of paramount importance. Because patients may have a depleted intravascular volume, a peripheral IV may be difficult to place. In an acute trauma setting, when a patient needs treatment rapidly, **intraosseous (IO) access should be attempted**. Once the patient has received some resuscitation, additional intravenous catheters, either peripheral or central, can be obtained.

The site typically used in children is the **anteromedial surface of the proximal tibia**, approximately 1–3 cm below the tibial tuberosity. The military has also used IO lines in

other sites, such as the **distal femur, humerus, and sternum**, though none of these are routinely used in children.

Complications of IO access include subperiosteal infiltration, osteomyelitis, fracture, and emboli. A study by Guy in 1993 showed high success rates of placement in the prehospital as well as hospital setting (28 out of 32 attempts), and it can be placed by a wide variety of health care workers. There are a wide variety of IO needles on the market from a handheld drill style (EZ-IO device, Vidacare, San Antonio, TX) to using bone marrow biopsy needles.

The time needed and difficulty of placing central lines in small children preclude their routine use in the pediatric trauma bay. Because most would not place an arterial line in the trauma bay to slow down a drip to the operating room, one would not place a central venous line at this time either.

In this patient with a positive FAST exam, **there is a potential advantage to placing an intravenous line above the diaphragm in case large vessels are injured**. However, due to time sensitivity, an IO line should be placed to help stabilize the patient and then additional access can be obtained.

KEY FACTS

- In the acute trauma setting, an intraosseous line should be attempted for rapid treatment of hypovolemia when peripheral IVs may be difficult to place.
- The site typically used in children is the anteromedial surface of the proximal tibia.
- Complications of IO access include subperiosteal infiltration, osteomyelitis, fracture, and emboli.

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17. ANSWER: C

Drowning is the second leading cause of death due to injury in children, second only to motor vehicle accidents. It most commonly occurs between the ages of 1 and 4 years, and again from 15 to 19 years. It is more common in males and is most likely to happen close to your own home. There is an increased risk of drowning in children with epilepsy. In the United States, most drownings occur in pools and spas; in the developing world, drownings occur in bodies of water used for daily activities.

Early initiation of CPR is the most important initial step in this scenario. If there is concern for trauma causing the fall, C-spine precautions should be taken as the child is removed from the pool. A C-spine injury prior to/contributing to a drowning occurs less than 0.5% of the time. Because CNS injury is the most common cause of mortality and long-term morbidity after drowning, early effective CPR is most important. It is unknown how long someone can be submerged and not suffer injury, but it is likely **less than 5 minutes**.

Drowning happens rapidly in small children, often struggling only 10–20 seconds before being submerged. Experiments have shown that as the subject initially panics and struggles trying to get to the surface, small amounts of water enter the hypopharynx. **The water causes laryngospasm and the subject becomes hypoxic**. This starts a cascade of decrease in oxygen saturation and loss of consciousness, and finally cardiac arrest from hypoxia.

While pulmonary aspiration occurs in all drowning victims, the amount aspirated is usually small and does not obstruct the airways. The water can easily move into the pulmonary circulation after positive-pressure ventilation and wash out surfactant, causing **V/Q mismatch and shunting**.

Hypothermia is often associated with drowning victims. Mild hypothermia is a temperature of 34°C–36°C, moderate is 30°C–34°C, and severe is less than 30°C. Even after the child is removed from the water, cooling will continue due to the wet clothing. Theoretically it is possible to fall into cold water and cool the victim to a neuroprotective level. There are some reports of victims submerged in icy water for long periods with good neurologic outcome. Overall, however, **hypothermia is a poor prognostic sign**. Because victims will continue to cool when removed from the water, it is important to dry them off quickly and replace wet clothing if possible.

EMS should be notified after a drowning to take the victim to a hospital. The victim should be observed for 6–8 hours, even if he or she is asymptomatic. Almost 50% of pediatric victims have some level of **respiratory distress or hypoxemia** that progresses to **pulmonary edema** during the first 4–8 hours.

Drowning is a large public health problem and can be prevented. The most effective way to decrease drowning is prevention, especially at residential pools.

KEY FACTS

- Drowning is the second leading cause of death due to injury in children; it is second only to motor vehicle accidents.
- Early initiation of CPR is the most important initial step, and the victim should be taken to a hospital to

observe for possible progression of respiratory distress and pulmonary edema.
- Hypothermia can be neuroprotective, but it is a poor prognostic sign.

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Shephard E, Quan L. "Drowning and Submersion Injury" in Kliegman RM, Stanton BF, St. Geme JW, Schor NF, Behrman RE, eds. *Nelson Textbook of Pediatrics*. 19th ed. Philadelphia, PA: Saunders Elsevier; 2011:341–8.

18. ANSWER: D

Burn patients need pain treatment for multiple reasons, even after their initial injury. They undergo burn dressing changes, debridement, skin grafting, and physical therapy, and they often have to undergo resection of scar tissue and contractures. Partial-thickness burns tend to be more painful than full-thickness burns because **there are more nerve endings remaining intact in a partial-thickness burn**. Pain tends to be the most intense from the freshly harvested donor sites as they have the greatest number of nerve endings. A tumescent solution can be used by the surgeons intraoperatively to help decrease the pain.

Due to the number of procedures these patients undergo, it is important to manage their analgesic and antianxiety medications well. Proper pain treatment minimizes the patient's metabolic demands, which in turn aids healing. As burn patients acutely undergo changes in their metabolism and organ functions, there are several issues to be aware of in managing their medications. There is also a typical **decrease in albumin and an increase in alpha-1 glycoprotein**. The patients typically have an increased volume of distribution and have increased clearance of most drugs. **The effective doses may need to be rapidly escalated** due to rapid receptor changes going on in the burn victim.

Many different analgesics can be used to treat burn pain. Fentanyl, morphine, and hydromorphone are all options. Methadone, as it also acts as an **NMDA antagonist**, may help in decreasing the **hyperalgesia** and **minimize opioid tolerance** that many burn patients experience over the course of their treatment. As drug kinetics are different in burn patients, the half-life of methadone may not be as consistent as in other patients, so they need close monitoring due to its long half-life. **Ketamine**, a noncompetitive NMDA-antagonist, may also help with **hyperalgesia**. NSAIDs and acetaminophen can also be considered, but the patients need to be watched closely for renal or hepatic problems. Ketorolac is also an option; however, it has a very limited role in chronic use. Agents such as remifentanil and alfentanil have minimal use in burn patients due to their ultra-short half-life. **Remifentanil** may also contribute to **hyperalgesia** and should probably be avoided for that reason.

Burn patients often need rapid escalations of their dosing regimen. Some of this is likely due to **tolerance**; however, the opiate receptors are also thought to undergo thermal injury, which causes the doses needed to escalate rapidly. There may also be changes in the nociceptive pathways, contributing to the hyperalgesia they experience. It may also be that local changes in nerve endings take place after the burn or grafting procedures. After the skin wound is closed, the need for opiates rapidly decreases. Opiates and anxiolytics should be slowly titrated down to minimize issues with withdrawal.

In general, burn pain is better treated in burn patients when it is on a **regular standing schedule**, rather than as needed. While boluses of pain medications should be given prior to interventions such as dressing changes and physical therapy, pain medications should not be limited to those times. **Ketamine** may be especially helpful at the time of dressing changes.

In addition to analgesics, other medications should be considered. Appropriate anxiolytics can help treat the psychological stress of the burn and help facilitate their pain treatment. Stool softeners should be started to prevent side effects from the opiates. Also, diphenhydramine should be considered in patients, especially children, who have healing burns. Any movement of the graft or shear forces on the graft can cause graft failure—itching of the graft sites, which may result from medication effects or from granulation tissue, can seriously impair the healing process.

KEY FACTS

- Burn patients require a good regimen for pain control because of the frequency in which they will receive dressing changes, debridement, skin grafting, and surgeries for resection of scar tissue and contractures.
- Burn patients often need rapid escalations of their dosing regimen. Methadone, as an NMDA antagonist, may help in decreasing hyperalgesia and opioid tolerance.
- A standing schedule of pain medications with boluses for painful interventions is the best regimen for burn patients.

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19. ANSWER: A

Burn injuries create a hypermetabolic state as the body tries to repair and recover. The metabolic rate increases as a function of the size of the burn. Patients with a 60% or greater total body surface area (TBSA) burn are also at risk for increased mortality. Catecholamines, glucagon, and glucocorticoids work together to elevate the basal energy expenditure (higher resting temperature), refractory tachycardia, increased oxygen consumption, and increased carbon dioxide production. The time after a burn is a catabolic state with increased gluconeogenesis, glucose intolerance, insulin resistance, increased urea formation, and nitrogen loss. This all leads to delayed wound healing and muscle wasting. Thyroid (T3 and T4) and parathyroid hormone levels are also decreased after a burn.

The first 48 hours of a burn injury are considered the acute phase. During the acute phase the patient typically loses a large amount of protein and is hypovolemic. In the subsequent phase (after 48 hours) the **patient enters a hypermetabolic phase**. Cardiac output is increased, with increases in blood flow through the liver and kidneys, and this can vary as the patient continues healing. As the patient's metabolic demands are highest in the first few days following a burn, early excision and skin grafting decrease the metabolic demands, expedite healing, and improve the patient's physiology. Skin grafting helps prevent the fluid and heat loss at the individual sites.

Cold rooms will increase the patient's caloric demand because the body will attempt to generate heat. Providing environmental temperatures of 28°C–33°C, adequate covering during transport and liberal use of analgesics and anxiolytics can decrease caloric demands.

Burn injury patients require good nutrition to promote healing. Enteral feeding not only helps with their nutrition but it also helps decrease their chances of getting septic. Enteral feeding is important to introduce calories, maintain GI motility, and protect the mucosa. Without enteral feeds, the risk of infection and sepsis increases. While parenteral feeds can be used, they do not help maintain the integrity of the mucosal barrier in the gut. The mucosal barrier helps prevent bacterial translocation. Gastroduodenal ulcers are a common problem, unless the patient is treated with preventative measures such as PPI, H2 receptor antagonists, or neutralizing agents. Feeding can also help decrease the incidence of stress ulcers following a burn.

In large burns having a postpyloric feeding tube is helpful to maintain around-the-clock feeding. If the patient is unable to take food by mouth, a feeding tube should be placed early to help with caloric intake as well as the other benefits of enteral feeding. Postpyloric feeding tubes are preferred. There is no consensus on whether postpyloric feeds should be stopped before anesthesia or sedation. If the patient is not hemodynamically stable and on vasoactive agents, enteral feeding may be held until the patient is more stable. Some sources advocate enteral feeding via a Dobhoff or nasogastric tube in patients with a 30%–40% TBSA burn because it will be difficult to meet their caloric requirements by oral feeding. For children the estimated protein requirements are 3 g/kg per day after a burn.

KEY FACTS

- 48 hours after a burn, the patient enters a hypermetabolic state, with increased gluconeogenesis, glucose intolerance, insulin resistance, increased urea formation, and nitrogen loss.
- Early burn excision and skin grafting decrease the metabolic demands, expedite healing, and improve the patient's physiology.
- Enteral feeding is important for promoting good nutrition, maintaining GI motility, and protecting the mucosa to decrease the risk of infection and sepsis.

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20. ANSWER: C

Hypothermia is broken into categories based on the core body temperature. **Mild hypothermia is 34°C–36°C, moderate 30°C–34°C, and severe <30°C.** Treatment depends on where in the spectrum of hypothermia the patient lies. In this scenario the patient is suffering from moderate hypothermia.

The initial physiologic response to cold-water immersion is involuntary reflex hyperventilation, eventually apnea, and a severe bradycardia that is followed by supraventricular and ectopic tachycardias, which can eventually lead to ventricular fibrillation or asystole.

In severe hypothermia, resuscitation should follow the current AHA guidelines. CPR should begin while the patient's temperature is being obtained. If ventricular fibrillation or pulseless VT is present, **shocks should be limited to three shocks until the temperature is over 30°C**. Active internal rewarming should be started.

In moderate hypothermia, resuscitation should continue to follow the current AHA guidelines. **The IV medications should be spaced out because they will not clear as quickly due to the hypothermia**. The child's trunk should actively be rewarmed, with the rest of the body

undergoing passive rewarming. Rewarming should continue until the patient is 32°C–34°C.

In mild hypothermia, efforts should be made to get patients dry as well as to passively rewarm them.

While it is important to rewarm patients who are found in cold water, not all patients need to be completely rewarmed to abandon resuscitation. After 30 minutes, if a patient remains asystolic and was *not* found in icy water, resuscitation can be discontinued.

There is no clear evidence that maintaining hypothermia or inducing hypothermia after a cardiac arrest is helpful in children. At this point, it cannot be recommended.

KEY FACTS

- Treatment for cardiac arrest depends on where in the spectrum of hypothermia the patient lies.
- If ventricular fibrillation or pulseless VT is present, shocks should be limited to three shocks until the temperature is over 30°C. IV medications should be spaced out because they will not clear as quickly due to the hypothermia. Active internal rewarming should be started.
- There is no clear evidence that maintaining hypothermia or inducing hypothermia after a cardiac arrest is helpful in children.

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21. ANSWER: B

Electrical burns occur when a person comes in contact with or helps complete a live circuit.

Minor or low-voltage electrical burns are usually found in children and are often **the result of biting on a cord**. Burns typically happen at home, and the voltage is low enough (usually less than 500 volts) that deep tissue trauma is usually limited to what the burn demarcates. If the child develops **bilateral oral commissure burns** from biting a cord, it can present **airway difficulties**. Low-voltage burns are typically treated with the same principles as thermal wounds/burns.

High-voltage, also called high-tension, burns require further monitoring and treatment. They typically involve over 1000 volts and occur outside the home at places like electric power stations, railroads, and electric boxes. They carry a mortality rate of **3%–15%** and have a **high morbidity**, including **limb amputation**. The deep muscle is typically involved and is difficult to assess initially. Cardiac rhythm disturbances are common and may manifest as ventricular fibrillation or cardiac arrest. Without initial cardiac disturbances, all patients with high-voltage burns require EKG monitoring until they are completely assessed. Due to the number of organs involved in high-voltage injuries, **these victims should have all organ systems assessed as if they were polytrauma patients.**

The electricity enters through one point, but the patient may have **several exit wounds** and have tissue and organ damage in areas remote from the site of entry. **Entrance wounds** typically occur on the **upper extremities** with the **exit wounds** on the **lower extremities**. All of the intervening tissues (muscles, blood vessels, nerves) can be damaged as the electricity finds the fastest way to exit the body. Occasionally arcing occurs and results in a flame burn and clothing catching on fire.

Patients can develop **renal problems** from **deep muscle necrosis and myoglobinuria**. It is important to have early and aggressive **removal of all dead and devitalized tissue** to help facilitate wound closure. Early removal of dead tissue and debridement can facilitate earlier tissue closure and will decrease the metabolic demands. It is important to initially care for the patient's injuries and then proceed with more extensive plastic surgery to help improve function once the patient is stabilized.

KEY FACTS

- Minor or low-voltage electrical burns typically happen at home and are often the result of biting on a cord. Low-voltage burns are typically treated with the same principles as thermal wounds/burns and can present with airway difficulties.
- High-voltage burns carry a mortality rate of 3%–15% and have a high morbidity, including limb amputation and multiple-organ damage. Renal problems can develop from deep muscle necrosis and myoglobinuria.
- Entrance wounds typically occur on the upper extremities, and exit wounds on the lower extremities. There may be several exit wounds remote from the site of entry.

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22. ANSWER: D

Recently there has been an increased number of bombings throughout the world, many related to war but also many unrelated to war. Due to this, it is important to have some familiarity with blast injuries. Blast injury is broken into primary, secondary, tertiary, and quarternary.

Primary: injury caused simply by the increased pressure from the explosion itself, a rate injury

Secondary: most common and results from projectiles from the explosion

Tertiary: blunt force trauma as the victim is forced through the air and hits a structure

Quaternary: burns from the explosion

Primary blast injuries involve **air-filled structures**. The most common site injured is the **tympanic membrane,** which is ruptured in up to 20% of victims. This is followed by **lung and bowel** (most commonly cecum) injury at 7% and <1%. Tympanic membranes can be ruptured at 5 psi; alveoli can hemorrhage at 15 psi. If a patient does not have a tympanic membrane injury, a lung or bowel injury can still be possible. Lung injury is treated with airway and ventilator support.

While primary blast injuries just involve injuries from the pressure, secondary blast injuries are the most common. The type of projectiles may vary greatly—from a piece of the bomb itself to pieces of surrounding structures that are damaged in the blast and then hit the victims. There can be many victims with wounds from projectiles/shrapnel that may have been far enough from the blast as not to develop overpressure injuries as described.

After a blast injury, due to effects of the explosion, smoke, and injuries such as a TM perforation, the victims can be very disoriented. Children will often go to areas that are quiet or they find comfortable, away from the aftermath of the explosion. While this may provide some temporary solace, it may lead to **fatal entrapment**. Children are also not good at distinguishing escape routes and may easily become trapped.

KEY FACTS

- Primary blast injuries involve air-filled structures. The most common site injured is the tympanic membrane, which is ruptured in up to 20% of victims.
- Other injuries in primary blast injuries include lung and bowel injury.
- Secondary blast injuries that result from projectiles from the explosion are most common.

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23. ANSWER: D

Acute renal dysfunction or failure after a burn injury is a very real concern. **Intravascular volume depletion and hypoperfusion** contribute. Due to acute muscle breakdown/rhabdomyolysis, myoglobin can induce tubular damage and cause a mechanical obstruction from casts of myoglobin as well as products of hemolysis. **Electrical burn victims** are at an increased possibility of renal problems due to the large amount of muscle often involved in their burns and tissue breakdown.

To combat this potential renal damage, some steps can be taken:

1. **Adequate hydration**. As discussed previously, very important in these patients is the loss of large amounts of fluid from their open skin surfaces. This is likely the most important step in maintaining renal perfusion and preventing renal dysfunction in this scenario.
2. **Sodium bicarbonate** can be infused to help alkalinize the urine and prevent cast formation.
3. A Foley catheter with an urimeter should be placed in the burn victim to monitor and maintain urine output at 1 to 1.5 mL/kg per hour.
4. **Mannitol**, an osmotic diuretic, can be given to help maintain forward flow and prevent mechanical obstruction from casts. Due to the potential for these patients to be volume depleted, it is very important to make sure the patient has undergone volume replacement prior to giving mannitol. Then it is also important to also **replace the fluid that the patient loses after diuresis has started.**
5. **Furosemide has not been shown to be helpful** in this scenario and should be avoided. **It may worsen renal failure**.

In addition to these steps, thermally damaged tissue may release atrial natriuretic peptide (**ANP**), which will help maintain the intravascular volume. This can improve renal blood flow and urine output that may occur from a low-flow state.

It is also important to monitor for **hyperglycemia**. Due to the significant stress response from a burn, hyperglycemia may occur. Large amounts of glucose will act as an **osmotic diuretic** and worsen the intravascular volume.

KEY FACTS

- Intravascular volume depletion, hypoperfusion, and rhabdomyolysis all contribute to acute renal dysfunction and failure after a burn injury.
- Treatment options include adequate hydration to maintain urine output at 1 to 1.5 mL/kg per hour, sodium bicarbinate, and mannitol. Use of furosemide

and hyperglycemia can worsen renal failure and should be avoided.
- Atrial natriuretic peptide is released to help maintain intravascular volume and improve renal blood flow.

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24. ANSWER: A

Hypertonic saline offers the advantage of helping volume resuscitate the patient while concurrently lowering the intracranial pressure (ICP). Hypertonic saline has the advantage that **it does not create an osmotic diuresis**, as mannitol would, at a time when this patient likely is hypovolemic and would benefit from an increased intravascular volume. In the short term, fentanyl may interfere with a neurological assessment and will not address the patient's issues with elevated ICP. It is important to balance treating the patient's pain with needing to assess neurological function. Mannitol may eventually need to be given in this patient but could acutely worsen the patient's intravascular volume, shortly after presentation to the hospital.

Hypertonic saline can be bolused 2–4 mL/kg acutely and then infused at 0.1–1 mL/kg per hour. It works by increasing the serum osmolality and can help maintain the intravascular volume for longer periods than an isotonic solution. It also creates an osmotic gradient between the intravascular and interstitial fluid compartments and leads to **shrinkage of brain tissue**. It needs to be given cautiously as **central pontine myelinolysis** can result if given too rapidly, along with coagulopathies, electrolyte abnormalities, and fluid overload. It can also lead to a **non-anion gap acidosis**.

Mannitol lowers the ICP by lowering the cerebral blood volume while maintaining cerebral blood flow. It acts as an osmotic diuretic. The diuresis can lead to **hypotension**, especially if the patient is already hypovolemic, as this patient likely is. If mannitol is given, it is important to have a Foley catheter in place to help monitor the urine output so that volume can be replaced in the patient.

If the ICP is significantly high following a head injury, **mannitol and hypertonic saline can be given simultaneously** while monitoring for many of the side effects previously discussed.

KEY FACTS

- Hypertonic saline increases the serum osmolality while also maintaining the intravascular volume. It creates an osmotic gradient between the intravascular and interstitial fluid compartments and leads to shrinkage of brain tissue.
- If given too rapidly, a patient can develop central pontine myelinolysis, coagulopathy, electrolyte abnormalities, and fluid overload.
- Mannitol can also lower ICP, but it acts as an osmotic diuretic and can result in hypotension.

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25. ANSWER: B

The primary survey in a trauma patient is to assess the airway, breathing, circulation, disability (neurologic), and exposure/control of the environment. Secondary and tertiary surveys take it further and do a more in-depth study of the issues found in the primary survey.

The goal of the primary survey is to **quickly assess and treat life-threatening issues**. These typically include airway obstruction, respiratory insufficiency, shock from hemorrhage, and CNS injury. Once those things are established, the investigation can proceed further.

A FAST exam stands for **focused assessment with sonography for trauma.** This exam is noninvasive and can quickly assess the following four areas: perihepatic and hepatorenal space, perisplenic space, pelvis, and pericardium. It is most commonly used for **abdominal trauma** but can also be used when the patient is hypotensive or has a head injury and may not be reliable in the patient's history.

If the FAST exam is negative, and there is still concern for abdominal injury or trauma, the patient can be taken for a CT scan, if hemodynamically stable. If the patient is not hemodynamically stable and there is concern for hemorrhage, the patient should often be rapidly taken for an exploratory laparotomy in the operating room.

If the FAST exam is positive, **the patient likely needs operative treatment**. It is important, however, in polytrauma patients to not forget about the other organs that are potentially damaged, including the brain and central nervous system. It is also important to evaluate for bilateral breath sounds to evaluate for a hemothorax/pneumothorax.

Also, in the trauma bay or operative setting, if the patient rapidly needs a life-saving operation, it is important to not

delay the surgical care of the patient by delaying operative treatment with procedures such as arterial line placement. If the patient actively needs surgery, surgery can be started and arterial lines can be placed afterward.

It is also important, if in the primary survey an issue is found early on, to not get distracted and fail to complete the entire workup of the patient. One of the challenges of polytrauma in pediatric patients is that **it can be difficult to have multiple people assessing the patient at once time due to the patient's physical size**. Thankfully, most pediatric trauma patients do not require operative care and are often managed conservatively in the ICU or on the ward.

KEY FACTS

- The primary survey in a trauma patient is to assess airway, breathing, circulation, disability (neurologic), and exposure/control of the environment.
- A FAST exam is noninvasive and assesses the perihepatic and hepatorenal space, perisplenic space, pelvis, and pericardium.
- Most pediatric trauma patients do not require operative care and are often managed conservatively in the ICU or on the ward.

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SECTION IV

CLINICAL SCIENCE OF ANESTHESIA

20.

EVALUATION OF COEXISTING DISEASE

Jacob T. Arnett and Chien-Hsiang Chow

1. A 7-month-old female is referred for a transthoracic echo due to a murmur that her pediatrician auscultated on physical exam. A 0.4 cm ASD is visualized at the center of the intra-atrial septum and is believed to be an ostium secundum defect. The echo report shows a pulmonary-to-systemic blood flow (Qp:Qs) of 1.2. The most appropriate treatment at this time is:

A. Open surgical closure as right heart failure is likely in the near future
B. Medical therapy with indomethacin
C. Observation
D. Percutaneous closure to avoid Eisenmenger's syndrome in the future

2. A 1-year-old-male with a history of Tetralogy of Fallot presents for a sedated transthoracic echocardiogram. His cardiac surgeon is in the process of surgical planning and needs a repeat echocardiogram. During an IM induction the child becomes hypoxic and cyanotic. You quickly flex his hips and knees and begin a phenylephrine infusion, in addition to a fluid bolus. His blood pressure is stable but his oxygen saturations are slow to increase. The next step in pharmacologic management includes which of the following?

A. Small boluses of esmolol
B. Deepening the anesthetic by increasing the inhaled anesthetic concentration
C. Starting a milrinone infusion to reduce pulmonary artery pressures
D. Small boluses of epinephrine to increase systemic vascular resistance and reduce pulmonary pressures

3. Which of the following best describes autism?

A. Psychiatric disorder characterized by culturally inappropriate behaviors
B. Psychiatric disorder characterized by impairment in development of culturally normal relationships
C. Organic disorder characterized by developmental delay
D. Organic disorder characterized by seizures of varying frequency

4. An 11-year-old male with a history of dyskinetic cerebral palsy is seen with his parents prior to placement of a baclofen intrathecal pump. The mother relays that no medications were taken for 2 days prior to surgery, as he refused to take them. A peripheral IV is placed in the induction area and dexmedetomodine is started as a premedication for anxiolysis. Five minutes later the nursing staff requests your immediate presence. The child is unresponsive and appears to be having a tonic-clonic seizure. The most likely cause of the seizure is:

A. Side effect from dexmetetomidine
B. Electrolyte abnormality
C. Subacute meningitis
D. Medication withdrawal

5. Succinylcholine use is likely considered acceptable in which of the following patients?

A. A 7-year-old male having an open-reduction, internal fixation of a supracondylar humeral fracture whose mother has a history of malignant hyperthermia
B. A 13-year-old female with a history of a 70% BSA deep burn sustained 5 months ago having a contracture release
C. A 9-year-old male with a history of spastic cerebral palsy having an Achilles tendon lengthening procedure
D. An 11-year-old male with notable pseudohypertrophy of the calves scheduled for a muscle biopsy under general anesthesia

6. A 9-year-old male with a history of cystic fibrosis is evaluated prior to laparoscopic appendectomy. Preoperative labs show an elevated PT and INR but normal PTT and platelet values. What is the most likely cause of the elevated PT/INR?

A. Intestinal malabsorption
B. Warfarin use
C. Perioperative enoxeparin use
D. Hemophilia A

7. A 2-year-old male with a history of Trisomy 21 is scheduled for an ophthalmic exam under anesthesia. With regard to planning airway management, which of the following statements regarding the airway management is true?

A. Microglossia may make for a challenging direct laryngoscopy.
B. Hypertonia may be present, causing upper airway obstruction.
C. Macrognathia is a common finding.
D. Airway manipulation may be limited due to potential for cervical spine instability.

8. A 3-year-old child with recurrent tonsillitis is evaluated prior to a tonsillectomy. The parents report that the child's pediatrician noted a heart murmur at a recent visit, but they have no other details. The mother relates that the child is doing very well and she did not have any concerns prior to the pediatrician's visit. You observe the child smiling and appearing comfortable in her mother's arms. When auscultating the heart, you appreciate a II/VI systolic murmur at the left-lower sternal border. The child moves in her mother's arms and the murmur becomes very faint and difficult to appreciate. Which of the following is most likely true?

A. The child should be referred for an electrocardiogram (ECG) and a transthoracic echo prior to anesthesia.
B. The murmur may not be significant during activities of daily living (ADLs) but will likely be an issue during an inhalational induction when systemic vascular resistance decreases.
C. The murmur is most likely not clinically significant and she can proceed to surgery without further diagnostic testing.
D. The murmur likely represents significant underlying cardiac pathology; she should be sent to the emergency room for admission and a complete workup.

9. A 9-week-old male is scheduled for a pyloromyotomy for pyloric stenosis. He was admitted 20 hours prior to the time of surgery and was resuscitated in the pediatric intensive care unit (PICU). The PICU team reports his electrolytes have normalized, and he appears euvolemic. In reviewing the child's labs you notice his hemoglobin is 10.1 g/dL. This hemoglobin level:

A. Likely reflects an iron-deficient anemia from malabsorption/chronic vomiting
B. Likely reflects a gastrointestinal bleed with acute blood loss anemia, which will require blood transfusions in the operating room
C. Likely reflects hemodilution from the IV fluid resuscitation
D. Likely represents a normal lab finding for a 9-week-old male

10. A 9-month-old male is seen in preop prior to a circumcision, which is being completed for cosmetic reasons. His parents report a normal perinatal history with no major problems since the time of birth. During a review of systems, his father reports that he has been able to sit alone and recently showed the ability to stand up. He babbles but has yet to speak any words. He smiles and plays "peek-a-boo" with his mother but does not seem to play with his twin brother. The above developmental status of this child is likely:

A. Normal and appropriate for his age
B. Globally abnormal and indicates developmental delay
C. Motor development is normal but social development is delayed
D. Social development is normal but motor development is delayed

11. With regard to child and parental preoperative anxiety and emotional stress in the preoperative period, which of the following is true?

A. Children younger than 7 years experience less anxiety than older children because they do not understand the danger of anesthesia/surgery.
B. Midazolam given for preoperative anxiety gives satisfactory anxiolysis and sedation in approximately one third of children.
C. Discussion of specific anesthetic risks will significantly increase parental anxiety in the preoperative period.
D. Child temperament is generally not indicative of preoperative anxiety and coping strategies.

12. A 4-year-old female has a broken arm and is scheduled for an open reduction internal fixation of the humerus. During the preoperative evaluation the

mother requests that she be present during induction of anesthesia. What could be done to adequately prepare the mother for her presence during the induction of anesthesia?

A. Nothing, it is not routinely recommended
B. Explaining that the most upsetting areas for parents are when the child goes limp and when the parent has to leave the child
C. Telling the mother that she should be quiet during induction and not to distract her daughter as she goes to sleep
D. Explaining to the mother that studies have shown unequivocally that pediatric patient anxiety is lowest with a parent present during induction

13. An 8-year-old male with an anterior mediastinal mass comes to the preop clinic for preoperative evaluation prior to a mediastinoscopy. On evaluation the patient is able to tolerate lying supine, but you notice that he has distended neck veins, facial swelling, and has been complaining of difficulty breathing. Which of the following test/s should be ordered in the evaluation of this mass?

A. Exercise electrocardiogram
B. Gastric motility study
C. Positron emission tomography (PET) scan
D. Pulmonary function tests

14. A 12-year-old male with an anterior mediastinal mass is scheduled for a mediastinoscopy. On evaluation the patient is able to tolerate laying supine and the patient's preoperative echocardiogram shows no signs of vascular compression. Which of the following is the most appropriate technique to induce anesthesia in this patient?

A. Rapid sequence induction with cricoid pressure
B. Intravenous induction with propofol
C. Inhalational induction
D. Intravenous opioid-based induction for hemodynamic stability

15. An 8-month-old with a history of spina bifida occulta is scheduled for a repair of a umbilical hernia. During the initial history the patient's family states that the child has had rashes after dental procedures. During the procedure the child suddenly develops hives, becomes hypotensive, and difficult to ventilate. What type of hypersensitivity reaction is responsible for the patient's symptoms?

A. Type 1 hypersensitivity reaction
B. Type 2 hypersensitivity reaction
C. Type 3 hypersensitivity reaction
D. Type 4 hypersensitivity reaction

16. Neonates and infants with gastroesophageal reflux disease (GERD) can present with which of the following symptoms?

A. Prolonged PT/INR
B. Failure to thrive
C. Renal insufficiency
D. Rhinorrhea

17. An 8-month-old infant presents to the hospital for repair of an inguinal hernia. Other than moderate GERD, the patient is healthy but was born at 29 weeks gestation. Which of the following would be appropriate premedication and/or intervention in this child prior to induction of anesthesia?

A. Proceeding with surgery 4 hours after breast milk
B. Famotidine
C. Pantoprazole
D. Magnesium

18. Which of the following is most consistent with asthma and management of asthma?

A. Wheezing is produced by a combination of upper airway inflammation and bronchospasm.
B. Appropriate therapy includes bronchodilators, anti-inflammatories, mast cell stabilizers, and leukotriene inhibitors.
C. Immunoglobulin D is associated with the disease process.
D. Manifestations of the disease include accessory muscle use, coughing, and prolonged inspiration.

19. A 1-year-old is to undergo a laparoscopic Nissen fundoplication in the morning. Three hours prior to surgery the patient was given formula by her parents. What is the appropriate fasting interval for this particular situation?

A. 2 hours
B. 4 hours
C. 6 hours
D. 8 hours

20. Which of the following decreases the risk of respiratory complications in the setting of upper respiratory infection?

A. Delaying surgery 3 weeks
B. Using an LMA in place of an endotracheal tube
C. Preoperative beta agonists (albuterol)
D. Cavity, head, or neck surgery

21. Select the statement most true regarding anesthetic risk:

A. Risk for both major and minor adverse event in pediatric patients exceeds that for adult patients.
B. Nausea is the most common adverse event in all pediatric patients.
C. Children between the ages of 1 and 12 months are at greatest risk for major adverse event among pediatric patients.
D. Children between the ages of 1 and 12 months undergo cardiac surgery more frequently than other pediatric patients.

22. Please select which of the following qualities is true in the context of pediatric patient consent?

A. Children younger than 7 years of age are typically capable of assenting due to their decision-making ability.
B. Between the ages of 7 and 14 years, children reliably develop decision-making skills.
C. Children above the age of 14 years may reliably hold adequate decision-making skills.
D. Children above the age of 14 years have developed the cognitive and emotional skills required to fully participate in the process of consent.

23. A 14-year-old male presents to a preoperative clinic 2 weeks prior to a planned knee arthroscopy. The patient had myringotomy with drainage tubes placed at 2 years of age without incident. The patient has no medical issues aside from his knee. What would be the most appropriate assessment tool?

A. Complete blood count and basic metabolic panel
B. Complete blood count and electrocardiogram
C. Complete blood count
D. No lab assessment

24. Select the answer which is most consistent with parental presence on induction of anesthesia (PPI).

A. PPI is absolutely contraindicated above the patient age of 18 years.
B. PPI is a benign process for the parent.
C. A possible benefit of PPI is reduction in need for preoperative sedation.
D. A possible benefit of PPI is reduction of parent anxiety.

25. Choose the correct statement regarding psychosocial preparation of pediatric patients preoperatively.

A. Children aged 5–10 years receive little benefit from preparation programs aimed at enhancing coping skills.
B. Children under the age of 3 years receive a great deal of benefit from preparation programs aimed at enhancing coping skills.
C. Prior hospitalization routinely aids in calming children undergoing surgery.
D. Parental anxiety is strongly associated with child anxiety.

26. Which severe disease state is commonly associated with seizure disorder and is strongly associated with impaired oromotor function and recurrent aspiration pneumonia?

A. Idiopathic scoliosis
B. Cerebral palsy
C. Cystic fibrosis
D. Trisomy 21

27. An 11-year-old Caucasian male with cystic fibrosis presents with abdominal pain and is scheduled for a laparoscopic appendectomy. Which of the following treatment plans optimizes his postoperative outcomes?

A. Cessation of preoperative bronchodilators
B. Prophylactic broad spectrum antibiotics
C. Incentive spirometry and postural drainage
D. Low-calorie diet, continuation of pancreatic enzyme replacement, and fat-soluble vitamin supplements

28. A 2-month-old infant who was born at 30 weeks gestation with complete bladder extrophy presents for exploratory laparotomy and intestinal stricture resection. This is her fourteenth general anesthetic. Once a new Foley catheter is placed in the operating room, her electrocardiogram (EKG) demonstrates sinus tachycardia, a noninvasive blood pressure cannot be obtained, and the ventilator alarms because her peak airway pressures acutely increase >40 cm H_2O. Which of the following is most important in treating this patient?

A. Administer H1 and H2 blockers
B. Administer epinephrine
C. Administer corticosteroid
D. Send blood specimen for mast cell tryptase level

29. A 13-year-old otherwise healthy boy presents for resection of an anterior mediastinal mass. He and his parents note that for the last 9 months, he has not been able to participate during recess at school because of progressive tiredness, he has a constant dry cough, and he uses two pillows to sleep comfortably at night. As you examine him, you notice plethora of his neck and face. Which of the following preoperative studies best detects evidence of dynamic airway compression in this patient?

A. Chest X-ray
B. CT scan
C. Cardiac echocardiogram
D. Pulmonary function tests

30. A talkative 7-year-old boy with Williams syndrome presents for tonsillectomy and adenoidectomy for sleep apnea and recurrent tonsillitis. Which of the following findings is most alarming during your preoperative assessment?

A. Moderate aortic stenosis
B. Rhinorrhea and dry cough
C. Micrognathia with prominent incisors
D. 4 + tonsils

31. A 3-year-old boy with Tetralogy of Fallot is scheduled for urgent left groin exploration with possible orchiopexy versus orchiectomy for left testicular torsion. He has had groin pain for 4 hours and arrives from the emergency department with three failed intravenous attempts. As he begins to cry in the preoperative holding area, you notice his lips turning blue. Bearing in mind hemodynamic goals for a patient with Tetralogy of Fallot, what should you do next?

A. Administer oral midazolam and provide oxygen by facemask.
B. Administer intramuscular ketamine and provide oxygen by facemask.
C. Place a peripheral intravenous to increase his intravascular volume.
D. Find a junior partner to do the case for you.

32. If this same 3-year-old boy with Tetralogy of Fallot and testicular torsion is now in the operating room and is crying, what is the best way to safely attenuate a hypercyanotic episode in this patient with Tetralogy of Fallot and no intravenous access?

A. Use EMLA, then place an intravenous to administer an anxiolytic, crystalloid, and phenylephrine.
B. Proceed with mask induction with cricoid pressure, high inspired concentration of sevoflurane, and 100% FiO_2.
C. Proceed with mask induction with cricoid pressure, high inspired concentration of sevoflurane, and 80% N_2O/20% O_2.
D. Administer intramuscular ketamine and provide supplemental oxygen.

33. A chubby 2-year-old with Down syndrome has severe obstructive sleep apnea with an apnea-hypopnea index of 42 and presents for tonsillectomy and adenoidectomy. She feeds well, her parents report appropriate weight gain with no sweating or cyanotic episodes with feeds, and she walks without difficulty in the preoperative holding area. As you examine the patient, you notice Down facies, macrocephaly, macroglossia, and you hear a holosystolic murmur on auscultation. What should you do next?

A. Obtain a chest X-ray.
B. Obtain an EKG and cardiac echocardiogram.
C. Obtain a cardiac stress test.
D. Proceed with surgery.

34. A 13-year-old severely autistic adolescent presents for dental rehabilitation. Dentists have been unsuccessful in examining his teeth in the office because he is a "biter." He has poor dental hygiene because he will not allow anyone to brush his teeth or place anything near his face. Which of the following options is most reliable in inducing general anesthesia in this severely autistic patient?

A. Intravenous induction with propofol and fentanyl
B. Inhalational induction with sevoflurane
C. Oral midazolam, then inhalational induction with sevoflurane
D. Intramuscular ketamine, then inhalational induction with sevoflurane

35. A 14-year-old girl with asthma and idiopathic scoliosis with a Cobb angle of 60 degrees presents for T2-pelvis posterior spinal fusion with instrumentation. She appears thin, tearful, and nervous in the preoperative area. Her parents inform you that they are Jehovah's Witnesses and do not want any transfusion of blood or blood products to their daughter. She is in the middle of menses now. What is your most important perioperative concern for this patient and her upcoming major surgery?

A. Discussion of anxiolytic strategy
B. Discussion of blood conservation strategies
C. Discussion of neuromonitoring and possible wake-up test
D. Discussion of susceptibility to malignant hyperthermia

36. A neonate with hypertelorism, midface hypoplasia, seizures, and tetany presents for omphalocele repair. Given the nature of this major surgery, which will likely involve large fluid shifts and potential transfusion of blood products, which of the following is the most important part of your preoperative evaluation?

A. Focused airway exam
B. Cardiovascular workup

C. Evaluation of electrolyte abnormalities
D. Ensuring appropriate urine output

37. A full-term 3 kg neonate male with a large, prenatally diagnosed myelomeningocele presents for myelomeningocele repair and placement of a VP shunt for hydrocephalus. What is your primary reasoning for recovering this patient in an ICU-level setting?

A. Fluid resuscitation
B. Postoperative respiratory monitoring
C. Proper patient positioning
D. Maintaining euthermia

38. An ex-28-week, now 6-week-old twin B has a unilateral inguinal hernia. He is now 4 kg. You administered a single-shot spinal with 0.4 cc 0.5% bupivacaine for your anesthetic, in your efforts to avoid post-operative apnea in this former preterm infant. After the hernia sac has been dissected, the infant starts moving his legs. Since he is under the surgical drapes, you cannot repeat the spinal. Which of the following techniques safely prevents postoperative apnea in this baby?

A. Ask the surgeon to supplement with local to the surgical field.
B. Induce general anesthesia but use fentanyl instead of morphine.
C. Induce general anesthesia but administer no narcotic.
D. Supplement with ketamine to keep the baby breathing spontaneously.

39. A full-term, now 6-week-old firstborn male presents with 4 days of nonbilious projectile vomiting, and an ultrasound confirms hypertrophic pyloric stenosis. He is scheduled for laparoscopic pyloromyotomy for hypertrophic pyloric stenosis. Which of the following sets of laboratory values best indicates that this infant is ready for surgery?
Na^+ K^+ Cl^- HCO_3^-

A.	130	3.1	89	34
B.	142	3.8	105	25
C.	150	3.2	102	32
D.	142	3.6	92	28

40. An ex-31-week, now 4-year-old boy presents for circumcision for phimosis. He has received no vaccinations and has been febrile for the past 36 hours. As you examine him in the preoperative holding area, you observe rhinorrhea, hear diffuse rales in his lung fields bilaterally, and see the patient cough up yellow sputum. How do you proceed?

A. Proceed with GA, use an LMA to avoid intubation, supplement with a dorsal penile block.
B. Administer albuterol in preop holding, then proceed with GA.
C. Administer steroids and azithromycin, then proceed with GA.
D. Postpone this elective procedure for at least 4 weeks.

41. A 16-year-old, African American male with sickle cell disease presents for laparoscopic cholecystectomy. He is maintained on chronic folic acid and hydroxyurea therapy. Which of the following would be most deleterious to him in the perioperative period?

A. Liberal use of analgesics
B. Transfusion of phenotype-matched, leukocyte-reduced blood to target hemoglobin 10 g/dL
C. Hyperventilation to $EtCO_2$ < 25 mm Hg
D. Intraoperative use of inhaled nitric oxide

42. A 5-year-old girl with Beckwith-Wiedemann syndrome has hemihypertrophy and presents for left distal femur epiphysiodesis. Her parents report that she had a perinatal omphalocele repair with no complications, and that all of her follow-up screens for somatic tumors have been negative. You plan a combined general anesthetic and femoral nerve block catheter for postoperative analgesia. Which of the following studies would most strongly influence your perioperative care for this patient?

A. Fingerstick glucose
B. Liver function tests
C. Cardiac echocardiogram
D. Caffeine-contracture testing for malignant hyperthermia susceptibility

CHAPTER 20 ANSWERS

1. ANSWER: C

Atrial septal defects (ASDs) are common congenital cardiac lesions and can vary in severity and timing of presentation. The vast majority (75%) of ASDs are ostium secundum defects that occur at the center of the interatrial septum in the region formerly occupied by the foramen ovale. Septum primum ASDs are due to endocardial cushion defects, which leave a large opening in the center of interatrial septum. There are also sinus venosum defects, which are rarer.

In the absence of other major cardiac anomalies, ASDs will initially be acyanotic lesions as blood generally shunts left to right. Small ASDs, such as in this question, are generally watched and not intervened upon. They typically create a **systolic ejection murmur** at the left upper sternal border, which may be mistaken for a flow murmur, particularly in a well-appearing child. Larger lesions (e.g., approaching 2 cm in diameter) can lead to significant shunting causing increased flow through the pulmonary circulation. An echo that reveals a **Qp:Qs of > 1.5** signifies significant shunting and may warrant closure, either open or by percutaneous intervention. The long-term consequences include **right-heart failure**, **pulmonary hypertension**, and if untreated, **reversal of the shunt** if right-heart pressure exceeds the pressure in the left heart.

Anesthetic considerations for patients with ASDs are based around management of the SVR:PVR ratio. If the PVR drops considerably, there will be increased shunting and worsened right-heart signs/symptoms. Conversely, if the PVR is allowed to rise due to hypoxia, hypercarbia, acidosis, or hypothermia, this may lead to transient development of a cyanotic lesion. It is imperative to remember than even if only left-to-right shunting is present on echo, there is still a risk of **paradoxical emboli**. Many patients do well for years, and the ASD may actually be undetected, in which case they may not present until adulthood.

KEY FACTS

- In the absence of other major cardiac anomalies, ASDs will initially be acyanotic lesions as blood generally shunts left to right.
- Larger lesions with a Qp:Qs of > 1.5 and significant shunting may lead to right-heart failure, pulmonary hypertension, and reversal of shunt flow if untreated.
- Anesthetic considerations for patients with ASDs are rooted in management of the SVR:PVR ratio.

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2. ANSWER: A

Tetralogy of Fallot (TOF) is the **most common** congenital *cyanotic* lesion, accounting for 10% of congenital heart disease cases. The four components of the lesion are (1) a VSD, (2) an "overriding" aorta that covers ventricles, (3) RVOT obstruction, and (4) right ventricular hypertrophy (RVH). This child is experiencing a hypercyanotic "Tet" spell, indicating that the **volume of blood shunting from right to left has increased**. After increasing preload (fluid bolus, flexing the hips) and increasing afterload (flexing the hips and using phenylephrine), the next step is to reduce the obstruction to RV outflow. Though it may seem logical to reduce PA pressures with milrinone or epinephrine, the distal pulmonary pressures are generally low and not a significant factor in the degree of shunting. **The obstruction to RV outflow is at the level of the RVOT.** This may be subvalvular, valvular, supravalvular, and occasionally at the pulmonary arterial branches. Esmolol will slow heart rate to allow for adequate preload and will also relax the infundibular (subvalvular) region of the RVOT, allowing more blood to leave the RV into the RVOT. For children with recurrent Tet spells, **propanolol** is often indicated for outpatient use.

An anesthetic for a child with TOF must be well planned and tailored to the patient. **Premedication** is often recommended as crying and struggling can worsen breathing and cause desaturations. Midazolam has been shown to be effective. The induction of anesthesia on patients with TOF can cause significant hemodynamic changes, which can quickly lead to cyanosis. **Ketamine** is often used as an induction agent. The increase in SVR with ketamine will reduce the right-to-left shunt. An inhaled induction is acceptable, but one must remember that the reduction in SVR will cause an increase in the shunt. Historically, **halothane** has been the preferred inhalational agent for induction as it maintains a relatively stable SVR but causes direct myocardial depression, helping to relax the infundibulum. Although still in use in some centers, the popularity of halothane has decreased due to the risk of fulminant hepatic necrosis. **Positive-pressure ventilation, hypercarbia, and hypoxia** will raise pulmonary pressures and increase the right-to-left shunt, so effective airway management is imperative when balancing SVR and PVR. Care should also be taken to avoid high airway pressures and allow adequate time for expiration to avoid increased intrathoracic pressures. As with all cardiac lesions involving shunts, care must be taken to avoid air in the IV tubing due to risk of **paradoxical emboli**.

KEY FACTS

- TOF is the most common congenital *cyanotic* lesion and consists of a VSD, an "overriding" aorta, RVOT obstruction, and RVH.
- A child experiencing a "tet" spell has increased right-to-left shunting, and is treated by increasing preload and afterload as well as reducing the RVOT obstruction. This can be accomplished by giving beta blockers.
- Positive-pressure ventilation, hypercarbia, and hypoxia will raise pulmonary pressures and increase the right-to-left shunt, so effective airway management is imperative when balancing SVR and PVR.

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3. ANSWER: B

Autism is a poorly understood psychiatric disorder that manifests in multiple fashions, most centrally as an **inability to develop interpersonal relationships** as considered normal in a given culture. Associated findings may include developmental delay, seizures, and culturally inappropriate behaviors but are not central to the diagnosis. Behaviors vary among autistic patients and could be largely considered as either **hyperreactive** or **hyporeactive**. Among hyperreactive patients, it is paramount that the anesthesiologist inquire about **triggers** for patients in order to provide a safe environment. Likewise, it is important to distinguish hyporeactive behaviors because they mimic common perioperative issues such as hypoglycemia, anesthetic overdose, and hypothermia. Currently no curative treatment exists for autism. Life span is normal with continuation of childhood symptoms into adulthood being relatively common.

Substantial consideration must be given to the details of the operative experience when the patient is autistic in order to deliver the safest experience possible. Details such as lighting, stimulation, calming techniques, and agitation triggers are most easily explored with the parent. In addition, child life specialists are tremendously helpful in this arena, freeing the anesthesiologist to devote mental resources to medical concerns such as preoperative sedation and pain control.

Emergence from general anesthesia is a particularly difficult time for autistic patients. Changes in sedation level, coupled with abrupt changes in location, present a challenge to all children, but these are particularly challenging for autistic children. Coupled with surgical pain, temperature changes, and hunger, emergence and transition through the postanesthetic care unit can be a time of particular difficulty with autistic patients.

KEY FACTS

- Autism is a poorly understood psychiatric disorder that manifests in multiple fashions, most centrally as an inability to develop interpersonal relationships as considered normal in a given culture.
- Behaviors vary among autistic patients and could be largely considered as either hyperreactive or hyporeactive. For hyperreactive patients, it is important to explore the triggers for agitation (lighting, touch, sounds, etc.) and calming techniques from the parents.
- Coupled with surgical pain, temperature changes, and hunger, emergence and transition through the postanesthetic care unit can be a time of particular difficulty with autistic patients.

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4. ANSWER: D

Cerebral palsy (CP) is a nonprogressive neurologic disorder that is multifactorial in origin but is generally related to a variety of **prenatal, perinatal, and postnatal insults**. The disease process is not well understood, and contributing factors can range from prematurity to infection to intracerebral hemorrhage. Perinatal asphyxia was once thought to be the most common etiology but is now believed to cause less than 10% of CP. The key feature of CP is a disorder of movement and posture. There may be varying degrees of mental retardation and developmental delay, depending on the etiology of the cerebral palsy. Multiple classification systems have been developed for CP; a commonly used system is based on the type of neurologic impairment (i.e., spastic, dyskinetic, atheoid, mixed). Spastic CP is the most common, accounting for 70% of cases.

Children with CP frequently have **seizure disorders** with an incidence of at least 30%. They are often on antiepileptic drugs, in addition to antispasmodic medications, and withdrawal can trigger seizures as in this scenario. In the perioperative period it is important to review all medications and administer preoperatively, if necessary.

Dexmedetomidine is an alpha-2 agonist often used as an adjunct for general anesthesia. It has potent sedative effects and provides analgesia, which can be opioid sparing. There have been no case reports of seizures/convulsions in humans.

KEY FACTS

- CP is a nonprogressive neurologic disorder that is multifactorial in origin but is generally related to a variety of prenatal, perinatal, and postnatal insults. It is a disorder of movement and posture, with varying degrees of mental retardation and developmental delay.
- Spastic CP is the most common, accounting for 70% of cases, and other types are based on the neurologic impairment (i.e., spastic, dyskinetic, atheoid, mixed).
- Children with CP frequently have seizure disorders with an incidence of at least 30%.

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5. ANSWER: C

Gastroesophageal reflux disease (GERD) is quite common in patients with cerebral palsy (CP) and clinicians often opt for an RSI prior to intubation. Due to CP being a neuromuscular disease, anesthesia trainees often assume depolarizing NMBs are contraindicated, but this is not true. There have been no case reports of hyperkalemia after succinylcholine administration despite many years of use. This is due to only **minimal upregulation of ACh receptors** around the neuromuscular junction despite having spastic paresis.

Answers C (burns) and D (myopathy that is classic for Duchenne muscular dystrophy) represent conditions that may lead to hyperkalemia following succinylcholine use due to upregulation of ACh receptors.

Malignant hyperthermia (MH) is a condition involving **abnormal intracellular handling of calcium**, often related to the ryanodine receptor at the sarcoplasmic reticulum. Succinylcholine is one of the known triggering agents and should be avoided in patients with a known or suspected family history of MH, as in Answer B.

KEY FACTS

- Conditions that cause upper or lower motor neuron defects, burns, and prolonged immobilization can lead to upregulation of ACh receptors, causing hyperkalemia after succinylcholine use.
- Despite the neuromuscular disease, succinylcholine use does *not* seem to cause hyperkalemia in CP patients.
- If there is concern for malignant hyperthermia, succinylcholine should be avoided.

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6. ANSWER: A

Cystic fibrosis (CF) is an autosomal recessive disorder that affects 1 in 2000 Caucasian births in the United States and is the most common fatal inherited disease in white individuals. The genetic basis for the disease is a mutation in the CFTR gene on chromosome 7. This gene codes for a chloride transporter located on epithelial cells in several organs, including the lungs, pancreas, liver, and gastrointestinal tract. Decreased chloride transport results in decreased sodium and water transport into the luminal surface of the organs. This yields **thick, dehydrated secretions** that cause luminal **obstruction** with subsequent **inflammation** and **scarring**. The lungs are generally affected at a young age with decreased clearance of the thick secretions being the impetus for **recurrent bacterial infections**, with later findings of **bronchiectasis** and **emphysema**. The lungs account for nearly 90% of the morbidity and mortality of CF.

The GI tract is affected with pancreatic exocrine insufficiency, poor GI motility, and altered enterohepatic circulation. More than 90% of CF patients have **pancreatic dysfunction,** and most are prone to recurrent episodes of pancreatitis. Due to **malabsorption** and **liver dysfunction**, CF patients may have **vitamin K deficiency** and reduced levels of clotting factors II, VII, IX, and X. The deficiencies would **prolong the PT** but generally not the PTT and would not affect platelet levels. In the absence of clinically significant bleeding, there are no screening labs that must be obtained prior to surgery, but one should keep vitamin K deficiency in mind when evaluating a patient with CF.

KEY FACTS

- CF is an autosomal recessive disorder that affects 1 in 2000 Caucasian births in the United States and

is the most common fatal inherited disease in white individuals.
- Decreased chloride transport results in decreased sodium and water transport into the luminal surface of the organs, yielding thick, dehydrated secretions that cause obstruction with subsequent inflammation and scarring.
- Due to malabsorption and liver dysfunction, CF patients may have vitamin K deficiency and reduced levels of clotting factors II, VII, IX and X, causing a prolonged PT.

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7. ANSWER: D

Down syndrome (Trisomy 21) is relatively common occurring in 1:700–800 live births, and affected children may present for a variety of procedures. In addition to a complete history and physical, one should concentrate on the **airway examination**. Brachycephaly, macroglossia, micrognathia, hypotonia, and subglottic tracheal stenosis are common findings, which may make positioning, direct laryngoscopy, and successful intubation difficult. The narrowed subglottic diameter makes **postintubation croup** more common, so consideration should be given to using a **smaller endotracheal tube.**

In addition to airway abnormalities, there may be considerable laxity in the cervical spine, with both occiput-C1 and C1-C2 instability having been described. Parents should be questioned about the child's history of cervical spine instability, complaints of neck pain, inability to move the neck, gait abnormalities, sensorimotor deficits, and bowel/bladder incontinence. The medical record should be reviewed for **prior cervical spine films,** which typically include lateral flexion-extension plain films. **Symptomatic children are screened via radiographs between 3 and 5 years of age** in accordance with recommendations from the American Academy of Pediatrics, while the guidelines do not recommend routine radiographs of asymptomatic children. The anesthesiologist should be careful to **minimize neck hyperextension** during mask ventilation or direct laryngoscopy, even in the absence of a history that suggests cervical instability. Positioning during the case should also be a point of concern, particularly during head/neck procedures where the surgeon may ask for a position that could compromise the cervical spine.

KEY FACTS

- Down syndome (Trisomy 21) is a common occurrence and is likely to be encountered by a pediatric anesthesiologist.
- Airway abnormalities include brachycephaly, macroglossia, micrognathia, hypotonia, and subglottic tracheal stenosis.
- Cervical spine laxity may be present, and a focused history and physical as well as review of the medical record are important to avoid subluxation.

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8. ANSWER: C

Murmurs are often appreciated on children during preoperative examinations, and the pediatric anesthesiologist will frequently be tasked with guiding what, if any, diagnostic testing must be completed prior to undergoing surgery. In this scenario, the murmur likely represents a so-called innocent murmur. The term "innocent" implies that there are no cardiac abnormalities present; the murmur is caused by flow through normal anatomic structures. Because these are flow dependent, they will **change with position or maneuvers** that alter venous return and cardiac output. In contrast, a fixed murmur would imply a structural abnormality. Innocent murmurs are **exclusively systolic,** not graded more than III/VI on auscultation. A common example is Still's murmur, which is low pitched and typically appreciated at the left lower sternal border without radiation across the precordium. A **Valsalva maneuver** will greatly reduce the murmur or make it disappear entirely. No clicks or other abnormal heart sounds can be appreciated with Still's murmur. The rest of the physical exam, including the pulmonary exam, peripheral pulses, and signs of normal perfusion (e.g., capillary refill and skin color) should be normal.

The evaluation of the murmur should begin with a good history from the child's parents. They should be questioned about the birth history, perinatal events, issues with feeding, **episodes of cyanosis**, ability to perform physical tasks similar to children of their age, and any complaints from the child related to chest pain, syncope/presyncope, or dyspnea. A family history of significant heart disease should be elicited. Children with a completely normal history are less likely to have significant underlying cardiac pathology.

In this case, the fact that the child's movement changed the intensity of the murmur and her general state of well-being make an innocent murmur the most likely etiology, and further workup is generally not required prior to anesthesia.

KEY FACTS

- Innocent murmurs are exclusively systolic, not graded more than III/VI on auscultation. A common example is Still's murmur, which is low pitched and typically appreciated at the left lower sternal border without radiation across the precordium.
- The rest of the physical exam, including the pulmonary exam, peripheral pulses, and signs of normal perfusion (e.g., capillary refill and skin color) should be normal.

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9. ANSWER: D

Though all of the choices are possible, hemoglobin (Hb) of 10 g/dL represents a normal finding for an infant at 9 weeks of age. A term neonate typically has a hemoglobin level of 17–18 g/dL. This is caused by very high erythropoietin (EPO) levels in fetal circulation due to the low oxygen tension in the uterine environment and the leftward position of the fetal hemoglobin-oxygen dissociation curve. The elevated EPO levels cause Hb levels considerably higher than in older children or adults. As oxygen levels rise in the neonate, there is a sharp decline in EPO and hematopoiesis is reduced. In addition, fetal hemoglobin (HbF) production is reduced as adult hemoglobin (HbA) production begins to rise. The nadir of the resultant anemia is generally seen at 8–12 **weeks** of age with Hb levels in the 10–12 g/dL range. This is referred to as a **physiologic anemia,** indicating that normal physiology accounts for the laboratory values without underlying pathology.

Of note, there are no guidelines that have established "safe" Hb levels for pediatric surgery. For routine cases not expected to cause significant bleeding, checking hemoglobin in healthy children prior to surgery is **generally not indicated**. Several authors have studied preoperative Hb/Hct values in large numbers of children and found very low rates of anemia. Preoperative coagulation studies rarely delay surgery or change management; the utility of these tests is often questioned. Evidence also indicates that the abnormal lab values are often ignored without being followed by repeat studies or interventions to correct the abnormalities. In addition to adding to increasing health care costs, the unwarranted testing exposes the child to undue stress and needle sticks. Despite these findings, significant numbers of physicians continue to order screening labs prior to surgery.

KEY FACTS

- Term neonates have elevated Hb levels in the 15–20 g/dL range.
- Due to reduced EPO levels and a reduction in HbF synthesis, Hb levels drop to 10–12 g/dL with the nadir in the 8- to 12-week range.
- A further workup for this physiologic anemia is not generally indicated.
- Routine laboratory testing for minor procedures is not warranted unless there are specific concerns to be addressed.

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10. ANSWER: A

The scenario represents normal development for a healthy child. Inquiring about the development of a pediatric patient is extremely important in assessing the child's overall health status. One very commonly used screening method to assess development makes use of milestones as defined by the Denver Developmental Screening Test (DDST). The milestones are described in broad categories: gross motor (e.g., sitting, standing), fine motor (pincer grasp, playing with blocks), language (e.g., talking), and personal-social (e.g., smiling, separation anxiety, playing with others). The American Academy of Pediatrics recommends a developmental assessment using the milestones at 9 months, 18 months, and 30 months, but many practitioners assess aspects of developmental at all well-child visits. When used as a screening method, the sensitivity and specificity of the milestones are >70%.

While the anesthesiologist may not frequently complete a full developmental screening test, understanding the expected norms based on a child's age will help in planning an anesthetic tailored to the child. This will make for a smoother induction, avoid postoperative behavioral issues, and potentially change the pharmacologic approach to the anesthetic. Behavioral and developmental delays are incredibly common, present in 15%–18% of pediatric patients. It is important to remember that while missing a specific milestone may not affect an anesthetic plan, it may be a clue that a larger issue is present.

Table 8–1 in *Nelson's Essentials of Pediatrics*, sixth edition (copyright 2011), is a good overview of the milestones and provides the salient information without excessive detail.

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11. ANSWER: D

Preoperative anxiety and the need for proper psychosocial preparation represents one of the most important aspects of pediatric anesthesia. Up to 50% of all children undergoing anesthesia will have high levels of anxiety regarding the process. In addition to stress on the child, this complicates the anesthetic induction and puts considerable distress on the parents. It may also lead to **emergence agitation** and **postoperative behavioral issues**. Understanding the causative factors for preoperative anxiety will help identify those at risk and guide treatment. Children younger than 7 years generally experience **more anxiety** than older children, as the older children tend to develop coping mechanisms to deal with the anxiety. Several studies have demonstrated that shy, withdrawn children will experience more anxiety than other children their age. This makes it important to observe the child and question the parents regarding the child's personality and reactions to stressful situations. A history of a negative experience with anesthesia or surgery will likely influence the preoperative anxiety as well, making it important to inquire about past anesthetic experiences.

Treatment of preoperative anxiety is typically multimodal and should be tailored to the child. Research on the subject has been done for years, but no solid guidelines exist for treatment. Preoperative education (i.e., pamphlets, hospital tours, role playing) completed in the days before surgery is effective, but it must be **timed well**. One author reported that children who underwent **preoperative preparation** 5–7 **days** prior to surgery experienced low levels of anxiety, whereas those who underwent the program 24 hours preoperatively experienced the highest levels of anxiety. Distraction techniques such as music, television, and video games are also valuable methods for reducing anxiety.

Premedication is commonly used, with midazolam and clonidine being the best studied agents. Midazolam is effective due to its sedating and anxiolytic effects, as well as the anterograde amnesia that results from administration. A recent study reported satisfactory results in 75% of children who were given oral midazolam preoperatively. Other studies have shown that there may be a higher incidence of postoperative behavioral issues, when midazolam has been administered, so one must be careful to use it only when indicated.

KEY FACTS

- Up to 50% of all children undergoing anesthesia will have high levels of anxiety regarding the process.
- Children younger than 7 years generally experience more anxiety than older children, as the older children tend to develop coping mechanisms to deal with the anxiety.
- Midazolam is effective due to its sedating and anxiolytic effects, as well as the anterograde amnesia that results from administration. A recent study reported satisfactory results in 75% of children who were given oral midazolam preoperatively.

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12. ANSWER: B

Parental presence during anesthesia has long been a topic of controversy. The benefits of parental presence are thought to minimize the need for premedication and to avoid the trauma and struggling that comes with separation from the parents. In addition, there may be more controversial

benefits like decreasing the child's anxiety as well as the long-term stigma that is associated with surgery and anesthesia. It is clear that multiple studies have proven that parents and children generally prefer to be together during procedures, but this does not necessarily make it a desirable situation or one that has improved patient outcomes.

If parental presence is allowed, the patient and family must be counseled during the preoperative evaluation about the induction of anesthesia and how they can comfort their child. It must be stressed that being present is not a right but a privilege and the parent may be removed at any time if there is new or additional risk to the child. It is crucial to explain specific events during the process to decrease the anxiety parents may feel during the induction. After explaining to the parents what they might see during induction, it is not unusual for the parents to no longer wish to be present during induction. At no time should the parents be coerced or forced to be present in the operating room.

KEY FACTS

- The benefits of parental presence during induction over premedication is still a topic of debate.
- It is crucial to explain specific events during the induction process that are normal to decrease the anxiety parents may feel during the induction.

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13. ANSWER: D

This patient is exhibiting signs of SVC syndrome such as distended neck veins, facial swelling, and dyspnea. The underlying pathology, however, is vascular congestion resulting from compression of the SVC by the mass. This is one of the many unique anesthetic challenges that anterior mediastinal masses can create for anesthesiologists and thus they must be worked up in a logical manner.

An anterior mediastinal mass (AMM) can be primary or metastatic, with the most common being **lymphoblastic lymphoma** and **Hodgkin's lymphoma**. Other less common tumors that may be the cause include teratomas, thymomas, parathyroid, mesenchymal, and thyroid tumors. In addition, because non-Hodgkin's lymphoblastic lymphoma has a 12-hour doubling time, there often is a rush to obtain a tissue diagnosis and to begin treatment.

When evaluating a patient with an AMM, one should look for signs and symptoms of **vascular and/or airway compromise**, which may include dyspnea, pain, coughing, SVC syndrome, orthopnea, and/or pleural effusions. Patients should then undergo testing, which would include computed tomography (CT), echocardiography, and PFT test when feasible. Vascular and/or airway compression detected on a CT is associated with a high incidence of serious complication during the induction of anesthesia. Echocardiogram detects the compression of the SVC and the pulmonary outflow tract, while PFTs detect evidence of the dynamic compression of the airways.

Substantial effort should be made to obtain a tissue diagnosis using minimally invasive techniques such as **lymph node biopsy** or **bone marrow biopsy,** so that general anesthesia can be avoided. If obvious signs of vascular and/or airway compromise exist, one must consider performing the mediastinoscopy under local, initiating chemo/radiation to shrink the tumor prior to induction or giving a short dose of corticosteroid therapy, which can also shrink the size of the tumor. These treatments are not without consequence, however, and may actually make it more difficult to obtain an adequate amount of tissue for a diagnosis; thus, the oncologist may choose to avoid such an option.

KEY FACTS

- An AMM can be primary or metastatic, with the most common being lymphoblastic lymphoma and Hodgkin's lymphoma.
- When evaluating a patient with an AMM, you should look for signs and symptoms of vascular and/or airway compromise, which may include dyspnea, pain, coughing, SVC syndrome, orthopnea, and/or pleural effusions.
- If obvious signs of vascular and/or airway compromise exist, one must consider doing the mediastinoscopy under local, initiating chemotherapy or radiation to shrink the tumor prior to induction or giving a short dose of corticosteroid therapy, which can also shrink the size of the tumor.

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Hammer, Gregory B. "Anesthesia for Thoracic Surgery" in Cote CJ, Lerman J, Todres ID, eds. *A Practice of Anesthesia for Infants and Children*. 4th ed. Philadelphia, PA: Saunders Elsevier; 2009:290–2.

14. ANSWER: C

Patients with anterior mediastinal mass (AMM) can have primary or metastatic disease, with the most common being **lymphoblastic lymphoma** and **Hodgkin's lymphoma**. Other less common tumors that may be the cause of the patient's pathology include teratomas, thymomas, parathyroid, mesenchymal, and thyroid tumors. In addition, because non-Hodgkin's lymphoblastic lymphoma has

a **12-hour doubling time**, there often is a rush to obtain a tissue diagnosis and to begin treatment.

When evaluating a patient with an AMM, one should look for signs and symptoms of **vascular and/or airway compromise**, which may include dyspnea, pain, coughing, SVC syndrome, orthopnea, and/or pleural effusions. Patients should then undergo testing, which would include CT, echocardiography, and pulmonary function tests when feasible. Vascular and/or airway compression detected on a CT is associated with a high incidence of serious complications during the induction of anesthesia. **Echocardiogram** detects the compression of the SVC and the pulmonary outflow tract, while **PFTs** detect evidence of the dynamic compression of the airways.

Even if a patient has undergone testing and shows no evidence of vascular and/or airway compromise, severe airway and circulatory collapse may still occur with the induction of anesthesia. In light of this fact, it is recommended that an **inhalational induction** be performed with **maintenance of spontaneous respiration**. In addition, the use of continuous positive airway helps maintain functional residual capacity lost during the induction of anesthesia and may help keep the airway from collapsing. **Elevating the patient's head** to 30–45 degrees may decrease the deleterious effects of supine positioning. Neuromuscular blockers decrease chest wall tone and **should be avoided** because this can increase the chance of airway compromise. Finally, some have advocated using **heliox** to decrease the airway resistance and to promote laminar flow.

One must be prepared for the chance of airway/vascular compromise should the event arise. In circumstances where this has occurred, **quick repositioning to a prone or lateral position** can be lifesaving. In a situation where airway collapse is the main issue, placing a **rigid bronchoscope** distal to the point of obstruction may also be necessary. Finally, in catastrophic situations, it has been advocated to perform a median sternotomy and **initiate cardiopulmonary bypass**. Cardiopulmonary bypass would, however, take some time to initiate and would be impractical unless access for partial bypass was done prior to the induction of anesthesia.

KEY FACTS

- Patients with AMM can have primary or metastatic disease, with the most common being lymphoblastic lymphoma and Hodgkin's lymphoma.
- When evaluating a patient with an AMM, you should look for signs and symptoms of vascular and/or airway compromise, which may include dyspnea, pain, coughing, SVC syndrome, orthopnea, and/or pleural effusions.
- Severe airway and circulatory collapse can still occur with induction. It is recommended that an inhalational induction is performed with maintenance of spontaneous respiration.

REFERENCE

Hammer, Gregory B. "Anesthesia for Thoracic Surgery" in Cote CJ, Lerman J, Todres ID, eds. *A Practice of Anesthesia for Infants and Children*. 4th ed. Philadelphia, PA: Saunders Elsevier; 2009:290–2.

15. ANSWER: A

Latex allergy is extremely common and tends to develop after **repeated exposures** to latex through urinary catheterizations, surgical gloves, and other products found in the hospital. While there has clearly been a more intensive effort at recognizing the significance of the problem and thus more products have become latex-free, latex still exists in many products and some facilities are unable to accommodate latex-free cases.

The first step in avoiding such a reaction is taking an adequate history and in particular looking for reactions with exposure to **latex or rubber** (toy balloon). Nearly **50%** of patients with a latex allergy will have their first reaction at the dentist's office, where there is a tendency to use more latex-containing equipment. Finally, one should be cognizant of the link between spina bifida patients and an increased incidence of latex allergy, as with this patient.

The presentation of latex allergies is extremely variable. Some patients manifest with a simple contact reaction (type 4), while others can manifest with **anaphylaxis**. These patients can manifest with variable degrees of rash, bronchospasm, and/or circulatory collapse. This reaction is due to a **type 1 hypersensitivity reaction**.

Treatment of an anaphylactic reaction involves quickly recognizing the problem and washing out the source of contamination. The patient should be given 100% oxygen and volume loaded with a balanced salt solution (10–20 mL/kg) with additional boluses given to maintain blood pressure. Epinephrine should be given as soon as possible at 0.01–0.02 mg/kg and additional vasoactive medications used to maintain blood pressure. In addition, **beta-agonists** can be used to relieve **bronchoconstriction**, **corticosteroids** to diminish mediator formation and release, and **antihistamines** (H1 and H2 antagonists) to block the action of histamine.

KEY FACTS

- Nearly 50% of patients with a latex allergy will have their first reaction at the dentist's, where there is a tendency to use more latex-containing equipment.
- There is an association between spina bifida and an increased incidence of latex allergy.
- Anaphylaxis is a type 1 hypersensitivity reaction.

REFERENCE

Everett, Lucinda L.; Fuzaylov, Gennadiy; Todres, I. David. "Pediatric Emergencies" in Cote CJ, Lerman J, Todres ID, eds. *A Practice of Anesthesia for Infants and Children*. 4th ed. Philadelphia, PA: Saunders Elsevier; 2009:779.

16. ANSWER: B

Gastroesophageal reflux disease (GERD) is common in neonates and preterm infants, with up to **40% of newborns** regurgitating their food. This is thought to be due at least partially to the inability to coordinate swallowing and respiration, which does not fully develop until about **4–5 months gestational** age. In addition, lower esophageal sphincter pressures are diminished and take 3–6 weeks to achieve adult levels. **Neonatal duodenal maturity does not occur until 29–32 weeks** and may be a relevant contributor in the preterm infant. Finally, CNS changes may also contribute.

GERD must be initially differentiated from developmental abnormalities such as pyloric stenosis, duodenal stenosis, annular pancreas, malrotation, tracheoesophageal fistula, and esophageal atresia. In general, developmental abnormalities usually present within the **first 24–36 hours of life**—upper intestinal abnormalities generally present as recurrent vomiting and regurgitation, while lower abdominal abnormalities present with abdominal distention and failure to pass meconium. The exception would be **pyloric stenosis,** which typically presents in the third week of life. The diagnosis of GERD often takes an accurate history and physical examination as well as one or more of the following tests: (1) barium swallow, (2) PH probe, (3) upper GI endoscopy, (4) gastric emptying study.

GERD in the infant and neonate typically presents with **irritability**, persistent **vomiting**, **failure to thrive**, and in severe cases **hematemesis** and **anemia** and can be occasionally complicated with stricture formation. In addition, reflux into the pulmonary system may lead to **recurrent pneumonia**, **irritability**, **wheezing**, and **stridor**.

KEY FACTS

- GERD is common in neonates and preterm infants, with up to 40% of newborns regurgitating their food.
- Developmental abnormalities usually present within the first 24–36 hours of life—upper intestinal abnormalities generally present as recurrent vomiting and regurgitation, while lower abdominal abnormalities present with abdominal distention and failure to pass meconium.
- GERD typically presents with irritability, persistent vomiting, failure to thrive, and in severe cases hematemesis and anemia, and can lead to recurrent pneumonia, irritability, wheezing, and stridor.

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17. ANSWER: B

This question tackles many of the issues that are associated with patients with GER in the peri-induction period. Gastroesophageal reflux (GER) is common in neonates and preterm infants, with up to 40% of newborns regurgitating their food. In general, infants with the diagnosis are otherwise healthy but may occasionally have concomitant developmental abnormalities. This is a more common scenario. It is also important to note that the risk of aspiration on induction is increased in all children that are **developmentally delayed**, have had a **previous esophageal surgery**, have had a difficult airway, were obese, underwent traumatic injury, and have coexisting GER.

Whether the patient has GER or not, it is important to recognize the recommended fasting periods for elective surgery in healthy patients and their limitations. Keep in mind that the goal of fasting is to **reduce gastric volume** and that because children are often induced via inhalation their risk for aspiration is often protracted. Table 20.1 shows recommendations that are found in ASA practice guidelines.

Premedication for GERD and the prevention of aspiration pneumonitis classically involves antacids, H2 antagonists, proton pump inhibitors, and gastrointestinal motility agents. Antacids work by increasing pH, and nonparticulate antacids should be used such as sodium citrate. Particulate antacids can cause a severe pneumonitis if aspirated and should be avoided. H2 antagonists work by inhibiting acid secretion in the gastric mucosa leading to increased pH and decreased residual volume. Proton pump inhibitors work in a similar manner; however, no PPI has been approved in children below the age of 1 year. It is important to recognize that H2 blockers and PPI **need at least 30 minutes** to be effective and 45 minutes–1 hour for peak

Table 20.1 ASA RECOMMENDATIONS FOR FASTING PERIODS FOR ELECTIVE SURGERY

Clears	**2 hr**
Breast milk	**4 hr**
Infant formula	**6 hr**
Solids	**8 hr**

SOURCE: Reprinted with permission from Cote CJ, Lerman J, Todres ID, eds. *A Practice of Anesthesia for Infants and Children*. 4th ed. Philadelphia, PA: Saunders Elsevier; 2009:167.

Table 20.2 PREMEDICATION FOR GASTROESOPHAGEAL REFLUX AND THE PREVENTION OF ASPIRATION PNEUMONITIS DOSING IN THE PEDIATRIC POPULATION

Bicitra	30 mL
Metoclopramide (prokinetic)	0.1–0.15 mg/kg
Ranitidine (H2 antagonist)	2.0–2.5 mg/kg
Famotidine (H2 antagonist)	0.3–0.4 mg/kg

effect. **Promotility** agents such as **metoclopramide** work by increasing lower esophageal tone, relaxing the pyloric sphincter, and promoting gastric motility while decreasing gastric volume. Metoclopramide works 1–2 minutes after IV administration. Table 20.2 shows the recommended dosing in the pediatric population.

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18. ANSWER: B

Asthma is a complicated disease process that is likely a family of related disease processes which present with a common finding of wheezing.

Critical to the understanding of asthma is an appreciation that **lower airway reactivity** and **spasm** are merely components of the overall disease process. **Inflammation** is a critical component underlying intermittent bronchospasm. Chronic inflammation leads to loss of appropriate bronchoalveolar interaction and permanent airway remodeling.

Therapy for asthma is directed at **reducing underlying inflammation** while controlling acute symptomatology. **Beta agonists** as well as ipratropium decrease smooth muscle contraction and thus reduce bronchospasm. Methylxanthines such as **theophylline** additionally reduce bronchospasm but are associated with toxicity and are becoming historical rather than practical. **Corticosteroids**, both inhaled and systemic, are commonly prescribed and used in asthmatic patients. These agents reduce swelling and are well tolerated but are associated with hyperglycemia, hypertension, and loss of endocrine homeostasis. It is useful to note that inhaled corticosteroids do induce systemic effects as the dose escalates in comparison to patient size. Infants may be at risk for systemic effects of inhaled corticosteroids. **Leukotriene inhibitors** and **mast cell stabilizers** are two final classes of agents commonly encountered in this patient population.

Immunoglobulin E–mediated **atopy** is a common finding among asthmatics. Atopic asthmatics tend to have less well-controlled disease as compared to nonatopic patients. Nonatopic asthmatics may, in fact, have a subtly different pathophysiologic process from atopic asthmatics evidenced by the fact that nonatopic patients exhibit reduction of symptoms with age.

Asthmatics present with a variety of symptoms, ranging from subtle **chest tightness** to **respiratory failure**. Patient presentation may include air hunger, wheezing, accessory muscle use, coughing, pneumothorax, mental status change, and **prolonged expiration** among other associated symptoms. Asthma, like other obstructive respiratory diseases, does not manifest as prolonged inspiration.

KEY FACTS

- Asthma is a complicated disease that involves chronic inflammation and lower airway reactivity.
- It commonly presents with air hunger, wheezing, accessory muscle use, coughing, pneumothorax, mental status change, and prolonged expiration.
- Treatment includes beta-agonists, corticosteroids, leukotriene inhibitors, and mast cell stabilizers.

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Firth, Paul G.; Kinane, T. Bernard. "Essentials of Pulmonology" in Cote CJ, Lerman J, Todres ID, eds. *A Practice of Anesthesia for Infants and Children*. 4th ed. Philadelphia, PA: Saunders Elsevier; 2009:229–32.

19. ANSWER: C

Infants and children as well as adults are fasted prior to operations to decrease gastric volume and minimize the risk of aspiration. The thinking behind this is that in the fasted child the only thing that would remain in the stomach would be basal gastric secretions. The risk and incidence of aspiration in routine procedures without risk factors is small, and it is recommended that in children without additional risk factors be **fasted for 2 hours** after the consumption of clear liquids. These recommendations come from studies that showed no additional decrement in risk when fasting a child greater than 2 hours. Clear liquids include **water, fruit juices without pulp, carbonated beverages, clear tea, and black coffee**. Finally, the gastric residual half-life of clear liquids is approximately 15 minutes, and this information could be used to guide additional fasting time for patients with some risk factors. The benefits of fasting for 2 hours but not longer include a decreased risk for **hypoglycemia, hypovolemia, decreased thirst,**

Table 20.3 PREOPERATIVE FASTING RECOMMENDATIONS IN INFANTS AND CHILDREN

Clear liquids*	2 hours
Breast milk	4 hours
Infant formula	6 hours†
Solids (fatty or fried foods)	8 hours

*Include only fluids without pulp, clear tea, or coffee without milk products.

†Some centers allow plain toast (no dairy products) up to 6 hours prior to induction.

SOURCE: Reprinted with permission from Warner MA, Caplan RA, Epstein B. Practice guidelines for preoperative fasting and the use of pharmacologic agents to reduce the risk of pulmonary aspiration: application to healthy patients undergoing elective procedures: a report by the American Society of Anesthesiologist Task Force on Preoperative Fasting. *Anesthesiology*. 1999;90:896–906.

decreased hunger, decreased risk for hypotension on induction, and improved child cooperation.

Breast milk has a **high lipid content,** which delays gastric emptying and can cause significant pulmonary injury if aspirated. Furthermore, studies have shown that gastric emptying times for breast milk when compared to clear liquids are substantially greater. In addition, gastric emptying times for **formula** are substantially greater than breast milk. It is because of these studies that the ASA recommended guidelines, as shown in Table 20.3.

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20. ANSWER: B

The issues surrounding the child with upper respiratory infection have best been described as vexing. While management of children on the extreme ends of the infectious spectrum is fairly straightforward from the surgical planning perspective, the majority of children present with nuanced symptoms such as rhinorrhea.

Postponement of surgery is an option in children with any infectious symptomatology. Such a stance is, however, rather restrictive. Given that 20% to 30% of children will present with upper respiratory infection (URI) symptoms, the distinct possibility of another cold occurring during convalescence is present. Layering on top of this information, the very nature of many pediatric surgeries is aimed at reducing the frequency and severity of infection. Examples of such surgery include adenoidectomy, tonsillectomy, and myringotomy. While postponing surgery **7 weeks** (the time frame required for spirometry studies to normalize) will reduce the chance of respiratory complications, this is a practice that may not be compatible with real life and may even put the anesthesiologist in the position of postponing surgery that could ultimately break the cycle of infection.

Noninvasive airway management (mask or LMA) has demonstrated a benefit in reducing respiratory complications in the setting of URI. Interestingly, **positive-pressure ventilation alone** appears to increase the risk of respiratory complication in such patients, placing a premium on **spontaneous ventilation**.

While pharmacologic intervention is tempting for the patient with a URI, few medications have demonstrated a positive effect. Bronchodilators given preoperatively in otherwise healthy children having minor surgery have shown no protective effect. Anticholinergics have shown little added benefit in this arena as well. Humidification of gasses as well as adequate vascular hydration have some benefit in reducing respiratory complications.

The nature of the surgery is distinctly important in the frequency of respiratory complications in children with a URI. **Head and neck surgery** as well as thoracic or intra-abdominal surgery is associated with **more frequent respiratory complications** in affected children.

A discussion of degree of illness is warranted. Viral respiratory illness appears to be less severe than bacterial illness. Discerning the difference between these two states is at times difficult. Generally speaking, presence of a productive, moist **cough** is associated with more severe bacterial infection. Additionally, **fever** greater than 38.5°C, **wheezing** or **rales** on lung exam, and **behavioral changes** are associated with severe disease. In addition, formerly premature children and young (less than 1 year) children tend to have more severe responses to URIs and should be considered separately from the otherwise healthy children discussed thus far. Household smoking also appears to worsen the outcome in affected patients.

KEY FACTS

- Noninvasive airway management (mask or LMA) has demonstrated a benefit in reducing respiratory complications in the setting of a URI.
- Positive-pressure ventilation alone appears to increase the risk of respiratory complication in such patients, placing a premium on spontaneous ventilation.
- Fever greater than 38.5°C, productive cough, wheezing or rales on lung exam, and behavioral changes are associated with severe disease.

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Firth, Paul G.; Kinane, T. Bernard. "Essentials of Pulmonology" in Cote CJ, Lerman J, Todres ID, eds. *A Practice of Anesthesia for Infants and Children*. 4th ed. Philadelphia, PA: Saunders Elsevier; 2009:226–9.

21. ANSWER: A

Anesthetic risk for children differs from that of adult patients. In fact, adverse events (major and minor collectively) have been reported to occur in **35%** of pediatric cases as compared to **17%** in adult anesthesia. This difference in risk is multifaceted and includes patient characteristics as well as surgical characteristics. Children present a number of anatomic and physiologic challenges for the anesthesiologist. These challenges generally become more pronounced with decreasing patient age and size. Empirically, children 1 month of age and younger have been reported to have the **highest** rate of adverse event. Importantly, the same database that yielded this finding also reported that children under 1 month of age underwent cardiac and major vascular surgery more frequently than did children in other age groups.

Particular organ systems appear to be more prone to adverse event than others. In a second database, **respiratory** adverse events accounted for 53% of all intraoperative events. Infants, patients undergoing ENT surgery, patients in whom the trachea was intubated, and patients with ASAPS scores of 3 and above were more likely to have a respiratory adverse event. **Cardiac** adverse events accounted for 12.5% of all such events. Nausea occurred in 6% of cases and appeared (in both databases) to occur in older children. Cohen reports that one third of 5-year-old patients experienced vomiting in recovery.

KEY FACTS

- Adverse events have been reported to occur in 35% of pediatric cases, as compared to 17% in adult cases.
- Children 1 month of age and younger have been reported to have the highest rate of adverse event.
- Most adverse events are respiratory (53%) or cardiac (12.5%) in nature.

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22. ANSWER: C

Informed consent, a complicated concept for adult patients, is significantly more complicated in the arena of pediatrics because children are widely deemed to lack the cognitive, emotional, and decision-making skills required to participate alone through the consent process. Assent, however, is obtainable according to the child's capability. A "rule of sevens" aids in this assent process. Children younger than 7 years of age are typically incapable of assent due to a lack of decision-making ability. Between the ages of 7 and 14 years, children may develop decision-making skills, but it is unlikely that a patient in this age range will reliably demonstrate such skill. Children above the age of 14 years may reliably hold adequate decision-making skills. It is critical that the practitioner not confuse this ability with the ability to engage in informed consent because children of this age **lack cognitive and emotional skills** required to fully participate in the process of consent.

There are **four fundamental steps** to informed consent. First, the patient or surrogate (often a parent) must be **supplied adequate information** to understand both his or her medical condition and the procedure planned for him or her. Second, the practitioner must assess the patient or surrogate for **understanding** of the information laid out in the first step. Third, the practitioner must assess the patient/surrogate for **capacity** (cognitive, emotional, and decision making) to engage in consent. Fourth, the practitioner must deliver an assurance that the patient/surrogate may make the decision **free of coercion**.

Pediatric informed consent is further complicated by several unique situations. First, the surrogate may (and often does) ask the physician what the physician would do in a given setting. This question is fundamentally flawed because the child simply is not the physician's. Any declarative answer to this question is simply a guess. No physician knows his or her patient well enough to claim to know or understand all the complexity of the parent–child relationship. The best answer to this question will be one that **addresses the goals that the family is attempting to achieve** and the values they hold. Second, some children obtain emancipated minor status via the legal system. These individuals are typically **adolescent** and either **married**, **parents**, in the **military**, or **economically independent** of their parents for any of a variety of reasons. Each state handles these individuals and their rights uniquely, but in general they are recognized as holding the right to participate in informed consent. Third, there exist religious and cultural differences between patients and families. Of common concern are **children of Jehovah's Witnesses**. Without great detail, such families generally refuse blood transfusion. Practitioners may or may not agree with this choice. Furthermore, it is debatable whether the child must be treated as an informed practitioner of the religion or cultural practice. Each clinician must decide on a case-by-case basis whether to support this decision. Consultation with representatives of the legal system prior to surgery may be wise prior to surgery if a conflict exists between the practitioner and the family/patient regarding such religious and cultural norms and their impact on medical care.

KEY FACTS

- Children above the age of 14 years may reliably hold adequate decision-making skills, but they often lack

the cognitive and emotional skills required to fully participate in the process of consent.
- An emancipated minor (adolescents that are married, parents, in the military, or economically independent) is generally recognized as holding the right to participate in informed consent.
- Consultation with representatives of the legal system prior to surgery may be wise if a conflict exists between the practitioner and the family/patient regarding such religious and cultural norms and their impact on medical care.

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23. ANSWER: D

Lab testing and other studies such as EKG and lung function tests are certainly useful in aiding the assessment of the appropriate patient. Metabolic and electrolyte testing is useful in patients with disorders of the cardiac, gastrointestinal, and genitourinary systems as well as patients receiving **psychiatric medications**. Blood counts are useful in the setting of **significant blood loss** and **hematologic disorders** as well as children with **oncologic disorders**. More important than memorizing tests is that the practitioner arrive at a point where he or she understands why a test is being used and when it is warranted.

A fundamental understanding of the patient's current physiology and the anticipated surgical procedure are essential in driving preoperative assessment. A useful starting point is to obtain laboratory studies that will either (a) **yield information** regarding the patient's current status, (b) **alter further assessment** (such as blood typing and screening for anemic patients), or (c) **alter the patient's surgical planning** (such as electrolyte testing for dehydrated patients).

A discussion regarding echocardiography in particular is warranted. In the context of congenital heart disease (CHD) it is often useful to obtain a recent echocardiogram. Given that children with CHD undergoing surgery often manifest symptoms consistent with cardiac failure, visualization of current anatomy and function provides the practitioner a wealth of information. Cardiac failure in children may manifest much more obscurely than in adults. Simple failure to match peers in growth raises many questions regarding a neonate's cardiac status. Rarely is the same true for adults. Given that cardiac dysfunction is difficult to diagnose clinically in pediatrics, **empiric evaluation via echocardiography is frequently warranted**. Children with cardiac disease often have undergone repeated echocardiography, which may be useful in assessment. A discussion with the patient's cardiologist is often helpful to this end.

Given that the patient described in this question has no comorbidities and is undergoing a benign surgical procedure with little anticipated blood loss, no testing is warranted.

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24. ANSWER: C

Parent presence on induction of anesthesia (PPI) is a process of variable popularity that holds many potential advantages as well as disadvantages. Each practitioner and institution must carefully develop and adopt a position regarding the practice of PPI; no national standard is available. Commonly, patient age comes under question in development of such a plan. While it is intuitive that adult patients often do not require or request PPI, unique patients may benefit from PPI. Such patients may be **developmentally delayed** or even **demented**, calling into question the appropriateness of more broad practices such as **family present induction** for the elderly.

Both benefits and challenges exist in regard to PPI. Potential benefits include a lessened requirement for preoperative sedation medications, less frequent emergence delirium, and a more benign induction process. Importantly, data regarding these benefits are mixed, and it cannot be conclusively stated that these benefits in fact exist across all patients. Disadvantages of PPI include requirement of **additional staff**, possible disruption of the operating room and sterile area, and **harm either to or inflicted by the parent**. The parent, it must be recognized, is not an inert cog in this machine but brings with him or her a degree of unpredictability. The parent must be counseled regarding what will be seen in the operating room and what each individual's role is in the event of an emergency, parent included. Beyond the possibility that the parent may disrupt the operative environment, the operative environment may harm the parent! Data exist describing elevations in heart rate, blood pressure, and skin conductance in parents participating in PPI. While no harm has been reported to parents during PPI, it is important that practitioners fully recognize the gambit of outcomes that may develop in the context of PPI.

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25. ANSWER: D

Psychosocial preparation of the pediatric patient is multifaceted in regard to both breadth and patient applicability. Common techniques aim at creating trusting relationships with health care providers, using age-appropriate terminology, and developing coping skills.

Of interest, patient age is an important consideration in psychosocial preparation programs. The fundamental consideration appears to be the child's ability to **discern between fantasy and reality**. At approximately 3 years of age, children become able to differentiate between these two states. With this development, the child becomes able to benefit from simulation meant to prepare him or her for upcoming surgery. As such, children younger than 3 years may not benefit from such programs.

Older children demonstrate an interesting nuance to preparatory programs as well. Children aged 6 years and older have demonstrated an increase in anxiety leading up to the date of preoperative preparation. In fact, this anxiety peaked in the days surrounding such preparation and **fell below baseline levels 5 days following preparation**. Given this trend, it is critical that older children be **scheduled for preparation a week in advance** of surgery.

Regarding a parent's influence on a child's level of anxiety, it is not surprising that the values positively correlate. Anxious parents beget anxious children. Preparation must include the family in addition to the patient. Furthermore, ideal preparation will clearly convey to the parent how directly their state of mind influences that of their child.

Children who have been hospitalized in the past are a unique population. A trend toward an enhanced emotional response to hospitalization is present in children who have been hospitalized in the past. A prior negative medical experience additionally promotes anxiety. Appropriate preparation for such patients may be best targeted at specific experiences.

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Ghazal, Elizabeth A.; Mason, Linda J.; Cotè, Charles J. "Preoperative Evaluation, Premedication, and Induction of Anesthesia" in Cote CJ, Lerman J, Todres ID, eds. *A Practice of Anesthesia for Infants and Children*. 4th ed. Philadelphia, PA: Saunders Elsevier; 2009:39–41.

26. ANSWER: B

Cerebral palsy, a **static encephalopathy**, is the most common childhood movement disorder (Table 20.4). Cerebral palsy has an incidence of 1/7000 births and a prevalence of 1/5000. Often there are no identifiable risk factors, and the diagnosis is made when a patient exhibits delayed motor development. Despite the static nature of neurologic damage, the clinical picture for this disease state is variable and may change. It is thought that insults to the immature CNS or congenital anomalies cause cerebral palsy, as birth asphyxiation, prematurity, and intrauterine growth retardation are known associations. Approximately **75% of cases involve in utero insults** to the immature CNS, 10% of cases occur during birth, and the remaining 15% of cases occur shortly after birth. Despite immature CNS

Table 20.4 CEREBRAL PALSY

TYPE/ETIOLOGY	MOTOR DEFICIT	DISTRIBUTION	COMPLICATIONS
Hypotonic Syndromic Dysgenesis Insult: hypoxia-ischemia	Low axial tone Variable limb tone Deep tendon reflexes usually increased	Diffuse	Learning disability Contractures Epilepsy Feeding dysfunction Hearing/vision impairment Respiratory infections
Spastic Insult: hypoxia-ischemia, vascular	Increased tone: pyramidal type Increased deep tendon reflexes	Monoparesis Diparesis Hemiparesis Triparesis Tetraparesis	
Choreoathetoid Insult: hypoxia-ischemia; neonatal hyperbilirubinemia; metabolic	Involuntary movement: often a mixture of chorea athetosis dystonia	May be diffuse (tetraparesis) or confined to one or more limbs Often coexists with spasticity	Hearing impairment Contractures Intellect often maintained
Ataxic Cerebral dysgenesis	Ataxia usually generalized truncal and limb May coexist with spasticity	May be diffuse but often associated with diparesis	Few, may be mild

SOURCE: Reprinted with permission from: Cote CJ, Lerman J, Todres ID, eds. *A Practice of Anesthesia for Infants and Children*. 4th ed. Philadelphia, PA: Saunders Elsevier; 2009:493.

injury, cognitive impairment is not a consistent feature of cerebral palsy.

Cerebral palsy is classified according to its severity, distribution, and nature of motor deficit. The four major classifications of cerebral palsy are spastic, athetoid or dyskinetic, ataxic, and mixed. Without the normal gravitational muscular stresses, abnormal skeletal muscle development ensues, and patients with cerebral palsy often require multiple orthopedic surgeries to **loosen tight muscles and joint contractures**, and to straighten abnormal long bone twists and kyphoscoliosis.

Although severe scoliosis compromises respiratory reserve, idiopathic scoliosis by itself is not strongly associated with impaired oromotor function or recurrent aspiration pneumonia.

Similarly, pulmonary reserve is compromised in patients with cystic fibrosis (CF), but severe CF does not affect oromotor function. Rather, severe CF disrupts electrolyte transport in epithelial cells of sweat ducts, airway, pancreatic duct, intestinal, biliary tree, and vas deferens. Although Trisomy 21 is associated with duodenal atresia and generalized hypotonia, **severe cerebral palsy is more often associated with severe seizure disorder, impaired bulbar function, and recurrent aspiration pneumonia**. With severe bulbar dysfunction, some patients with cerebral palsy have difficulties feeding and speaking. Coupled with significant gastroesophageal reflux disease and poor laryngeal reflexes, patients with cerebral palsy can have recurrent aspiration pneumonia and subsequent reduced pulmonary reserve.

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27. ANSWER: C

Cystic fibrosis (CF) demonstrates autosomal recessive inheritance and occurs in 1/2000 Caucasian births. The pathophysiology for CF involves **chronic infection, mucus plugging, inflammation, and epithelial injury**, as the mutation in the gene encoding CF transmembrane conductor regulator disrupts electron transport via chlorine channel in various epithelial cells. This renders CF patients to the symptoms of **productive cough, hemoptysis, recurrent respiratory infections, atelectasis, and maldigestion**.

Treatment for CF focuses on **nutritional repletion** with high-calorie diets, continuation of **pancreatic enzyme replacement**, and fat-soluble vitamin supplements; and relief of airway obstruction, including pre- and postoperative **bronchodilator use**, **incentive spirometry**, **postural drainage**, and **pathogen-specific antibiotics** for lung infection. Other areas currently being evaluated for treatment of CF include anti-inflammatory medication and lung transplant. Answer A is incorrect because preoperative bronchodilators should be continued to optimize postoperative outcomes. Answer B is incorrect because pathogen-specific antibiotics should be administered. In addition, prophylactic broad-spectrum antibiotics may harbor multidrug resistance. Answer D is incorrect because postoperative outcomes are optimized when CF patients continue high-calorie diets, coupled with replacement of pancreatic enzymes and fat-soluble vitamin supplements.

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28. ANSWER: B

The best way to prevent latex allergy is to remove latex from hospitals. To this end, many children's hospitals are converting to completely latex-free environments. **Latex allergy is IgE mediated**, and clinical diagnosis requires a high index of suspicion.

The following individuals are at **increased risk of anaphylaxis to latex**: children with neural tube defects such as **spina bifida** and **myelomeningocele**, children with **urinary tract anomalies** requiring frequent bladder catheterization, children with an immunologic predisposition, children undergoing multiple surgical procedures, individuals with an **allergy to tropical fruits such as banana and kiwi,** and health care workers exposed to latex.

Although it has been demonstrated that pretreatment with antihistamine and corticosteroid can prevent a reaction to intravenous contrast, these preventative treatments do not reliably prevent anaphylaxis to latex. Thus, Answers A and C are incorrect.

If anaphylaxis is clinically suspected, the most important treatment is **intravenous epinephrine** (1–10 μg/kg) to prevent further mast cell degranulation. In addition, the offending agent should be removed or diluted, 100% oxygen should be administered, the patient should be intubated if not already, acute volume loading should occur, and the patient may require an infusion of epinephrine or other

vasoactive mediations to support the patient's blood pressure. If possible, a blood sample should be sent for mast cell **tryptase** test to confirm anaphylaxis, but this is certainly not the first or most important step in treating anaphylaxis.

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29. ANSWER: D

Pediatric anterior mediastinal masses may be primary or metastatic tumors of the lung, mediastinum, and pleura. Associated signs and symptoms are typically due to **airway or vascular compression** and include stridor, dyspnea, orthopnea, cough, pain, pleural effusion, and SVC syndrome. This patient demonstrates dyspnea, orthopnea, cough, and SVC syndrome.

Preoperative CT scan, cardiac echocardiogram, and pulmonary function tests should be obtained for anterior mediastinal masses. However, this question asks which preoperative study is most appropriate to detect **dynamic airway compression**. A plain chest X-ray does not detect dynamic airway compression. Images from CT scan are static and may not necessarily identify dynamic airway compression, which may occur with the induction of general anesthesia. Cardiac echocardiogram can show SVC or pulmonary outflow tract compression, but flow-volume studies are most effective in detecting evidence of dynamic airway compression. Depending on the location of this anterior mediastinal mass, this patient may demonstrate **extrathoracic** or **intrathoracic** variable or fixed obstruction, and this would be apparent on flow-volume studies (see Fig. 20.1).

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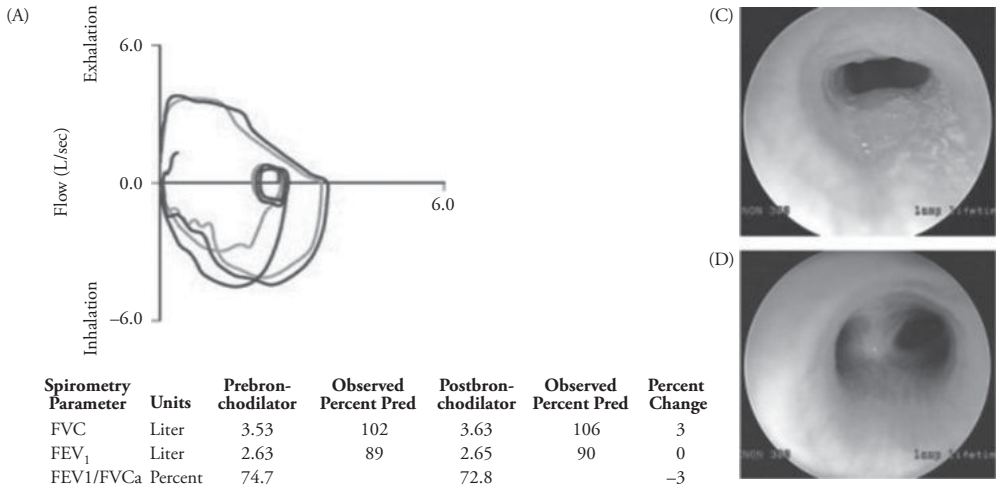
30. ANSWER: A

Although potential symptoms of a URI and a potential difficult airway should alert any pediatric anesthesiologist, the cardiovascular assessment of this patient with Williams syndrome supersedes other perioperative concerns. With only rhinorrhea and a dry cough, some would argue that this child does not have an active URI. Micrognathia with prominent incisors does not necessarily equate with difficult airway, but it would be prudent to have advanced and alternative airway equipment readily available to intubate this patient.

Williams syndrome occurs in 1/20,000 children and involves a **deletion of chromosome 7,** which alters the elastin gene. Patients with Williams syndrome have characteristic elfin facies, outgoing personalities, endocrine abnormalities, mental retardation, growth deficiency, and altered neurodevelopment. Associated cardiovascular pathology



Spirometry Parameter	Units	Prebron-chodilator	Observed Percent Pred	Postbron-chodilator	Observed Percent Pred	Percent Change
FVC	Liter	3.53	102	3.63	106	3
FEV_1	Liter	2.63	89	2.65	90	0
FEV1/FVCa	Percent	74.7		72.8		–3

Figure 20.1 Pulmonary function test from a child with an intrathoracic airway obstruction (vascular ring). (A)The flow-volume curve shapes suggest a fixed expiratory obstruction. The shape of the inspiratory link is normal; the expiratory flow limb is flattened on both the prebronchodilator and postbronchodilator flow-volume curves. (B) A magnetic resonance angiogram accompanies the flow loop. (C) Slit-like tracheal compression before repair. (D) Note the marked improvement in the tracheal lumen after division of the vascular ring. Post, postbronchodilator; Pre, prebronchodilator; Pred, predicted. (Reprinted with permission from Cote CJ, Lerman J, Todres ID, eds. *A Practice of Anesthesia for Infants and Children*. 4th ed. Philadelphia, PA: Saunders Elsevier; 2009:227.)

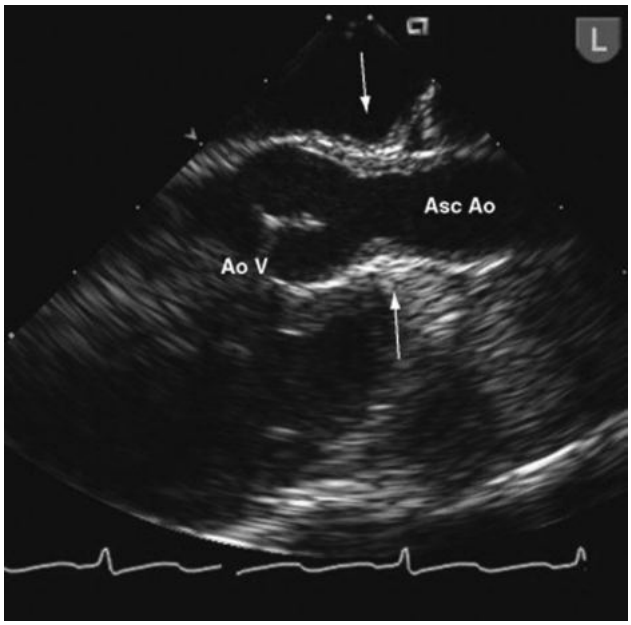


Figure 20.2 Echocardiogram displaying the classic supravalvar aortic narrowing in a patient with Williams syndrome (*arrows*). Ao V, aortic valve; Asc Ao, ascending aorta.

includes **valvular and supravalvular aortic stenosis**, and coarctation of the aorta. These children also demonstrate arteriopathy that may involve the origin of the coronary arteries.

Children with Williams syndrome are predisposed to increased anesthetic morbidity and potential mortality in the form of **coronary artery stenosis** and **severe biventricular outflow tract obstruction**, which may occur with the induction of general anesthesia. The need for surgery and general anesthesia should be seriously considered, and thorough cardiac evaluation should be pursued, with special attention to cardiac echocardiogram (Fig. 20.2) and, if possible, cardiac catheterization data. With potential coronary artery stenosis in the setting of aortic stenosis with already compromised coronary artery filling during diastole, this patient is at a greatly increased risk of cardiac morbidity and mortality with anesthesia.

KEY FACTS

- Williams syndrome occurs in 1/20,000 children and involves a deletion of chromosome 7, which alters the elastin gene.
- Associated cardiovascular pathology includes valvular and supravalvular aortic stenosis, and coarctation of the aorta.
- Children with Williams syndrome are predisposed to increased anesthetic morbidity and potential mortality in the form of coronary artery stenosis and severe biventricular outflow tract obstruction, which may occur with the induction of general anesthesia.

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Slesnick TC, Gertler R, Miller-Hance WC. "Essentials of Cardiology" in Cote CJ, Lerman J, Todres ID, eds. *A Practice of Anesthesia for Infants and Children*. 4th ed. Philadelphia, PA: Saunders Elsevier; 2009:303–4.

31. ANSWER: A

Many children with congenital heart disease will present for noncardiac surgeries, so pediatric anesthesiologists should be well versed in the appropriate hemodynamic goals and appropriate management of these patients. This scenario presents an urgent case where a young boy may lose a testis if his testicular torsion is not corrected in a timely manner.

Tetralogy of Fallot (TOF) is the **most common cyanotic cardiac** condition and is characterized by the tetrad of pulmonary stenosis, right ventricular outflow tract obstruction, overriding aorta, and ventricular septal defect (Fig. 20.3). With TOF, right-to-left shunt results in **cyanosis**, and these patients are prone to "tet spells" or hypercyanotic episodes. Tet spells occur when pulmonary blood flow is decreased in patients who already have significant right ventricular outflow tract obstruction. **Crying and**

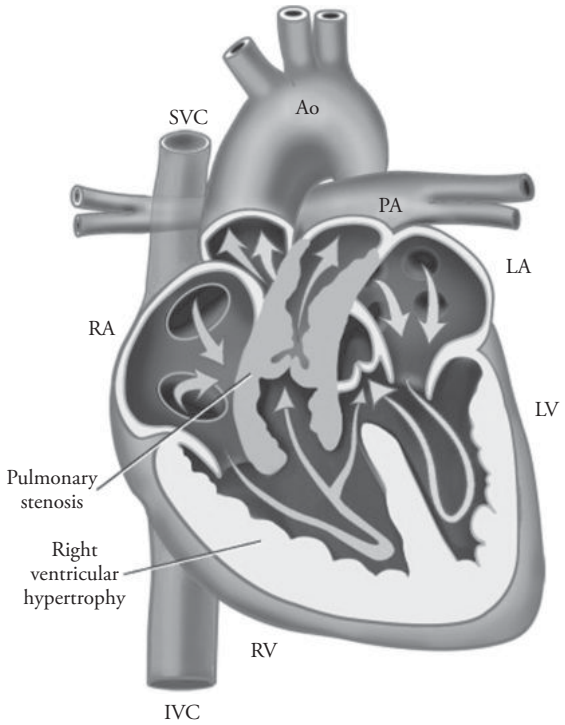

Figure 20.3 Tetralogy of Fallot. This diagram shows the features of the tetralogy: VSD, overriding aorta, right ventricular hypertrophy, and pulmonary stenosis. Shown here is both pulmonary and subpulmonary obstruction. The result is right-to-left shunting resulting in cyanosis. AVC, superior vena cava; RA, right atrium; RV, right ventricle; LA, left atrium; LV, left ventricle; PA, pulmonary artery; Ao, aorta. (Reprinted with permission from: Cote CJ, Lerman J, Todres ID, eds. *A Practice of Anesthesia for Infants and Children*. 4th ed. Philadelphia, PA: Saunders Elsevier; 2009:348.)

inadequate depth of anesthesia are known triggers for tet spells and **exacerbate right-to-left shunting**.

Nonpharmacological treatment of tet spells includes **Valsalva maneuvers** and assuming the **squatting** position. Further treatment of tet spells includes **increasing anesthetic depth, systemic vascular resistance, intravascular volume, and inspired oxygen concentration**. SVR is typically increased pharmacologically with **phenylephrine**. Crystalloid or colloid may be used to **increase intravascular volume**. Patients already under general anesthesia may also benefit from **lowered inspiratory ventilator pressures** or **beta blockade**, as these decrease pulmonary vascular resistance and infundibular spasm, respectively.

With regard to the answer choices listed, oral midazolam has great bioavailability, but it requires a cooperative patient and 10–15 minutes for maximal sedating effects. With supplemental oxygen, this benzodiazepine will sedate the child so he will separate from his parents easily and tolerate mask induction, all within the safe time frame to begin this urgent surgery.

The sympathomimetic effects of intramuscular ketamine and the intramuscular route of administration are not ideal in this situation. Although an argument could be made that intramuscular ketamine will sedate the child, the intramuscular route of administration will likely cause more crying, and the sympathomimetic properties of ketamine may worsen infundibular spasm in this child having a hypercyanotic episode.

Further attempts at awake peripheral intravenous placement are also likely to cause additional pain and crying in this patient, who is already experiencing a hypercyanotic episode. Although increasing intravascular volume is part of the management strategy for this patient, it is more important to increase the patient's level of sedation and provide increased inspired oxygen content in a timely manner. It would be irresponsible to not immediately treat this patient who requires urgent surgery.

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32. ANSWER: B

A TOF patient having a hypercyanotic episode, no intravenous access, and presenting for urgent surgery demands thoughtful perioperative consideration. The urgency of this surgery should be reiterated, as the patient's torsed testis may potentially be saved if its blood supply is restored soon. Most testes can be saved if surgery is performed **within 6 hours of the onset of pain**. This salvage rate decreases to 50% if surgery is performed between 6 and 12 hours of the onset of pain.

Patients with testicular torsion should be considered to have **full stomachs**. To safely anesthetize this TOF patient with a full stomach, no intravenous access, and an urgent surgery requires balancing of anesthetic goals. The most important considerations are to increase depth of anesthesia and inspired oxygen concentration in a timely and safe manner.

Although inhalation induction will likely be **slower** in this patient because of **reduced pulmonary blood flow** given his TOF physiology, the best way to attenuate this child's tet spell with the given answer choices is to increase FiO_2 and inhaled concentration of sevoflurane. In efforts to prevent regurgitation of gastric contents, cricoid pressure should be used during inhalation induction. After the induction of anesthesia, an intravenous should be quickly placed and the patient's airway secured.

A eutectic mixture of local anesthetics (EMLA; 2.5% lidocaine and 2.5% prilocaine) requires **30 minutes** to have maximal benefit, so this is not the best choice to relieve a tet spell in this patient already in the operating room, as there will not be enough time to allow this medication to work. If EMLA was not used, or a peripheral intravenous was placed prior to maximal effectiveness of EMLA, this patient would likely continue crying, which would worsen the **infundibular spasm** already associated with this hypercyanotic episode.

Similarly, an intramuscular dose of ketamine would increase the patient's level of sedation but at the expense of worsening the hypercyanotic episode, as the intramuscular route of drug delivery would likely worsen crying and infundibular spasm because of pain and ketamine's sympathomimetic properties.

An inhalational induction could theoretically be expedited via second gas effect from nitrous oxide and sevoflurane, but decreased FiO_2 is not congruent with the management strategy for a child having a tet spell, so Answer C is incorrect.

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33. ANSWER: B

Although tonsillectomy and adenoidectomy are commonly performed ENT procedures, it would be irresponsible for the anesthesiologist caring for this child to not know the extent of cardiac defect that this child has prior to administering a general anesthetic.

Trisomy 21 was first described by John Langdon Haydon Down in 1887 and is the most common chromosomal abnormality. It has an incidence of approximately 1/800 live births. Advanced maternal age is a known risk factor

for Down syndrome, and Down syndrome may affect up to 4% of children born to women over the age of 40.

Roughly **40%–50% of patients** with Down syndrome have some sort of cardiac abnormality. These range from innocent childhood murmurs to **complete atrioventricular septal defects (AVSDs)**. Atrioventricular septal defects, or endocardial cushion defects, may be partial or complete. Complete AVSDs typically consist of a large septal defect with atrial and ventricular components and a common atrioventricular valve, and may include conduction abnormalities.

Although a plain chest X-ray may give information regarding cardiomegaly, which may reflect congestive heart failure, this preoperative study does little to confirm the patient's functional or cardiovascular status and is more useful when compared to prior imaging. Moreover, congestive heart failure is not suspected in this patient who is growing well and has no sweating or cyanotic episodes with feeds.

Similarly, a cardiac stress test is unlikely to yield substantial clinically important data, as there are no immediate concerns regarding myocardial ischemia in this child. A cardiac stress test would be more pertinent in a patient with coronary artery abnormalities, aortic stenosis, or exercise-induced arrhythmias.

Based on the pertinent history obtained by the parents, this child does not have overt signs of congestive heart failure, as she feeds well and does not sweat or become cyanotic with feeds. Children with congestive heart failure may have **nasal flaring, grunting with respirations, chest retractions, poor feeding and growth, and diaphoresis**.

The most appropriate answer selection is to clarify the child's cardiac defect and physiology by obtaining an EKG and cardiac echocardiogram. This information should be used to tailor this child's anesthetic, as a Down syndrome patient with complete atrioventricular septal defect may have **severe pulmonary hypertension**, may have severe conduction abnormalities, and may require inotropic support (Fig. 20.4). Elucidation of the extent of this patient's cardiac defect affects anesthetic technique and postoperative recovery placement.

Additional cardiovascular concerns for Down syndrome patients include the propensity for **bradycardia** with the induction of general anesthesia, and the potential for **pulmonary hypertension**, either from cardiac pathology or chronic hypoxia from upper airway obstruction, especially in this patient who also has severe obstructive sleep apnea.

Other major perioperative concerns for Trisomy 21 include airway and vascular access concerns. Patients with Trisomy 21 often have chronic pulmonary infections, **macroglossia** with anterior, smaller airways, the potential for **atlanto-occipital dislocation**, increased incidence of **postextubation stridor**, and potential for **difficult vascular access**.

KEY FACTS

- Roughly 40%–50% of patients with Down syndrome have some sort of cardiac abnormality.
- Children with congestive heart failure may have nasal flaring, grunting with respirations, chest retractions, poor feeding and growth, and diaphoresis.

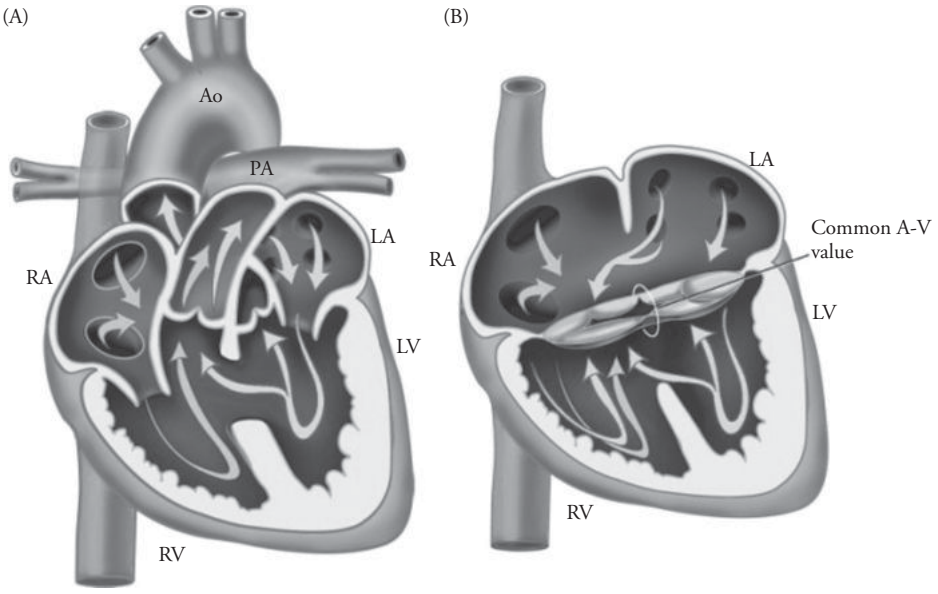

Figure 20.4 (A) Diagram of ventricular septal defect showing left-to-right shunt. (B) Diagram of complete atrioventricular septal defect (AVSD) with great vessels removed showing left-to-right shunt through both atrial and ventricular components of the defect and also a single common atrioventricular valve. RA, right atrium; RV, right ventricle; LA, left atrium; LV, left ventricle; PA, pulmonary artery; Ao, aorta. (Reprinted with permission from: Cote CJ, Lerman J, Todres ID, eds. *A Practice of Anesthesia for Infants and Children*. 4th ed. Philadelphia, PA: Saunders Elsevier; 2009:346.)

- Additional cardiovascular concerns for Down syndrome patients include the propensity for bradycardia with the induction of general anesthesia and the potential for pulmonary hypertension, either from cardiac pathology or chronic hypoxia from upper airway obstruction.

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34. ANSWER: D

Patients with autism spectrum disorder have a unique set of perioperative concerns. Disease states along the autism spectrum include milder forms like Asperger's syndrome and severe autism, which may be associated with schizophrenia. When assessing patients with autism spectrum disorders preoperatively, the patient's cognitive capacity and potential effects of psychiatric medications should be considered.

Answer A is not the most reliable method of inducing general anesthesia because intravenous placement is often one of the **most challenging aspects** of pediatric anesthesiology, especially for an awake autistic teenager who will not even allow caretakers to brush his teeth. This patient likely will not cooperate with an awake intravenous placement.

Similarly, **inhalational induction is not always reliable** in this patient population. Parental presence or use of familiar comfort devices such as headphones may ease an autistic patient and make an inhalational induction possible, but this is not the most reliable means of inducing general anesthesia in this patient either.

Although oral midazolam has good bioavailability, it requires a cooperative patient who will reliably ingest this potentially bitter-tasting medication, and it requires 10–15 minutes to work. If this patient does not take the complete oral dose of midazolam or spits it out, as may occur with severely autistic children, then this medication will not work. So Answer C is not the most reliable method of inducing general anesthesia for this child.

Given these answer choices, the most reliable way to induce general anesthesia with this severely autistic patient is with **intramuscular premedication with ketamine**, then inhalational induction with sevoflurane after the patient is sedated. Alternatively, one could also place a peripheral intravenous once the patient is adequately sedated, then proceed with an intravenous induction. Dosing of intramuscular ketamine should take into account the anticipated length of surgery, so as to avoid prolonged hospital recovery or time to discharge from overzealous ketamine administration.

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35. ANSWER: B

Teenagers having surgery are commonly anxious; judicious use of preoperative anxiolytics may allay this nervousness. Oral or intravenous anxiolytics may be administered in the preoperative area. Although important to ensure the smooth induction of a general anesthetic, anxiolysis is not the most important concern for this patient and her upcoming major surgery.

Thoughtful discussions of blood conservation strategies are the most important part of this patient's perioperative discussion and would have ideally begun weeks prior to this scheduled surgery. Had this discussion begun weeks prior, then the patient could have been started on **erythropoietin** and **iron supplements** to increase her production of red blood cells.

Major blood loss can occur with posterior spinal surgery because of bleeding from epidural vessels during the posterior surgical approach. Proper positioning of patients in the prone position without undue abdominal pressure will **avoid venous congestion** and may minimize intraoperative blood loss attributable to positioning. Other potential strategies to prevent or limit blood loss in a Jehovah's Witness include the aforementioned preoperative iron and erythropoietin supplementation, appropriate prone positioning, **intraoperative cell savage**, use of colloid volume expanders, use of **antifibrinolytics** epsilon aminocaproic acid (EACA, Amicar) or transexamic acid, maintenance of **normothermia**, surgical use of **fibrin glue**, and **staged surgery** or agreeing to stop surgery after a predefined total blood loss or hematocrit have been determined.

Some Jehovah's Witness patients are agreeable to intraoperative cell savage so long as the entire system remains in continuity with their vasculature. Whether or not this patient and her family agree to cell savage is an important aspect of this patient's surgical care that should be elucidated preoperatively. Similarly, the potential use of albumin should be discussed preoperatively. Jehovah's Witnesses may object to albumin because it is prepared from pools of human plasma, so other plasma expanders like the synthetic colloid **hetastarch** should be considered. Hetastarch may be associated with renal insufficiency in select patients, so its use is controversial.

Antifibrinolytics are lysine analogs that bind plasminogen and plasmin and effectively prevent fibrinolysis. They have

been shown to significantly decrease intraoperative bleeding in major surgeries like posterior spinal fusion and open heart surgery. Transexamic acid has 6 to 10 times the potency of epsilon aminocaproic acid and has a longer half-life.

Other blood conservation strategies for patients who are willing to accept transfusion of blood or blood products include preoperative **autologous donation**, acute **normovolemic hemodilution**, and **deliberate hypotension**. Autologous blood units may be stored for up to 42 days, but this is not a viable option for patients with ischemic heart disease or active infections. With acute normovolemic hemodilution, units of blood are removed at the beginning of surgery and replaced with crystalloid and colloid so that fewer red blood cells are lost per volume of blood lost during surgery. These units of blood are then available for transfusion toward the latter portion of surgery. This strategy intentionally **decreases the oxygen-carrying capacity** and reduces the margin of safety to prevent cerebral and spinal cord ischemia. Deliberate hypotension is meant to decrease surgical bleeding by intentionally **decreasing MAP**. However, this technique may risk both cerebral and spinal cord ischemia and end-organ damage. Moreover, it is unknown exactly what minimum MAP is required or is safe, as lower MAPs also affect neuromonitoring signals.

Advances in neuromonitoring have made posterior spinal surgery safer, but no single neuromonitoring test is 100% reliable. Somatosensory evoked potentials monitor the integrity of the **dorsal columns**, and motor evoked potentials monitor the integrity of the **anterior motor portion** of the spinal cord. Motor evoked potentials have been associated with complications such as cognitive defects, seizures, bite injuries, intraoperative awareness, scalp burns, and arrhythmias.

Neuromonitoring is affected by anesthetics, so a commonly employed balanced anesthetic technique includes infusions of propofol and fentanyl with <0.5 MAC of volatile agent for these surgeries. If neuromonitoring signals are lost intraoperatively, another way to test the integrity of the patient's neurologic circuitry is a wake-up test. For a wake-up test, the patient's plane of anesthesia is lightened until the patient can follow simple directions and move all extremities to command. Once this was demonstrated, the plane of anesthesia would then be quickly deepened, and surgery would continue. This test requires a cooperative patient and only evaluates gross motor function. Potential complications of the wake-up test include extubation, dislodgment of invasive lines, venous air embolism, dislodgment of surgical instrumentation, patient injury from falling off the surgical frame, and intraoperative awareness.

Idiopathic scoliosis does not automatically place this patient at an increased risk of malignant hyperthermia. Central core disease, King-Denborough syndrome, and Duchenne and other muscular dystrophies are associated with malignant hyperthermia, but idiopathic scoliosis is not (see Box 20.1).

Box 20.1 SURGICAL AND ANESTHETIC PRINCIPLES OF BLOODLESS MEDICINE MANAGEMENT

Preoperative Assessment and Planning

Management of anemia
Management of anticoagulation and congenital and drug-induced coagulopathies
Prophylactic interventional radiology and embolization
Prescribing and scheduling of cell salvage apparatus
Restricted diagnostic phlebotomy

Intraoperative Blood Conservation

Meticulous surgical hemostasis
Blood salvage
Hemodilution
Pharmaceutical enhancement of hemostasis
Maintenance of normothermia
Surgical positioning to minimize blood loss and hypertension

Postoperative Blood Conservation

Blood salvage
Tolerance of anemia
Optimum fluid and volume management
Restricted diagnostic phlebotomy
Adequate analgesia, maintenance of normothermia
Maintain appropriate fluid resuscitation. Significant normovolemic anemia is well tolerated in hemodynamically stable patients.
In actively bleeding patients, the first management priority must be to stop the bleeding. Avoid attempts to normalize blood pressure until bleeding is stopped.
Prevent or treat coagulation disorders promptly.
Oral or parenteral iron may be used to improve iron stores.
Exogenous erythropoietin therapy effectively increases red blood cell mass.

Hematology and Oncology

Aggressive exogenous erythropoietin therapy and iron therapy for the prophylaxis of anemia
Individualized chemotherapy protocols to minimize hematologic toxicity
Pharmacologic prophylaxis and treatment of bleeding
Tolerance of anemia
Restricted diagnostic phlebotomy

Source: From Miller RD, Eriksson LI, Fleisher L, Wiener-Kronish JP, eds. *Miller's Anesthesia*. 7th ed. Philadelphia, PA: Churchill Livingstone; 2010:1791.

KEY FACTS

- Blood preservation strategies include preoperative iron and erythropoietin supplementation, appropriate prone positioning, intraoperative cell savage, use of colloid volume expanders, use of antifibrinolytics epsilon aminocaproic acid (EACA, Amicar) or transexamic acid, maintenance of normothermia, surgical use of fibrin glue, and staged surgery or agreeing to stop surgery after a predefined total blood loss or hematocrit has been determined.
- Other blood conservation strategies include preoperative autologous donation, acute normovolemic hemodilution, and deliberate hypotension.

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36. ANSWER: B

The neonate introduced in the question stem has DiGeorge syndrome. If the clinical diagnosis of DiGeorge syndrome was not immediately made, the fact that this neonate requires **omphalocele** repair should prompt a thorough cardiac evaluation.

Omphalocele occurs in 1/6000 births and is commonly associated with **congenital heart disease**, bladder extrophy, and Beckwith-Widemann syndrome. The primary defect with omphalocele is a midline failure of gut migration from the yolk sac into the abdomen. Large fluid shifts often occur with omphalocele repairs, and although ensuring appropriate volume status and urine output are important, this is not as important as a thorough preoperative cardiac evaluation for this patient with both DiGeorge syndrome and omphalocele.

DiGeorge syndrome, conotruncal face, and velocardiofacial syndromes are encompassed by 22q11.2 deletion syndrome, which is also known as **CATCH 22 syndrome**. The acronym CATCH 22 includes cardiac defects, abnormal facies, thymic hypoplasia, cleft palate, and hypocalcemia, and involves deletions of chromosome 22.

DiGeorge syndrome occurs in approximately 1/3000–5000 live births and is the second most common genetic cause of congenital heart defects. Patients with DiGeorge syndrome have a variety of congenital heart defects, including interrupted aortic arch, vascular rings, and hypoplastic left ventricle. The extent and magnitude of congenital cardiac defects must be elucidated preoperatively with cardiac echocardiogram to tailor the neonate's appropriate anesthetic technique.

Approximately 60% of DiGeorge patients have characteristic facial abnormalities, including small dysplastic ears, hypertelorism, short downward-slanted palpebral fissures, midface hypoplasia, retrognathia, high arched palate, and bifid uvula. These neonates often present with **tetany** and seizures from **hypocalcemia**. A detailed electrolyte evaluation is helpful to confirm hypocalcemia in this patient who has seizures and tetany, but it is not the most important preoperative evaluation in this patient.

Large fluid shifts are often associated with major neonatal abdominal surgeries like omphalocele repair, but the distractor of potential transfusion of blood products in a hypocalcemic patient should not lead the reader to incorrectly choose Answer C instead of Answer B. Similarly, a focused airway examination is important, as the majority of patients with DiGeorge syndrome have dysmorphic facies and may have challenging airways, but the most important preoperative evaluation of this patient is a thorough cardiac evaluation.

Patients with DiGeorge syndrome should be considered **immunocompromised** because thymic hypoplasia diminishes the number and function of their T-cells. Neonates with DiGeorge syndrome often have recurrent infections within the first 6 months of life. With this upcoming major surgery, blood products that are CMV-negative and irradiated should be available to prevent potential graft versus host disease (GVHD) from blood product transfusion. In addition, strict aseptic technique should be followed during vascular access.

KEY FACTS

- Omphalocele occurs in 1/6000 births and is commonly associated with congenital heart disease, bladder extrophy, and Beckwith-Widemann syndrome.
- DiGeorge syndrome occurs in approximately 1/3000–5000 live births and is the second most common genetic cause of congenital heart defects.
- Patients with DiGeorge syndrome should be considered immunocompromised because thymic hypoplasia diminishes the number and function of their T-cells.

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37. ANSWER: B

Most children with myelomeningocele present for closure within the first 48 hours of life to minimize risk of infection. As with this neonate, many are scheduled for surgical repair prenatally because the defect is usually detected on ultrasound. Major anesthetic considerations for this surgery include **positioning**, potential for **massive fluid and blood loss**, and postoperative **respiratory difficulties**.

With such a large posterior defect, it is important to ensure that there is no direct pressure on the myelomeningocele during the induction of general anesthesia and while securing the neonatal airway. Depending on the size of the defect, general anesthesia may be induced with the area surrounding the patient's defect **well padded in the supine position**, or alternately induction and intubation may occur in the **lateral decubitus** position. For very large defects, it may be safest to induce general anesthesia and intubate with the patient in the lateral decubitus position, so as to avoid undue pressure on the lesion.

With myelomeningocele repair, there is the potential for considerable blood and fluid loss. Because a large portion of the baby's skin surface area will be exposed for surgery, maintaining adequate volume status and euthermia are important perioperative considerations, and third space losses can be considerable.

All of the answer choices are valid concerns for a neonate undergoing myelomeningocele repair and VP shunt placement, but the most important reason for recovering this patient in the ICU is to monitor his respiratory status postoperatively.

Patients with myelomeningocele often have **sleep-disordered breathing, central apnea, hypoventilation, and obstructive sleep apnea**. Since this baby is <60 weeks postconceptual age, he is already at an increased risk of postoperative apnea. Coupled with potential postoperative respiratory challenges following myelomeningocele repair and VP shunt placement, it would be **advisable to monitor this patient in an ICU level** setting postoperatively, since he now has multiple reasons to have sleep-disordered breathing.

Hydrocephalus, tethered cord, and type II Arnold-Chiari malformations often accompany lesions like myelomeningocele. Moreover, if this neonate also has a type II Arnold-Chiari malformation that contributes to his hydrocephalus and need for a VP shunt, then his **ventilatory response to hypoxia and hypercarbia** may be **diminished** or **absent** postoperatively. In addition, depending on the degree of hydrocephalus, this neonate may have the **potential for brainstem herniation** and may also have a cranial nerve palsy that would result in inspiratory stridor. This patient thus has several reasons to have his respiratory status closely monitored in the ICU setting postoperatively.

Patients with myelodysplasias like myelomeningocele are at an **increased risk of developing latex sensitivity** because of repeated exposures to latex, such as occurs with repeated bladder catheterization. Strict adherence to latex-free environments must be followed.

KEY FACTS

- Major anesthetic considerations for repair of myelomeningoceles include positioning, potential for massive fluid and blood loss, and postoperative respiratory difficulties.
- For very large defects, it may be safest to induce general anesthesia and intubate with the patient in the lateral decubitus position, so as to avoid undue pressure on the lesion.
- Hydrocephalus, tethered cord, and type II Arnold-Chiari malformations often accompany lesions like myelomeningocele, and ventilatory responses to hypoxia and hypercarbia may be diminished or absent postoperatively.

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38. ANSWER: A

This question highlights why a single-shot spinal is considered a preferred anesthetic technique for a former preterm infant. By using a complete regional technique, one can **potentially avoid administering narcotics** and **a general anesthetic**, both of which may contribute to postoperative apnea in this **former premature twin** whose postconceptual age is <60 weeks. Unfortunately, it appears that his single-shot spinal has worn off.

Answer A would prevent postoperative apnea in this patient. It should be clearly communicated to the surgeon what dose of local anesthetic is safe and appropriate for this 4 kg infant, as a small volume of local anesthetic quickly becomes a toxic dose for small infants receiving bupivacaine. Since the infant has already received 0.4 cc of 0.5% bupivacaine in the subarachnoid space, the surgeon should be limited to 3.2 cc of 0.25% bupivacaine for infiltration. If no narcotics are administered, the patient will be at no increased risk of postoperative apnea with this strategy.

Answer B does not prevent postoperative apnea. It makes no difference what narcotic is administered. **Any administration of narcotic** has been **associated with postoperative apnea** in former preterm infants with a postconceptual age <60 weeks.

Answer C does not reliably prevent postoperative apnea either. Even if no narcotic medication is administered, former preterm infants with a postconceptual age <60 weeks undergoing **general anesthesia** are at increased risk of postoperative apnea.

Answer D is attractive since the N-methyl-D-aspartate (NMDA) antagonist ketamine is often used to maintain spontaneous respirations while also providing analgesia. However, when ketamine is used to supplement neonatal spinal anesthesia, the incidence of postoperative apnea is actually **greater** than with a general anesthetic.

Spinal anesthesia is an attractive option for this patient and surgery because of its association with less postoperative apnea, and timing of surgery meshes well with unilateral inguinal hernia repair. There is a lower risk of total spinal in neonates, but there are several technical considerations when performing a neonatal spinal. Among these considerations is the **appropriate positioning and bracing of the baby** while the spinal is being performed. **Excessive neck flexion** should be **avoided**, as this may **obstruct** the patient's airway. Since the conus medullaris is located at L3 in neonates and infants, spinal anesthesia should be performed at the L4/5 or L5/S1 level. When the subarachnoid space has been entered, the local anesthetic should be administered slowly with a tuberculin syringe.

Any repositioning of the infant after placement of the spinal should be performed carefully. In particular, any **Trendelenburg position should be avoided**, as sometimes occurs when a neonate's legs are lifted to place an electrocautery pad on the patient's back. This seemingly innocuous maneuver could potentially cause cephalad spread of the local anesthetic and a resultant **high spinal**.

KEY FACTS

- By using a complete regional technique, one can potentially avoid administering narcotics and a general anesthetic, both of which may contribute to postoperative apnea in this former premature twin whose postconceptual age is <60 weeks.
- Any administration of narcotic has been associated with postoperative apnea in former preterm infants with a postconceptual age <60 weeks.
- Former preterm infants with a postconceptual age <60 weeks undergoing general anesthesia are at increased risk of postoperative apnea.
- When ketamine is used to supplement neonatal spinal anesthesia, the incidence of postoperative apnea is actually greater than with a general anesthetic.

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39. ANSWER: B

Pyloric stenosis is a medical emergency, not a surgical emergency. It is common in firstborn males within the first 3 to 6 weeks of life. Perioperative concerns for this patient include **full stomach precautions** and severe **dehydration**. Volume status for patients with pyloric stenosis coming to the operating room must be adequate, and **metabolic alkalosis from repeated vomiting** should be corrected with vigorous fluid resuscitation prior to surgical correction.

Answer B best indicates that the patient is ready for surgery, as his electrolyte imbalances have been corrected. Specifically, his **hypokalemia, hypochloremia, and increased bicarbonate level** from his contraction alkalosis have been appropriately corrected with fluid resuscitation. Other signs of adequate volume status in this patient include appropriate urine output (wet diapers), normal behavior (not irritable or lethargic), normal skin turgor, tears if the child is crying, and anterior fontanelles that are not depressed.

Answer A is incorrect because the patient's potassium, chloride, and bicarbonate levels have not yet been corrected. These laboratory values are consistent with metabolic alkalosis and likely are the values that this infant with pyloric stenosis initially presented with. Neither Answer C nor D is correct because the bicarbonate levels have not been appropriately corrected with adequate fluid resuscitation.

Patients with pyloric stenosis have a full stomach that may contain radiocontrast dye from confirmatory imaging studies. It is advisable to **suction the stomach with a large-bore catheter** with the patient in the supine, right, and left lateral decubitus positions. One study found that this technique removes 98% of gastric contents. After the stomach has been suctioned, options for intubation include **awake** or **rapid sequence** intubation. Either technique is reasonable, but a study comparing awake versus rapid sequence intubation demonstrated increased success with first pass intubation when muscle relaxant was used.

Postoperative analgesia for laparoscopic or open pyloromyotomy typically consists of local anesthetic infiltration and acetaminophen. **Narcotics are not routinely required for postoperative analgesia** for this surgery.

KEY FACTS

- Perioperative concerns for patients with pyloric stenosis include full stomach precautions and severe dehydration.

- Metabolic alkalosis (hypokalemia, hypochloremia, and increased bicarbonate) from repeated vomiting should be corrected with vigorous fluid resuscitation prior to surgical correction.
- Signs of adequate volume status in this patient include appropriate urine output (wet diapers), normal behavior (not irritable or lethargic), normal skin turgor, tears if the child is crying, and anterior fontanelles that are not depressed.

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40. ANSWER: D

Pediatric anesthesiologists must be able to anticipate and recognize signs and symptoms of active upper respiratory infections. This former preterm child has several symptoms of an active URI. Since this surgery is elective, it should be **postponed at least 4 weeks** until symptoms of this active URI have resolved. Moreover, since this child has not received any vaccinations, he may also have a more serious illness like varicella or measles, and this should be investigated further.

Other predictors for an acute URI include parental reports of the child having a "cold," nasal congestion, snoring, exposure to secondhand smoking, and parental reports that the child appears ill, which indicate changes in mental status or behavior.

Having an active URI increases this child's risks of **perioperative airway complications** such as bronchospasm, laryngospasm, and major desaturation episodes up to 10-fold. Furthermore, since he is a former preterm infant, his risks of respiratory complications are increased. These risks should be highlighted and discussed with the child's parents in the preoperative area, as cancellation of surgery may impose emotional and economic burdens on the parents with the challenges of rescheduling elective surgery.

Answer A is incorrect because this patient has an active URI and has other risk factors that increase his likelihood of having perioperative respiratory complications, even if a laryngeal mask airway is used instead of tracheal intubation. Bronchospasm has been found to occur more frequently in patients with active URIs who are intubated. Overall incidence of laryngospasm in patients with active URIs is similar independent of endotracheal tube versus LMA use. LMA use may decrease this child's propensity for bronchospasm, but it will not decrease the chance of laryngospasm in this patient with an active URI.

Answer B is incorrect. A study found that healthy children with URIs undergoing surgery not involving the airway or body cavity **did not benefit from preoperative bronchodilator administration** of either albuterol or ipratropium.

Answer C is incorrect. There are no data to support the routine use of steroids and broad-spectrum antibiotics in children with active URIs.

Unless this surgery is urgent or emergent, it should be postponed. Active URIs in children scheduled for cardiac surgery warrant special consideration, as there are risks that the child's heart or clinical disease process will deteriorate while awaiting the child to recover from an active URI. The child scheduled for cardiac surgery should be optimized preoperatively, and a thorough discussion of the perioperative risks of an active URI with general anesthesia should be explained to the child's parents.

An active URI was determined to be an independent risk factor for postoperative infections and other postoperative complications in children undergoing cardiac surgery. In a prospective study of children scheduled for cardiac surgery, overall incidence of respiratory adverse events, multiple postoperative complications, and bacterial infection were **significantly higher in children with active URIs**. Postoperative ICU duration was higher in the URI group, but duration of hospital stay was not significantly increased among children with or without active URIs.

There are rare instances when postponing surgery is not an option, such as occurs with solid organ transplant, and the risks should be explained and documented, and vigilance should be employed to watch for potential respiratory complications. Recognizing URI signs and symptoms and appropriately balancing risks and benefits for each patient are fundamental in the clinical acumen of pediatric anesthesiologists (see Box 20.2 and Table 20.5).

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Box 20.2 DIFFERENTIAL DIAGNOSIS OF A CHILD WITH A RUNNY NOSE

Noninfectious Causes

Allergic rhinitis: seasonal, perennial, clear nasal discharge, no fever
Vasomotor rhinitis: emotional (crying), temperature changes

Infectious Causes

Viral infections
Nasopharyngitis (common cold)
Flu syndrome (upper and lower respiratory tract)
Laryngotracheal bronchitis (infectious croup)
Viral exanthems
Measles
Chickenpox
Acute bacterial infections
Acute epiglottitis
Meningitis
Streptococcal tonsillitis

Table 20.5 FACTORS AFFECTING DECISION FOR ELECTIVE SURGERY IN CHILD WITH UPPER RESPIRATORY TRACT INFECTION

PRO	CON
Child has "just a runny nose," no other symptoms, "much better"	Parents confirm symptoms: fever, malaise, cough, poor appetite, just developed symptoms last night
Active and happy child	Lethargic, ill appearing
Clear rhinorrhea	Purulent nasal discharge
Clear lungs	Wheezing, rales
Older child	Child <1 year, ex-preemie
Social issues: hardship for parents to be away from work, insurance will run out	Other factors: history of reactive airway disease, major operation, endotracheal tube required

SOURCE: Reprinted with permission from: Cote CJ, Lerman J, Todres ID, eds. *A Practice of Anesthesia for Infants and Children*. 4th ed. Philadelphia, PA: Saunders; 2009: 61.

41. ANSWER: C

Sickle cell disease (SCD) encompasses a group of inherited hemoglobinopathies, with HbSC (sickle cell/HbC) and HbSD (sickle cell/HbD) having the greatest potential for significant clinical sickling. This sickling occurs when sickled erythrocytes accumulate in the microvascular of susceptible patients in the setting of factors that promote the **deoxygenation of hemoglobin** and interferes with **peripheral perfusion**. The accumulation of sickled erythrocytes causes ischemia, further sickling, and eventually end-organ failure.

Many organ systems are affected by sickle cell disease, and patients with this disease are predisposed to acute chest syndrome (ACS), recurrent episodes of **vaso-occlusive crises**, infection, renal insufficiency, osteonecrosis, and cholelithiasis. Chronic pulmonary and neurologic diseases like **stroke** are causes of significant morbidity and mortality in this patient population.

In the perioperative period, the most common complications in children with SCD include **ACS, fever, infection, vaso-occlusive crisis, and transfusion-related events**. Because this patient is predisposed to ACS and vaso-occlusive crisis, **liberal analgesics** should be administered, and **regional techniques** should be considered.

Similarly, **hypoxia should be avoided** by ensuring adequate oxygenation and oxygen-carrying capacity of hemoglobin, usually on the order of 10 g/dL. Transfusion of blood corrects anemia, dilutes the concentration of HbS erythrocytes, and can prevent severe complications like stroke. Since sickle cell patients often receive multiple transfusions of blood products, it is important that the blood they receive is **phenotype matched**, **leukocyte reduced**, and **screened for sickle cells**, as these patients have a high rate and risk of alloimmunization.

Aside from hypoxia, acidosis and circulatory stasis also contribute to sickling in susceptible individuals. Acid-base status should be closely monitored, and circulatory status can be optimized by providing appropriate fluid resuscitation and **avoiding excessive or prolonged tourniquet use**.

Because patients with SCD are already at an increased risk of developing stroke, hyperventilating to an end-tidal CO_2 < 25 mm Hg is not advised, as that would further compromise already **tenuous cerebral blood flow.**

Older patients with SCD like this patient may develop **restrictive lung disease and pulmonary hypertension**. This results from repeated ACS-like injury, chronic inflammation, and deficiency of nitric oxide. In addition, chronic intravascular hemolysis decreases the production of NO, and increased scavenging of NO reduces its bioavailability. **Endothelial dysfunction** and **NO deficiency** cause complications like pulmonary hypertension, priapism, and skin ulceration. Studies have shown that **inhaled NO ameliorates the symptoms of ACS**, so inhaled nitric oxide would not be deleterious for this patient and may potentially improve ventilation (see Box 20.3).

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Box 20.3 PERIOPERATIVE CONSIDERATIONS AND CONCERNS IN SICKLE CELL DISEASE

Preoperative

Screening if unknown status in at-risk children
Admission to hematology service (under most circumstances)
History of acute chest syndrome, vaso-occlusive pain crises, hospitalizations, transfusions, transfusion reactions
Neurologic assessment (strokes, cognitive limitations)
History of analgesic and other medication use
Hematocrit
Oxygen saturation (room air), chest radiograph
Pulmonary function tests (when appropriate)
Echocardiography (when appropriate)
Neurologic imaging (when there are recent changes)
Renal function studies
Transfusion crossmatch (antibody-matched, leukocyte reduced, sickle negative)
Transfusion to correct anemia (under most circumstances)
Parenteral hydration while NPO
Pain management
Aggressive bronchodilator therapy
Appropriate antibiotic therapy, including pre-splenectomy antibiotics and immunizations, where indicated

Intraoperative

Maintenance of oxygenation, perfusion, normal acid-basis status, temperature, hydration
Availability of appropriately prepared blood (when appropriate)
Replacement of blood loss
Anesthetic technique appropriate for procedure and postoperative analgesic requirements
Physiologic effects of laparoscopy on circulatory and respiratory function
Appropriate antibiotic therapy
Judicious use of tourniquets, cell saver, and cardiopulmonary bypass

Postoperative

Management by hematology service
Monitoring for complications, especially acute chest syndrome and vaso-occlusive pain crises
Maintenance of oxygen saturation monitoring and supplementation as needed, including supplemental oxygen the first 24 hours regardless of oxygen saturation
Appropriate hydration (oral + parenteral)
Appropriate antibiotic therapy
Aggressive pain management
Early mobilization

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42. ANSWER: C

Beckwith-Wiedemann syndrome usually occurs sporadically and consists of **exomphalos, macroglossia, gigantism, organomegaly, and hypoglycemia**. It has an incidence of approximately 1.5 per 100,000 with an increased incidence in West India, and occurs as a result of failure of normal biparental inheritance of chromosome 11p15, which contains growth-promoting and tumor-suppressor genes, resulting in increased insulin-like growth factor 2 (IGF-2). This **increased IGF-2** is responsible for **somatic overgrowth**, the predisposition for tumors, and **hypoglycemia**.

As with this patient, early visceromegaly occurs, and neonates with Beckwith-Wiedemann syndrome often present for repair of omphalocele, anomalies of intestinal rotation, and diaphragmatic eventration. Sometimes patients with Beckwith-Wiedemann syndrome have **midface hypoplasia**, so a full preoperative airway evaluation is important, as securing this patient's airway may be challenging. It would be prudent to have a **difficult airway cart** and various LMAs available for instrumenting this child's airway.

Several organ systems may be involved with Beckwith-Wiedemann syndrome. Cardiomegaly, hepatosplenomegaly, visceromegaly, and several malignant tumors have been associated with Beckwith-Wiedemann syndrome. When patients with Beckwith-Wiedemann syndrome have hemihypertrophy, an increased incidence of malignant tumors like adrenal carcinoma, Wilms tumor, hepatoblastoma, thoracic neuroblastoma, rhabdomyosarcoma, and congenital gastric teratoma has been reported. Proper preoperative workup of this patient with Beckwith-Wiedemann syndrome and hemihypertrophy thus includes screens for **somatic tumors** and **a full cardiac workup**.

Answer C is correct, as a cardiac echocardiogram will evaluate for cardiomegaly, cardiomyopathy, congenital cardiac lesions, or cardiac hamartoma. Data from this study will more strongly influence decisions regarding this patient's anesthetic and choice of intraoperative medications. Inotropes and bacterial endocarditis prophylaxis may be indicated for this patient, depending on what her cardiac echocardiogram shows.

Answer A is incorrect. Although it would be nice to know the patient's fasting glucose level, this data will not significantly alter the patient's anesthetic, as this data point is not absolutely required to maintain intraoperative euglycemia.

Similarly, Answer B is incorrect. Beckwith-Wiedemann syndrome is associated with hepatosplenomegaly, but

knowing the patient's LFTs will not significantly alter her anesthetic plan. If a neuraxial block were planned for postoperative analgesia, then coagulation studies and a platelet count could alter the anesthetic plan. However, this data will not change the decision regarding the planned femoral peripheral nerve block catheter.

Answer D is a distractor, as Beckwith-Wiedemann syndrome has not been associated with susceptibility to malignant hyperthermia.

KEY FACTS

- Beckwith-Wiedemann syndrome usually occurs sporadically and consists of exomphalos, macroglossia, gigantism, organomegaly, and hypoglycemia.
- Beckwith-Wiedemann syndrome is associated with midface hypoplasia, and airway management can be difficult.
- Proper preoperative workup of this patient with Beckwith-Wiedemann syndrome and hemihypertrophy thus includes screens for somatic tumors and a full cardiac workup.

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21.

FLUID, ELECTROLYTE, AND TEMPERATURE MANAGEMENT

Cornelius Sullivan and Robert Brustowicz

1. A Jehovah's Witness patient is scheduled for surgery where considerable blood loss is anticipated. With the understanding that there are isolated case reports where otherwise healthy patients managed with a high inspired oxygen tension have done well with a hematocrit as low as 4% and assuming that the patient is normovolemic, what is the generally accepted hematocrit at which one might first anticipate subendocardial myocardial ischemia to develop?

A. 25%
B. 20%
C. 15%
D. 10%

2. The main reason why newborns are subject to increased heat loss (compared to an adult) is:

A. Higher surface area to mass ratio
B. Thicker subcutaneous fat layer
C. Higher dermal keratin content
D. Predominantly nonshivering thermogenesis

3. An 8-year-old girl is undergoing resection of a posterior fossa tumor in the sitting position. A sudden decrease in end-tidal carbon dioxide (CO_2) associated with an audible change in the precordial Doppler tones most likely originates from:

A. Bone edges
B. Epidural veins
C. Bridging veins
D. Intracranial venous sinuses

4. Which panel of clinical and laboratory assessments is most consistent with the syndrome of inappropriate ADH secretion (SIADH)?

	Serum Na+ mEq/L	Serum mOsm/L	Urine mOsm/L	Volume Status
A.	128	275	350	Normal to high
B.	130	300	400	Normal
C.	138	290	210	Normal
D.	128	264	430	Normal to low

5. Which panel of clinical and laboratory assessments is most consistent with cerebral salt wasting syndrome (CSW)?

	Serum Na+ mEq/L	Serum mOsm/L	Urine mOsm/L	Volume Status
A.	128	275	350	Normal to high
B.	130	300	400	Normal
C.	138	290	210	Normal
D.	128	264	430	Normal to low

6. A previously healthy 2-year-old boy presents to the emergency department with a history of vomiting and diarrhea. Vital signs are a heart rate of 188 beats per minute, a blood pressure of 76/38 mm Hg, and a respiratory rate of 28 breaths per minute. His skin is dusky and cool, the eyes appear sunken, skin turgor is notably abnormal, and he is lethargic and drowsy. Urine specific gravity is 1.035. His weight is about 15% less than that recorded in a well-child visit last month. The best estimate of the patient's fluid deficit is:

A. 25 mL/kg
B. 50 mL/kg
C. 100 mL/kg
D. 150 mL/kg

7. The best *initial* treatment plan for the patient in Question 6 would administer in the first hour:

A. Dextrose 5% ½ Normal saline, 30 mL/kg
B. Normal saline, 30 mL/kg
C. Lactated Ringer's solution, 30 mL/kg
D. 5% albumin, 10 mL/kg

8. The thermoneutral temperature is defined as the temperature of:

A. The patient, after reaching steady state post induction temperature
B. The room, at which patient oxygen consumption is minimized temperature
C. The patient, at which active warming can be discontinued temperature
D. The room, at which active warming can be discontinued temperature

9. Which of the following mechanisms is primarly responsible for heat loss in infants?

A. Radiation
B. Convection
C. Evaporation
D. Conduction

10. An 11-year-old male with idiopathic scoliosis complains of being unable to see in the postanesthesia care unit (PACU) after a posterior fusion in the prone position. This does not improve over the next 2 days. The most likely mechanism is thought to be:

A. Central retinal artery occlusion
B. Posterior ischemic optic neuropathy
C. Retinal detachment
D. Central retinal vein occlusion

11. In a full-term neonate, the largest fraction of total body water resides in the:

A. Intracellular space
B. Interstitial space
C. Extracellular space
D. Transcellular space

12. A 36-week-gestation newborn is undergoing emergency closure of a gastroschisis. Because of limited glycogen reserves, intraoperative dextrose administration is recommended at approximately what empiric rate?

A. 500 μg/kg per minute
B. 5 mg/kg per minute
C. 5 mg/kg per hour
D. No glucose administration necessary unless serum glucose falls below 45 mg/dL

13. A 15-year-old male, who has been chronically ill and malnourished, had a small-bowel resection for Crohn's disease 7 days ago. During the transition from parenteral nutrition to aggressive enteral feeding, which of the following electrolyte abnormalities is most likely to be encountered if refeeding syndrome occurs?

A. Hypocalcemia
B. Hypermagnesemia
C. Hypophosphatemia
D. Hyperglycemia

14. An 11-year-old girl in the intensive care unit (ICU) the evening following resection of a pituitary microadenoma is noted to have an elevated urine output. A urine dipstick is negative for glucose, and no diuretics have been given. Which of the following is most consistent with a diagnosis of appropriate diuresis after overgenerous intravenous fluid administered perioperatively as opposed to new-onset central diabetes insipidus?

A. Urine output of 2 cc/kg per hour
B. Serum sodium of 140 meq/L
C. Serum osmolality of 298 mosm/kg
D. Urine osmolality of 450 mosm/kg

15. Following a motor vehicle accident, a 5-year-old girl is hemodynamically unstable in the emergency department and requires rapid volume resuscitation. If a 20-gauge IV can be placed (average inner diameter of 1.5 mm), the infusion flow rate achieved when compared to a 24-gauge IV (average inner diameter of 0.75 mm) will be increased by a factor of:

A. 4
B. 8
C. 16
D. 32

16. Assuming a 20-gauge IV can be successfully placed in the patient from Question 15, choosing a catheter 30 mm in length will change the infusion rate by what factor compared to a catheter 15 mm in length?

A. 0.5 (flow will be reduced by 50%)
B. 0 (flow will be unchanged)
C. 2 (flow will be doubled)
D. 0.25 (flow will be reduced by 75%)

17. Which of the following sites for temperature monitoring is considered as accurate as the pulmonary artery for measuring core temperature?

A. Tympanic membrane
B. Esophagus
C. Bladder
D. Rectum

18. Hypercalcemia in infancy is most commonly associated with:

A. Williams syndrome
B. Shprintzen syndrome
C. DiGeorge syndrome
D. CHARGE association

19. A 3.5 kg, 5-week-old male infant is diagnosed with pyloric stenosis after presenting with 3 days of vomiting. Serum electrolytes are: sodium132 mEq/L, potassium 2.8 mEq/L, chloride 96 mEq/L, and bicarbonate 27 mEq/L. The best fluid with which to *begin* intravenous fluid resuscitation is:

A. Normal saline (NS)
B. Lactated Ringer's solution
C. D5 ¼ NS with 20 mEq KCL/500 mL
D. 5% albumin

20. A 4.0 kg neonate, delivered via cesarean section at 32 weeks, from a pregnancy complicated by poorly controlled gestational diabetes, is irritable, "twitchy," and feeding poorly at 12 hours of life. A brief seizure may have been observed. A glucose level is measured at 50 mg/dL. The most likely etiology of these symptoms is:

A. Hypoglycemia
B. Hypermagnesemia
C. Hypocalcemia
D. Maternal opiod use

CHAPTER 21 ANSWERS

1. ANSWER: C

During acute **normovolemic hemodilution,** there is an improvement in the flow characteristics of blood. Generally patients with healthy myocardial function will be able to maintain adequate oxygen delivery to peripheral tissues at a **hematocrit below 25%** because of this increase in flow. As the hematocrit decreases below 20%, oxygen extraction increases. As the hematocrit declines further, below 15%, **subendocardial myocardial ischemia** may develop. As a result, many practitioners recommend keeping the hematocrit closer to 20% and not allowing it to drop below 15%.

KEY FACTS

- During acute normovolemic hemodilution, there is an improvement in the flow characteristics of blood.
- As the hematocrit declines below 15%, subendocardial myocardial ischemia may develop.

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2. ANSWER: A

Thermoregulation is a challenge for all mammals, but none so much as those just born. Several anatomic and physiologic differences from the adult can be found to explain this vulnerability. **The proportionately larger head (usually with a circumference greater than the chest) is reflected in an increase in the ratio of skin surface area to body mass** (around 1.0 in the term neonate, compared to about 0.4 in the adult). This is also the reason that radiation is the quantitatively greatest mechanism of heat loss in this population.

Neonates have greater evaporative heat loss than adults, due to less dermal keratin content, as well as increased conductive loss due to a thinner layer of subcutaneous fat.

Nonshivering thermogenesis is an increase in heat production due to metabolism of brown fat, which constitutes somewhere around 2%–6% of body weight at term. **Brown fat** is so named because of the characteristic appearance (after staining) of tightly packed mitochondria in the cytoplasm of these multinucleate cells, which can uncouple oxidative phosphorylation and preferentially generate heat over ATP production. Moreover, this action somehow recruits additional local blood flow, reportedly up to 25% of cardiac output, thus directly transferring heat to the circulation. Anatomically, this appears concentrated in the area between the scapulae, the axillae, the mediastinum, and the perinephric retroperitoneum. Unanesthetised infants can effectively **double their basal metabolic rate**, and this mechanism is preserved certainly through the first, and possibly through the second year of life. Because the musculoskeletal system is immature and its mass relatively small, **shivering thermogenesis** does not contribute significantly to preservation of body heat in the neonate; moreover, it would be effectively shut down under anesthesia anyway.

KEY FACTS

- The skin surface to body mass ratio is elevated in neonates in comparison to adults (around 1.0 in the term neonate, 0.4 in the adult).
- Neonates have greater evaporative heat loss than adults, due to less dermal keratin content, as well as increased conductive loss due to a thinner layer of subcutaneous fat.
- Nonshivering thermogenesis is an increase in heat production due to metabolism of brown fat, which constitutes around 2%–6% of body weight at term.
- Because the musculoskeletal system is immature and its mass relatively small, shivering thermogenesis does not contribute significantly to preservation of body heat in the neonate.

REFERENCE

Cote CJ, Lerman J, Anderson B, eds. *A Practice of Anesthesia for Infants and Children*. 5th ed. Philadelphia, PA: Saunders; 2013:558.

3. ANSWER: D

Venous air embolism is a potential complication in any procedure in which there exists a possible negative pressure differential between the right atrium and venous elements in the operative field. Consequently, either a **large hydrostatic gradient (height above heart) or relatively low central filling pressure** can exacerbate the risk. In neurosurgery, the greatest risk is presented by the **dural venous sinuses**, because of their **anatomic resistance to collapse**. **Bone edges** are problematic because of the difficulty obtaining a perfect seal even with bone wax; the other sites are usually controlled more easily by cautery.

KEY FACTS

- A negative pressure differential between the right atrium and venous elements in the operative field increases the risk of venous air embolism.

- Either a large hydrostatic gradient (height above heart) or relatively low central filling pressure can exacerbate the risk.
- The greatest risk of venous air embolism in neurosurgery is presented by the dural venous sinuses because of their anatomic resistance to collapse.

REFERENCE

Cote CJ, Lerman J, Anderson B, eds. *A Practice of Anesthesia for Infants and Children*. 5th ed. Philadelphia, PA: Saunders; 2013:519.

4. ANSWER: A

Untreated **SIADH** results in a **hypoosmolar hyponatremia** with either **eu- or hypervolemia**, and inappropriately **concentrated urine**. While classically associated with CNS disease (trauma, hemorrhage, infection) and neoplasm (bronchogenic carcinoma of the lung, lymphoma), **ADH secretion** is also transiently increased under any anesthetic and surgical stress. **Treatment** centers on free water restriction and dealing with the underlying cause. Mineralocorticoids have been useful as well in SIADH. In Europe, the vasopressin receptor antagonist tolvaptan is available. Correction of serum sodium should proceed slowly to prevent osmotic central **pontine myelinolysis**.

KEY FACTS

- SIADH results in a hypoosmolar hyponatremia with either eu- or hypervolemia, and inappropriately concentrated urine.
- Treatment of SIADH consists of free water restriction and management of the underlying cause.
- Correction of serum sodium should proceed slowly to prevent osmotic pontine myelinolysis.

5. ANSWER: D

Hyponatremia is the most common electrolyte abnormality encountered in postoperative neurosurgical patients. **Cerebral salt wasting syndrome** is a hypovolemic hyponatremia resulting from increased renal excretion of sodium, probably due to decreased reabsorption in the proximal tubule in the setting of circulating natriuretic peptides (both atrial and brain type) and altered sympathetic tone. **Treatment** is repletion of salt and water with normal saline, as opposed to the free water restriction needed to treat SIADH. In severe cases where concern exists for transtentorial herniation, **hypertonic saline** has been used with success.

KEY FACTS

- Cerebral salt wasting syndrome is a hypovolemic hyponatremia resulting from increased renal excretion of sodium, probably due to decreased reabsorption in the proximal tubule in the setting of circulating natriuretic peptides (both atrial and brain type) and altered sympathetic tone.
- Treatment is repletion of salt and water with normal saline, as opposed to the free water restriction needed to treat SIADH.

REFERENCE

Wright WL. Sodium and fluid management in acute brain injury. *Curr Neurol Neurosci Rep*. 2012;12(4):466–73.

6. ANSWER: D

Clinical estimates of dehydration remain very useful in pediatric patients, and it can guide therapy while laboratory studies are pending. While **healthy infants can tolerate a greater degree of dehydration than adults** without symptoms due to a higher ratio of total body water to weight, they can also deteriorate more rapidly, especially with losses from the GI tract. This patient shows signs of severe dehydration, corresponding to a deficit of about 150 mL/kg (15% weight loss: 0.15 × 1000 ml/ 1 kg = 150 ml/kg which is primarily fluid loss from vomiting and diarrhea).

KEY FACTS

- While healthy infants can tolerate a greater degree of dehydration than adults without symptoms due to a higher ratio of total body water to weight, they can also deteriorate more rapidly, especially with losses from the GI tract.

REFERENCE

Davis PJ, Cladis FP, Motoyama EK, eds. *Smith's Anesthesia for Infants and Children*. 8th ed. St. Louis, MO: Elsevier Mosby; 2011:Chapter 5.

7. ANSWER: B

Normal saline remains the fluid of choice for initial resuscitation of dehydrated infants and children. Answer A would lead to excessive extravascular water, while the lactate in Ringer's may not be metabolized to bicarbonate in the hypoperfused liver. **Colloid solutions** are seldom if

ever recommended as the *initial* choice in this setting, and 10 cc/kg would be insufficient even if chosen.

KEY FACTS

- Normal saline remains the fluid of choice for initial resuscitation of dehydrated infants and children.
- Colloid solutions are seldom if ever recommended as the initial choice in the dehydrated child.

REFERENCE

Davis PJ, Cladis FP, Motoyama EK, eds. *Smith's Anesthesia for Infants and Children*. 8th ed. St. Louis, MO: Elsevier Mosby; 2011:Chapter 5.

8. ANSWER: B

Thermoneutrality is defined as the ambient temperature at which oxygen demand and metabolic heat production are minimized. Typically this means that cutaneous arteriovenous shunts are open and skin blood flow is maximal. This temperature is approximately 28°C in the unclothed adult, 32°C in the neonate, and 34°C in the preterm infant, but there is no defined room temperature that assures thermoneutrality in every imaginable clinical scenario. The temperature gradient from **skin to environment is more clinically relevant than that from core to environment**; experimentally a skin-to-environment gradient of 2°C to 4°C is observed to minimize oxygen consumption. While healthy infants can respond to cold stress by **increasing both cardiac output and brown fat metabolism** (nonshivering thermogenesis), the former may be limited by poor cardiovascular reserve and the latter is severely attenuated by volatile anesthetics. The final common pathway of hypothermia and increased oxygen consumption is **end-organ dysfunction and metabolic acidosis**.

KEY FACTS

- Thermoneutrality is defined as the ambient temperature at which oxygen demand and metabolic heat production are minimized.
- The temperature gradient from skin to environment is more clinically relevant than that from core to environment.
- While healthy infants can respond to cold stress by increasing both cardiac output and brown fat metabolism (nonshivering thermogenesis), the former may be limited by poor cardiovascular reserve and the latter is severely attenuated by volatile anesthetics.

REFERENCE

Cote CJ, Lerman J, Anderson B, eds. *A Practice of Anesthesia for Infants and Children*. 5th ed. Philadelphia, PA: Saunders; 2013:562.

9. ANSWER: A

Mechanisms of heat loss in humans include radiation, convection, evaporation, and conduction. Radiation can result in the greatest loss of heat in neonates. Perhaps because early modern humans evolved in Africa, our physiology is much better adapted to dissipating heat than preserving it. **Vasodilation raises skin temperature**, which increases energy exchange by radiation as quantified by the Stefan-Boltzmann equation $H = esA\ (T1^4 - T0^4)$ where H is the loss in joules/sec, e is the emissivity, s is the Boltzmann constant, A is the surface area, and T1 and T0 are the temperatures of the two bodies. In the normal neonate, this is the **primary route of heat loss**. **Evaporative heat loss** occurs through sweating, insensible loss (through skin and by humidification of dry airway gas), and evaporation of liquids (prep solutions, etc.) from the skin. This is driven by the difference in the vapor pressure of water between skin or mucosa and air, so relative humidity and minute ventilation can be important factors. Because evaporation requires a phase transition of water, the latent heat of vaporization quantifies the energy requirement at about 2500 joules/gram. In an adult, this can represent about 1.4 kilowatts. Because sweat glands mature at about 30 weeks, term infants can sweat in a warm room, and in fact when air temperature is at or above body temperature, sweating is the only mechanism by which heat can be dissipated.

KEY FACTS

- Mechanisms of heat loss in humans include radiation, convection, evaporation, and conduction.
- In the normal neonate, radiation results in the largest magnitude of heat loss.
- Evaporative heat loss occurs through sweating, insensible loss (through skin and by humidification of dry airway gas), and evaporation of liquids from the skin.

REFERENCE

Cote CJ, Lerman J, Anderson B, eds. *A Practice of Anesthesia for Infants and Children*. 5th ed. Philadelphia, PA: Saunders; 2013:562.

10. ANSWER: B

Postoperative visual loss after surgery is a rare but devastating complication after spine surgery in the prone position. In one study, children have almost six times greater risk than healthy adults. **Hypotension, anemia, prolonged procedure, and high volume crystalloid resuscitation** are known risk factors, along with diabetes and peripheral vascular disease in adults. **Retinal perfusion pressure** can be defined as mean arterial pressure (MAP) – intraocular pressure (IOP); the latter is known to be elevated in the prone position. When retinal perfusion pressure declines

below a critical threshold, a watershed type infarct occurs, referred to as posterior ischemic optic neuropathy (PION).

Central retinal artery occlusion (CRAO) is an infarct caused by platelet fibrin thromboembolism as a result of atherosclerotic disease. Risk factors include arterial hypertension, diabetes mellitus, carotid artery disease, coronary artery disease, transient ischaemic attacks (TIAs) or cerebral vascular accidents, and smoking tobacco. These same risk factors apply to central retinal vein occlusion, which is also related to thrombophilic states such as hyperhomocysteinemia, MTHFR gene mutation, factor V Leiden mutation, protein C and S deficiency, antithrombin deficiency, prothrombin gene mutation, anticardiolipin antibodies, and lupus anticoagulant.

Retinal detachment is not associated with anesthesia and surgery in the prone position; in fact, some studies suggest that patients treated for retinal detachment actually do better if placed prone for 2 hours postop.

KEY FACTS

- Children have almost six times greater risk than healthy adults for postoperative visual loss.
- Hypotension, anemia, prolonged procedure, and high-volume crystalloid resuscitation are known risk factors, along with diabetes and peripheral vascular disease in adults.
- Retinal perfusion pressure can be defined as MAP – IOP.

REFERENCES

dell'Omo R, Semeraro F, Guerra G, et al. Short-time prone posturing is well-tolerated and reduces the rate of unintentional retinal displacement in elderly patients operated on for retinal detachment. *BMC Surg*. 2013;13(Suppl. 2):S55.

Patil CG, Lad EM, Lad SP, Ho C, Boakye M. Visual loss after spine surgery: a population-based study. *Spine*. 2008;33(13):1491–6.

11. ANSWER: C

The distribution and composition of bodily fluids change significantly from birth to maturity, and an understanding of these concepts is important in the rational use of intravenous fluids, electrolytes, and medications. As pointed out by Harris (1957), a normal newborn infant who weighs 3 kg is one third the size of an adult in length but one ninth the adult size in body surface area and one twentieth of adult size in weight.

In the adult, **total body water** is about 60% of body weight, of which two thirds (40% of body weight) is intracellular and one third (20% of body weight) is extracellular.

The **extracellular compartment** can be subdivided into one-fifth intravascular (or plasma) volume and four-fifths interstitial fluid. Most of total body sodium is contained in this category, which is the distribution volume for both crystalloid and colloid solutions.

The **transcellular fluids** are those separated from blood by both endothelium and epithelium, such as cerebrospinal, pleural, peritoneal, and synovial fluids, and are considered a negligible specialized subset of extracellular fluid.

The **full-term neonate** has both a larger fraction of total body weight as fluid and a higher fraction of total body water as extracellular, about 60%. This fraction is even higher in the preterm infant.

KEY FACTS

- In the adult, total body water is about 60% of body weight, of which two thirds (40% of body weight) is intracellular and one third (20% of body weight) is extracellular.
- The extracellular compartment can be subdivided into one-fifth intravascular (or plasma) volume and four-fifths interstitial fluid.
- The full-term neonate has both a larger fraction of total body weight as fluid and a higher fraction of total body water as extracellular, about 60%. This fraction is even higher in the preterm infant.

REFERENCES

Barash PG, Cullen BF, Stoelting RK, eds. *Clinical Anesthesia*. 5th ed. Philadelphia, PA: Lippincott Williams & Wilkins; 2005:170.

Motoyama EK, Davis PJ, eds. *Smith's Anesthesia for Infants and Children*. 8th ed. St. Louis, MO: Elsevier Mosby; 2011:Chapter 5.

12. ANSWER: B

The fetus begins to produce **glycogen stores** in the final month of gestation; the term newborn holds about 5% of body weight in hepatic glycogen. Most of this is consumed through **gluconeogenesis** in the first 48 hours of life. Typical newborn fluid requirements are approximately **75 mL/kg for the first 24 hours** of of life. As D10W contains 100 mg dextrose per milliliter, this corresponds to 7500 mg/kg per day or 312 mg/kg per hour, which is about 5 mg/kg per minute.

KEY FACTS

- The fetus begins to produce glycogen stores in the final month of gestation; the term newborn holds about 5% of body weight in hepatic glycogen.
- Most of this is consumed through gluconeogenesis in the first 48 hours of life.
- Typical newborn fluid requirements are approximately 75 mL/kg for the first 24 hours of life.

REFERENCE

Cote CJ, Lerman J, Anderson B, eds. *A Practice of Anesthesia for Infants and Children*. 5th ed. Philadelphia, PA: Saunders; 2013:164.

13. ANSWER: C

The **refeeding syndrome** was first described among survivors in camps liberated at the end of World War II, and its pathophysiology was elucidated after the development of total parenteral nutrition (TPN) in the 1980s. Total body and especially intracellular stores of phosphate are depleted during **catabolic starvation**. With **refeeding**, the reappearance of carbohydrates stimulates glucose over fat metabolism; the resulting insulin surge drives glucose, potassium, magnesium, and phosphate intracellularly. It is common for abnormalities of fluid balance and glucose metabolism to occur along with hypophosphatemia, hypomagnesemia, and hypokalemia. These sudden variances in cell membrane electrochemical balance are felt to be responsible for **the clinical manifestations of the syndrome**, which can include rhabdomyolysis, dysrhythmia, respiratory failure, and death.

KEY FACTS

- Total body and especially intracellular stores of phosphate are depleted during catabolic starvation.
- With refeeding, the reappearance of carbohydrates stimulates glucose metabolism; the resulting insulin surge drives glucose, potassium, magnesium, and phosphate intracellularly.
- The clinical manifestations of this syndrome can include rhabdomyolysis, dysrhythmia, respiratory failure, and death.

REFERENCE

Fuentebella J, Kerner JA. Refeeding syndrome. *Pediatr Clin North Am*. 2009;56(5):1201–10.

14. ANSWER: D

Diabetes insipidus occurs when the kidney either fails to receive (central DI) or fails to respond to (nephrogenic DI) hormonal (antidiuretic hormone) signaling to conserve water.

Central diabetes insipidus occurs not infrequently after pituitary surgery, and it can be transient or permanent depending on the degree of disruption of the hypothalamic/neurohypophysis axis. While no absolute lab values for the diagnosis have been established, the hallmark of DI is the inability to excrete a concentrated urine; consequently, a urine osmolarity of 450 would be incompatible.

KEY FACTS

- Diabetes insipidus occurs when the kidney either fails to receive (central DI) or fails to respond to (nephrogenic DI) hormonal (antidiuretic hormone) signaling to conserve water.
- Central DI occurs not infrequently after pituitary surgery, and it can be transient or permanent depending on the degree of disruption of the hypothalamic/neurohypophysis axis.

15. ANSWER: C (SEE DISCUSSION BELOW, RE: QUESTION 16)

16. ANSWER: A

The **Hagen-Poiseuille equation** describes the flow rate of noncompressible Newtonian fluids through cylindrical conduits for a given pressure drop across the system:

$\Delta P = 8VLQ/\pi R^4$
OR
Flow rate $(Q) = \Delta P \pi R^4/8VL$
V = viscosity
L = length
Q = flow rate
R = radius

In other words, flow rate varies as the fourth power of the radius; therefore, doubling the inner diameter of the IV catheter will result in increasing flow rate by 2^4, or 16 times.

Conversely, flow rate is inversely proportional to the length of the conduit, so doubling the catheter length would reduce flow by half if the system otherwise remains the same.

REFERENCE

Batchelor GK. *An Introduction to Fluid Dynamics*. Cambridge, UK: Cambridge University Press; 2000;180.

17. ANSWER: C

Core temperature is the primary factor in thermoregulatory control in mammals, conceptually representing the initiator of hypothalamic "set-point" responses; unfortunately, there is no single measurement site that is ideal in all clinical settings. While pulmonary artery temperature is widely considered the most accurate, its clinical usefulness is limited, particularly in children. Nasopharyngeal measurement can be highly accurate at reflecting hypothalamic temperature if properly positioned near the soft palate. However, this can be falsely low with an uncuffed endotracheal tube with a

significant leak. Bleeding remains the major issue with this approach. Similarly, esophageal probes are commonly used, but if they prolapse into the stomach, measurement can again be falsely low. Skin and axillary temperatures are notoriously inaccurate, while tympanic temperatures are inconvenient for continuous measurement. The rectal temperature can also be highly accurate unless the probe becomes insulated in feces or is close to the peritoneal reflection in the setting of warm or cool abdominal irrigation. Bladder temperature is highly accurate unless the urine output is low.

KEY FACTS

- Core temperature is the primary factor in thermoregulatory control in mammals, conceptually representing the initiator of hypothalamic "set-point" responses.
- While pulmonary artery temperature is widely considered the most accurate, its clinical usefulness is limited, particularly in children.
- Nasopharyngeal measurement can be highly accurate at reflecting hypothalamic temperature if properly positioned near the soft palate.
- Skin and axillary temperatures are notoriously inaccurate, while tympanic temperatures are inconvenient for continuous measurement.
- The rectal temperature can also be highly accurate unless the probe becomes insulated in feces or is close to the peritoneal reflection in the setting of warm or cool abdominal irrigation.
- Bladder temperature is highly accurate unless the urine output is low.

REFERENCE

Cote CJ, Lerman J, Anderson B, eds. *A Practice of Anesthesia for Infants and Children*. 5th ed. Philadelphia, PA: Saunders; 2013:559.

18. ANSWER: A

Williams syndrome is a congenital disorder associated with a deletion on the long arm of chromosome 7 and an abnormality of the elastin gene product. Clinical associations include the so-called elfin facies, an outgoing personality, retardation, cardiac disease (aortic stenosis, coarctation), and endocrine abnormalities (hypercalcemia and hypothyroidism). DiGeorge and Shprintzen syndromes are part of the 22q11.2 deletion or velocardiofacial spectrum and, in addition to cardiac anomalies, are associated with hypocalcemia. Abnormalities of calcium homeostasis are not a feature of CHARGE association.

KEY FACTS

- Williams syndrome is a congenital disorder associated with a deletion on the long arm of chromosome 7 and an abnormality of the elastin gene product. Clinical associations include the so-called elfin facies, an outgoing personality, retardation, cardiac disease (aortic stenosis, coarctation), and endocrine abnormalities (hypercalcemia and hypothyroidism).
- DiGeorge and Shprintzen syndromes are part of the 22q11.2 deletion or velocardiofacial spectrum and, in addition to cardiac anomalies, are associated with hypocalcemia.

REFERENCE

Cote CJ, Lerman J, Anderson B, eds. *A Practice of Anesthesia for Infants and Children*. 5th ed. Philadelphia, PA: Saunders; 2013:304.

19. ANSWER: A

A large number of experimental observations indicate that **chloride depletion** plays a pivotal role in the development of the **normotensive hypochloremic, hypokalemic, metabolic alkalosis** classically associated with hypertrophic pyloric stenosis. **Prolonged vomiting** loses gastric fluid rich in both hydrogen and chloride ions, resulting in both metabolic alkalosis and hypochloremia. Despite the presence of some potassium in the gastric fluid, most of the **potassium deficit** is due to urinary losses triggered by secondary hyperaldosteronism. **Initially serum pH is preserved** by excretion of an alkaline urine with sodium and potassium loss, but chloride depletion promotes the reabsorption of bicarbonate in the proximal tubule and decreases its secretion in the collecting tubule, resulting in the paradoxical aciduria characteristic of late presentation. **Normal saline, containing 154 mEq/L of both sodium and chlorine ions, provides significantly more chloride than its closest competitor, lactated Ringer's at 130 mEq/L.** While some clinicians advocate including 5% dextrose in the initial treatment, combining this with ¼ normal saline (38 mEq/L) would be suboptimal. Situations in which initial resuscitation of pediatric surgical patients would best be accomplished with colloid solutions are indeed rare.

KEY FACTS

- Prolonged projectile vomiting associated with hypertrophic pyloric stenosis results in chronic chloride depletion with hypochloremic, hypokalemic, metabolic alkalosis.
- Most of the potassium deficit is due to urinary losses triggered by secondary hyperaldosteronism.

REFERENCE

Miozzari HH, Tonz M, von Vigier RO, Bianchetti MG. Fluid resuscitation in infantile hypertrophic pyloric stenosis. *Acta Paediatr*. 2001;90:511–4.

20. ANSWER: C

Hypocalcemia manifests as symptoms of neuromuscular irritability. In adults and older children, this may present as **perioral numbness or tingling, anxiety, arrhythmia, congestive heart failure, a prolonged QT interval, or the classic Chvostek's or Trousseau's signs**. Infants and younger children may have **cyanosis, feeding intolerance, laryngospasm, vomiting, or seizures**. Neonates, particularly premature, are at increased risk due to reduced PTH levels. In addition, maternal diabetes and glycosuria can produce hypomagnesemia in both mother and neonate. Hypocalcemia is a common complication of hypomagnesemia (not hypermagnesemia), and successful treatment may require repletion of both cations. **A glucose level of 50 mg/dL is within the normal range for neonates.** Emergency treatment of hypocalcemia can consist of 2–4 mg elemental calcium (usually as 10% calcium gluconate, preferably into a large or central vein, with continuouse electrocardiographic monitoring) over 5–10 minutes. If hypomagnesemia coexists, 6 mg elemental magnesium/kg (usually as 50% magnesium sulfate) can be infused over an hour.

KEY FACTS

- Hypocalcemia manifests as symptoms of neuromuscular irritability.
- In adults and older children, hypocalcemia may present as perioral numbness or tingling, anxiety, arrhythmia, congestive heart failure, a prolonged QT interval, or the classic Chvostek's or Trousseau's signs.
- Infants and younger children may have cyanosis, feeding intolerance, laryngospasm, vomiting, or seizures.

REFERENCE

Davis PJ, Cladis FP, Motoyama EK, eds. *Smith's Anesthesia for Infants and Children*. 8th ed. St. Louis, MO: Elsevier Mosby; 2011:Chapter 5.

22.

REGIONAL ANESTHESIA

Michael R. King, Nisha Kandiah, Karen Boretsky, and T. Anthony Anderson

1. A 2-year-old male is scheduled for circumcision. He undergoes general anesthesia and the urologist places a dorsal penile block for postoperative pain. Bupivacaine is chosen as a local anesthetic due to its long duration of action. Which of the following properties of bupivacaine best explains its duration?

A. pKa
B. Protein binding/lipid solubility
C. Amide structure
D. Molecular weight

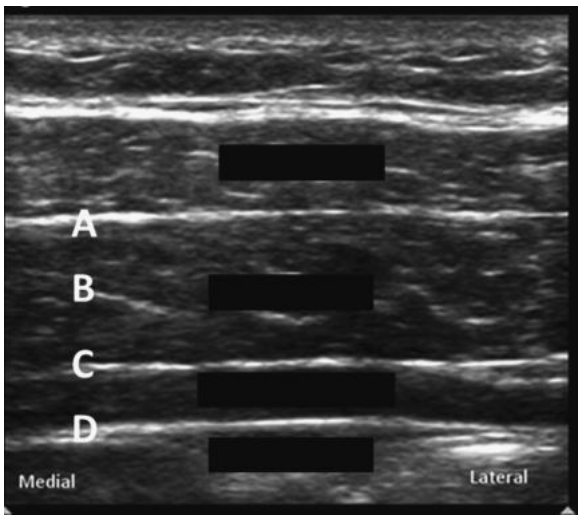
2. A 7-year-old, 20 kg female with appendicitis undergoes laparoscopic appendectomy. At the conclusion of the procedure, a bilateral transversus abdominis plane block is performed with 0.2% ropivacaine with 5 mcg/ml epinephrine for postoperative analgesia. What is the maximum volume of 0.2% ropivacaine with 5 mcg/ml epinephrine that should be used in this patient?

A. 15 mL
B. 25 mL
C. 30 mL
D. 50 mL

3. A 16-year-old male baseball player presents for surgical repair of a torn ligament in his elbow. The patient and his parents consent to a brachial plexus block, supraclavicular approach, for postoperative pain. The block is placed under ultrasound guidance preoperatively with 0.5% bupivacaine with 5 mcg/ml epinephrine. At which level of the brachial plexus is the supraclavicular block performed?

A. Roots/trunks
B. Trunks/divisions
C. Cords
D. Branches

4. Which of the images in the figure below correctly identifies the space where local anesthetic should be injected in order to perform a transversus abdominis plane block?



Ultrasound images of the muscles forming the anterior abdominal wall as the linear ultrasound (US) transducer is placed from midline to lateral positions over the anterior abdominal wall. (Reprinted with permission from Mandeep S, Chin KJ, Chan V. Ultrasound-guided transversus abdominis plane (TAP) block: a useful adjunct in the management of postoperative respiratory failure. *J Clin Anesth*. 2011;23(4):303–6.)

5. A 9-month-old male undergoes hypospadias repair. At the conclusion of the procedure, the anesthesiologist performs a caudal block with 0.25% bupivacaine without epinephrine for postoperative pain control. Which of the following are potential complications of caudal blockade with preservative-free bupivacaine?

A. Postoperative urinary retention
B. Hypertension
C. Postoperative apnea
D. Allergic reaction to para-aminobenzoic acid

6. A 2-month-old, 4.5 kg infant presents for right inguinal hernia repair. She has an intravenous line placed, undergoes uneventful intravenous induction and intubation, and is maintained on sevoflurane. The patient receives no opiate medication, but the surgeon injects local anesthetic at the conclusion of the procedure. She emerges briskly and is brought to the postanesthesia care unit (PACU). In the PACU, her pulse oximeter readings are 87% on room air and do not respond to supplemental oxygen by facemask. Which of the following medications could have caused this patient's condition?

A. Lidocaine
B. Procaine
C. Prilocaine
D. Tetracaine

7. Which of the following complicates lumbar epidural placement in infants compared to adults?

A. The spinal cord extends less caudally
B. A steeper angle is required for the approach to the epidural space
C. There is a greater mechanical resistance when crossing the ligamentum flavum
D. There is a shorter distance to the subarachnoid space

8. Which of the following lowers the risk of local anesthetic toxicity in infants compared to adults?

A. An increased volume of distribution
B. Decreased cytochrome P450 activity
C. A decreased ability to report neurologic symptoms of toxicity
D. Decreased plasma protein concentrations

9. A 4-year-old girl undergoes repair of an open left ankle fracture under general anesthesia. Prior to emergence, a combined saphenous and sciatic block is performed in the popliteal fossa for postoperative analgesia. On the first postoperative day, it is noted that the patient is ambulating poorly. Neurologic exam reveals decreased plantar flexion and a decreased response to pinprick on the sole of the foot. Which of the following nerves was injured?

A. Saphenous nerve
B. Sural nerve
C. Deep peroneal nerve
D. Tibial nerve

10. A 14-year-old male undergoes open reduction and fixation of a fracture at the surgical neck of the humerus. He receives a brachial plexus block, interscalene approach, preoperatively and undergoes general anesthesia for the procedure. After surgery the patient is comfortable except for some pain at the medial aspect of the upper arm just below the axilla. Failure to block which of the following nerves resulted in this distribution of pain?

A. Supraclavicular nerve
B. Intercostobrachial nerve
C. Musculocutaneous nerve
D. Medial antebrachial cutaneous nerve

11. When using an ultrasound for peripheral nerve block placement, decreasing the frequency of the probe improves which of the following?

A. Resolution
B. Penetration
C. Gain
D. Clarity

12. A 17-year-old otherwise healthy football player presents for rotator cuff repair following injury. He undergoes a brachial plexus block, interscalene approach, preoperatively for postoperative pain control. Which of the following is the most likely complication of interscalene blockade?

A. Vertebral artery injection
B. Subarachnoid injection
C. Ipsilateral pneumothorax
D. Ipsilateral phrenic nerve blockade

13. A 13-year-old boy presents for removal of a 7 cm lipoma on his anterior right thigh. A femoral nerve block is performed after the induction of general anesthesia using a nerve stimulator to guide injection. The femoral nerve is most likely to be blocked if which of the following muscle twitches is observed at the point of injection?

A. Inversion of the foot
B. Adduction of the hip
C. Flexion of the hip
D. Extension at the patella

14. An 8-year-old boy suffers a third-degree burn on the lateral dorsum of his right hand proximal to fingers one, two, and three. He is scheduled for skin grafting, and a field block is planned for the procedure. Injecting local anesthetic at which of the following locations will successfully block the operative site?

A. In and around the coracobrachialis muscle
B. Proximal to the ulnar head at the medial epicondyle

C. Lateral to the biceps tendon near the lateral epicondyle in the antecubital space
D. In the wrist between the palmaris longus and flexor carpi ulnaris

15. The highest volume of cerebrospinal fluid on a per kilogram basis is found in:

A. Preterm neonates
B. Full-term neonates
C. Toddlers
D. Adolescents

16. Which of the following is an absolute contraindication to caudal anesthesia?

A. Central core disease
B. Cerebral palsy
C. Epilepsy
D. Myelomeningocele

17. A 5 kg, 3-month-old male, former 32-week-premature infant presents with malrotation with midgut volvulus. He undergoes an open Ladd's procedure. Using fluoroscopic guidance, you place an epidural catheter at the end of the surgery to aid with postoperative pain control and improve respiratory mechanics while decreasing the risk of apnea. You extubate the patient and take him to the neonatal intensive care unit (NICU). During signout to the NICU staff, you are asked what rate the local anesthetic should infuse through the epidural catheter. What is the maximum recommended bupivacaine infusion rate for a prolonged epidural catheter?

A. 0.1 mg/kg per hour
B. 0.25 mg/kg per hour
C. 0.5 mg/kg per hour
D. 0.75 mg/kg per hour

18. A 2-year-old, 14 kg boy undergoes bilateral transversus abdominis plane nerve blocks using 0.25% bupivacaine with epinephrine under general anesthesia with laryngeal mask airway (LMA). At the time of injection, the heart rate is noted to increase. Moments later, the rhythm strip looks like the ECG strip in Figure 22.1 and the patient has no carotid pulse.

Which of the following is the most appropriate next step in management?

A. Begin chest compressions.
B. Initiate intralipid infusion.
C. Administer IV epinephrine 10 μg/kg.
D. Remove the LMA and intubate the patient.

19. A 9-month-old is undergoing circumcision under general anesthesia. A caudal block is performed for postoperative pain control. When correctly performing a caudal block, which of the following structures is traversed?

A. Ligamentum flavum
B. Sacral foramen
C. Sacral hiatus
D. Pia mater

20. Which of the following is true regarding spinal anesthesia in neonates?

A. Spinal anesthesia without sedation makes neonates agitated, worsening surgical conditions.
B. Spinal anesthesia without supplemental sedation reduces rates of postoperative apnea compared to general anesthesia.
C. Spinal anesthetics are typically placed at the L3-L4 interspace.
D. The subarachnoid space is typically 2 cm from the skin.

21. An 11-month-old, otherwise healthy female presents for right-sided cleft lip repair. Following mask induction with sevoflurane and nitrous oxide, an intravenous line is placed and the patient is intubated. The anesthesiologist then performs an infraorbital block for postoperative analgesia. The infraorbital nerve is an extension of which of the following cranial nerves?

A. Facial nerve (VII)
B. Ophthalmic nerve (V1)
C. Maxillary nerve (V2)
D. Mandibular nerve (V3)

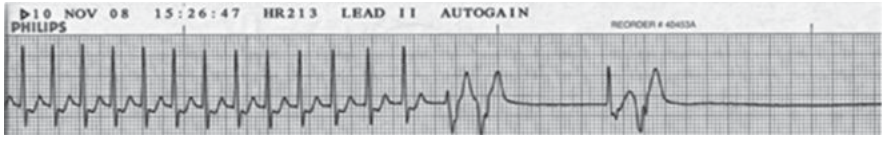


Figure 22.1 ECG strip for the patient in Question 18. (Modified from http://tmedweb.tulane.edu/tmedwiki/doku.php/ecg_interpretation_of_arrhythmias.)

22. Which of the following patients is most likely to suffer cardiotoxicity following accidental intravascular injection of bupivacaine?

A. A nervous, tachypneic 7-year-old about to undergo open reduction of a radial fracture
B. A 14-year-old undergoing craniotomy who received furosemide at induction
C. A 4-year-old with a perforated appendix and symptoms of sepsis
D. A 1-month-old male with pyloric stenosis and metabolic alkalosis

23. An 8-month-old female undergoing bilateral ureteral reimplantation receives a single-shot caudal block for postoperative analgesia. The anesthesiologist opts to add clonidine as an adjunct to a solution of 0.125% bupivacaine to inject into the caudal space. An increase of which of the following is associated with both neuraxially administered clonidine and neuraxially administered opioids?

A. Nausea
B. Urinary retention
C. Somnolence
D. Ileus

24. Which of the following statements regarding local anesthetics is true?

A. The unionized form of local anesthetics blocks sodium channels while the ionized form does not.
B. Ester local anesthetics undergo breakdown into methylparaben, which can cause allergic reactions.
C. Motor fibers are the most sensitive to local anesthetic blockade.
D. Local anesthetics potentiate neuromuscular blockade.

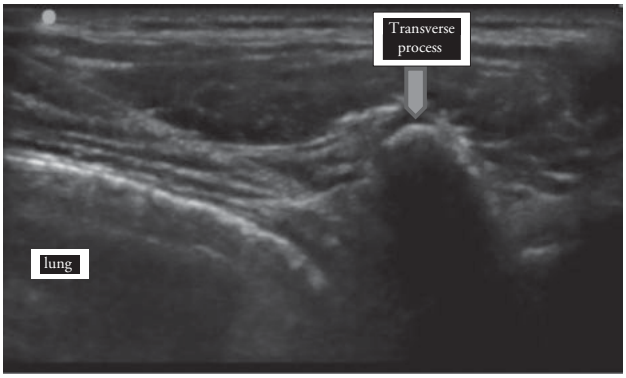
25. A 14-year-old patient with primary pulmonary hypertension awaiting lung transplantation falls into a glass panel and sustains a deep laceration over the lateral aspect of the forearm as well as smaller lacerations of the hand. Which of the following blocks is most appropriate for analgesia in this patient?

A. Brachial plexus block, axillary approach, and musculocutaneous block
B. Brachial plexus block, axillary approach
C. Brachial plexus block, supraclavicular approach
D. Brachial plexus block, interscalene approach

26. Which of the following combinations of regional block and surgery is correct?

A. Femoral nerve block; club foot with lateral incision
B. Interscalene approach, brachial plexus block; reimplantation of the 4th and 5th hand digits
C. Sciatic nerve block; distal femoral osteotomy
D. Greater auricular nerve block; tympanomastoidectomy

27. When considering the following picture, which of the statements is true?



A. Needle is out of plane.
B. Transducer configuration is curvilinear.
C. Needle direction is medial to lateral.
D. There is an acoustic shadow under the transverse process.

28. A 6-month-old baby has a thoracic epidural placed at the T4 level for analgesia following resection of a cystic adenomatous malformation via a thoracotomy incision. Which of the following is NOT an accepted method to confirm epidural tip placement in infants:

A. Fluoroscopy
B. Electrical stimulation
C. Loss of resistance to air
D. Ultrasound

29. Which of the following is true of a unilateral thoracic paravertebral block:

A. Hypotension occurs in >10% of patients.
B. Intrathecal injection can occur.
C. Urinary retention is common.
D. The cardiac accelerator nerves are frequently affected.

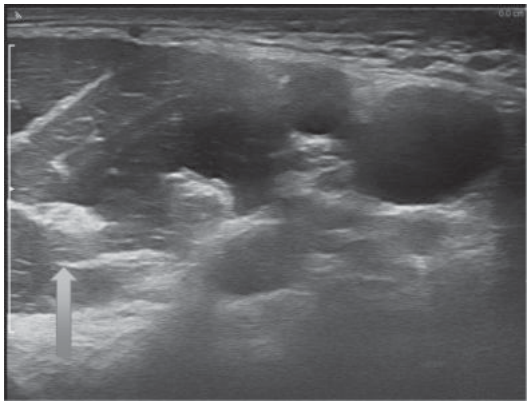
30. Contraindications to caudal approach to the epidural space include all of the following EXCEPT:

A. Localized skin infection over sacral hiatus
B. Age less than 5 days
C. Coagulopathy/thrombocytopenia
D. Allergy to local anesthetic

31. A 6-year-old child is having an open reduction, internal fixation (ORIF) of the hip via an incision over the greater trochanter. When used alone, which of the following blocks is most likely to result in inadequate analgesia?

A. Fascia iliaca block
B. Lumbar plexus block
C. L2 lumbar epidural block
D. Sciatic nerve block

32. Which adjustment to the ultrasound settings will best improve the quality of the image of the median nerve depicted in the following image?

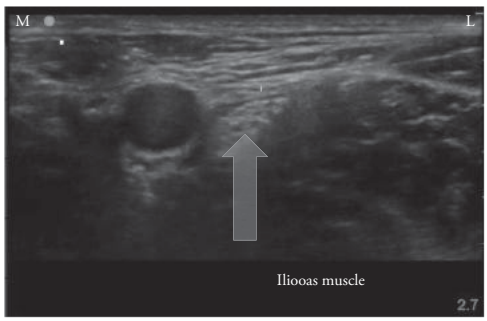


A. Decrease gain
B. Increase gain
C. Decrease depth
D. Decrease frequency

33. A 4 kg, 2-month-old infant with intestinal malrotation is having a laparotomy via a midline abdominal incision. A thoracic epidural is placed at the T8 level. Which of the following is an appropriate local anesthetic infusion?

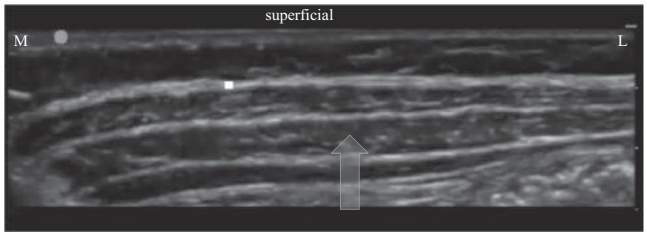
A. Bupivicaine 0.1% at 1.0 mL/hr
B. Ropivicaine 0.1% at 2.0 mL/hr
C. 3% 2-chloroprocaine at 2.0 mL/hr
D. 2% lidocaine at 2.0 mL/hr

34. Ultrasound guided blockade of the structure indicated by the arrow in the image below would be appropriate for the following surgery:



A. Polydactyly correction of the hand
B. Anterior cruciate ligament repair
C. Bunionectomy
D. Unilateral inguinal herniorraphy

35. The arrow in this image indicates which structure of the abdominal wall?



A. Internal oblique muscle
B. Quadratus lumborum muscle
C. Rectus abdominus muscle
D. Transversus abdominis muscle

36. Immediately after the administration of a caudal block with 8 mL of 0.25% bupivacaine, a 9-month old, 10 kg infant develops PVC, bradycardia and subsequent ventricular tachycardia. Which of the following is NOT appropriate?

A. Call for cardiopulmonary bypass setup.
B. Initiate PALS protocol.
C. Ventilate with 100% oxygen.
D. Bolus with 1.5 mL/kg of 1% intralipid.

37. A 3.5 kg, 3-week old neonate with severe retrognathia presents for a laparotomy via a midline abdominal incision for intestinal malrotation. A thoracic epidural is placed at the T9 level. Which of the following is correct?

A. Neonates are at increased risk for bupivacaine toxicity due to increased alpha-1 acid glycoprotein availability.
B. The addition of hydromorphone to the epidural solution in this patient is appropriate.
C. The prolonged elimination half-time of chloroprocaine makes it an inappropriate choice of local anesthetic for neonates.
D. Amide local anesthetics are dependent on mature hepatic function and adequate hepatic blood flow for metabolism.

38. A 10-year-old child is undergoing an ORIF of a proximal fibula fracture via an incision located lateral to the tibial tubercle. Foot drop postoperatively can be caused by all of the following EXCEPT:

A. Tightly placed cast
B. Vascular disruption

C. Femoral nerve block
D. Traumatic disruption of sciatic nerve

39. A 90 kg, 14-year-old is scheduled for a proximal tibial/fibula osteotomy under general anesthesia with a subgluteal sciatic nerve block for postoperative analgesia. Which of the following statements is true concerning ultrasound transducers?

A. A linear probe has a range of view equal to the footprint of the probe.
B. A linear probe has a range of view wider than the footprint of the probe.
C. A curvilinear probe has a range of view equal to the footprint of the probe.
D. A transducer transmitting at 16 MHz is preferred for ultrasound imaging of deep structures.

40. Which of the following combinations of ultrasound probe and planned regional block is most appropriate:

A. Linear array probe, 14 MHz; gluteal approach to the sciatic nerve block for a 13-year-old, 75 kg patient
B. Curved array probe; 6 MHz; paravertebral block for a 3-year-old, 15 kg patient
C. Linear array probe, 16 MHz; femoral nerve block for a 13-year-old, 40 kg patient
D. Linear array probe, 5 MHz; transversus abdominus plane block for a 2-month-old, 3 kg patient

41. Which of the following contribute to the increased susceptibility of neonates to local anesthetic systemic toxicity from ropivacaine compared to adults:

A. An increased serum fibrinogen concentration
B. Decreased systemic uptake of local anesthetic
C. A decreased serum alpha-1 acid glycoprotein concentration
D. Increased cytochrome P450 enzyme activity

42. Which of the following statements is true concerning the anatomy of the central nervous system in a newborn?

A. Conus medullaris ends at L3; dural sac ends at S3
B. Conus medullaris ends at L1; dural sac ends at S1
C. Conus medullaris ends at L3; dural sac ends at S1
D. Conus medullaris ends at L1; dural sac ends at S3

43. When comparing spinal anesthesia in neonates with spinal anesthesia in older children, which of the following is increased in neonates?

A. Dose requirement
B. Duration of action
C. Hemodynamic changes
D. Motor density

44. Which of the following is not considered a contraindication to neuraxial blockade?

A. INR = 1.5
B. Postoperative warfarin without INR monitoring prior removal of catheter
C. Prophylactic enoxaparin (0.5 mg/kg) subcutaneously BID, last dose given 13 hours ago
D. Discontinuation of ticlopidine 8 days ago

CHAPTER 22 ANSWERS

1. ANSWER: B

The three properties of a local anesthetic that are important to know are the lipid solubility, pKa, and protein binding. A drug that is highly lipid soluble will be more potent than one that is more water soluble because it will more easily enter the nerve cell. Local anesthetic (LA) potency directly correlates with octanol solubility, meaning increased lypophilicity and increased ability to cross lipid membranes. Potency will increase with the addition of large hydrophobic (alkyl) groups. The amount of LA necessary to block nerve conduction is affected by **nerve fiber size, type, myelination, pH, nerve stimulation frequence, and serum electrolyte levels**. The LA action onset depends on lipid solubility and the ratio of unionized to ionized molecule; the unionized molecule is more lipid soluble.

Local anesthetics with a pKa closest to physiological pH will have (at physiological pH) a greater fraction of nonionized base that more readily permeates the nerve cell membrane, generally facilitating a more rapid onset of action. A drug with a higher pKa will exist predominantly in the unionized form at physiologic pH, making it easier to pass into cells and thus have a quicker time to onset. This is the logic behind adding bicarbonate to local anesthetics in order to speed their onset. It is the lipid-soluble form that more readily diffuses across the neural sheath (epineurium) and passes through the nerve membrane. Once inside the cell, the ionized molecule is what binds to the Na channel more readily. The pKa is not the only factor affecting the onset of LA action as 2-chloroprocaine, which has the fastest onset, has the greatest pKa of the commonly used LAs.

LA duration is directly linked to potency and lipid solubility. More lipid-soluble LAs have a longer duration because they diffuse more slowly away from the tissue. Also, the more lipid soluble a LA, the greater the amount of plasma protein binding, mostly to alpha1-acid glycoprotein and somewhat to albumin. Molecular weight may contribute to the duration of action, but by itself it does not determine potency, pKa, or duration.

KEY FACTS

- The three properties of a local anesthetic that are important to know are the lipid solubility, pKa, and protein binding.
- A drug that is highly lipid soluble will be more potent than one that is more water soluble.
- Local anesthetics with a pKa closest to physiological pH will have (at physiological pH) a greater fraction of nonionized base that more readily permeates the nerve cell membrane, generally facilitating a more rapid onset of action.
- LA duration is directly linked to potency and lipid solubility.

REFERENCE

Morgan GE, Mikhail MS, Murray MJ. *Clinical Anesthesiology*. 4th ed. New York, NY: McGraw-Hill Medical; 2006:264–8.

2. ANSWER: C

Although somewhat arbitrary, consensus among anesthesiologists is that **each local anesthetic has a maximum dose that should be administered in order to avoid complications of local anesthetic toxicity, which at worst can manifest as seizures or cardiovascular collapse**. For ropivacaine the consensus is a maximum dose of 3 mg/kg, which for a 20 kg patient would be 60 mg. A 0.2% solution of ropivacaine contains 2 mg/mL. Dividing 60 mg by 2 mg/mL gives us 30 mL. Note that recommended maximum doses of local anesthetics have never been evaluated by randomized control trials for obvious reasons and what constitutes a toxic dose depends on various factors that affect the degree of vascular absorption.

The location where local anesthetic is deposited affects the rate of absorption. Rate of absorption of local anesthetic will affect serum levels and risk of toxicity (see Table 22.1).

Rate of absorption by site of injection:

Tracheal > intercostal > caudal > paracervical > epidural > brachial > sciatic > subcutaneous

Table 22.1 MAXIMUM RECOMMENDED DOSES (IN MG/KG) OF LOCAL ANESTHETICS

Esters	
Benzocaine	**Unknown**
2-Chloroprocaine	**12–20**
Cocaine	**3**
Procaine	**12**
Tetracaine	**1.5**
Amides	
Lidocaine	**4 (7 with epinephrine)**
Bupivacaine	**2.5–3 (with or without epinephrine)**
Ropivacaine	**3 (with or without epinephrine)**
Mepivacaine	**7**
Prilocaine	**6–8 (with or without epinephrine)**

KEY FACTS

- Each local anesthetic has a maximum dose that should be administered in order to avoid complications of local anesthetic toxicity, which at worst can manifest as seizures or cardiovascular collapse.
- The location where local anesthetic is deposited affects the rate of absorption.
- Rate of absorption of local anesthetic will affect serum levels and risk of toxicity.
- Rate of absorption by site of injection:
  Tracheal > intercostal > caudal > paracervical > epidural > brachial > sciatic >subcutaneous

REFERENCES

Cote CJ, Lerman J, Todres ID, eds. *A Practice of Anesthesia for Infants and Children*. 4th ed. Philadelphia, PA: Saunders Elsevier; 2009:871.

Polaner DM, Suresh S, Cote CJ. Regional anesthesia. In: Cote CJ, Lerman J, Todres ID, eds. *A Practice of Anesthesia for Infants and Children*. 4th ed. Philadelphia, PA: Saunders Elsevier; 2009:882–4.

3. ANSWER: B

The **brachial plexus is divided into five regions** before forming the terminal branches. Moving proximally to distally, these **five regions are roots, trunks, divisions, cords, and branches** ("**R**obert **T**aylor **D**rinks **C**old **B**eer"). The plexus is anesthetized with blocks traditionally at one of four locations (**interscalene, supraclavicular, infraclavicular, and axillary**). The **interscalene** block is performed the most proximally at the level of the roots/trunks. The **supraclavicular** approach to the brachial plexus block (BPB) is commonly associated with the level of the trunks, but some of the lower segments may be blocked at the level of the divisions as well. **The infraclavicular** approach to the BPB target the cords, and the **axillary** approach targets the individual branches—this is easy to remember if you imagine that the axillary block requires anesthetizing individual nerves (see Fig. 22.2).

The **interscalene approach** to the brachial plexus peripheral nerve block is done at the level of the C6 vertebrae, cricoid cartilage. The roots/trunks (superior, middle, and inferior trunks) are located between the anterior and middle scalene muscles. This approach is typically used for surgeries of the shoulder and arm. The **supraclavicular approach** to the brachial plexus block is approached above the clavicle, lateral to the posterior border of the sternocleidomastoid muscle. The needle should not pass below the first rib. The divisions are usually located lateral to the subclavian artery. This approach is adequate for surgeries of the arm. The **infraclavicular approach** to the brachial plexus block is approached below the clavicle in the groove between the anterior deltoid and pectoralis muscles. The axillary artery is identified between the pectoralis major and minor muscles. The three cords of the brachial plexus (lateral, posterior, medial) typically are found around the artery. This approach is typically used for surgeries below the elbow. The **axillary approach** to the brachial plexus block is carried out on the inner arm. The axillary artery is located close to, but distal from, the

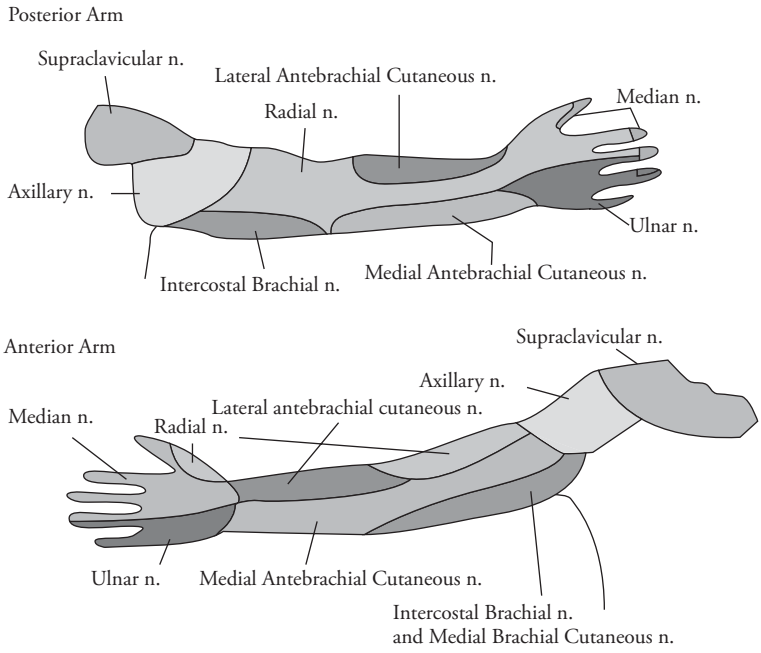


Figure 22.2 Upper-extremity dermatome. (From Arbona FL, Khabiri B, Norton JA, Hamilton C, Warniment, K. *Ultrasound-Guided Regional Anesthesia: A Practical Approach to Peripheral Nerve Blocks and Perineural Catheters*. Cambridge, UK: Cambridge University Press; 2011.)

pectoralis muscle. Axillary veins are usually medial to the artery. The median, ulnar, and radial nerves surround the axillary artery. The musculocutaneous nerve, which innervates the lateral forearm, is often missed and must be blocked separately, usually in the fascia between the biceps and coracobrachialis.

KEY FACTS

- The brachial plexus is divided into five regions before forming the terminal branches; moving proximally to distally, these five regions are roots, trunks, divisions, cords, and branches.
- The plexus is anesthetized with blocks traditionally at one of four locations (interscalene, supraclavicular, infraclavicular, and axillary).
- The interscalene approach is performed the most proximally at the level of the roots/trunks.
- The supraclavicular approach is commonly associated with the level of the trunks, but some of the lower segments may be blocked at the level of the divisions as well.
- The infraclavicular approach to the BPB target the cords.
- The axillary approach to the BPB targets the individual branches.

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Cote CJ, Lerman J, Todres ID, eds. *A Practice of Anesthesia for Infants and Children*. 4th ed. Philadelphia, PA: Saunders Elsevier; 2009:894–7.

Polaner DM, Suresh S, Cote CJ. Regional anesthesia. In: Cote CJ, Lerman J, Todres ID, eds. *A Practice of Anesthesia for Infants and Children*. 4th ed. Philadelphia, PA: Saunders Elsevier; 2009:882–4.

4. ANSWER: C

A = the fascial plane between the internal and external oblique muscles. B = the internal oblique muscle. D = the transversus abdominis muscle. The transversus abdominis plane (TAP) block has become increasingly popular and useful to aid with control of posteroperative pain after abdominal surgeries since the advent of ultrasound-guided regional anesthesia. **A TAP block is performed by advancing a needle into the space between the internal oblique muscle and the transversus abdominis muscle**, the "transversus abdominis plane," a potential space where the segmental nerves of the abdomen travel. **Terminal branches of the anterior rami of T7-T12 and L1 travel between these two muscle layers**. Injecting local anesthetic into this space bathes the nerves and results in unilateral analgesia of the abdominal wall skin, muscles, and parietal peritoneum. TAP blocks have been used for pain control after virtually all types of abdominal incisions as a sole analgesic or as an adjunct to IV analgesia.

KEY FACTS

- A TAP block is performed by advancing a needle into the space between the internal oblique muscle and the transversus abdominis muscle.
- The "transversus abdominis plane," between the internal oblique muscle and transversus abdominis muscle, is a potential space where the segmental nerves of the abdomen travel.
- Terminal branches of the anterior rami of T7-T12 and L1 travel between these two muscle layers.

REFERENCE

Mai CL, Young MJ, Quraishi SA. Clinical implications of the transversus abdominis plane block in pediatric anesthesia. *Paediatr Anesth*. 2012;22(9):831–40.

5. ANSWER: C

In general, one can think of the complications of caudal placement as the same as those of epidural placement. The most feared complications are epidural hematoma and epidural abscess, as both can potentially cause lifelong paralysis. However, fortunately these complications are very rare. As most of these blocks are performed while the patient is under general anesthesia, test doses have a limited role. The usual signs of neurotoxicity, sedation, and irritability will be masked by general anesthesia. Thus, the **first signs of toxicity** after inadvertent intravascular injection of local anesthetic may be **tonic-clonic seizure activity** (in the nonparalyzed patient), **arrhythmias, hypotension, and cardiopulmonary arrest**. Hypertension and tachycardia may result if epinephrine is present and a positive test dose is given, but in this instance no epinephrine was used. **Injection into the subarachnoid space can result in apnea due to total spinal blockade.** To avoid these complications, one should always aspirate from a catheter and follow with a test dose, which includes local anesthetic and epinephrine prior to injecting a full dose of local anesthetic into any neuraxial space in order to increase the chance of discovery of intravascular placement of the caudal needle/catheter. **Urinary retention** may occur following genitourinary surgery, but local anesthesia via either caudal or peripheral blockade has not been implicated as a causal factor. Neuraxially administered opioids, however, are associated with urinary retention. **Para-aminobenzoic acid (PABA)** is a metabolite of ester-type local anesthetics, so an amide such as bupivacaine does not pose a risk for an allergic reaction. If an **amide local anesthetic contained methylparaben as a preservative,** it could result in a reaction as methylparaben is metabolized into PABA.

KEY FACTS

- The most feared complications of caudal anesthesia are epidural hematoma and epidural abscess, as both can potentially cause lifelong paralysis.
- In the pediatric patient, with a block placed under general anesthesia, the first signs of toxicity after inadvertent intravascular injection of local anesthetic may be tonic-clonic seizure activity (in the nonparalyzed patient), arrhythmias, hypotension, and cardiopulmonary arrest.
- Injection into the subarachnoid space can result in apnea due to total spinal blockade.
- Local anesthesia via either caudal or peripheral blockade has not been implicated as a causal factor in urinary retention, although neuraxially administered opioids have.
- PABA is a metabolite of ester-type local anesthetics.
- If an amide local anesthetic contained methylparaben as a preservative, it could result in a reaction as methylparaben is metabolized into PABA.

REFERENCE

Polaner DM, Suresh S, Cote CJ. Regional anesthesia. In: Cote CJ, Lerman J, Todres ID, eds. *A Practice of Anesthesia for Infants and Children*. 4th ed. Philadelphia, PA: Saunders Elsevier; 2009:882–4.

6. ANSWER: C

This patient is exhibiting symptoms of methemoglobinemia, a condition that results from the oxidation of hemoglobin to methemoglobin by certain medications. **Methemoglobin can cause blood to appear a deep, chocolate brown**, a color that tricks the **pulse oximeter into reading an oxygen saturation in the mid 80s,** even though the PaO_2 may be greater than 100 mm Hg. The body possesses methemoglobin reductase to reduce methemoglobin back to hemoglobin, but **children less than 3 months of age lack sufficient levels** to prevent the onset of clinical symptoms. It is thus recommended that triggering medications be avoided in this age group. The local anesthetics **prilocaine and benzocaine have been implicated as triggers for methemoglobinemia.** Prilocaine is one of the local anesthetics in EMLA (eutectic mixture of local anesthetics) cream, which holds 2.5% prilocaine (25 mg/mL) and 2.5% lidocaine (25 mg/mL). The patient in this scenario may have received it for IV placement. Systemic absorption if placed on broken or inflamed skin can be much higher than normal. Treatment includes increased concentrations of inspired O_2 and intravenous methylene blue.

This patient could be having an allergic reaction to a local anesthetic as well. However, **allergic reactions** specifically caused by a local anesthetic are rare. If a reaction occurs after local anesthetic use, it is usually the result of **sensitivity to methylparaben, a preservative, or sulfites**, which prevent degradation of vasopressors such as epinephrine. **Ester-type local anesthetics** are much more likely to cause an allergic reaction compared to the amide-type local anesthetics because of the formation of **PABA during their metabolism**. PABA can cause allergic reactions ranging from urticaria to analphylaxis. Additionally, PABA forms during methylparaben metabolism, the preservative usually found in multidose vials of lidocaine.

KEY FACTS

- Methemoglobin can cause blood to appear a deep, chocolate brown.
- With methemoglobinemia, the pulse oximeter may display an oxygen saturation in the mid 80s, even though the PaO_2 may be greater than 100 mm Hg.
- Methemoglobin reductase reduces methemoglobin to hemoglobin, but children less than 3 months of age lack sufficient levels.
- The local anesthetics prilocaine and benzocaine have been implicated as triggers for methemoglobinemia.
- Prilocaine is one of the local anesthetics in EMLA cream, which holds 2.5% prilocaine (25 mg/mL) and 2.5% lidocaine (25 mg/mL).
- Allergic reactions specifically caused by a local anesthetic are rare and are usually the result of sensitivity to methylparaben, a preservative, or sulfites, which prevent degradation of vasopressors such as epinephrine.
- Ester-type local anesthetics are much more likely to cause an allergic reaction compared to the amide-type local anesthetics because of the formation of PABA during their metabolism.

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Nilsson A, Engberg G, Henneberg S, Danielson K, De Verdier CH. Inverse relationship between age-dependent erythrocyte activity of methemoglobin reductase and prilocaine-induced methemoglobinaemia during infancy. *Br J Anaesth*. 1990;64(1):72–6.

7. ANSWER: D

In infants it is typically preferable to **advance a caudal catheter to the lumbar or thoracic space** when higher levels of analgesia are desired (see Figure 22.3). However, experienced pediatric anesthesiologists can also perform

epidural placement between the lumbar or thoracic vertebrae. The **midline approach** to epidural placement is more common in pediatric patients as the spinous processes, even in the thoracic region, are almost horizontal. Thus, the epidural needle should be advanced almost perpendicular to the plane of the back. The technique for epidural placement in children is difficult because **infants have a thin, less dense ligamentum flavum that makes a loss of resistance difficult to feel**. In addition, **the neonatal spinal cord extends to L2-L3**, creating the potential for serious complications if the subarachnoid space is accidentally reached. The subarachnoid space is roughly 1 cm from the skin in a preterm neonate and increases with age.

Complications from epidural anesthesia in pediatric patients are similar to those in adults and include intravascular injection of local anesthetic, subarachnoid injection, intrathecal injection, spinal cord injury, epidural abscess, and epidural hematoma. However, epidurals in pediatric patients are very often completed under general anesthesia, a rare occurrence in adult patients. It may be more likely for **intraosseous local anesthetic injection because neonates and infants have decreased bone density and calcification**. Additionally, inadvertent catheter removal may occur with increased movement of children. Since the distance from skin to the epidural space is less than in adults, it is more likely that local anesthetic from the catheter infusion will leak, resulting in dressing removal.

KEY FACTS

- In infants it is typically preferable to advance a caudal catheter to the lumbar or thoracic space when higher levels of analgesia are desired.

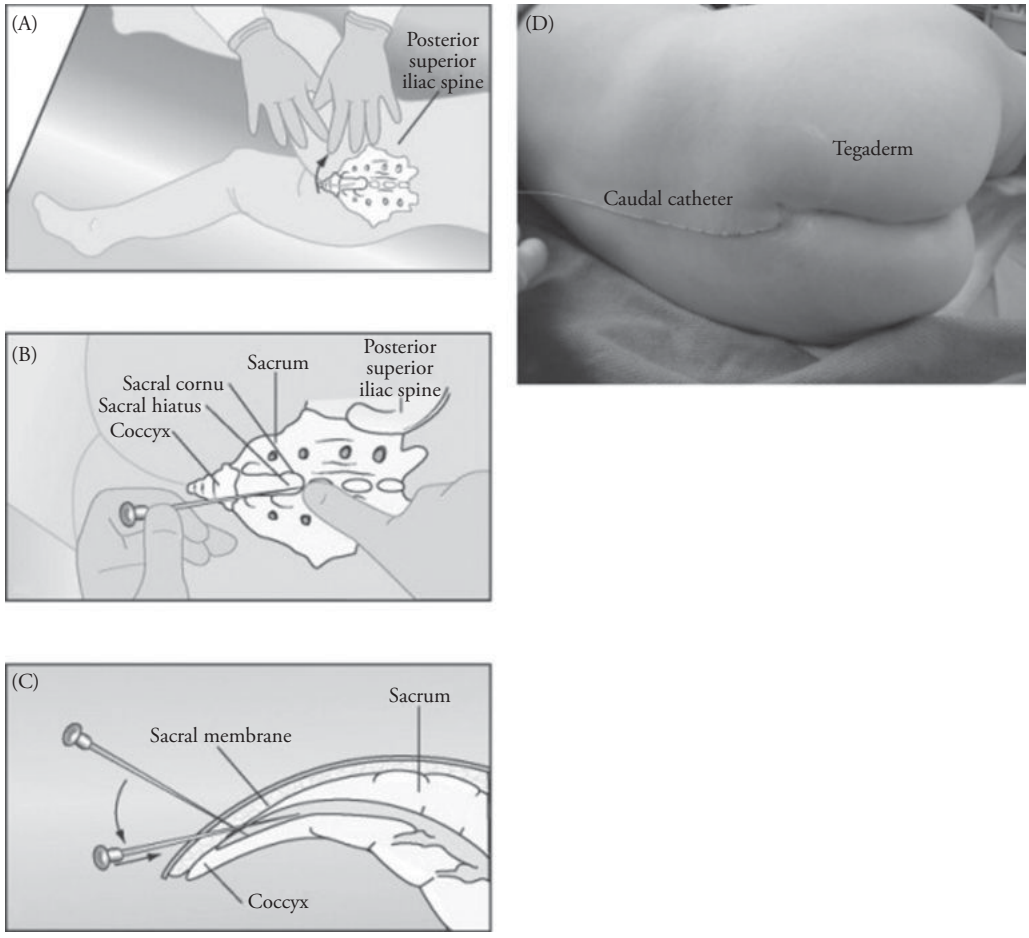

Figure 22.3 Performing a caudal block. The child is placed in a lateral decubitus position (A). The posterior superior iliac spines are located and the sacral cornu is palpated; either an intravenous needle, an intravenous catheter, or a Crawford needle of appropriate size is advanced at an angle of approximately 45 degrees until a distinct "pop" is felt as the needle pierces the sacrococcygeal ligament (B). The angle of the needle with the skin is reduced parallel to the sacrum, and the needle or intravenous catheter is advanced into the caudal canal (C). If a continuous technique is used, the caudal catheter is advanced to the mid level of the surgical incision (it usually readily passes in children younger than age 5 years), and the introducing needle or catheter is withdrawn. The catheter is secured with benzoin and an occlusive dressing (D). (From Cote CJ, Lerman J, Todres ID, eds. *A Practice of Anesthesia for Infants and Children*. 4 ed. Philadelphia, PA: Saunders Elsevier; 2009.)

- The midline approach to epidural placement is more common in pediatric patients as the spinous processes, even in the thoracic region, are almost horizontal.
- Infants have a thin, less dense ligamentum flavum that makes a loss of resistance difficult to feel.
- The neonatal spinal cord extends to L2-L3.
- The subarachnoid space is roughly 1 cm from the skin in a preterm neonate.
- In neonates and infants, intraosseous local anesthetic injection may be more likely due to decreased bone density and calcification.

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8. ANSWER: A

Infants actually have increased volumes of distribution for hydrophilic drugs compared to adults due to their higher aqueous volumes on a per kilogram basis. If a similar amount on a mg/kg basis were injected intravenously into an infant and an adult, the overall amount of drug would be diluted over a much larger amount of blood volume and therefore produce a lower concentration, although long-term infusions can lead to buildup of local anesthetics in the increased available volume. Most properties of infants put them at higher rather than lower risk of toxicity. **The concentrations of alpha1-acid glycoprotein and albumin are less in neonates,** resulting in a greater amount of free, non-protein-bound, local anesthetic in the serum. The concentration of local anesthetic in plasma is up to 30% more in infants less than 6 months of age, and higher in preterm infants. **The lidocaine serum concentration which results in neonatal cardiovascular and respiratory depression is half of that in adults.** Infants are unable to report the early signs of local anesthetic toxicity, which includes perioral paresthesias and tinnitus, but this of course does not mean that they are not still at risk for toxicity. **Decreased P450 activity in the liver** results in decreased clearance of amide local anesthetics when long infusions are used. In infants and children, epidural infusions of bupivacaine appear to result in its accumulation. It is recommended that for epidurals, **bolus and infusion doses are decreased by 30% for infants less than 6 months old** to reduce the chance of toxicity. Because infants are small, their maximum recommended doses of local anesthetics are reached more easily, making it easier to administer toxic levels of local anesthetics.

KEY FACTS

- Infants actually have increased volumes of distribution for hydrophilic drugs compared to adults due to their higher aqueous volumes on a per kilogram basis.
- The concentrations of alpha1-acid glycoprotein and albumin are less in neonates, resulting in a greater amount of free, non-protein-bound, local anesthetic in the serum.
- The lidocaine serum concentration which results in neonatal cardiovascular and respiratory depression is half of that in adults.
- Decreased P450 activity in the liver results in decreased clearance of amide local anesthetics when long infusions are used.
- It is recommended that for epidurals, bolus and infusion doses are decreased by 30% for infants less than 6 months old to reduce the chance of toxicity.

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9. ANSWER: D

A motor injury resulting in problems with plantarflexion combined with a sensory defect on the plantar surface of the foot is consistent with tibial nerve injury. The **tibial nerve** innervates the muscles of the posterior leg, which invert and plantarflex the foot as well as flexing the toes. The **saphenous nerve** does not innervate any motor structures, but it has sensory innervation of the medial leg and foot. The **deep peroneal nerve** has sensory innervation between the first and second digits and motor action in the anterior leg, dorsiflexing the foot and extending the toes. The **sural nerve** has no motor innervation and receives sensory information from the lateral leg, lateral sole, and dorsal fifth toe. The **superficial peroneal nerve** receives sensory information from the dorsum of the foot and its motor function involves ankle eversion.

KEY FACTS

- Ankle dorsiflexion is innervated by L4/L5 nerve roots, deep peroneal nerve
- Ankle plantar flexion is innervated by S1/S2 nerve roots, tibial nerve
- Ankle inversion, tibial nerve
- Ankle eversion, innervated by L5/S1 nerve roots, superficial peroneal nerve
- Toe dorsiflexion, deep peroneal nerve

REFERENCE

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10. ANSWER: B

The intercostobrachial nerve is not part of the brachial plexus but rather is a branch of T2. It is the lateral cutaneous branch of the second intercostal nerve. As a result, blockade of the brachial plexus at any location will fail to block its sensory innervation of the medial arm. For procedures in this area, the intercostobrachial nerve should be blocked by **injecting local around it in the proximal medial aspect of the arm, just below the axilla**. The **supraclavicular nerve** innervates the anterior shoulder and upper pectoralis major and is a branch of the cervical plexus. As it is also not a part of the brachial plexus, a shoulder incision will not be covered by a brachial plexus block unless a high enough volume of local anesthetic is used and it spreads to the superficial cervical plexus, which is superficial to the brachial plexus at the level of the interscalene block. The **musculocutaneous nerve**, **which gives rise to** the lateral antebrachial cutaneous nerve, has sensory innervation of the lateral forearm; it leaves the brachial plexus at the level of the proximal arm and can be missed with axillary or infraclavicular blocks. At the level of the proximal arm, the musculocutaneous nerve passes through the coracobrachialis muscle and travels between the biceps brachii and the brachialis muscles. The **medial antebrachial cutaneous nerve** is a branch of the medial cord, travels medial to the brachial artery, and supplies sensation to the medial arm and forearm.

KEY FACTS

- The intercostobrachial nerve is not part of the brachial plexus but rather is a branch of T2.
- The supraclavicular nerve innervates the anterior shoulder and upper pectoralis major and is a branch of the cervical plexus.
- The musculocutaneous nerve, which gives rise to the lateral antebrachial cutaneous nerve, has sensory innervation of the lateral forearm.
- The medial antebrachial cutaneous nerve is a branch of the medial cord, travels medial to the brachial artery, and supplies sensation to the medial arm and forearm.

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11. ANSWER: B

Ultrasound uses **sound waves of high frequency, 1–10 MHz**. **Frequency** is the number of oscillations per unit time and is measured in hertz. Hertz is cycles per second. Thus, MHz or megahertz is 10^6 Hz. A high-frequency sound wave is emitted by the ultrasound probe. The ultrasound probe, or transducer, contains peizo-electric crystals, which create sound waves of a particular frequency when they vibrate. A medium, or tissue, is required to use this technology for medical purposes. **Ultrasound images are produced by reflection of the ultrasound waves.** The ultrasound wave is reflected from tissue, alters the crystal shape within the ultrasound probe, and is translated into a picture. The greater the strength of the returning sound wave, the brighter the image displayed. Energy is lost, attenuated, when the sound waves interact with tissue through reflection, scattering, absorption, refraction, and diffraction. At the boundary between two materials, ultrasound waves will be reflected if they have different properties or different acoustic impedances.

Recall that **frequency and wavelength are inversely proportional,** and one must decrease if the other increases. An ultrasound transducer should be chosen based on the depth of the structure to be visualized. The signal from an ultrasound probe, which produces sound waves of lower frequency and higher wavelength of the pulses, travels further distance within a medium and has greater depth or "penetration." An ultrasound tranducer with **higher frequency** and lower wavelength has **less penetration**, but better clarity or "resolution" of the image. **Resolution**, or clarity, is the ability to detect objects as distinct entities that are close to one another. The higher the frequency, the greater the resolution, or ability to detect closely spaced objects as distinct entities. **Gain** is set by the ultrasound machine and refers to the degree of amplification of the returning sound waves. It is a measure of the amplitude that will be added to a signal output—this can make images easier to see, but high levels of gain will also amplify small, incidental reflections picked up by the probe and thus increase artifact. Image coupling is improved by the use of ultrasound gel, which acts to remove the air barrier that would otherwise exist between skin and the probe. This decreases impedence and decreases the amount of signal that is otherwise reflected and lost.

KEY FACTS

- Ultrasound uses sound waves of high frequency, 1–10 MHz.
- Frequency is the number of oscillations per unit time and is measured in hertz. Hertz is cycles per second.
- Ultrasound images are produced by reflection of the ultrasound waves.

- Frequency and wavelength are inversely proportional and one must decrease if the other increases.
- An ultrasound tranducer with higher frequency and lower wavelength has less penetration but better clarity or "resolution" of the image.
- The higher the frequency, the greater the resolution, or ability to detect closely spaced objects as distinct entities.

REFERENCES

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12. ANSWER: D

The **interscalene approach to the brachial plexus block** is carried out at the level of the cricoid cartilage, C6. At this level the brachial plexus is seen lateral to the carotid artery and internal jugular vein between the anterior and middle scalene muscles. The brachial plexus is deep to the prevertebral fascia, sternocleidomastoid muscle, and superficial cervical plexus. At this level, local anesthetic is placed near the trunks, sometimes roots, using direct visualization with an ultrasound, or less frequently with nerve stimulation. Typically, the interscalene approach to brachial plexus blockade is used for pain control of the ipsilateral shoulder and/or arm. With this approach, the lower roots/trunk may be missed, not providing optimal sensory blockade of the distal upper extremity, typically in the ulnar distribution.

It has been estimated that nearly 100% of properly placed interscalene blocks result in ipsilateral **diaphragmatic paralysis**, as the interscalene provides optimal blockade at the C3-C5 roots/trunks in close proximity to the **phrenic nerve.** The odds of blocking the phrenic nerve decrease as one approaches the brachial plexus for blockade more distally. If a patient has had open cardiac surgery, a preoperative chest roentogram should be reviewed to ascertain if the contralateral phrenic nerve was injured, as bilateral phrenic nerve paralysis may result in respiratory failure. In addition, many avoid this block in patients with severe chronic respiratory disease (restrictive lung disease, chronic obstructive pulmonary disease) and anyone using the accessory respiratory muscles. Approximately **50% of supraclavicular blocks will have phrenic nerve blockade** and very few infraclavicular blocks will. Blockade of the **recurrent laryngeal nerve** is common as well after this block. **Horner syndrome** from sympathetic chain blockade is common and will result in ipsilateral ptosis, anhidrosis, miosis, and nasal congestion. Reassurance is all most patients require.

Pneumothorax is uncommon with interscalene approach to the BPB but is more common with the supraclavicular and infraclavicular approaches. If the needle is positioned too posteriorly, it is possible to enter the vertebral artery or subarachnoid space. Additional vessels to avoid in this area are branches of the thyrocervical trunk: inferior thyroid artery, suprascapular artery, and transverse cervical artery. Subarachnoid injection would result in total spinal blockade and apnea, whereas vertebral artery injection would quickly result in seizure. Peripheral neuropathies can occur after trauma from a block needle but are rare.

KEY FACTS

- The interscalene approach to the brachial plexus block is carried out at the level of the cricoid cartilage, C6.
- The brachial plexus is seen lateral to the carotid artery and internal jugular vein between the anterior and middle scalene muscles.
- The brachial plexus is deep to the prevertebral fascia, sternocleidomastoid muscle, and superficial cervical plexus.
- At this level, local anesthetic is placed near the trunks, sometimes roots.
- Approximately 50% of supraclavicular blocks will have phrenic nerve blockade.
- Nearly 100% of properly placed interscalene approaches to he BPB result in ipsilateral diaphragmatic paralysis, as the interscalene provides optimal blockade at the C3-C5 roots/trunks in close proximity to the phrenic nerve.
- Blockade of the recurrent laryngeal nerve is common as well after this block.
- Horner syndrome from sympathetic chain blockade is common.

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13. ANSWER: D

Although less commonly used since the advent of ultrasound, nerve stimulator–guided regional anesthesia remains an effective method of determining where to place local anesthesia for peripheral nerve blockade. To date, **no study has shown a decreased complication rate after use of the ultrasound versus nerve stimulator for peripheral nerve blockade**. The **femoral nerve** is a branch of the lumbar plexus and arises from L2, L3, and L4. The nerve travels through the psoas muscle, exits from its distal, lateral border, and runs between the psoas and iliacus muscles before passing under the inguinal ligament to the thigh. At the inguinal ligament the femoral nerve is lateral and deep to the femoral artery. At the femoral crease, the nerve is superficial to the iliacus muscle but deep to the fascia iliaca.

The femoral nerve provides **motor innervation to the extensors of the thigh**. Stimulating the femoral nerve will result in a characteristic patellar twitch as a result of extensor action from the quadriceps. Plantar flexion and foot inversion are mediated by the sciatic nerve, which is typically blocked in the posterior thigh and can be used for blockade of the posterior thigh and most of the leg and foot. Adduction of the hip is mediated by the obturator nerve, which innervates the medial thigh and can be blocked inferolaterally from the pubic tubercle. **Flexion of the hip is also mediated by the femoral nerve**, but the fibers and the hip flexors themselves (the psoas muscles) are located much more proximally. Blockade of the femoral nerve this proximally is performed with a lumbar plexus block. Nerve branches to the sartorius muscle leave the femoral nerve proximally. Twitching of the sartorius muscle may be from stimulation of these branches and not the femoral nerve. Thus, motor response of the sartorius muscle should not be used to guide the nerve stimulator–guided femoral nerve block.

KEY FACTS

- No study has shown a decreased complication rate after use of the ultrasound versus nerve stimulator for peripheral nerve blockade.
- The femoral nerve is a branch of the lumbar plexus and arises from L2, L3, and L4.
- At the femoral crease, the nerve is superficial to the iliacus muscle but deep to the fascia iliaca.
- The femoral nerve provides motor innervation to the extensors of the thigh.
- Flexion of the hip is also mediated by the femoral nerve.

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14. ANSWER: C

The **lateral dorsum of the hand is innervated by the radial nerve**, which can be blocked at the elbow lateral to the biceps tendon at the intercondylar crease in the antecubital space. In addition, the radial nerve can also be blocked proximally just above the lateral epicondyle and at the wrist between the radial artery and flexor carpi radialis muscle. Injecting into or near the coracobrachialis is used to block the **musculocutaneous nerve** in the proximal medial arm and will provide sensory blockade of the lateral forearm. Injecting in the ulnar groove at the medial epicondyle blocks the ulnar nerve. At the level of the wrist, the **median nerve** runs between the palmaris longus and flexor carpi ulnaris tendons. The **intercostobrachial nerve,** an extension of T2, is blocked with a superficial field block at the proximal medial arm.

KEY FACTS

- The lateral dorsum of the hand is innervated by the radial nerve.
- Injecting into or near the coracobrachialis is used to block the musculocutaneous nerve in the proximal medial arm.
- Injecting in the ulnar groove at the medial epicondyle blocks the ulnar nerve.

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15. ANSWER: B

In adults, approximately 500 mL of cerebrospinal fluid (CSF) is made each day: **75% from the choroid plexus** and the other **25% from capillaries in the brain**. Spinal anesthesia is complicated in children by an **increased volume of CSF on a per kilogram of body weight basis**. Pediatric patients require a higher dose of local anesthetic to obtain the same level of blockade as in an adult. In addition, **the turnover of CSF is higher in children than adults**, resulting in a faster clearance of anesthetic and a quicker

resolution of the block. Although the studies are old, data suggest that full-term neonates have the highest volumes of CSF on a per kilogram basis, followed by preterm neonates, young children, and then adults. Of note, the CSF composition is slightly different in pediatric patients than adults. In pediatric patients, the CSF has a slightly greater glucose level, up to twice the concentration of total protein, and approximately a 10-fold greater concentration of immunoglobulin G.

In infants, **Truffier's line**, the line drawn between the highest point of the iliac crests, crosses the L4/L5 or the L5/S1 interspace versus the body of L4 in adults. In neonates, the spinal cord terminates at a lower level than in adults, L2-L3 versus L1. Thus, dural puncture in the neonate should be done more caudad than in an adult. The dural sac also ends at a lower level than in adults, S3 versus S1. This is important, especially when considering caudal anesthesia in a neonate, because passing a needle too cephalad may result in inadvertent dural puncture. In children, hypotension and bradycardia are much less common after spinal anesthesia, even with high blockade, and are not routinely given a fluid bolus prior to the anesthestic. In addition, the incidence of **postdural puncture headaches** is much less in pediatric patients than adults. Spinal anesthesia in children with neuromuscular diseases is controversial.

KEY FACTS

- In adults, approximately 500 mL of CSF is made each day: 75% from the choroid plexus and the other 25% from capillaries in the brain.
- Spinal anesthesia is complicated in children by an increased volume of CSF on a per kilogram of body weight basis.
- Pediatric patients require a higher dose of local anesthetic to obtain the same level of blockade as in an adult.
- The turnover of CSF is higher in children than adults, resulting in a faster clearance of anesthetic and a quicker resolution of the block.
- In infants, Truffier's line, the line drawn between the highest point of the iliac crests, crosses the L4/L5 or the L5/S1 interspace versus the body of L4 in adults.
- The incidence of postdural puncture headaches is much less in pediatric patients than adults.

REFERENCES

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16. ANSWER: D

Spina bifida occulta occurs when vertebrae overlying the spinal cord are incompletely formed, remaining open and unfused. **Spina bifida cystica with meningocele** is the least common form of spina bifida. In this condition, meninges protrude through the gap from the unfused vertebrae, but the spinal cord is in its normal location. The nervous system is not affected, and there is unlikely to be long-term consequences. **Spina bifida cystica with myelomeningocele** is most likely to result in severe nervous system deficits. In this condition, both the meninges and spinal cord protrude through the vertebral defect. The presence of a myelomeningocele makes the position of the spinal cord uncertain and significantly raises the risk for subarachnoid injection and is thus an absolute contraindication to caudal anesthesia.

Cerebral palsy is a nonspecific term for chronic, nonprogressive abnormal muscle tone, strength, coordination, and/or movement. It results from a cerebral insult before birth, during labor or delivery, or in the perinatal period. Other neurologic comorbities such as blindness, deafness, and epilepsy are common. The details, severity, and course of this illness vary greatly and it is not a contraindication to regional anesthesia.

Central core disease, a congenital myopathy, is an autosomal dominant illness resulting from point mutations in the ryanodine receptor gene, which encodes the skeletal muscle calcium-release channel of the sarcoplasmic reticulum. The nonprogressive disease is characterized by decreased fetal movements and breech presentation followed by hypotonia, delay in motor milestones, and difficulty with stair climbing, running, and standing from a seated position. There is mild face, neck, and proximal extremity weakness with legs affected more than arms. Skeletal abnormalities occur and include congenital hip dislocation, scoliosis, pes cavus, and clubbed feet. There is an association with malignant hyperthermia, and while controversial, regional anesthesia is not contraindicated.

Conditions that may deform joints, such as cerebral palsy, may complicate neuraxial anesthesia placement but are not contraindications. Toddlers who can walk are not ideal candidates for caudal anesthesia because they may fall due to prolonged motor blockade postoperatively. Caudal anesthesia becomes more difficult as patients age and the ligaments harden, but caudal blocks have even been performed in adults. Epilepsy is not a contraindication, although it is important to understand the risks of a caudal bupivacaine infusion in a neonate. (See answer to Question 17.) Due to decreased hepatic clearance and decreased serum protein levels and binding, the risk of toxicity after a prolonged bupivacaine infusion is increased in the neonate and young

infants. It is important to understand that a patient with epilepsy receiving a prolonged caudal bupivacaine infusion may have an increased risk of seizures.

KEY FACTS

- Spina bifida occulta occurs when vertebrae overlying the spinal cord are incompletely formed, remaining open and unfused.
- Spina bifida cystica with meningocele is the least common form of spina bifida.
- Spina bifida cystica with myelomeningocele is most likely to result in severe nervous system deficits; both the meninges and spinal cord protrude through the vertebral defect.
- Cerebral palsy is a nonspecific term for chronic, nonprogressive abnormal muscle tone, strength, coordination, and/or movement.
- Central core disease, a congenital myopathy, is an autosomal dominant illness resulting from point mutations in the ryanodine receptor gene.

REFERENCE

Dalens BJ. Regional anesthesia in children. In: Miller RD, Eriksson LI, Fleisher L, Wiener-Kronish JP, Young WL, eds. *Miller's Anesthesia*. 7th ed. New York, NY: Churchill-Livingstone; 2009:2527–8.

17. ANSWER: C

The Anesthesia Patient Safety Foundation reviewed a series of 10 convulsions that occurred during 20,000 infant and child epidural and intrapleural catheters bupivacaine infusions. Three of the ten pediatric patients had risk factors for seizures—hyponatremia, hypomagnesemia, and high fever. All other **patients had bupivacaine infusion rates greater than 0.5 mg/kg per hour**. Pharmacokinetic data subsequently have shown that epidural or intrapleural bupivacaine infusions over a prolonged period of time will lead to serum bupivacaine concentrations high enough to cause central nervous system toxicity. C. Berde recommends infusions of no more than 0.4 mg/kg per hour. As most pediatric regional anesthesia is performed while patients are under general anesthesia, it is imperative that careful attention is paid to the amount of local anesthetic given during a surgical procedure (see Table 22.2). Single-dose safe administration guidelines were developed from pharmacokinetic studies of pediatric patients who received wound infiltration, peripheral nerve blocks, epidural, and interpleural local anesthetic. The **elimination time in neonates is prolonged** compared to older children because of decreased hepatic clearance, decreased plasma protein levels, and binding. **Maturation is complete by 3–5 months** of age, but delayed clearance does not increase the risk of toxicity after a single injection of local anesthetic. However, it significantly increases the risk of toxicity after multiple boluses or an infusion.

KEY FACTS

- Pediatric patients with bupivacaine infusion rates greater than 0.5 mg/kg per hour are at risk for local anesthetic systemic toxicity.
- The elimination time in neonates is prolonged compared to older children because of decreased hepatic clearance, decreased plasma protein levels, and binding.
- Maturation is complete by 3–5 months of age, but delayed clearance does not increase the risk of toxicity after a single injection of local anesthetic.

REFERENCE

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18. ANSWER: A

The patient in this case has suffered intravenous injection of bupivacaine, resulting in complete cardiovascular collapse and cardiac arrest. **Bupivacaine has a higher affinity for myocardial sodium channels** compared with other local anesthetics. Whereas **lidocaine often presents with neurologic side effects first**—paresthesias, seizures, or tinnitus—**bupivacaine will typically present with cardiovascular side effects** due to its higher myocardial affinity. It is therefore crucial for the anesthesiologist to monitor for

Table 22.2 DOSING GUIDELINES FOR REGIONAL BLOCKADE

	SINGLE DOSE (MG/KG)		PROLONGED INFUSION (MG/KG/HR)	
	WITHOUT EPINEPHRINE	WITH EPINEPHRINE	OLDER INFANTS AND CHILDREN	NEONATES
Lidocaine	5	7	1.5–2	1
Bupivacaine	2–2.5	2–2.5	0.4	0.2

signs of cardiac toxicity—hypotension, arrhythmia, or complete cardiac arrest—after administration of bupivacaine.

When faced with a case of local anesthetic toxicity, as with any emergency it is essential to first remember the **ABCs** (airway, breathing, and circulation) and the pediatric advanced life support (PALS) guidelines. Chest compressions should be started as early as possible and epinephrine is also indicated given the asystolic rhythm; defibrillation is indicated for ventricular arrhythmias but not asystole or pulseless electrical activity. A patient who is not breathing should be ventilated with 100% oxygen and ultimately intubated if unresponsive, but this is not the most important first step if the patient can be adequately ventilated with a mask. Patients actively seizing should receive treatment, preferably with benzodiazepines. If local anesthetic toxicity is the suspected cause of arrest, then **treatment with lipid emulsion (intralipid) should be instituted**. Intralipid is a new agent that has shown great efficacy in the treatment of local anesthetic toxicity. It is thought to work by providing a lipophilic medium that bupivacaine will preferentially emulsify in, rather than remaining in cardiac ion channels. Intralipid is indicated to treat this patient; however, the first steps should be standard pediatric advanced life support, given that he is already in cardiac arrest.

KEY FACTS

- Bupivacaine has a higher affinity for myocardial sodium channels compared with other local anesthetics.
- Whereas lidocaine often presents with neurologic side effects first—paresthesias, seizures, or tinnitus—bupivacaine will typically present with cardiovascular side effects due to its higher myocardial affinity.
- If local anesthetic toxicity is the suspected cause of arrest, then treatment with lipid emulsion (intralipid) should be instituted.

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19. ANSWER: C

When a caudal block is performed correctly, the order of **structures encountered is skin > subcutaneous fat > sacrococcygeal ligament > sacral hiatus > caudal space**. The caudal space can be thought of as a continuation of the epidural space in children, and the performance of a caudal block thus has many parallels to epidural placement. When performing a caudal block, the skin and subcutaneous fat are traversed en route to entering the sacral hiatus with the needle. The **sacrococcygeal ligament** is felt as a thick structure that is eventually "popped" through with the needle, then entering the caudal canal—the sacrococcygeal ligament can therefore be thought of as analogous to the ligamentum flavum as both provide the resistance that is lost when entering the targeted space. Both the caudal and epidural spaces are filled with vessels and adipose tissue, although the caudal space undergoes changes with age, which contribute to the decrease in reliability and popularity of caudal blocks in older patients.

Although the sacrococcygeal ligament is analogous to the ligamentum flavum, the ligamentum flavum is only encountered in epidural placement and not in caudal placement. The **sacral foramina** are the holes on the left and right sides of the sacrum from which the sacral nerve roots exit the cauda equina and thus should not be encountered when a caudal block is placed correctly in the midline—it is essential to correctly identify landmarks before performing a caudal block so that a foramen is not accidentally entered, as this could potentially cause nerve damage. The **pia mater** is the innermost layer of the meninges and lies in contact with the spinal cord. The caudal space is encountered before entering the meninges, of which the first and most prominent layer is the dura. The anesthesiologist should always aspirate prior to injecting local anesthetic into the caudal space in order to avoid a subarachnoid injection, which could result in total spinal anesthesia.

KEY FACTS

- When a caudal block is performed correctly, the order of structures encountered is skin > subcutaneous fat > sacrococcygeal ligament > sacral hiatus > caudal space.
- The caudal space can be thought of as a continuation of the epidural space in children.
- The sacrococcygeal ligament can therefore be thought of as analogous to the ligamentum flavum, as both provide the resistance that is lost when entering the targeted space.
- The sacral foramina are the holes on the left and right sides of the sacrum from which the sacral nerve roots exit the cauda equina and thus should not be encountered when a caudal block is placed correctly in the midline.

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20. ANSWER: B

Spinal anesthesia is an attractive option in neonates having lower extremity or lower abdominal surgery because it avoids airway manipulation and other hazards of general anesthesia. Although the evidence is weak, several studies have suggested that **infants receiving spinal anesthesia without intravenous sedation have lower rates of postoperative apnea** than those receiving general anesthesia, making spinal anesthesia an attractive option for preterm neonates at high risk for postoperative apnea. **Spinal anesthesia tends to make neonates fall asleep** rather than become agitated—this is believed to be due to the decrease in sensory input when the lower body afferents are blocked. As neonates have undeveloped central nervous systems, a decrease in lower body sensory information is a significant loss of cortical stimulation from the spino-reticulo-thalamic pathway. The **subarachnoid space is typically 1.5 cm from the skin** in a newborn. The distance increases with age until adulthood but does not reach 2 cm until roughly 1 year of age. A key anatomical difference between pediatric patients and adults is the level of termination of the spinal cord. Because **the neonatal spinal cord ends at L3**, it is preferable to perform the spinal at either the L4-L5 or L5-S1 interspaces. Also in contrast to adults, pediatric patients also have distinctly different hemodynamic responses to spinal anesthesia due to their poorly developed sympathetic nervous systems. Whereas adults typically have a pronounced hypotensive response to heavy spinal anesthesia, **hypotension is typically not seen in neonates**. This is important clinically, as the first manifestation of a **high spinal in a neonate is likely to be apnea** rather than hypotension or bradycardia.

KEY FACTS

- Although the evidence is weak, several studies have suggested that infants receiving spinal anesthesia without intravenous sedation have lower rates of postoperative apnea than those receiving general anesthesia.
- Spinal anesthesia tends to make neonates fall asleep rather than become agitated—this is believed to be due to the decrease in sensory input when the lower body afferents are blocked.
- Because the neonatal spinal cord ends at L3, it is preferable to perform the spinal at either the L4-L5 or L5-S1 interspaces.
- Spinal anesthesia typically does not cause hypotension in neonates.
- The first manifestation of a high spinal in a neonate is likely to be apnea rather than hypotension or bradycardia.

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21. ANSWER: C

The **trigeminal nerve has three branches: the ophthalmic nerve (V1), maxillary nerve (V2), and mandibular nerve (V3)** that provide the majority of the sensory innervation of the face. Blocks of these nerves are performed by a variety of practitioners, including surgeons, dentists, pain physicians, and anesthesiologists, depending on the local practice and familiarity of each with the blocks themselves. **The skin over the maxilla, such as that involved in a cleft lip, is innervated by the maxillary nerve.** One of its branches is the **infraorbital nerve**, which can be blocked just below the orbit for pain relief for surgeries of the nose and upper lip. The **ophthalmic nerve** innervates the skin superior to the maxillary nerve on the face that covers the area around the eyes as well as the forehead. The **ophthalmic nerve is blocked by the supraorbital block**, which is performed along the supraorbital ridge superior to the iris. The **mandibular nerve** covers the lower jaw. This nerve is frequently blocked for dental procedures. The **facial nerve** has minimal sensory innervation around the ear and is also responsible for taste. It is occasionally blocked by pain physicians for the treatment of neuralgias and can be blocked anterior to the mastoid process below the external auditory meatus. The **glossopharyngeal nerve** innervates the pharynx superiorly from the anterior epiglottis. The glossopharyngeal nerve can be blocked in the mouth at the base of the palatoglossal arch (see Fig. 22.4).

KEY FACTS

- The trigeminal nerve has three branches—the ophthalmic nerve (V1), maxillary nerve (V2), and mandibular nerve (V3)—that provide the majority of the sensory innervation of the face.
- The skin over the maxilla, such as that involved in a cleft lip, is innervated by the maxillary nerve.
- The ophthalmic nerve innervates the skin superior to the maxillary nerve on the face that covers the area around the eyes as well as the forehead.
- The ophthalmic nerve is blocked by the supraorbital block.

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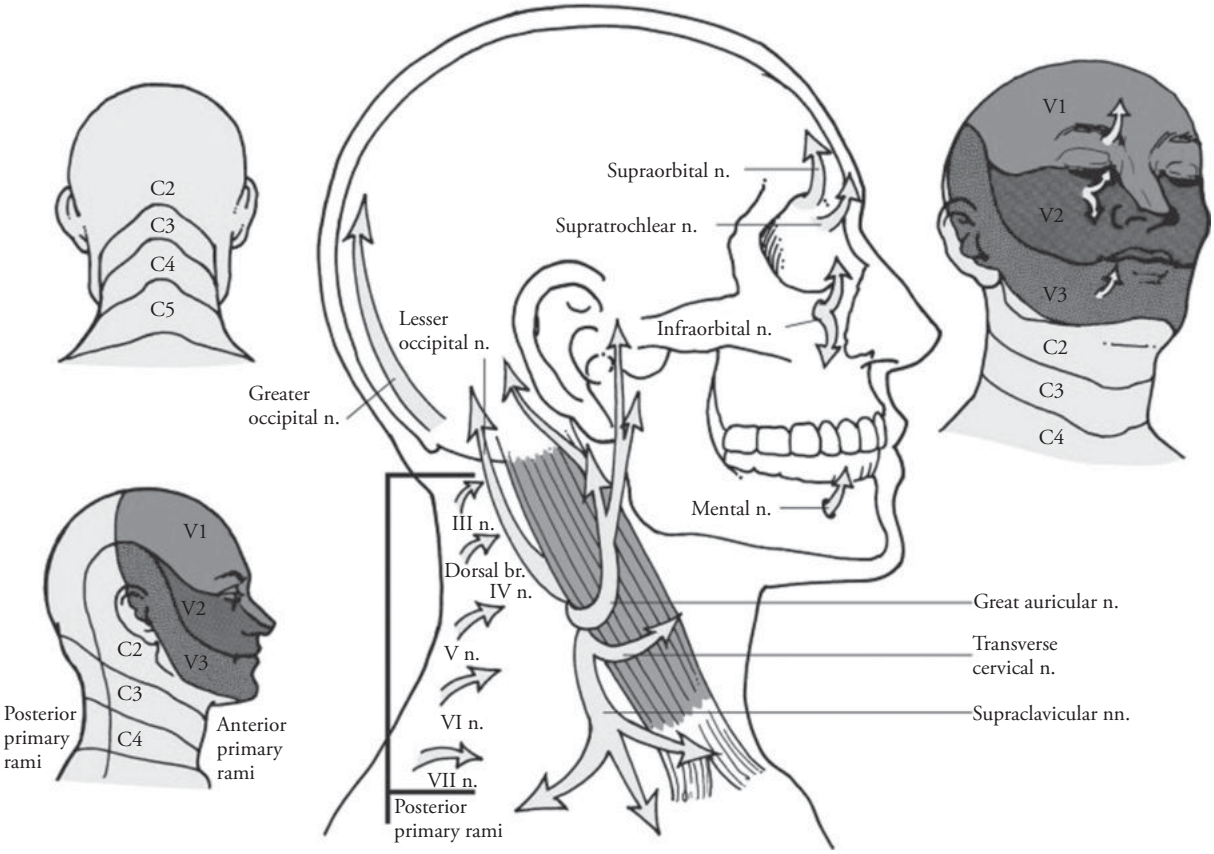

Figure 22.4 Dermatomal and nerve mapping of the head and neck. (From Brown DL. Atlas of Regional Anesthesia, 4 ed. Philadelphia, PA: Saunders Elsevier; 2010:18, 141–146. Copyright © 2010, 2006, 1999, 1992 by Saunders, an imprint of Elsevier Inc.)

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22. ANSWER: C

Bupivacaine and ropivacaine cardiotoxicity are potentiated by factors that increase the number of unbound local anesthetic molecules in the plasma, which include **decreased levels of serum proteins and decreased protein binding**. Decreased protein binding is caused by factors such as **hypoxemia and acidosis**. This phenomenon is due to the effects of changes in pH on the binding of local anesthetics to serum proteins such as alpha 1-acid glycoprotein and albumin. **As the pH of the plasma decreases, local anesthetics are decreasingly protein bound and increasingly found as free molecules in the plasma.** The free form is the form that interacts with channels and is able to pass through cell membranes, including those of cardiac muscle cells. As bupivacaine and ropivacaine already have a high affinity for myocardial sodium channels, an increase in the free concentration is of particular concern. In addition, bupivacaine and ropivacaine are highly protein bound at physiologic pH (roughly 95% bound), so even a slight decrease in the bound fraction can cause a significant increase in the free concentration. As a result, **any alteration of the pH** can cause a huge change in the amount of free molecules and the risk for cardiotoxicity. Other patients who are at risk for toxicity due to decreased concentrations of plasma proteins are pregnant women and neonates.

Conditions that increase the likelihood of their patients having **hypoxia, respiratory acidosis, or metabolic acidosis** will cause patients to have a lower pH and therefore a higher risk for bupivacaine cardiotoxicity. Sepsis frequently causes a lactic acidosis due to decreased organ perfusion, which would put patients at a higher risk. A tachypneic 7-year-old would instead have a respiratory alkalosis and thus decreased odds of toxicity. Similarly, patients with a metabolic alkalosis, such as those caused by diuretics (furosemide) or vomiting (pyloric stenosis), will have a higher pH and a lower risk of cardiotoxicity.

KEY FACTS

- Bupivacaine and ropivacaine cardiotoxicity are potentiated by factors that increase the number of unbound local anesthetic molecules in the plasma, which include decreased levels of serum proteins and decreased protein binding.
- Decreased protein binding is caused by factors such as hypoxemia and acidosis.

- As the pH of the plasma decreases, local anesthetics are decreasingly protein bound and increasingly found as free molecules in the plasma.
- The free form is the form that interacts with channels and is able to pass through cell membranes.
- Even a slight decrease in the bound fraction can cause a significant increase in the free concentration of local anesthetic.
- Conditions that increase the likelihood of their patients having hypoxia, respiratory acidosis, or metabolic acidosis will cause patients to have a lower pH and therefore a higher risk for bupivacaine cardiotoxicity.

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23. ANSWER: C

A**djuncts such as clonidine or opioids** are frequently added to local anesthetics when preparing mixtures for epidural or caudal administration. This technique allows the anesthesiologist to use less local anesthetic for the same level of analgesia while simultaneously taking advantage of the unique properties of the adjunct itself. Neuraxially administered opioids have a long history of safe use for improved pain control but do involve significant side effects. **Neuraxial opioids have extremely high rates of pruritus**, more than is typically seen with parenteral or oral administration. Opioids administered via any location can cause **nausea, constipation, or ileus. Urinary retention** has been noted to be a significant problem with neuraxially administerd opioids, one that may be of particular concern following urologic procedures. Postoperative **sedation** is also a concern with neuraxial opioid administration, particularly with hydrophobic opioids such as fentanyl as they more easily cross from the epidural or caudal space into the surrounding vessels, increasing bloodstream and ultimately brain concentrations.

Clonidine administered either intravenously or neuraxially has been gaining popularity because it has been shown to improve analgesia over local anesthetics alone while offering several benefits over opioid use, including less itching, ileus, nausea, and urinary retention. Clonidine is, however, a strong sedative and can lead to postoperative drowsiness and even respiratory depression or apnea when administered via either route. A mild level of drowsiness may be desirable in pediatric patients as they will often awaken agitated, but it is critical that the anesthesiologist use an appropriate dose of clonidine to avoid oversedation. It should be noted that opioids can cause increased drowsiness and respiratory depression as well, but clonidine should not be selected instead of an opioid in an effort to improve postoperative wakefulness.

KEY FACTS

- Adjuncts such as clonidine or opioids are added to local anesthetics for epidural or caudal administration as they allow the anesthesiologist to use less local anesthetic for the same level of analgesia while simultaneously taking advantage of the unique properties of the adjunct itself.
- Neuraxial opioids have extremely high rates of pruritus.
- Opioids administered via any location can cause nausea, constipation, or ileus.
- Urinary retention has been noted to be a significant problem with neuraxially administerd opioids.
- Postoperative sedation is also a concern with neuraxial opioid administration, particularly with hydrophobic opioids such as fentanyl, because they more easily cross from the epidural or caudal space into the surrounding vessels, increasing bloodstream and ultimately brain concentrations.

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24. ANSWER: D

By blocking voltage-gated ion channels, local anesthetics prevent afferent and efferent neurons from firing. As local anesthetics can create neuromuscular weakness on their own, it stands to reason that they could also potentiate neuromuscular blockade from nondepolarizing neuromuscular blockers, and this is indeed what was seen when the effect was studied.

Motor fibers are actually the last fibers to be blocked. **The order of blockade from fastest to slowest is actually sympathetic fibers > sensory fibers > motor fibers**. Some **ester local anesthetics are metabolized to p-aminobenzoic acid (PABA)**, which is implicated in the allergic reactions that are seen with local anesthetics. Because **amide local anesthetics** are not metabolized to PABA, they should be safe to use in a person with a true ester local anesthetic allergy. **Methylparaben** is a preservative with a similar structure that should be avoided in people with local anesthetic allergies, but it is not a breakdown product of local anesthetics. The **unionized form of local**

anesthetics is important for crossing membranes because this form lacks a charge and can freely pass into cells, but it is the ionized form that actually interacts with the sodium channels once the molecule has traversed the membrane and been reionized. **Epinephrine** can produce longer durations of action from local anesthetics because it constricts blood vessels that may carry the molecules away from the site of injection, whether it be central or peripheral. Because epinephrine is an unstable compound, local anesthetics that come premixed with epinephrine are prepared at lower pH levels, thus increasing the ionized fraction, making them less able to cross nerve cell membranes, and resulting in a slower onset than would be seen with preparations without epinephrine.

KEY FACTS

- The order of blockade from fastest to slowest is actually sympathetic fibers > sensory fibers > motor fibers.
- Some ester local anesthetics are metabolized to PABA, which is implicated in the allergic reactions that are seen with local anesthetics.
- Amide local anesthetics are not metabolized to PABA.
- Epinephrine can produce longer durations of action from local anesthetics because it constricts blood vessels that may carry the molecules away from the site of injection, whether it be central or peripheral.
- Methylparaben is a preservative with a similar structure that should be avoided in people with local anesthetic allergies.
- Local anesthetics that are pemixed with epinephrine are prepared at lower pH levels, thus increasing the ionized fraction, making them less able to cross nerve cell membranes, and resulting in a slower onset than would be seen with preparations without epinephrine.

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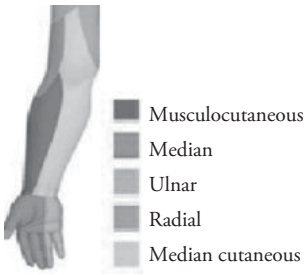
25. ANSWER: A

An axillary nerve block with supplementation of the musculocutaneous nerve would be appropriate for this type of injury. **An axillary approach to brachial plexus blockade will anesthetize the nerves of the hand (the radial, median, and ulnar) and the medial forearm.** The innervation of the skin of the lateral forearm is via the **musculocutaneous nerve**, which is **frequently missed with the axillary approach**. Therefore, this patient requires a supplemental musculocutaneous nerve block to cover the lateral forearm.



The **supraclavicular** and the **interscalene approaches to brachial plexus** blockade would both be less desirable choices as **pneumothorax** and **phrenic nerve paralysis** are known complications from both of these blocks and could result in respiratory failure in patients with preexisting pulmonary compromise.

KEY FACTS

- The axillary approach to brachial plexus blockade will anesthetize the radial, median, and ulnar nerve.
- The lateral forearm is innervated by the musculocutaneous nerve.
- A complication of the supraclavicular approach to the BPB is pneumothorax and a complication of the interscalene nerve block is phrenic nerve paralysis. These complications can be can be avoided in patients with preexisting pulmonary compromise by performing an axillary approach with supplementation of the musculocutaneous nerve.

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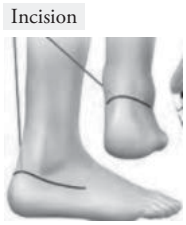
26. ANSWER: D

The **greater auricular nerve** supplies the sensory **innervation to the skin behind the ear,** thus making it an appropriate block for surgeries with an incision directly behind the ear.

A clubfoot deformity is corrected via tendon modification at the level of the ankle with the incision being made posterior with lateral extension just above the heel. The nerves to the skin of the **posterior and lateral lower**

extremity below the knee as well as the bones and underlying soft tissues are all supplied by the **sciatic nerve**.



The **femoral nerve** supplies the sensation to the skin over the **anterior thigh, the femur, quadriceps muscles, knee joint, and the skin of the medial aspect of the distal leg**. The femoral nerve is an appropriate block for knee surgery and surgery on the anterior thigh.

The **interscalene approach to the brachial plexus** does not reliably anesthetize the C8 and T1 nerve roots, which supply important branches to the ulnar and median nerves of the hand. An axillary approach to the nerves of the brachial plexus is the most reliable for achieving nerve coverage for hand surgery.

Surgery for a distal femoral osteotomy is approached through a lateral thigh incision where the cutaneous innervation is via the **lateral femoral cutaneous nerve**. The femur itself is innervated by the **femoral nerve**. The sciatic nerve supplies the cutaneous innervation of the posterior thigh and all of the distal leg (below the knee) with the exception of the skin of the medial aspect of the distal leg.

KEY FACTS

- The greater auricular nerve supplies the sensory innervation to the skin behind the ear.
- The sciatic nerve supplies sensory innvervation of the skin of the posterior and lateral lower extremity below the knee as well as the bones and underlying soft tissues.
- The interscalene approach to the brachial plexus block does not reliably anesthetize the C8 and T1 nerve roots, which supply important branches to the ulnar and median nerves of the hand.
- The lateral femoral cutaneous nerve innervates the skin of the lateral thigh.
- The femur bone is innervated by the femoral nerve.

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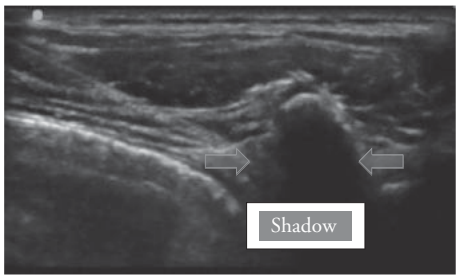
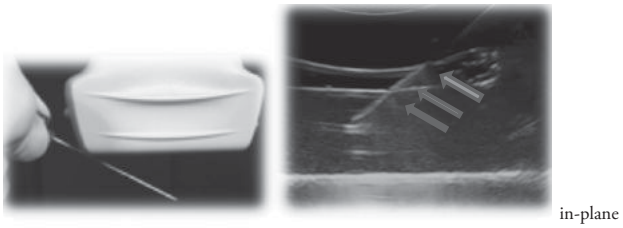
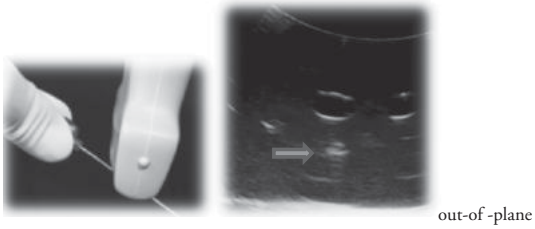
27. ANSWER: D

This is an image of a **paravertebral block** and the **transverse process is seen as the thumb-like projection just to the right of the midline.** The transverse process is ossified in this picture and the inability of ultrasound waves to pass thorough the bone creates a black shadow under the transverse process in which no underlying structures can be visualized. The technical term for this is an acoustic shadow.

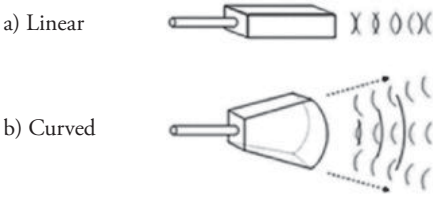


The needle orientation shown is **in-plane,** as evidenced by the **visualization of the entire length of the needle**. The ultrasound beams emit from the transducer in a 1-mm-thick, two-dimensional plane. When the needle is in-plane, the needle is advanced totally within this plane of the ultrasound beams and the ultrasound signal is reflected from the entire length of the needle. If the orientation is **out of plane**, the needle is perpendicular to the plane of the ultrasound signal and the **needle appears in cross section as a circular structure or dot**.


in-plane


out-of -plane

Square or rectangular borders to the image denote a linear configured probe. A curvilinear probe would be characterized by an arc at the top of the image with a larger arc at the bottom.



Anatomically, the lung is positioned lateral to the transverse process; therefore, the needle direction is lateral to medial.

KEY FACTS

- The needle approach during a paravertebral block is in-plane from lateral to medial.
- During a paravertebral block the transverse process is seen as the thumb-like projection just to the right of the midline.
- The transverse process creates a hypoechoic (dark) shadow under the transverse process in which no underlying structures can be visualized.

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28. ANSWER: C

The injection of air into the epidural space of infants can cause permanent paralysis, severe nerve injury, and even death. The etiology is likely to be air emboli lodging in small critical vessels.

Fluoroscopy is performed by injecting 0.5–2 mL of contrast dye through the catheter with correct placement identified by axial spread within the lateral borders of the transverse processes.

Electrical stimulation using a nerve stimulator attached to a stimulating catheter will cause contraction of the muscles innervated by the nerves in proximity to the catheter tip indicating tip placement.

Ultrasound can be used to identify any echogenic material in the catheter itself or the tip. The tip can also be identified by visualizing the injection of fluid and the displacement of tissue using ultrasound. Once patients are older than 9 months, the cartilage of the spinal canal ossifies and ultrasound visualization of the neuraxis is impeded by interference from the shadows created by the bone.

KEY FACTS

- The injection of air into the epidural space of infants can cause permanent paralysis, severe nerve injury, and even death. The etiology is likely to be air emboli lodging in small critical vessels.
- Fluoroscopy, electrical stimulation, and ultrasound can be used to confirm epidural tip position in infants.

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29. ANSWER: B

Intrathecal injection can occur during a thoracic paravertebral block. This is a rare complication but can occur due to the close proximity of the paravertebral space to the dural root sleeve.

Hypotension occurs less than 5% of the time and is usually reported in adults. **Hemodynamic stability is one of the advantages of thoracic paravertebral** compared to epidural analgesia.

Paravertebral nerve blocks do not cause urinary retention; thus, Foley catheters are not routinely indicated. The cardiac accelerators are spared with paravertebral blocks.

KEY FACTS

- Intrathecal injection is a rare complication of thoracic paravertebral blocks.
- Hemodynamic stability is one of the advantages of thoracic paravertebral compared to epidural analgesia.
- Paravertebral nerve blocks do not cause urinary retention.

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30. ANSWER: B

Neonates are at increased risk for inadvertent intrathecal puncture, but it is not a contraindication. Caution in advancing the needle in the caudal canal is advised in this age group.

Absolute contraindications to neuraxial regional techniques include the following:

1. **Skin infection** over the puncture site, which would increase the incidence of infectious complications such as meningitis, epidural abcess, and localized cellulitis.
2. **Bleeding disorders**, abnormalities of coagulation, and active anticoagulation therapy, which increase the risks of serious bleeding complications such as epidural hematoma. The ASRA guidelines recommend against neuraxial techniques if the platelet count is <50,000 or the INR is >1.4.
3. **Allergy to local anesthetic medications**

KEY FACTS

- Contraindications to neuraxial regional techniques include allergy to local anesthetics, skin infection over the puncture site, coagulopathy (INR >1.4), and thrombocytopenia (<50,000 platelet count).
- Caudal blocks in newborns have an increased risk for inadvertent intrathecal injection, but this is not a contraindication.

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31. ANSWER: D

The **sciatic nerve block** is used mostly for **surgeries performed below the knee, especially at the level of the ankle and foot**. A branch of the sciatic nerve supplies some of the innervation to the posterior aspect of the hip joint capsule, but the contribution to the sensory innervation is considered minor.

The **hip joint innervation** is complex with contributions mainly from the **femoral (L2-L4) and obturator (L2-L4) nerves, and the overlying skin of the lateral thigh is supplied by the lateral femoral cutaneous nerve (L2-L3).** The **lumbar epidural provides blockade of L2-L4 at the level of the spinal nerves,** in contrast to the **fascia iliaca and lumbar plexus blocks,** which provide coverage of the nerves after they have formed into the peripheral nerve configuration.

KEY FACTS

- The hip joint innervation is complex with contributions mainly from the femoral (L2-L4) and obturator (L2-L4) nerves.
- The overlying skin of the lateral thigh is supplied by the lateral femoral cutaneous nerve (L2-L3).
- The lumbar epidural provides blockade of L2-L4 at the level of the spinal nerves.
- The sciatic nerve block is used mostly for surgeries performed below the knee, especially at the level of the ankle and foot. The contribution to the sensory innervation of the hip is considered minor.

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Dilberovic F, Kapur E, Wong A, Wong C. Functional regional anesthesia anatomy. In: Hadzic A, ed. *Textbook of Regional Anesthesia and Acute Pain Management*. New York: McGraw Medical. 2007:49–77.

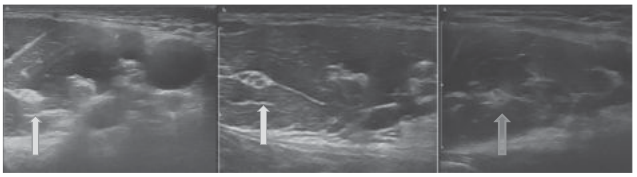
32. ANSWER: A

Decreasing the gain would improve this ultrasound image. The ultrasound signal produced by the transducer is reflected by the tissues and returns to the transducer where the signal is converted into an electronic signal. The gain controls the amplification of this electronic signal into the pattern observed on the display monitor as the image. **Too much gain gives the appearance of a snowstorm and too little gain makes the picture very dark with poorly differentiated structures.**

The median nerve is a superficial structure and decreasing frequency would compromise the clarity and definition of the superficial structures. Lower frequencies are used to penetrate deeper, while higher frequencies are used to highlight and enhance the detail of superficial structures. The depth setting is appropriate as the nerve is visible in the middle field of the screen.

KEY FACTS

- The gain controls the amplification of this electronic signal into the pattern observed on the display monitor as the image.
- Too much gain gives the appearance of a snowstorm and too little gain makes the picture very dark with poorly differentiated structures.
- Lower frequencies are used to penetrate deeper, while higher frequencies are used to highlight and enhance the detail of superficial structures.



Too much gain Optimal gain Too little gain

REFERENCE

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33. ANSWER: A

Infusions using parameters in answers B, C, and D all exceed recommended dosing in infants less than 4–6 months of age. **The appropriate dose of local anesthetic is dependent on site of perineural catheter, surgical site, size, and age of patient.** Although there are limited data on infusions regarding elimination and accumulation in neonates and infants, most standard textbooks are consistent in their recommendations. **Immaturity of the liver and decreased levels of plasma proteins compel recommendations of dose reduction of 30%–50% for infants ages less than 4–6 months of age when using amides.**

Lidocaine infusions have fallen out of favor due to decreased metabolism and clearance after several hours of administration resulting in unpredictable plasma levels. 2-chloroprocaine is recommended as a 1.5% solution.

KEY FACTS

- Immaturity of the liver and decreased levels of plasma proteins in infants compel recommendations of dose reduction of 30%–50 % for infants ages less than 4–6 months of age when using amides.
- Lidocaine infusions in infants are not indicated due to decreased metabolism and clearance after several hours of administration resulting in unpredictable plasma levels.
- 2-chloroprocaine is recommended as a 1.5% solution in infants.

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34. ANSWER: B

This ultrasound image captures the femoral nerve in cross section lateral to the femoral artery and deep to the fascia iliaca at the level of the inguinal ligament. The iliopsoas muscle underlies the femoral neurovascular structures. The femoral artery is easily identified as a round, noncompressible, pulsatile, hypoechoic structure medial to the femoral nerve and the femoral vein is located medial to the femoral artery (medial → lateral = V A N). At this level, the femoral nerve appears as a wedge-shaped hyperechoic structure with central "honeycombing" that reflects fascicular components of the peripheral nerve.

The knee joint is innervated anteriorly by the femoral nerve. Femoral nerve blockade is appropriate for postoperative analgesia in patients undergoing knee joint surgery, including and not limited to ACL, PCL, and meniscus repair.

The hand is innervated by the terminal branches of the brachial plexus, including the radial, median, and ulnar nerves. Blockade of the brachial plexus via the supra- and infra-clavicular approach, or the terminal branches at the level of the axilla or the wrist, is appropriate in patients having hand surgery.

Bunionectomy involves removal of a piece of bony growth of the great toe, which is innervated by the tibial and superficial

LOCAL ANESTHETIC	CLASS	METABOLISM	DOSE MAX: MG/KG/HR (INFUSION) >4–6 MONTHS	DOSE MAX: MG/KG/HR (INFUSION) <4–6 MONTHS 30%–50% REDUCTION AMIDES
Bupivicaine	**Amide**	**Cytochrome P450**	**0.4–0.5**	**0.2–0.35**
Ropivicaine	**Amide**	**Cytochrome P450**	**0.5–0.6**	**0.25–0.42**
Lidocaine	**Amide**	**Cytochrome P450**		
2-chloroprocaine	**Esther**	**Plasma cholinesterase**	**5–12**	**5–12**

For a 4 kg infant at 2 months of age, infusions would be as follows:

Bupivicaine 0.1% (10 mg/mL):	4 kg × 0.2 mg/kg/hr = 8 mg/hr =0.8 mL/hr	(lower)
	4 kg × 0.35 mg/kg/hr = 1.4 mg/hr = 1.4 mL/hr	(higher)
Ropivicaine 0.1% (10 mg/mL):	4 kg × 0.25 mg/kg/hr = 1.0 mg/hr = 1.0 mL/hr	(lower)
	4 kg × 0.42 mg/kg/hr = 1.65 mg/hr = 1.65 mL/hr	(higher)
2-chloroprocaine 3.0% (30 mg/mL)	4 kg × 5.0 mg/kg/hr = 20 mg/hr = 0.7 mL/hr	(lower)
	4 kg × 12 g/kg/hr = 48 mg/hr = 1.6 mL/hr	(higher)

peroneal branches of the sciatic nerve. A simple ankle block targeting these nerves or a sciatic nerve block is appropriate for analgesia after a bunionectomy. The saphenous nerve (a branch of the femoral nerve) provides innervation below the knee to the medial aspect of the lower leg and foot. Blockade of the saphenous nerve at a more proximal location along the leg or as part of the ankle block may also be required to help with analgesia to the medial aspect of the ankle/foot.

The inguinal area is innervated by the subcostal nerve (T12) and ilioinguinal and iliohypogastric nerves (L1). These nerves lie in close proximity to each other medial and superior to the anterior superior iliac spine. Blockade of these nerves are appropriate for postoperative analgesia in patients undergoing inguinal herniorraphy.

KEY FACTS

- The femoral nerve appears as a wedge-shaped hyperechoic structure with central "honeycombing" that reflects fascicular components of the peripheral nerve. It is located lateral to the femoral artery deep to the fascia iliaca at the level of the inguinal ligament.
- Femoral nerve blockade is appropriate for postoperative analgesia in patients undergoing knee joint surgery, including and not limited to ACL, PCL, and meniscus repair.
- Blockade of the brachial plexus via the supra- or infra-clavicular approach is appropriate for patients having hand surgery.
- An ankle block or a sciatic nerve block is appropriate for analgesia after a bunionectomy.
- The saphenous nerve (a branch of the femoral nerve) provides innervation below the knee to the medial aspect of the lower leg and foot.
- The inguinal area is innervated by the subcostal nerve (T12) and ilioinguinal and iliohypogastric nerves (L1). These nerves lie in close proximity to each other medial and superior to the anterior superior iliac spine.

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Karmakar M, Kwok W. Ultrasound-guided regional anesthesia. In: Cote CJ, Lerman, J, Todres D, eds. *A Practice of Anesthesia for Infants and Children*. 4th ed. Philadelphia, PA: Saunders;2009:895–900.

35. ANSWER: A

The figure depicts a sonographic image of the abdominal wall used to facilitate **transversus abdominis plane (TAP) blocks**. **Visualized from top to bottom: skin, subcutaneous fat, the three abdominal muscle layers: external oblique muscle, internal oblique muscle, and transversus abdominis muscle and peritoneum.** TAP blocks are used as part of an analgesic regimen for abdominal surgeries. The abdominal wall is innervated by the thoracolumbar (T6 to L1) spinal segmental nerves. The anterior divisions of these nerve roots emerge anterior to the quadratus lumborum muscle, penetrate the neurofascial plane (TAP) between the transversus abdominis muscle and the internal oblique muscle, and emerge through the rectus abdominis muscle to supply the skin anteriorly. Anteromedially, the aponeurosis of the three muscle tendons form the **rectus sheath,** which envelops the **rectus abdominis muscle**. The **quadratus lumborum muscle** is located posteriorly and is not seen on this image.

KEY FACTS

- TAP blocks are used as part of an analgesic regimen for abdominal surgeries.
- The abdominal wall layers visualized on ultrasound from superficial to deep include skin, subcutaneous fat, external oblique muscle, internal oblique muscle, and transversus abdominis muscle and peritoneum.

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Bhalla T, Beltran R, Martin D, Lucas S, Bigeleisen PE, Tobias JD. Ultrasound-guided regional anesthesia of the thorax, trunk, and abdomen in infants and children. In: Bigeleisen PE, Gofeld M, Orebaugh SL, eds. *Ultrasound-Guided Regional Anesthesia and Pain Medicine*. 2nd ed. Philadelphia, PA: Wolters Kluwer;2015:404–7.

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36. ANSWER: D

This infant is demonstrating **local anesthetic systemic toxicity (LAST)** either from intravenous absorption or injection of bupivacaine. **The initial focus should be on oxygenation, ventilation with 1.0 FiO_2, and cardiopulmonary resuscitation**. Prevention of hypercarbia is important as an increase in $PaCO_2$ displaces local anesthetic from their plasma protein binding sites worsening LAST. The American Society of Regional Anesthesia and Pain Medicine recommends alerting the nearest facility with CPB capability in the event of refractory arrest and initiating PALS/ACLS. Laboratory evidence shows that epinephrine can impair resuscitation from LAST and reduce the efficacy of intralipid therapy. It is therefore recommended that **smaller doses of epinephrine, for example, <1 mcg/kg, be used to treat hypotension**. Timing of intralipid therapy is controversial due to the potential risks such as infection, intravenous thrombophlebitis, altered inflammatory responses, anaphylaxis, fat emboli, and acute pancreatitis. In the neonate who is less likely to be able to handle a large lipid load, risk-benefit ratio should be weighed prior to dosing. Withholding intralipid therapy in the event of arrest from local anesthetic, however, would not be advised. The most reasonable approach is to implement lipid therapy on the basis of clinical severity and rate of progression of LAST. **The initial dose of intralipid is 1–1.5 mL/kg of 20% intralipid over**

1 minute, repeating the dose every 3 to 5 minutes during resuscitation up to a total of 3 mL/kg. On evidence of recovery an infusion at 0.25–0.5 mL/kg/min is started and continued for at least 10 minutes after recovery.

KEY FACTS

- In the setting of local anesthetic systemic toxicity (LAST) either from intravenous absorption or injection of bupivacaine, the initial focus should be on oxygenation, ventilation with 1.0 FiO_2, and cardiopulmonary resuscitation.
- Epinephrine can impair resuscitation from LAST and reduce the efficacy of intralipid therapy. It is therefore recommended that smaller doses of epinephrine, for example, <1 mcg/kg, be used to treat hypotension.
- The initial dose of intralipid is 1–1.5 mL/kg of 20% intralipid over 1 minute, repeating the dose every 3 to 5 minutes during resuscitation up to a total of 3 mL/kg. On evidence of recovery an infusion at 0.25–0.5 mL/kg/min is started and continued for at least 10 minutes after recovery.

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Hebl JR, Lennon RL, Hagen JV. *Maya Clinic Atlas of Regional Anesthesia and Ultrasound-Guided Nerve Blockade*. New York, NY: Mayo Clinic Scientific Press; 2010.

Neal JM, Bernards CM, Butterworth JF IV, et al. ASRA practice advisory on local anesthesic systemic toxicity. *Reg Anesth Pain Med*. 2010;35(2):152–93.

37. ANSWER: D

The choice of epidural solution is based on several factors: age and size of the child, the surgery, and the underlying medical conditions that may decrease the margin of safety of one of the agents. **Neonates are at increased risk for potential bupivacaine (an amide local anesthetic) toxicity because of decreased alpha-1 acid glycoprotein binding and resultant increased free fraction of drug, immature hepatic metabolism, and impaired hepatic blood flow.** The manifestation of local anesthetic toxicity in young **infants and neonates** may be more difficult to recognize than in adults; hence, a **conservative maximum infusion dose of bupivacaine of 0.2 mg/kg/hr for no longer than 48 hours** in this age group is strongly recommended.

The use of **hydromorphone** in this patient is inappropriate. Due to the hydrophilicity and associated rostral spread of hydromorphone, there is **increased risk of respiratory depression especially in infants <6 months of age with decreased drug clearance**. In addition, in light of this patient's airway anomalies and potential for difficult airway management, somnolence and hypopnea are undesirable. **Fentanyl**, a hydrophobic opioid with **minimal rostral spread due to greater binding to the receptors in the substantia gelatinosa of the spinal cord** adjacent to the area of administration, is a commonly used opioid in epidural solutions in this age group.

The ester **chloroprocaine** is **cleared extremely rapidly even in preterm infants**, with an elimination half-life of several minutes, making it a **highly desirable epidural local anesthetic choice in neonates and young infants. Amide local anesthetics are dependent on mature hepatic function and adequate hepatic blood flow for metabolism. Both are impaired in neonates and young infants.**

KEY FACTS

- Infants and neonates are at increased risk for potential bupivacaine (an amide local anesthetic) toxicity because of decreased alpha-1 acid glycoprotein binding and resultant increased free fraction of drug, immature hepatic metabolism, and impaired hepatic blood flow.
- The use of epidural hydromorphone in infants and neonates is inappropriate due to the hydrophilicity and associated rostral spread of hydromorphone with increased risk of respiratory depression.
- Chloroprocaine is cleared extremely rapidly even in preterm infants, with an elimination half-life of several minutes, making it a highly desirable epidural local anesthetic choice in neonates and young infants.

REFERENCES

Cote CJ, Lerman, J, Todres D, eds. *A Practice of Anesthesia for Infants and Children*. 4th ed. Philadelphia, PA: Saunders; 2009.

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Hebl JR, Lennon RL, Hagen JV. *Maya Clinic Atlas of Regional Anesthesia and Ultrasound-Guided Nerve Blockade*. New York, NY: Mayo Clinic Scientific Press; 2010.

38. ANSWER: C

Neurologic complications after peripheral nerve blocks can be related to factors associated with dense blockade of the nerve and block technique (needle trauma, intra-neuronal injection, neuronal ischemia, toxicity from local anesthetic) but common causes such as positioning, stretching, retractor injury, ischemia, and hematoma formation should be considered.

Foot drop in this setting is likely caused by **disruption to the function of the sciatic nerve**, specifically the **common peroneal nerve,** which winds around the neck of the fibula. The common peroneal nerve innervates the extensor muscles of the lower leg. Blockade or injury to the nerve will result in the inability to extend the foot or foot drop. In this

patient undergoing repair of a proximal fibular fracture, direct trauma to the common peroneal nerve from surgical manipulation, traction and compression of the nerve, compression by hematoma, ischemia from disruption of the vascular supply to the nerve, and compression by a tightly placed cast can result in injury.

The peripheral nerve block frequently performed to provide **analgesia to the lower leg is the sciatic nerve block above the popliteal fossa**. In addition to the motor innervation described, the sciatic nerve provides sensory innervation to the lower leg except for the medial aspect that is innervated by the saphenous nerve, a pure sensory branch of the femoral nerve. A femoral or saphenous nerve block may be performed if there is surgical involvement over the medial aspect of the lower leg. Because the femoral nerve does not provide motor innervation to the lower leg, foot drop will not be seen if there is dense femoral nerve blockade.

KEY FACTS

- Neurologic complications after peripheral nerve blocks can be related to needle trauma, intra-neuronal injection, neuronal ischemia, toxicity from local anesthetic, positioning, stretching of the nerve, retractor injury, ischemia, and hematoma formation.
- Foot drop in this setting is likely caused by disruption to the function of the sciatic nerve, specifically the common peroneal nerve, which winds around the neck of the fibula.

REFERENCES

Cote CJ, Lerman, J, Todres D, eds. *A Practice of Anesthesia for Infants and Children*. 4th ed. Philadelphia, PA: Saunders; 2009

Davis P, Cladis FP, Motoyama EK. *Smith's Anesthesia for Infants and Children*. 8th ed. Philadelphia, PA: Mosby; 2011.

Hebl JR, Lennon RL, Hagen JV. *Maya Clinic Atlas of Regional Anesthesia and Ultrasound-Guided Nerve Blockade*. New York, NY: Mayo Clinic Scientific Press; 2010.

39. ANSWER: A

When determining the appropriate probe for ultrasound visualization of a structure, the probe that provides the best resolution for the required depth should be chosen. **Linear probes** produce a **straight ultrasound beam and an image with a width equal to the size of the transducer footprint from the surface to the deeper structures**.

Curvilinear probes generate a **wedge-shaped ultrasound beam, which provides a broader view, rendering the image of deeper structures wider than the footprint of the probe**.

High-frequency (10–18 MHz) probes provide better resolution but less penetration and are therefore preferred for ultrasound imaging of superficial and not deep structures. Although the image resolution may be poorer, **low-frequency (2–6 MHz) probes provide higher penetration** and are often required for ultrasound **imaging of deep structures** such as the proximal sciatic nerve.

KEY FACTS

- Linear probes produce a straight ultrasound beam and an image with a width equal to the size of the transducer footprint from the surface to the deeper structures.
- Curvilinear probes generate a wedge-shaped ultrasound beam, which provides a broader view, rendering the image of deeper structures wider than the footprint of the probe.
- High-frequency (10–18 MHz) probes provide better resolution but less penetration and are therefore preferred for ultrasound imaging of superficial and not deep structures.
- Low-frequency (2–6 MHz) probes provide higher penetration and are often required for ultrasound imaging of deep structures.

REFERENCES

Cote CJ, Lerman, J, Todres D, eds. *A Practice of Anesthesia for Infants and Children*. 4th ed. Philadelphia, PA: Saunders; 2009.

Davis P, Cladis FP, Motoyama EK, eds. *Smith's Anesthesia for Infants and Children*. 8th ed. Philadelphia, PA: Mosby; 2011.

40. ANSWER: C

The probe that provides the best resolution for the required depth should be chosen when determining the appropriate probe to be used when performing a peripheral nerve block.

Linear array probes produce a **straight ultrasound beam** and an image with a width equal to the size of the transducer footprint from the surface to the deeper structures. It is used for imaging of more superficial structures such as the paravertebral compartment, femoral nerve, and transversus abdominis plane, where a wider image of deeper structures is not needed.

Curved array probes generate a **wedge-shaped ultrasound beam,** which provides a broader view, rendering the image of deeper structures wider than the footprint of the probe. It allows for imaging of deeper structures such as the sciatic nerve in the gluteal region.

High-frequency (10–18 MHz) probes provide better resolution but less penetration and are therefore preferred for ultrasound imaging of superficial and not deep structures. The sciatic nerve in the gluteal region in a 75 kg young teenager is deeply located requiring a lower frequency probe.

Although the image resolution may be poorer, **low-frequency (2–6 MHz) probes** provide higher penetration and are often required for ultrasound imaging of deep structures such as the proximal sciatic nerve. A higher frequency probe (10–16 Hz) and not 6 MHz is needed for more superficial imaging of the paravertebral compartment in a 3-year-old.

A probe oscillating at a low frequency of 5 MHz will make imaging of the superficially located transversus

abdominis plane in a 2-month-old difficult. In addition to needing a higher frequency probe, a linear and not a curved array probe should be utilized.

The femoral nerve in a 40 kg, 13-year-old is superficially located. A high-frequency (10–16 MHz) linear array probe is used for the imaging and placement of a femoral nerve block.

KEY FACTS

- High-frequency (10–18 MHz) probes provide better resolution but less penetration and are therefore preferred for ultrasound imaging of superficial and not deep structures. A high-frequency linear array probe is used for the imaging and placement of a femoral nerve block. A higher frequency probe is needed for more superficial imaging of the paravertebral compartment in a 3-year-old. A TAP block in a 2-month-old baby requires also a higher frequency linear probe.
- Low-frequency (2–6 MHz) probes provide higher penetration and are often required for ultrasound imaging of deep structures. The sciatic nerve in the gluteal region in a 75 kg young teenager is deeply located, requiring a lower frequency probe.

REFERENCES

Cote CJ, Lerman, J, Todres D, eds. *A Practice of Anesthesia for Infants and Children*. 4th ed. Philadelphia, PA: Saunders; 2009.

Davis P, Cladis FP, Motoyama EK, eds. *Smith's Anesthesia for Infants and Children*. 8th ed. Philadelphia, PA: Mosby; 2011.

41. ANSWER: C

Symptoms of local anesthetic systemic toxicity (LAST) range from mild symptoms to major central nervous system (CNS) and/or cardiac toxicity that can result in disability or death. A variety of factors influence the chances and severity of local anesthetic systemic toxicity (LAST), including but not limited to individual patient risk factors and specific local anesthetic compound.

Neonates, infants, and children may be at risk for LAST because of their relatively increased cardiac output and systemic uptake of the local anesthetic. Increase in available local anesthetic due to increase in systemic uptake may result in direct central nervous system and/or cardiac toxicity.

Amide anesthetics are protein bound in the plasma. Ropivacaine is more than 90% bound to two plasma proteins, alpha-1-acid glycoprotein and albumin. The free fraction of local anesthetic is responsible for its effect on the cardiovascular and central nervous system. Infants less than 6 months of age have decreased levels of plasma proteins, larger free fraction of local anesthetic, and greater risk for toxicity. The serum concentration of fibrinogen in neonates is similar to that of adults, but is so low at baseline that changes in its serum concentration would not significantly affect the serum concentration of free or protein-bound local anesthetic.

Amide local anesthetics include lidocaine, etidocaine, prilocaine, mepivacaine, bupivacaine, ropivacaine, and levobupivacaine. They undergo enzymatic degradation and metabolism by the cytochrome P450 system in the liver. **These enzymes reach adult activity by the first year of life and are immature in the neonatal and infant period.** Consequently, there is **decreased clearance of amide local anesthetics in this age group**.

KEY FACTS

- Neonates, infants, and children may be at risk for LAST because of their relatively increased cardiac output and systemic uptake of the local anesthetic.
- Increase in available local anesthetic due to increase in systemic uptake may result in direct central nervous system and/or cardiac toxicity.
- Infants less than 6 months of age have decreased levels of plasma proteins, larger free fraction of local anesthetic, and greater risk for toxicity.
- Amide local anesthetics undergo enzymatic degradation and metabolism by the cytochrome P450 system in the liver. These enzymes reach adult activity by the first year of life and are immature in the neonatal and infant period. Consequently, there is decreased clearance of amide local anesthetics in this age group.

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Cote CJ, Lerman, J, Todres D, eds. *A Practice of Anesthesia for Infants and Children*. 4th ed. Philadelphia, PA: Saunders; 2009.

Davis P, Cladis F, Motoyama EK, eds. *Smith's Anesthesia for Infants and Children*. 8th ed. Philadelphia, PA: Mosby; 2011.

42. ANSWER: A

The anatomy of the neuraxis is different between a newborn and a young child. **The conus medullaris is commonly described to be located at L3 in the newborn. At 1 year of age and onward, the conus medullaris is located at L1. The dural sac is described to end at S3 in the newborn and ascends to end at S1 also at 1 year of age.** The locations of the conus and end of the dural sac in the adult and young child are similar. The differences in anatomy are particularly important when performing a spinal anesthetic technique.

KEY FACTS

- The conus medullaris is commonly described to be located at L3 in the newborn.
- At 1 year of age and onward, the conus medullaris is located at L1.
- The dural sac is described to end at S3 in the newborn and ascends to end at S1 also at 1 year of age.

REFERENCES

Cote CJ, Lerman, J, Todres D, eds. *A Practice of Anesthesia for Infants and Children*. 4th ed. Philadelphia, PA: Saunders; 2009.
Davis P, Cladis F, Motoyama EK, eds. *Smith's Anesthesia for Infants and Children*. 8th ed. Philadelphia, PA: Mosby; 2011.

43. ANSWER: A

Several factors are important to consider when dosing spinal anesthetics. **There is an increase in total volume of CSF in a neonate (4 mL/kg compared to 2 mL/kg in adults) and an increase in CSF volume in the spinal subarachnoid space (half of total CSF volume compared to one fourth in adults).** This causes a dilution of the injected local anesthetic into the spinal space. As a result, neonates and **infants require higher volumes of local anesthetic per weight**.

Although there is requirement for higher volume of local anesthetic, **the duration of action of the spinal local anesthetic is shorter than in adults**. 0.01 mL/kg of epinephrine is frequently added to the local anesthetic to increase the duration of action of the spinal anesthetic.

Adults experience **hemodynamic collapse** (bradycardia, hypotension, cardiac arrest) with a total spinal block due to preganglionic sympathetic blockade. This is **not ordinarily seen in young children and infants/neonates likely due to immaturity of their sympathetic nervous system**. In addition to lack of hemodynamic sympathectomy, it is also postulated that because there is less blood volume in their extremities there is consequently less venous pooling and less hemodynamic changes when compared to an older child or adult.

There is no difference in density of motor blockade between a neonate and adult.

KEY FACTS

- There is an increase in total volume of CSF in a neonate (4 mL/kg compared to 2 mL/kg in adults) and an increase in CSF volume in the spinal subarachnoid space (half of total CSF volume compared to one fourth in adults). As a result, neonates and infants require higher volumes of local anesthetic per weight.
- The duration of action of the spinal local anesthetic is shorter than in adults.
- Adults experience hemodynamic collapse (bradycardia, hypotension, cardiac arrest) with a total spinal block due to preganglionic sympathetic blockade. This is not ordinarily seen in young children and infants/neonates likely due to immaturity of their sympathetic nervous system.
- There is no difference in density of motor blockade between a neonate and adult.

REFERENCES

Cote CJ, Lerman, J, Todres D, eds. *A Practice of Anesthesia for Infants and Children*. 4th ed. Philadelphia, PA: Saunders; 2009.
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44. ANSWER: C

The recent **American Society of Regional Anesthesia (ASRA) guidelines for regional anesthesia in the anticoagulated** patient **recommend an INR value of ≤1.4 as acceptable for the placement of a neuraxial block**.

Postoperative warfarin is often administered for the prevention of deep venous thrombosis. The ASRA recommendation is for the INR value to be ≤1.4 prior to removal of the epidural catheter.

Patients who are on **low molecular weight heparin (LMWH) should have their neuraxial block (needle/catheter placement or catheter removal) performed at least 12 hours after the last prophylactic dose of enoxaparin (0.5 mg/kg BID) OR 24 hours after therapeutic doses of enoxaparin (1mg/kg BID or 1.5 mg/kg QD) and 24 hours after dalteparin or tinzaparin.** LMWH can be administered 2 hours after the epidural catheter is removed.

The ASRA recommends **discontinuation of clopidrogel and ticlopidine** (antiplatelet aggregation oral anticoagulants) **7 and 10–14 days, respectively, prior to placement of a neuraxial block.**

KEY FACTS

- The recent American Society of Regional Anesthesia (ASRA) guidelines for regional anesthesia in the anticoagulated patient recommend an INR value of ≤1.4 as acceptable for the placement or removal of a neuraxial catheter.
- Patients who are on low molecular weight heparin (LMWH) should have their neuraxial block (needle/catheter placement or catheter removal) performed at least 12 hours after the last prophylactic dose of enoxaparin (0.5 mg/kg BID) OR 24 hours after therapeutic doses of enoxaparin (1 mg/kg BID or 1.5 mg/kg QD) and 24 hours after dalteparin or tinzaparin.
- LMWH can be administered 2 hours after the epidural catheter is removed.
- The ASRA recommends discontinuation of clopidrogel and ticlopidine 7 and 10–14 days, respectively, prior to placement of a neuraxial block.

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23.

GENERAL ANESTHESIA

Bryan M. Sabbe

1. Which combination of patient factors would place a patient at highest risk for emergence delirium?

A. Age 3 years old + inhaled sevoflurane
B. Age 8 years old + inhaled sevoflurane
C. Age 14 years old + inhaled sevoflurane
D. Any age + TIVA (total intravenous anesthesia)

2. During mask induction of a 3-month-old male for myringotomy and tympanostomy tube placement using sevoflurane 8%, N_2O 70%, and O_2 30%, spontaneous respirations are initially maintained, but as depth of anesthesia increases (sevoflurane end tidal concentration now 6%), positive-pressure ventilation support is begun with sudden loss of chest rise and $ETCO_2$, no IV access is present, and no medications have been administered. Auscultation reveals the absence of high-pitched breath sounds. Repositioning of the mask is reattempted but again mask ventilation remains difficult. What is the most likely cause leading to mask ventilation difficulty in this setting?

A. Laryngospasm
B. Provider-induced nasal compression
C. Provider-induced airway occlusion at the mandibular ridge
D. Gastric overdistention

3. You are called to the emergency department to help manage a 2-year-old, 12 kg male with massive hemoptysis. He has a history of congenital cystic adenomatoid malformation resected as a neonate due to respiratory distress requiring right lower lobectomy. Chest X-ray shows diffuse haziness in the right lung, and the only equipment present at the bedside includes video and standard laryngoscopes along with single-lumen endotracheal tube (ETT). As they are attempting to find a double-lumen ETT and fiberoptic bronchoscope, the child begins to desaturate. What would be the best maneuver at this time to intubate this child and provide lung isolation?

A. Place 4.5 cuffed ETT with bevel facing anteriorly, rotating child's head to the left, and advance until breath sounds are only heard on the right.
B. Place 4.5 cuffed ETT with bevel facing posteriorly (rotated 180 degrees from anterior), rotating child's head to the right, and advance until breath sounds are only heard on the right.
C. Place 4.5 cuffed ETT with bevel facing anteriorly, rotating child's head to the left, and advance until breath sounds are only heard on the left.
D. Place 4.5 cuffed ETT with bevel facing posteriorly (rotated 180 degrees from anterior), rotating child's head to the right, and advance until breath sounds are only heard on the left.

4. A mother of a 6-year-old girl has requested to come to the operating room for induction of anesthesia. You agree to this plan after describing to the mother the expected sights, sounds, and changes in behavior during your planned inhalational induction. In attempting to perform a distraction technique on the girl, you ask her to "blow up your balloon" as much as she can using big deep breaths while you are providing N_2O/O_2 in a 70%/30% combination along with a planned stepwise increase of delivered sevoflurane from 2%-6%-8%. She has been taking increasingly larger vital capacity breaths, and as you go to increase the inspired sevoflurane concentration from 6% to 8%, you can no longer feel any movement in the bag reservoir, and end-tidal sevoflurane concentration is 4.5%. The mother is still present in the room. What has most likely happened?

A. Breath holding
B. Laryngospasm
C. Provider-induced obstruction
D. Apnea

5. Which of the following is most true about parental presence at induction of anesthesia?

A. Calm parents have little impact on improving behavior in anxious children.
B. Very beneficial in developmentally delayed children <6 months age
C. Decreased patient anxiety or increased cooperation during induction
D. Increased parental satisfaction scores

6. A 12 kg, 3-year-old boy with a history of reasonably well-controlled asthma has just undergone tonsillectomy and adenoidectomy under general anesthesia with an atraumatically placed cuffed ETT with a leak of <20 cm H_2O when the cuff is deflated. The decision is made to wake him up in the operating room before transferring to the postanesthesia care unit (PACU). During emergence he coughs quite extensively against the ETT, but he does not show evidence of overt bronchospasm. He is furrowing his eyebrows, wincing, and reaching for the ETT, so the decision is made to extubate. He is transferred to a stretcher and you auscultate the chest; no expiratory wheeze is heard, but faint inspiratory stridor is present. No sternal or intercostal retractions are noticed and there is mist present in the face mask with O_2 at 6 L and SaO_2 at 97%. He is transferred to the PACU uneventfully but has increasing inspiratory stridor and hoarseness still without intercostal retractions, nasal flaring, or expiratory wheezing. What would be your first-line therapy for this child at this time?

A. Humidified mist
B. Nebulized albuterol
C. Dexamethasone 6 mg IV
D. Nebulized racemic epinephrine

7. In preparation for intubating a 3-year-old with a presumed difficult airway, you have planned to perform a fiberoptic intubation through a laryngeal mask airway (LMA). You have completed a successful inhalational induction and have a good initial seal with the LMA, and you proceed to pass your fiberoptic bronchoscope through the LMA, when suddenly there is a complete loss of view through the fiberoptic bronchoscope due to bloody secretions. You quickly remove the scope and no longer have $ETCO_2$ from the LMA, and mask ventilation proves unsuccessful. The SaO_2 is now beginning to drop, there is no immediately available otolaryngologist to help perform rigid bronchoscopy or surgical airway, and you decide to attempt retromolar intubation. What particular aspects of a patient's airway make this approach preferred over classic midline laryngoscopy?

A. Midface hypoplasia and limited neck extension
B. Large tongue and small mandible
C. Cleft palate and glossoptosis
D. Laryngeal edema and retrognathia

8. Which of the following syndromes associated with known possible difficult airway is caused by abnormal development of the first and second branchial arches?

A. Pfeiffer syndrome
B. Treacher Collins syndrome
C. Beckwith-Wiedemann syndrome
D. Apert syndrome

9. Inhalational induction is planned for a child with N_2O/O_2 in 70%/30% concentration along with increasing levels of inspired sevoflurane. As induction ensues, the end-tidal concentration of sevoflurane is 2.5%, and N_2O end tidal concentration is now 0% as you have converted to 100% O_2 in anticipation for intubation. In which age group would this not be consistent with the minimum alveolar concentration (MAC) of sevoflurane?

A. 0–6 months old
B. 6 months–1 year old
C. 1 year old–4 years old
D. >4 years old

10. What specific feature about spontaneous ventilation protects against cardiovascular collapse compared to controlled ventilation during inhalational induction using volatile anesthetics?

A. Minimal cardiovascular depression
B. Decreased solubility
C. Negative feedback on spontaneous ventilation at higher concentrations
D. Utilization of overpressure technique

11. You are beginning an inhalational induction in a 3-year-old infant for a hypospadias repair. As you commence your induction using sevoflurane in combination with N_2O/O_2, you begin to have some airway obstruction and place an oropharyngeal airway. You suddenly lose end-tidal CO_2 and the patient is now having significant retractions. You place your stethoscope on the patient's chest and now hear a loud holosystolic murmur and the patient is beginning to desaturate. You give intramuscular succinylcholine, remove the oral airway, and can still no longer mask ventilate. A nasal airway is attempted to be placed, but significant resistance is felt upon insertion. Based on this

clinical presentation, what is the most likely syndrome this patient has?

A. Crouzon syndrome
B. CHARGE syndrome
C. Prader-Willi syndrome
D. DiGeorge syndrome

12. When deciding to perform a rapid sequence intubation for a patient with presumed full stomach, which of the following is not a significant risk factor for pulmonary aspiration?

A. Emergency surgery
B. Increased intracranial pressure
C. Congenital heart disease
D. Obesity

13. In a 9-year-old patient preparing to undergo a thoracotomy for a cystic adenomatoid malformation, the decision is made to proceed with one-lung ventilation. If it is decided upon that a double-lumen tube (Covidien) can be used for this case, the smallest pediatric size available in the United States is equivalent to what size cuffed (Sheridan) endotracheal tube?

A. 4.5
B. 5.0
C. 5.5
D. 6.0

14. What feature of neonatal physiology contributes to the more rapid increase in FA/FI during an inhalational induction compared to an adult?

A. Lower cardiac index
B. Greater distribution of cardiac output to the vessel-rich group (VRG)
C. Increased percentage of total body water
D. Smaller alveolar ventilation to functional residual capacity (Va/FRC) ratio

15. An unrepaired 10-month-old male with Tetralogy of Fallot presents for placement of a gastrostomy tube. The patient does not have an IV in place and has a baseline SaO_2 of 82%, and you review previous cardiac catheterization data and find that his Qp:Qs ratio is 0.8. The decision is made to proceed with an inhalational induction using 100% FiO_2 and sevoflurane. What would be expected in regard to the speed of his inhalational induction compared to a patient without intracardiac shunting along with his Qp:Qs ratio?

A. Faster induction, increased Qp:Qs ratio
B. Faster induction, unchanged Qp:Qs ratio
C. Slower induction, increased Qp:Qs ratio
D. Slower induction, unchanged Qp:Qs ratio

16. Laryngeal mask airway (LMA) is associated with relatively few iatrogenic mechanical complications. When considering the placement and management of this device in the pediatric population, what is the most likely feature to minimize the risk of complications such as sore throat or nerve injury (i.e., lingual, hypoglossal, or recurrent laryngeal nerve)?

A. Confirmation of position using direct visualization via a fiberoptic bronchoscope
B. Removal of all air prior to placement in the oropharynx
C. Adequate jaw thrust during placement
D. Ensuring laryngeal mask intracuff pressures are less than 40 cm H_2O

17. When performing an elective sedated intubation in a 3-year-old using a flexible fiberoptic bronchoscope through the oral route, you are able to successfully view the glottic opening. But upon attempting to pass the endotracheal tube, there is significant resistance met. What is the optimal configuration when setting up your endotracheal tube and fiberoptic bronchoscope to minimize the likelihood of this happening?

A. Choosing a smaller sized cuffed endotracheal tube than predicted by patient size and weight
B. Load endotracheal tube on bronchoscope with bevel facing down (Murphy eye up)
C. Load endotracheal tube on bronchoscope with bevel facing up (Murphy eye down)
D. Using an uncuffed endotracheal tube

18. In attempting to intubate a 10-month-old patient via direct laryngoscopy, you find a repeated grade 3 glottic view; this is the first anesthetic the patient has received and did not have anatomic predictors or history suggesting difficult intubation. The patient has remained an easy mask ventilation throughout your attempts and you call for the GlideScope Cobalt® (video laryngoscope) to help facilitate intubation. Compared to direct laryngoscopy using a Macintosh blade in a homogeneous population of presumed nondifficult airway pediatric patients among experienced providers, the duration of time to successful intubation is:

A. Shorter
B. Longer
C. Equal
D. Has not been evaluated

19. Although no formally accepted algorithm is present for pediatric difficult airway, the Difficult

Airway Society (DAS) has proposed an algorithm for management of "Unanticipated difficult tracheal intubation—during routine induction of anaesthesia in a child aged 1 to 8 years old." According to this algorithm, if four intubation attempts have been done without success, what is the next proposed step in the management of this situation?

A. Two-hand mask ventilation
B. Video-assisted laryngoscopy
C. Fiberoptic intubation
D. Placement of supraglottic device

20. When considering removal of an LMA during a deep stage of anesthesia, which of the following has the highest risk for complications following removal either in the operating room or in the PACU?

A. Use of desflurane
B. Use of isoflurane
C. Abdominal surgery
D. Concomitant use of opioids

21. According to the Pediatric Perioperative Cardiac Arrest (POCA) Registry findings from 2000, what clinical aspect of patient management in the peri-induction period with the use of halothane led to an increased risk of cardiac arrest?

A. Anesthesia provider experience
B. Nonacademic institution
C. Concomitant administration of succinylcholine
D. Controlled ventilation following intubation

22. You are evaluating a 15-year-old female for scoliosis repair surgery. During your preoperative evaluation you notice a systolic ejection murmur, the presence of a cleft palate, a low posterior hairline, and a hoarse voice. There is no significant restrictive lung disease, and this will be her first anesthetic. She says she is nervous about the procedure and that she has been having increasing tingling in her fingers with occasional pain shooting from her shoulder down to her middle finger. What underlying disease or syndrome should you be worried about with this presentation, and what particular aspect of her anesthetic should be of greatest concern?

A. Marfan syndrome—aortic dissection in the setting of hypertension during laryngoscopy
B. Duchenne muscular dystrophy—rhabdomyolysis with volatile anesthetic administration
C. Heterotaxy syndrome—complete heart block during volatile anesthetic maintenance
D. Klippel-Feil syndrome—difficult intubation due to limited neck extension

23. What feature of patients with Treacher Collins syndrome makes mask ventilation and direct laryngoscopy increasingly difficult with age?

A. Hypoplastic zygomatic arches
B. Increasing basilar kyphosis of the cranial base
C. Cleft palate
D. Increasing tongue size

24. You are caring for a 7-year-old, 24 kg female with thoracic neuroblastoma encasing the descending aorta, and the surgeons have requested one-lung ventilation for a left thoracotomy. The decision is made that that the safest means of achieving this is to place a 5.5 cuffed ETT along with an intraluminal 5 French bronchial blocker to achieve single-lung ventilation. The placement is uneventful and the lung has collapsed nicely in the surgical field. During the course of the case the left chest is packed to minimize ongoing blood loss when suddenly you have a significant decrease in tidal volumes while using pressure control ventilation, decrease in $ETCO_2$, and oxygen desaturation. What is the most likely etiology of this problem based on this presentation?

A. Migration of bronchial blocker beyond the left upper lobe takeoff
B. Deflation of the bronchial blocker
C. Migration of the ETT into the left mainstem bronchus
D. Migration of the ETT into the right mainstem bronchus

25. You are performing a right thoracotomy in a 15 kg, 3-year-old female for a right upper lobe congenital cystic adenomatoid malformation that has recurred since infancy. The plan at this time is to perform a right upper lobectomy. She is intubated simultaneously with a 4.5 cuffed ETT and 5 French Arndt bronchial blocker on the outside of the ETT. Under fiberoptic guidance the bronchial blocker is successfully positioned in the right mainstem bronchus with good achievement of lung isolation following entry into the right chest. She tolerates the procedure well, but following placement of the surgical stapler across the right upper lobe bronchus, the entire right lung re-expands and limits the ability to remove the stapler and surgical specimen. What most likely occurred in this situation?

A. Surgical stapling across the bronchial blocker
B. Displacement of the inflated bronchial blocker into the trachea
C. Distal advancement of the bronchial blocker into bronchus intermedius
D. Advancement of the ETT into the left mainstem bronchus

CHAPTER 23 ANSWERS

1. ANSWER: A

Emergence delirium (ED) is a problem not unique, but frequently seen in pediatric anesthesia. With the introduction of sevoflurane into pediatric anesthesia, there was an increase in this phenomena, thought to be somehow related to the decreased solubility of this volatile agent (compared to previous volatiles used such as halothane), with the greatest frequency seen following sevoflurane > desflurane > isoflurane >> TIVA. There is currently no agreed-upon definition of ED due to its heterogeneous clinical presentation, but it has been described as a **dissociated state of consciousness** in which the child is irritable, uncompromising, uncooperative, incoherent, and inconsolably crying, moaning, kicking, or thrashing. The incidence of ED largely depends on definition, age, anesthetic technique, surgical procedure, and application of adjunct medication. Typically the cited incidence range is between 10% and 50%, but it may be as high as 80%, with the **peak age of ED seen in early childhood between the ages of 2 and 6 years** (Answers B and C), with the same age distribution between both males and females. The delirium typically lasts 10–15 minutes and is terminated spontaneously or following a single dose of fentanyl IV 1–2 μg/kg, propofol IV 0.5–1.0 mg/kg, midazolam IV 0.02–0.10 mg/kg, or a single bolus dose of dexmedetomidine 0.5 μg/kg. Deciding whether or not to treat ED with additional medication depends on the duration and severity of symptoms; many studies have shown **spontaneous resolution of symptoms** without pharmacological intervention. Possible etiological factors of ED include **rapid emergence, intrinsic characteristics of an anesthetic, postoperative pain, surgery type, age, preoperative anxiety, child temperament, and adjunct medication**. **Sevoflurane** is often implicated as the volatile associated with the **highest risk of causing ED** due to several postulated factors. Some authors feel that sevoflurane causes irritation to the central nervous system (CNS), while others speculate that although sevoflurane degradation products appear to cause no organ damage themselves, there is a paucity of data on the possible interactions with other types of medications. During sevoflurane anesthesia, epileptiform activity has been reported in both patients and volunteers with no medical history of seizures; however, these cases have been sporadic and were not associated with abnormal recoveries from anesthesia. This is also in contrast to desflurane, which has no proconvulsant properties but has been associated with a similar if not greater incidence of ED compared with sevoflurane. With this information it appears that the causality between the CNS effects of sevoflurane and ED is unlikely. **TIVA** shows the **lowest incidence** of emergence delirium compared to volatile anesthetics (Answer D).

Surgical procedures that involve the **tonsils, thyroid, middle ear, and eye** have been reported to have higher incidences of postoperative agitation and restlessness, suggested to perhaps be secondary to a "sense of suffocation" during emergence; however, there are no data to support this speculation. One key aspect of ED is differentiating this phenomenon from **postoperative pain**. Several studies have evaluated ED following different surgical procedures using nonvalidated delirium scales leading to much confusion regarding the nature, cause, and treatment of ED. Subsequently a **Pediatric Anesthesia Emergence Delirium (PAED)** score was developed and validated as an objective measure of ED, with a score >10 indicative of the presence of ED (however, some studies have suggested a score of >12 to be more specific); see Table 23.1.

Other scales exist including the Watcha scale (Table 23.2), with a score >2 suggesting ED; and the Cravero scale (Table 23.3), with a score >3 suggesting ED.

KEY FACTS

- Emergence delirium is described as a dissociated state of consciousness, with the peak age seen in early childhood between the ages of 2 and 6 years.
- Surgical procedures that involve the tonsils, thyroid, middle ear, and eye have been reported to have higher incidences of postoperative agitation and restlessness.
- Possible etiological factors of emergence delirium include rapid emergence, intrinsic characteristics of an anesthetic, postoperative pain, surgery type, age, preoperative anxiety, child temperament, and adjunct medication.

Table 23.1 THE PEDIATRIC ANESTHESIA EMERGENCE DELIRIUM SCALE

POINT	DESCRIPTION	NOT AT ALL	JUST A LITTLE	QUITE A BIT	VERY MUCH	EXTREMELY
1	The child makes eye contact with the caregiver	4	3	2	1	0
2	The child's actions are purposeful	4	3	2	1	0
3	The child is aware of his/her surroundings	4	3	2	1	0
4	The child is restless	0	1	2	3	4
5	The child is inconsolable	0	1	2	3	4

Table 23.2 WATCHA BEHAVIOR SCALE FOR EMERGENCE DELIRIUM

LEVEL	DESCRIPTION
1	Calm
2	Crying but can be consoled
3	Crying but cannot be consoled
4	Agitated and thrashing around

Table 23.3 CRAVERO EMERGENCE AGITATION SCALE

LEVEL	DESCRIPTION
1	Obtunded with no response to stimulation
2	Asleep but responsive to movement or stimulation
3	Awake and responsive
4	Crying (for >3 min)
5	Thrashing behaviour that requires restraint

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2. ANSWER: C

The **most common** provider-induced error during mask ventilation is to tightly **compress the submental triangle** with fingers placed below the mandibular ridge, thereby partially occluding the airway. Minimal pressure is required, and the fingers should rest on the mandible. Another common problem arises when the **mouth is completely closed** while the face mask is being applied. In this setting if excess pressure is also placed on the nasal bridge, one or both nares can also become obstructed, leading to **total upper airway obstruction** during both spontaneous and manual ventilation. Careful attention should be paid to not place excess pressure on the upper portion of the face mask on the nasal bridge to prevent this obstruction. If the mouth is closed, either remove the mask, using a finger or the mask itself to slightly open the mouth; consider placement of an **oral airway**; or completely remove the fingers from the mandible and face, placing a single finger on each coronoid process. Lift toward the hairline to sublux the temporomandibular joint, opening the mouth and pulling the tongue and other soft tissues off the posterior pharyngeal wall. During one-handed mask ventilation the second hand should be on the reservoir bag at all times to monitor spontaneous respirations and effectiveness of ventilation and to provide continuous positive airway pressure (CPAP) if needed to keep the airway patent. Airway obstruction during anesthesia or loss of consciousness appears to be most frequently related to **loss of muscle tone in the pharyngeal** and **laryngeal structures,** as opposed to apposition of the tongue to the posterior pharyngeal wall, despite the tongue occupying a greater portion of the oral cavity in children compared to adults. With increasing depth of anesthesia there is progressive airway obstruction seen at the level of the **soft palate and epiglottis** primarily. Increasing concentrations of both propofol- and sevoflurane-based anesthetics have shown dose-dependent decreases in pharyngeal space within children studies, primarily occurring in the anteroposterior dimension. Propofol anesthesia with increasing depth in children specifically shows upper airway narrowing throughout with the most pronounced effects in the **hypopharynx** at the level of the epiglottis. This narrowing can be offset by **extension of the head at the atlantooccipital joint** with anterior displacement of the cervical spine into the classic "sniffing position," which will improve hypopharyngeal airway patency, but does not alter the position of the tongue, supporting the concept that upper airway obstruction is not primarily caused by changes in tongue position but is more likely related to **collapse of the pharyngeal structures**.

Given the absence of high-pitched upper airway sounds and likely adequate depth of anesthesia evident by end-tidal sevoflurane concentration of 6%, laryngospasm is a less likely cause of the airway obstruction (Answer A). Nasal compression could certainly be contributing to the airway obstruction, but it is not as likely as submandibular compression by the operator's hand, particularly with repositioning of the mask and subsequent difficulty in masking where the hand could have been misplaced in the submandibular region (Answer B). Another possible contributing factor to difficult mask ventilation is gastric overdistention, but this typically arises as a problem following a period of vigorous positive-pressure ventilation with peak inspiratory pressures large enough to open the gastroesophageal junction and insufflate the stomach. This is less likely the cause in this case given the fact that the patient was breathing spontaneously prior to attempting positive-pressure ventilation and abrupt loss of $ETCO_2$ and chest rise.

KEY FACTS

- The most common provider-induced error during mask ventilation is to tightly compress the submental triangle with fingers placed below the mandibular ridge, thereby partially occluding the airway.
- With increasing depth of anesthesia there is progressive airway obstruction seen at the level of the soft palate and epiglottis primarily.

- Upper airway narrowing can be offset by extension of the head at the atlantooccipital joint with anterior displacement of the cervical spine into the classic "sniffing position," which will improve hypopharyngeal airway patency.

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3. ANSWER: D

Single-lung ventilation (SLV) is extremely valuable in multiple aspects of pediatric surgery and anesthesia. Similar to the adult population, there are absolute and relative indications (see Boxes 23.1 and 23.2) for single-lung ventilation; however, in the pediatric population it is important to recognize that the surgical field is obviously of smaller size, leading to potential complications with retractor placement, compression of thoracic and mediastinal structures, and the greater likelihood of endotracheal tube (or other lung isolation device) malpositioning with movement of the patient's body or head, or from manipulations within the surgical field itself.

There are several safe, reliable, and effective means of achieving SLV ventilation in the pediatric population. However, there are several important limitations based on the size of pediatric patients, their respective anatomy, and the commercially available devices to achieve SLV. The **simplest means** of providing SLV is to intentionally intubate the ipsilateral mainstem bronchus of the side desired to be ventilated with a single-lumen endotracheal tube (ETT). The right and left mainstem bronchi have different characteristics with the **right mainstem bronchus being larger, shorter, and more vertical** than the left mainstem bronchus, making right mainstem intubation the easiest means of achieving SLV, as the ETT is simply advanced until breath sounds are no longer heard on the left with absolute confirmation achieved by either fiberoptic bronchoscopy or fluoroscopy. The **left mainstem bronchus** comes off at a **more oblique angle,** making left mainstem intubation more challenging without the assistance of an imaging technique. In the situation described the patient most likely has hemoptysis stemming from previous surgery on the right lung; to avoid contaminating the presumably normally functioning left lung, selective isolation of the left lung should quickly be achieved (absolute indication for lung isolation). Due to the lack of immediately available resources for direct imaging in this scenario, several maneuvers can be attempted to **selectively isolate and intubate the left mainstem bronchus**. The recommended approach is to **rotate the bevel of the ETT 180 degrees** (bevel now facing posteriorly), rotate the child's head to the right, intubate, and auscultate until breath sounds are no longer heard on the right. This is obviously not the preferred means to accomplish SLV, and **ideally a fiberoptic bronchoscope** would be available to confirm positioning, but in some circumstances this equipment may not immediately be available and in cases such as **massive hemoptysis or contralateral tension pneumothorax** achieving lung isolation is an emergency. It should be noted than when selectively intubating the left mainstem bronchus, it is also **possible to occlude the left upper lobe** orifice when a cuffed ETT is used; therefore, the distance from the proximal cuff to the tip of the ETT must be less than the length of the mainstem bronchus. Many other devices are available to achieve SLV, including double-lumen ETTs, bronchial blockers, and Fogarty catheters, but may have functional limitations and should be chosen carefully when anatomic limitations are likely present.

Box 23.1 **ABSOLUTE INDICATIONS FOR LUNG ISOLATION**

1. Isolation of each lung to prevent contamination of a healthy lung
   a. Infection: abscess, infected cyst
   b. Massive hemorrhage
2. Control of distribution of ventilation to only one lung
   a. Bronchopleural fistula
   b. Bronchopleural cutaneous fistula
   c. Unilateral cyst of bullae
   d. Major bronchial disruption or trauma
3. Unilateral lung lavage

4 Video-assisted thoracoscopic surgery

Box 23.2 **RELATIVE INDICATIONS FOR LUNG ISOLATION**

1. Surgical exposure—high priority
   a. Thoracic aortic aneurysm
   b. Pneumonectomy
   c. Upper lobectomy
2. Surgical exposure—low priority
   a. Esophageal surgery
   b. Middle and lower lobectomy
   c Thoracoscopy under general anesthesia

KEY FACTS

- The simplest means of providing SLV is to intentionally intubate the ipsilateral mainstem bronchus of the side desired to be ventilated with a single-lumen ETT.
- When selectively intubating the left mainstem bronchus, it is also possible to occlude the left upper lobe orifice when a cuffed ETT is used; therefore, the distance from the proximal cuff to the tip of the ETT must be less than the length of the mainstem bronchus.
- Other devices are available to achieve SLV, including double-lumen ETTs, bronchial blockers, and Fogarty catheters, and a fiberoptic bronchoscope would be used to confirm positioning.

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4. ANSWER: D

Through an inhalational induction many of the classic characteristics describing ether-based general anesthesia can be witnessed, although they are less dramatic than described by Ernest Guedel. There are **four characteristic stages** of general anesthesia. Patients in **stage 1 have intact airway reflexes** and some **analgesia**, but they can respond to verbal stimulation, have intact reflexes, and have normal respiratory patterns. As depth progresses to **stage 2, excitatory patterns** are seen; patients in this stage have delirium with associated unconsciousness, **irregular** and **unpredictable respiratory patterns** (including hyperventilation), **nonpurposeful movements**, and **increased risk of reflex activity, including laryngospasm, vomiting, and arrhythmias**. Progressing to **stage 3** denotes entry into **surgical anesthesia**, where there are more **regular and periodic respirations** and MAC is achieved. Stage 4 is typically described as an "overdose" of anesthesia, where there can be loss of respiratory drive along with cardiovascular collapse. With the use of **intravenous-based induction** agents, patients often bypass stage 1 and stage 2 and progress directly into stage 3, where airway instrumentation and other noxious stimuli are typically tolerated. Sevoflurane leads to both decreased volume and increased respiratory rate, but typically not to the point of apnea, as described in the stem above (at least not until stage 4 is achieved or other respiratory depressants have been administered). In this particular scenario **the patient likely has depressed her $PaCO_2$** significantly to the point where she decreased her central respiratory drive. In a situation such as this the provider must now consider **administering positive-pressure ventilation** to maintain airway patency, and this increases the risk of untoward reflex activity such as laryngospasm or vomiting if the patient has not achieved an appropriate depth of anesthesia during the inhalational induction. If the mother is still present in this situation, it would be wise to escort the mother from the operating room at this time to decrease the likelihood of her witnessing resuscitation during this high-risk period of induction.

Breath holding (Answer A) is possible but unlikely, given the scenario described and the increasing vital capacity breaths prior to abrupt apnea. Breath holding occurs as irregular breathing patterns most commonly seen during stage 2 of general anesthesia.

Laryngospasm (Answer B) is another possibility, but again it is less likely, given the scenario described. Laryngospasm can be abrupt or insidious with progressively increasing difficulty maintaining airway patency. It is often associated with other clinical findings as long as spontaneous ventilation is maintained, including inspiratory stridor, sternal, and/or intercostal retractions.

Provider-induced airway obstruction (Answer C) is another possibility, but the described scenario is more likely associated with apnea, not obstruction. Although provider-induced airway obstruction can initially lead to presumed loss of spontaneous respirations, it is important to look for other signs of upper airway obstruction if this is presumed, and attempting certain maneuvers to alter airway patency can likely quickly verify whether or not airway obstruction is the cause. Maneuvers such as repositioning the mask, opening the mouth, placing an oropharyngeal airway, and ensuring excessive pressure is not placed in the submandibular region or nasal bridge can all help quickly assess whether airway obstruction or apnea is present.

KEY FACTS

- There are four characteristic stages of general anesthesia:
  - Stage 1—intact airway reflexes and some analgesia but can respond to verbal stimulation, have intact reflexes, and normal respiratory patterns
  - Stage 2—excitatory patterns, delirium, unconsciousness, irregular and unpredictable respiratory patterns (including hyperventilation), nonpurposeful movements, and increased risk of reflex activity, including laryngospasm, vomiting, and arrhythmias
  - Stage 3—surgical anesthesia, more regular and periodic respirations, MAC is achieved
  - Stage 4—loss of respiratory drive along with cardiovascular collapse
- With intravenous-based induction, patients often bypass stage 1 and stage 2 and progress directly into stage 3,

where airway instrumentation and other noxious stimuli are typically tolerated.

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5. ANSWER: D

Parental presence at induction of anesthesia (PPIA) is a controversial topic within pediatric anesthesia. Several studies have been done to evaluate the potential benefit of parental presence in the operating room and the reduction in anxiety among pediatric patients. This practice has increased significantly in the United States over the past decade. Two systematic reviews have summarized the published evidence regarding this topic and determined that PPIA **reduced anxiety among parents but not children** (Answer C) but did show **increased parental satisfaction scores**. It has been found that parents who are most insistent on being present during induction are often the **most disruptive**, the least likely to calm their child, and actually **worsen noncompliant behavior** in their child. However, the calm parents accompanying anxious children have shown a measurable benefit (Answer A), but there is no significant impact if both the child and the parent are both deemed to be calm. Children will rarely experience separation anxiety **before 8 months of age** (Answer B), even in developmentally delayed children. Those between the **ages of 1 and 6 years are most likely** to benefit from PPIA. From a medicolegal standpoint it is important to remember that parents should be told that they "may accompany" their child for the induction of anesthesia rather than be invited by the provider due to the fact that the provider and hospital may be held liable for any unexpected events which the parent may experience. Parents need to be **instructed** on what to expect as their child undergoes the induction of general anesthesia, particularly that they might cry, have abnormal breathing, roving eye movements, uncontrolled movement of their extremities, and/or flaccid appearance. Instructing parents and preparing for PPIA can reduce anxiety and significantly improve the outcome of PPIA, including teaching distraction techniques and avoiding reassuring behavior. Parents should be escorted quickly from the operating room upon loss of consciousness, and the anesthesiologist should obviously be prepared to reassure and respond quickly should anything go wrong during induction. When choosing which parents will be most effective during PPIA, it is important to **determine the demeanor of both the child and the parent,** as this can significantly impact the effectiveness of PPIA.

KEY FACTS

- It has been found that parents who are most insistent on being present during induction are often the most disruptive, the least likely to calm their child, and actually worsen noncompliant behavior in their child.
- Children will rarely experience separation anxiety before 8 months of age, and those between the ages of 1 and 6 years are most likely to benefit from PPIA.
- Instructing parents and preparing for PPIA can reduce anxiety and significantly improve the outcome of PPIA, including teaching distraction techniques and avoiding reassuring behavior.

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6. ANSWER: A

This patient most likely has **postintubation croup**. This presents as **inspiratory stridor**, **hoarseness**, and often the seal-like "barking" **cough**. Typically this does not lead to respiratory distress except in more severe cases where intercostal retractions or nasal flaring can be seen with increased work of breathing. The mechanism for postintubation croup is most likely due to **mechanical trauma** or **mucosal ischemia** from the endotracheal tube and/or cuff leading to tracheal edema and airflow restriction. The reported incidence ranges from 0.1% to 1% of children who are intubated with associated risk factors, including an ETT with an outer diameter that is too large for the child's airway (i.e., no appreciable ETT or cuff leak at >25 cm H_2O, or resistance to advancement during insertion), **positional changes** during the procedure leading to mechanical shearing force trauma, positions other than supine, **traumatic intubations**, patients between 1 and 4 years old (such as this patient), surgery lasting greater than 1 hour, coughing while the ETT remains in place (such as this patient), and a previous history of croup. There is conflicting evidence whether upper respiratory infection is an additional risk factor because some studies have shown an association and others have shown it to be unrelated. It is important to note that there are two types of croup: **postintubation** and **infectious**. These two processes are not identical and

although the treatment modalities are similar, treatment for postintubation croup has not been proven in controlled trials and the rationale for the treatments administered stem from experience in treating infectious croup. The first-line treatment for presumed postintubation croup is **supportive care,** including delivery of **humidified mist**. Additional therapies include **dexamethasone** 0.5 mg/kg up to 10 mg, and ultimately the addition of **nebulized racemic epinephrine** in severe cases where increased work of breathing, sternal or intercostal retractions, or nasal flaring is present (Answers C and D). Close attention should be paid in this last group because there is potential for rebound edema after the racemic epinephrine has worn off, warranting close observation of these children to ensure that symptoms do not recur and or are exacerbated. When evaluating a child for postintubation croup, it is important to first **rule out more severe causes of upper airway obstruction** such as laryngospasm, vocal cord injury, or foreign body aspiration.

Nebulized albuterol is helpful in treating bronchospasm, but it would not be first-line therapy in this patient.

KEY FACTS

- The mechanism for postintubation croup is most likely due to mechanical trauma or mucosal ischemia from the endotracheal tube and/or cuff leading to tracheal edema and airflow restriction.
- Treatment for postintubation croup is supportive care, including delivery of humidified mist, with dexamethasone 0.5 mg/kg up to 10 mg and nebulized racemic epinephrine in severe cases.

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7. ANSWER: B

Retromolar intubation, also known as the paraglossal or lateral approach, utilizes a **straight blade** such as a Miller and is ideally used in situations where classic direct midline rigid laryngoscopy fails due to a large tongue or small mandible. The technique is accomplished by turning the child's head **slightly to the left,** advancing a small straight blade such as a Miller #1 from the furthest right side of the mouth between the tongue and the lateral pharyngeal wall, thereby sweeping the tongue completely to the left and ideally bypassing any obstruction to viewing the glottic opening. To further optimize this technique, a small retractor (such as a Senn) or an assistant can further pull back on the right side of the mouth to increase the space for ETT placement. The blade is advanced while staying to the right overlying the bicuspids and lateral incisors until the epiglottis or glottis is visualized; once in view, the tip of the straight blade can be used to lift the epiglottis and optimize view of the glottic opening. Once a view is achieved, the proximal portion of the blade can be rotated toward the left (midline) to allow for increased room when trying to place and advance the ETT. **Shorter length straight blades** are preferred because the distance to the glottic opening is significantly shorter when this approach is used compared to midline. The improved view with this approach is due to several aspects; first, there is **reduced need for soft tissue displacement** and compression because by placing the blade in the lateral position, the tongue is bypassed. This is particularly useful in children with **micrognathia,** as the space to displace the tongue is significantly reduced during the midline approach. The second aspect is an improved line of visualization because the incisors and maxillary structures are also bypassed when inserting the blade from the lateral position and shifting the head to the left. Third, the straight blade **minimizes the chance of obstructing the laryngeal view** compared to a curved blade. Fourth, the angle and distance from the insertion of the straight blade at the right commissure of the mouth are reduced, allowing for **easier view of the glottic opening,** particularly during difficult intubation, compared to the midline approach.

Midface hypoplasia could lead to potential difficult mask ventilation (Answer A), and limited neck extension might limit the ability to perform adequate direct laryngoscopy from either the midline or the lateral approach.

Cleft palate and glossoptosis (Answer C) are two components of Pierre Robin sequence (third feature being micrognathia), a known anatomic configuration with risk for difficult intubation, but this answer is incorrect because a patient with a cleft palate should not have significant limitation with the midline approach to direct laryngoscopy, and glossoptosis without micrognathia could lead to difficult midline approach to intubation but would certainly lead to a greater likelihood of airway obstruction. Retromolar intubation has been shown to be useful in patients with Pierre Robin sequence, but without micro/retrognathia as a choice in addition to cleft palate and glossoptosis, Answer B is a better choice.

Laryngeal edema (Answer D) itself could make direct laryngoscopy from either the midline or the lateral position difficult; in a patient with this condition, preparation for possible surgical airway and or the use of a fiberoptic bronchoscope may be the best means to secure the airway. Retrognathia is a feature that would make the retromolar approach potentially a better option, but when paired with laryngeal edema, this again makes Answer B a better choice.

KEY FACT

- Retromolar intubation, also known as paraglossal or lateral approach, utilizes a straight blade such as a Miller and is ideally used in situations where classic direct midline rigid laryngoscopy fails due to a large tongue or small mandible.

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8. ANSWER: B

Certain syndromes have a known association with difficult airway, stemming from typically one of six etiologies: maxillary size, mandibular size, tongue and soft tissue, cervical spine, larynx, or mandibular sliding and hinge function. Airway management of each of these abnormalities requires meticulous attention to the specific challenges which can be faced during **attempted mask ventilation, positioning, direct or video laryngoscopy, fiberoptic intubation, and extubation**. Of the syndromes listed, Treacher Collins syndrome is caused by deficient development of the branchial arches, particularly the first and second branchial arches. Several facial anomalies and their associated syndromes are secondary to anomalies or defects in the branchial arches. Presentations can include external ear deficiencies, auricular tags, and persistent branchial clefts or cysts. Micro- or macrostomia results from abnormal merging of the maxillary and mandibular prominences, while micrognathia, which is also an anomaly of the first branchial arch, is a result of retarded mandibular development by any mechanism whether intrinsic developmental defect or direct compression during late gestation. Syndromes associated with **branchial arch malformations** include Treacher Collins syndrome, Robin sequence, and Goldenhar syndrome and hemifacial microsomia (oculo-auriculovertebral spectrum). Treacher Collins syndrome has an incidence of 1:50,000 live births with major clinical features, including midface hypoplasia, micrognathia, microtia, conductive hearing loss, and cleft palate. The gene associated with this abnormality has been mapped to **chromosome 5q31.3–32**. Abnormalities are typically **bilateral, symmetrical,** and confined to the **craniofacial complex**. Possible associated nonfacial features include choanal atresia, ophthalmic features (microphthalmia, coloboma of the eyes, and notched lower eyelids), absent parotid gland(s), renal anomalies, and congenital heart disease. Typically mental development is not affected. The characteristic facial appearance is a dysmorphic mandible and maxillary-malar complex, with a narrow face, down-sloping palpebral fissures, depressed cheekbones, and a large down-turned mouth. Airway difficulties are found also due to an abnormal cranial base angle that is decreased, leading to **positioning of the posterior pharynx forward**; also pharyngeal dimensions are reduced by **hypoplastic skeletal elements**. Airway difficulties tend to increase with increasing age. Surgical options for correcting upper airway obstruction stemming from mandibular deficiency include **mandibular distraction** osteogenesis, avoiding tracheostomy, and allowing for future growth of the mandible.

Pfeiffer syndrome (Answer A) is a craniosynostosis defect classified among the acrocephalosyndactylies (Acrocephalosyndactyly Type V), where a mutation in the FGFR-1 gene and sometimes the FGFR-2 gene results in premature cell maturation and bony suture closure, typically leading to hypertelorism, proptosis, maxillary hypoplasia, mandibular prognathism, and malocclusion. There is both a potential for difficult mask ventilation and difficult intubation in these patients.

Beckwith-Wiedemann syndrome (Answer C) is most commonly a sporadically occurring syndrome with exomphalos, macroglossia, gigantism, and hypoglycemia caused by hyperinsulinism. The 11p15 chromosome region contains a growth-promoting and a tumor-suppression gene. The genetic anomaly results in increased expression of the IGF-2, which is responsible for the somatic overgrowth and predisposition to tumors. Associated clinical features include macroglossia (98% of cases), visceromegaly (possibly leading to omphaloceles and umbilical hernias), midface hypoplasia, prominent occiput, ear anomalies, somatic gigantism, and neonatal hypoglycemia. There is an increased incidence of benign tumors. Macroglossia and midface hypoplasia make mask ventilation and direct laryngoscopy potentially difficult in these patients.

Apert syndrome (Answer D) is also a craniosynostosis defect (Acrocephalosyndactyly Type I) that results from mutations in the gene encoding FGFR-2, which leads to abnormal osseous development resulting in irregular bridging of mesenchymal tissue that eventually transforms into bone. Features include midface hypoplasia and symmetrical syndactyly of the hands and feet involving at least the second, third, and fourth digits. There is both a potential for difficult mask ventilation and difficult intubation in these patients.

KEY FACTS

- Defects in the branchial arches can lead to external ear deficiencies, auricular tags, persistent branchial clefts or cysts, micro/macrostomia, and micrognathia.
- Syndromes associated with branchial arch malformations include Treacher Collins syndrome, Robin sequence, and Goldenhar syndrome and hemifacial microsomia (oculo-auriculovertebral spectrum).
- Airway difficulties found in Treacher Collins syndrome are due to an abnormal cranial base angle, leading to forward positioning of the posterior pharynx and reduced pharyngeal dimensions.

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9. ANSWER: A

Sevoflurane was introduced in the 1990s and has become the primary volatile anesthetic used for inhalational inductions in pediatric anesthesia. It is a fluorinated methyl isopropyl ether with low blood solubility correlating with blood-gas coefficient of 0.68. It can be delivered in concentrations up to 8% without significant breath holding, coughing, or laryngospasm and leads to rapid induction and recovery. Compared to other volatile anesthetics, it has an increased MAC in neonates and infants <6 months old with an associated MAC of 3.3% in this group, compared to 2.5% in children between 6 months and 5 years old (Answers B, C, and D), increasing to 2.0% in adults. The explanation for this different relationship compared to other volatile anesthetics remains unclear. Sevoflurane has **minimal cardiovascular side effects,** producing less hypotension compared to desflurane, less tachycardia compared to isoflurane, and less direct myocardial compression or arrhythmias due to sensitization of the myocardium to catecholamines such as epinephrine compared to halothane. It has been shown to be an **effective bronchodilator** and decreases minute ventilation and respiratory frequency in infants at 1 MAC but only slightly increased end-tidal carbon dioxide levels. Neurologic effects show cortical epileptiform electroencephalographic (EEG) readings without evidence of frank seizures. There is some **metabolism** of sevoflurane up to 5% into inorganic fluoride with secretion in the urine, but it is still below the acceptable nephrotoxic levels of 50 mmol/L. There is a **higher probability of postemergence delirium** with the use of sevoflurane compared to other volatile anesthetics, by a yet to determined mechanism, with treatment typically consisting of dexmedetomidine, fentanyl, or propofol in small doses.

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10. ANSWER: C

The depth of anesthesia during inhalational induction and maintenance, particularly during spontaneous respirations, has a specific **protective mechanism** described as a negative-feedback respiratory response. There are two methods to achieve a successful inhalational induction; the first is with an incremental increase in the amount of volatile anesthetic delivered (stepwise approach) with resultant slow increases in delivered anesthetic and progressive increase in the depth of anesthesia. This is an acceptable means of induction in a cooperative child who will tolerate a mask seal while awake. The second method is referred to as an overpressure technique, in which the inspired concentration of inhalational anesthetic to be delivered is several fold greater than the MAC of that particular agent (i.e., setting sevoflurane concentration to 8% during a single-breath inhalational induction), which is more useful in children who are combative and require a quicker means of induction and airway control. During the initial phase of inhalational induction, there is a **rapid increase in the FA/FI** (alveolar/inspired) ratio with accompanying increases in blood levels, particularly to the vessel-rich group (VRG) consisting of the brain, heart, splanchnic bed (including liver), kidney, and endocrine glands. As this level, there is a **negative feedback** effect **slowing minute ventilation** and subsequent **further washin of volatile anesthetic**, subsequently decreasing the uptake by the blood of further anesthetic and slowing the delivery of further anesthetic to the VRG. When

the partial pressure in the VRG again drops (particularly in the brain, which is controlling minute ventilation), anesthetics move along their partial pressure gradients from the VRG back into the blood, thereby decreasing the depth of anesthesia and further promoting increased minute ventilation again resumption of uptake of anesthetic gases from the alveoli. If ventilation were to be **controlled**, for example, in a situation where a spontaneously breathing child during an inhalational induction goes into laryngospasm, is treated with succinylcholine, and then has controlled ventilation with continued high doses of volatile agent, this negative-feedback mechanism is abolished and there is a real possibility of significant volatile anesthetic overdose. This is of particular importance in **neonates and small infants** who are more susceptible to the cardiovascular depressant effects of volatile agents compared to older children.

The minimal cardiovascular depression (Answer A) seen with sevoflurane in particular compared to halothane is protective in minimizing the possibility of cardiovascular collapse during an inhalational induction, but it is not the physiological protective mechanism.

Decreased solubility (Answer B) affects the speed of induction and amount of uptake, but it does not directly affect spontaneous ventilation during an inhalational induction.

The overpressure technique (Answer D) refers to increasing the inspired concentration of volatile anesthetic to several fold greater than the MAC for that particular agent during an inhalational induction (i.e., delivery of 8% sevoflurane), which quickly increases the depth of anesthesia but does not directly affect the maintenance of spontaneous respirations as long as the patient is allowed to continue with spontaneous respirations without augmentation using neuromuscular blocking agents, opioids, or other respiratory depressants and subsequent controlled ventilation with continued delivery of high concentrations of inhaled anesthetics.

KEY FACTS

- During the initial phase of inhalational induction there is a rapid increase in the FA/FI (alveolar/inspired) ratio with accompanying increases in blood levels.
- There is a negative feedback effect slowing minute ventilation and subsequent further washin of volatile anesthetic, subsequently decreasing the uptake by the blood of further anesthetic and slowing the delivery of further anesthetic to the VRG.

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11. ANSWER: B

The clinical scenario described here suggests airway obstruction occurring during spontaneous ventilation followed by difficult mask ventilation in the setting of an oropharyngeal airway being in place. The retractions seen suggest significant upper airway obstruction with a wide differential of diagnoses. Succinylcholine was given with no improvement, helping eliminate laryngospasm, but the cardiac murmur and difficulty passing the nasal airway suggest the possibility of both an intracardiac defect and choanal atresia, two findings seen in **CHARGE syndrome**. CHARGE syndrome is an acronym for the constellation of life-threatening anomalies consisting of *c*oloboma, *h*eart anomaly, choanal *a*tresia, mental and growth *r*etardation, *g*enital anomalies, and *e*ar anomalies. The embryological basis of CHARGE syndrome is a **midline developmental defect** attributed to an arrest in embryologic differentiation during early organogenesis; more than 90% of cases occur sporadically with an incidence of 1:13,000 to 1:15,000 live births. Diagnosis consists of having **four of seven findings** described in the acronym, including at least one major anomaly. These patients may present with **extreme respiratory distress or feeding difficulties as neonates**. Heart anomalies are present in up to 80% of patients with a wide variety of defects represented, including ASD/VSD, AV canal defects, conotruncal malformations, Tetralogy of Fallot, hypoplastic left heart syndrome, PDA, pulmonary stenosis, and coarctation of the aorta. **Airway findings** include choanal atresia (bilateral in 50% of patients), laryngomalacia, laryngeal cleft, and subglottic stenosis. Abnormal facial features can also **contribute to difficult mask ventilation,** in particular midface hypoplasia, micrognathia, and cleft lip/palate. Nerve palsies are often seen, with sensorineural hearing loss being the most common feature present in CHARGE syndrome. **Heart defects** and **postoperative pulmonary complications** have the greatest contribution to perioperative morbidity and mortality. Airway management can be particularly challenging in this population because the midface hypoplasia, micrognathia, choanal atresia, small mouth, and cleft lip can make mask ventilation very challenging. Laryngomalacia leads to upper airway obstruction despite placement of an adequately sized oropharyngeal airway. Anteriorly displaced larynx can make direct laryngoscopy also quite challenging. Airway management becomes more difficult with age. Spontaneous ventilation should be maintained until the airway is secure, if at all possible.

Crouzon syndrome (Answer A) is also known as acrocephalosyndactyly type II. Patients have

characteristic facial features due to craniosynostosis of the coronal or sagittal suture. This leads to maxillary hypoplasia, relative mandibular prognathism, parrot beaked nose, shallow orbits, proptosis, hypertelorism, high-arched palate, bifid uvula, mild mental retardation, possible herniation of cerebellar tonsils due to increased intracranial pressure, and broad tarsal bones or fused tarsal bones. Mask ventilation and airway difficulties should be anticipated, and there is the possibility of cardiac defects, but this association is not as strong as in the CHARGE syndrome.

Prader-Willi syndrome (Answer C) results from loss of paternal copy of chromosome 15q11.2–13, leading to short stature, mental retardation, severe obesity, small hands and feet, hypotonia in infancy, and diabetes mellitus. There is certainly the possibility of difficult mask airway and intubation given the obesity of these children, but there is not associated structural airway abnormalities or associated cardiac defects.

DiGeorge syndrome (Answer D) is an autosomal dominant 22q11.2 microdeletion syndrome characterized by cardiac outflow tract abnormalities, hypoparathyroidism, hypocalcemia, thymic hypoplasia/aplasia with associated immune defects, and airway/craniofacial abnormalities (small dysplastic ears, hypertelorism, anteverted nostrils, short philtrum, cupid bow mouth, midface hypoplasia, retrognathia, micrognathia, high-arched palate, and bifid uvula). This patient could present with the findings of cardiac murmur and difficult airway management but have a lower likelihood of difficulty placing nasal airway (no significant association with choanal atresia).

KEY FACTS

- CHARGE syndrome is an acronym for the constellation of life-threatening anomalies consisting of *c*oloboma, *h*eart anomaly, choanal *a*tresia, mental and growth *r*etardation, *g*enital anomalies, and *e*ar anomalies.
- Heart defects and postoperative pulmonary complications have the greatest contribution to perioperative morbidity and mortality.
- Airway management can be particularly challenging in this population because the midface hypoplasia, micrognathia, choanal atresia, small mouth, and cleft lip can make mask ventilation very challenging.

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12. ANSWER: C

The pediatric population, similar to adults, has several risk factors that predispose them to pulmonary aspiration at some point during general anesthesia. The initial assessment of the child should include NPO status and time from last clear liquid, solid meal, or breast milk in infants.

Guidelines recommend the following NPO times:

Clear liquids: 2 hours

Breast milk: 4 hours

Infant formula: 6 hours

Solids (fried or fatty foods): 8 hours

In patients where surgery is emergent it should be assumed that a full stomach is present and the induction of anesthesia should be adjusted accordingly based on the patients' other comorbidities and/or presence of trauma, which could potentially increase the challenges of successful airway management. Studies have shown a wide range in the incidence of pulmonary aspiration of gastric contents during elective surgery in children with ranges from 1:1163 to 1:10,000, with reported incidences **several times higher (ranges from 1:373 to 1:4544 in children undergoing emergency procedures** (Answer A) due to decreased gastric motility in the setting of either receiving opioids or pain. Several specific comorbidities have been shown to be **independent risk factors** for perianesthetic aspiration, including neurologic or esophagogastric abnormalities, emergency surgery, ASA physical status of >3, intestinal obstruction, increased intracranial pressure, increased intraabdominal pressure, obesity, and the skill and experience of the anesthesiologist. Altered mental status perhaps secondary to increased intracranial pressure can lead to inability to adequately maintain protective airway reflexes in addition to the possibility of decreased gastric emptying (Answer B). Decreased gastric emptying and possible increased gastric volume leads to increased risk for aspiration in the pediatric obese population (Answer D). Similar to adults, most aspiration events in children occur **during the induction of anesthesia** with only 13% occurring during emergence and extubation, compared to a 30% of aspiration events occurring during emergence in adults. Infants and young children are predisposed to aspiration due to a number of factors, including decreased competence of the lower esophageal sphincter, excessive air swallowing during preinduction crying episodes, strenuous diaphragmatic breathing, and decreased esophageal length. Particular note should be given to cases where the patient has not received **neuromuscular blockade** during intubation. In this situation, when the airway is manipulated without either adequate depth of anesthesia or neuromuscular blockade, the patient can gag or cough, leading to regurgitation and aspiration. Fortunately, the mortality of aspiration in children

is very low and is reported between 0 and 1:50,000. In elective surgery, morbidity and mortality are very low, both correlating to the patient's ASA status, with clear gastric contents typically having minimal to no sequelae.

KEY FACTS

- Several specific comorbidities have been shown to be independent risk factors for perianesthetic aspiration, including neurologic or esophagogastric abnormalities, emergency surgery, ASA physical status of >3, intestinal obstruction, increased intracranial pressure, increased intraabdominal pressure, obesity, and the skill and experience of the anesthesiologist.
- Most aspiration events in children occur during the induction of anesthesia.
- Infants and young children are predisposed to aspiration due to decreased competence of the lower esophageal sphincter, excessive air swallowing during preinduction crying episodes, strenuous diaphragmatic breathing, decreased esophageal length, and reduced use of neuromuscular blockade.

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13. ANSWER: D

Double-lumen endotracheal tubes (DLTs) are the gold standard for lung isolation in the adult population. It is essentially two tubes of unequal length molded together. Each of the two tubes is designed to lie within the trachea (shorter tube) and the mainstem bronchus (either right or left; the longer tube). With the tracheal cuff inflated it is possible to deliver positive-pressure ventilation; and when the bronchial cuff is inflated, the positive-pressure ventilation can be diverted to either or both lungs depending on whether the gas delivery to that lumen is patent (i.e., clamped or unclamped). The **bronchial cuff prevents contamination from secretions, purulent material, or blood originating from the contralateral side**. DLTs also allow for deflation of either lung with selective clamping of gas delivery to that lumen, promoting optimal visualization during video-assisted thoracoscopic surgery or during open thoracotomy. Within the pediatric population there are many means of providing one-lung ventilation, but the limiting factor for most modalities is the **size of the patient** and the ability of the trachea or mainstem bronchus to accommodate a correctly sized airway device without causing trauma or excessive mucosal pressure. Due to the tremendous variability in pediatric airway dimensions at any given age, textbooks have suggested that the earliest acceptable age to consider a DLT is **between 8 and 10 years old**. Based on sizing tables from the Cote textbook, it can be seen that a 26 French DLT (Covidien) is the smallest commercially available DLT in the United States. This DLT has an outer diameter (OD) of approximately 8.7 mm, equivalent to approximately a 6.0 inner diameter (ID) cuffed ETT (Sheridan). Other alternative devices for one-lung ventilation that can be used for this age patient include a 5 French Bronchial Blocker or a 3.5 Univent Tube.

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14. ANSWER: B

Several factors determine the wash-in rate of inhaled anesthetics, including the inspired concentration, alveolar ventilation (Va), functional residual capacity (FRC), cardiac output, agent solubility, and alveolar to venous partial pressure gradient. In infants there are several factors that lead to faster wash-in rates compared to adults, including greater ratio of alveolar ventilation to functional residual capacity (Va/FRC), greater fraction of the cardiac output distributed to the vessel-rich group (VRG), reduced tissue/blood solubility, and reduced blood/gas solubility. Typically the **rate of increase in FA/FI is inversely related to changes present in cardiac output (CO)** (i.e., larger CO leads to slower increase in FA/FI due to more anesthetic being removed from the lungs at a faster rate. In infants this relationship is the opposite; a paradoxical response is seen despite the greater cardiac index present in neonates compared to adults, leading to a faster increase in FA/FI. It is thought that this is due to the increased percentage of CO distributed to the vessel-rich group of organs (brain, heart, kidney, splanchnic organs, and endocrine glands). In neonates the VRG comprises **18% of total body weight compared to 8% in adults**, leading to a greater proportion of the CO going to these organs. The increased blood flow leads to more rapid equilibration of inhaled anesthetic partial pressures in the venous blood returning to the lungs and the inspired gas at the alveolar level. This feature of

rapid increase in FA/FI is partially responsible for the rapid decline in cardiac performance and ultimately cardiac output when more soluble agents (particularly halothane) are administered to neonates and infants through controlled ventilation.

Neonates actually have a higher cardiac index compared to adults (Answer A), which typically would lead to more rapid rise in FA/FI due to more rapid equilibration of the inspired anesthetic levels at the alveolar level when less blood flow is present to "wash away" incoming inhaled anesthetics. As described earlier, a paradoxical response is seen in neonates despite higher cardiac index, which is due to the increased blood flow to the VRG.

Total body water is greatest in preterm neonates and decreases throughout gestation, into the postnatal period, and subsequently into adulthood. Total body water, however, has no specific effect on the rate of increase in FA/FI (Answer C).

The Va/FRC ratio is the primary determinant of anesthetic delivery to the lungs. Higher Va/FRC ratios lead to more rapid increases in FA/FI with more soluble anesthetics being affected more than less soluble ones. The Va/FRC ratio is approximately 5:1 in neonates and 1.5:1 in adults (Answer D) and is thought to be secondary to the greater O_2 requirement and metabolic rate in neonates and subsequent three times greater Va in neonates compared to adults.

KEY FACTS

- In adults, the rate of increase in FA/FI is inversely related to changes present in CO.
- In infants this relationship is the opposite, likely due to the increased percentage of cardiac output distributed to the vessel-rich group of organs (18% of total body weight compared to 8% in adults).

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15. ANSWER: D

The presence of intracardiac shunting affects the uptake and distribution of potent inhalational agents. Computer models have been designed to evaluate the potential changes in inhalational induction times in patients with both right-to-left and left-to-right shunts. The results show that i**nduction of anesthesia using inhaled agents is slowed by the presence of central right-to-left shunts, slowed less by mixed shunts, and changed little by pure left-to-right shunts**, with the magnitude of the changes proportional to the size of the shunt. It is important to note that this was a computer model assuming a constant cardiac output. The results of this model also showed that the effects are greatest for the least soluble gases (i.e., nitrous oxide); more soluble gases are less affected. Animal models have also shown the same increase in time for inhalational induction in those with right-to-left shunts, but unfortunately studies in children with right-to-left shunts are not available. In practice it appears that inhalational induction in patients with right-to-left shunts are slower, but this is typically not a marked increase. The physiology behind this increase in time can be explained by dilution of deoxygenated venous return to the right side of the heart shunting to the left side of the heart without exposure to alveolar gas and inhaled anesthetics. Once this shunted blood mixes with the alveolar blood that has returned through the pulmonary venous circulation to be ejected systemically, the partial pressure of inhaled anesthetic is diluted, slowing the distribution and increase in tissue levels of anesthetic. In a patient with Tetralogy of Fallot a right-to-left shunt is present due to the obstruction to pulmonary blood flow and VSD.

The Qp:Qs ratio describes the amount of blood flowing through the pulmonary circuit in relation to the amount of blood flowing through the systemic circulation. This ratio is typically 1:1 under normal circumstances, and in lesions with left-to-right shunting the value becomes greater than 1; conversely, in lesions with right-to-left shunting the value becomes less than 1 as more blood is being circulated through the systemic circuit rather than the pulmonary circuit. The following equation shows how Qp:Qs is calculated (simplified formula):

$$Qp/Qs = \frac{SAO_2 \text{ saturation} - MVO_2 \text{ saturation}}{PVO_2 \text{ saturation} - PAO_2 \text{ saturation}}$$

In a patient with uncorrected Tetralogy of Fallot, the right-to-left shunting should lead to a Qp:Qs ratio less than 1. The direct effect of inhaled anesthetics on Qp:Qs ratio appears to be limited. A study investigating sevoflurane, halothane, isoflurane, and fentanyl/midazolam for anesthetic maintenance in patients with ASD and/or VSD did not appear to alter Qp:Qs ratios when given with 100% FiO_2.

KEY FACTS

- Induction of anesthesia using inhaled agents is slowed by the presence of central right-to-left shunts, slowed less by mixed shunts, and changed little by pure left-to-right shunts.
- The effects are greatest for the least soluble gases (i.e., nitrous oxide).
- The Qp:Qs ratio is typically 1:1 under normal circumstances, greater than 1 in left-to-right shunts, and less than 1 in right-to-left shunts.

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16. ANSWER: D

Laryngeal mask airways (LMAs) are typically not associated with significant problems caused by mechanical trauma. The placement of these devices is simple, easily learned, and associated with a high success rate even by inexperienced operators. No muscle relation is required, nor is any means of direct visualization. The introduction of LMAs changed clinical practice of anesthesiology, allowing for a rescue tool to be immediately available in situations where mask ventilation and intubation prove difficult or impossible. This is of particular utility in the pediatric population, where craniofacial anomalies may limit the ability to safely perform and accomplish postinduction direct laryngoscopy in patients with syndromes such as Pierre-Robin, Treacher Collins, or Goldenhar. The LMA can be used to facilitate fiberoptic bronchoscope placement along with endotracheal intubation through the larger lumen of the LMA. Studies evaluating the complications from LMA placement have shown that the **incidence of sore throat is as common as with endotracheal intubation, correlating to LMA intracuff pressures above 40 cm H_2O**. Other possible complications from LMA placement can include nerve injury to lingual, hypoglossal, or recurrent laryngeal nerves with possible decreased incidence through the monitoring of LMA cuff pressures. Rarely are LMAs associated with mechanical trauma to the tracheal mucosa or vocal cords, based primarily on their more cephalad position compared to an endotracheal tube, allowing more frequent repetitive use over short time periods with minimal risk of developing postanesthetic croup or subglottic stenosis (LMAs are supraglottic devices).

Confirmation of correct position using a fiberoptic bronchoscope (Answer A) does not ensure that pressure injuries are occurring due to excessive LMA cuff pressure, which optimally should be less than 40 cm H_2O.

Removal of all air prior to placement in the oropharynx (Answer B) may aid in the placement of the LMA, as air placement into the LMA cuff should occur following insertion and can give some feedback as to proper seating, but again it will not alter the likelihood of developing pressure injuries. Adequate jaw thrust during placement (Answer C) may aid in placement and proper seating of the LMA, but this has not been associated with decreased risk of complications.

KEY FACTS

- The incidence of sore throat with LMA placement is as common as with endotracheal intubation, correlating to LMA intracuff pressures above 40 cm H_2O.
- Other possible complications from LMA placement can include nerve injury to lingual, hypoglossal, or recurrent laryngeal nerves.

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17. ANSWER: B

Fiberoptic intubation using a bronchoscope still remains the gold standard for endotracheal intubation in a difficult situation. Direct visualization within the naso or oropharynx down to the glottic opening is possible with either use of the eyepiece or connected video equipment. The utility of the bronchoscope is vast, spanning from awake/sedated oral/nasal intubations in known difficult airways to asleep intubations, through again either the oral/nasal route with or without use of an LMA as an entry conduit. One challenge that can be faced despite adequate visualization of the glottic opening and entry into the trachea with the bronchoscope is significant resistance upon attempting to pass the ETT over the presumably appropriately located bronchoscope. This was evaluated and discussed in a 1992 paper when intubating mannequins to model the human airway and intubation both orally and nasally was attempted using a fiberoptic bronchoscope. The findings suggested that in a majority of cases when resistance was encountered during oral fiberoptic intubation, the point of obstruction was the **distal end of the ETT bevel being caught on the right arytenoid** despite correct placement of the bronchoscope in the trachea (see Fig. 23.1a). The proposed solution to minimize this complication is to **place the ETT bevel facing down** when performing orotracheal fiberoptic intubation (Answers B and C). Nasotracheal intubation showed that the obstruction encountered was the tip of the ETT being caught on the epiglottis (see Fig. 23.1b). The proposed solution for minimizing this complication is to place the **bevel facing up during nasotracheal fiberoptic intubation** (this can be accomplished by rotating the ETT 90

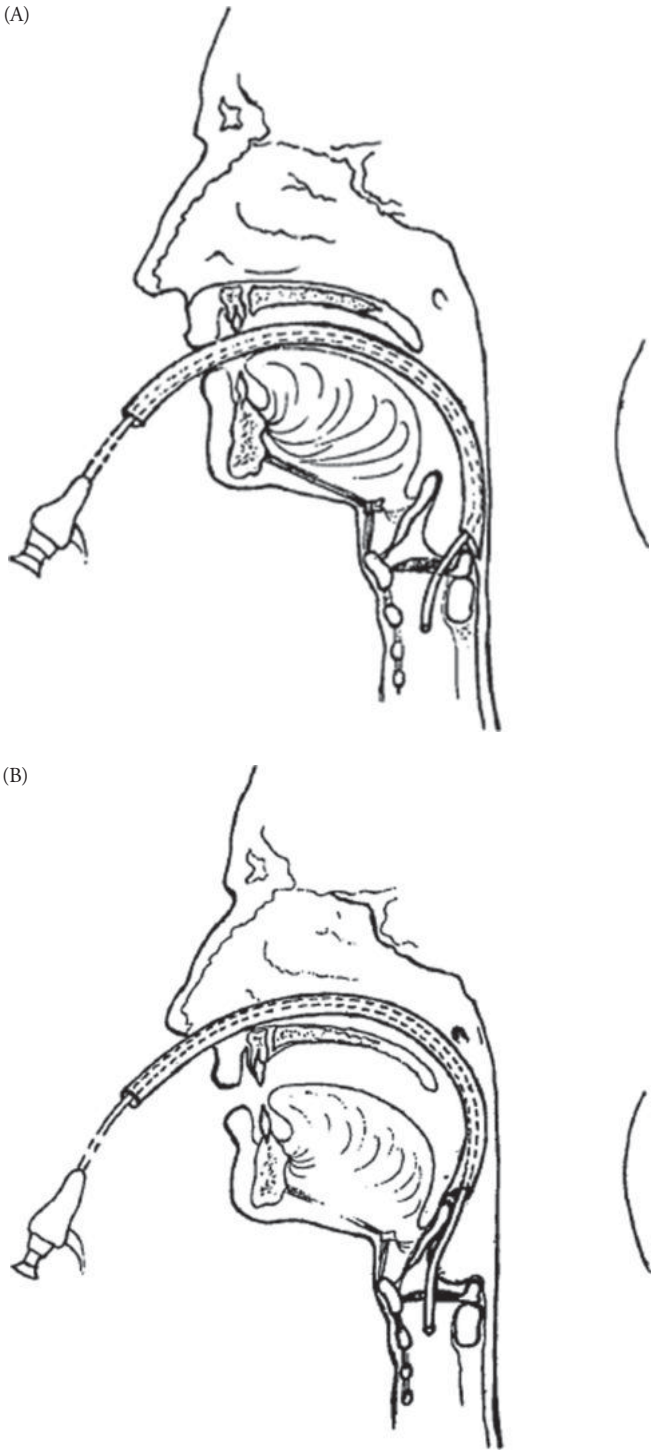

Figure 23.1 (A) Common location of obstruction and resistance when performing oral fiberoptic intubation found to occur when ETT bevel is caught on the right arytenoid. Maneuver to minimize this complication is to place the ETT bevel facing downward during orotracheal intubation. (B) Common location of obstruction and resistance when performing nasal fiberoptic intubation found to occur when the tip of the ETT is caught on the epiglottis. Maneuver to minimize this complication is to place the ETT bevel facing upward during nasotracheal intubation. (Reprinted with permission from: Katsnelson T, Frost EA, Farcon E, Goldiner PL. When the endotracheal tube will not pass over the flexible fiberoptic bronchoscope. *Anesthesiology*. 1992;76:151–2.)

degrees clockwise from its usual orientation). Other means of troubleshooting if resistance is still encountered include rotating the ETT 90 to 180 degrees. A mnemonic proposed by Katsnelson T et al. is "UNDO": bevel UP for NASAL intubation; bevel DOWN for ORAL intubation.

An appropriately sized ETT should always be chosen (Answer A) as if there is no mechanical obstruction from the tip of the ETT; it should fit appropriately through the glottis and past the cricoid cartilage into the trachea. Using an uncuffed ETT (Answer D) would not matter; when the cuff itself is appropriately deflated, it should not cause significant resistance during fiberoptic intubation.

KEY FACTS

- In oral fiberoptic intubation, the point of obstruction was the distal end of the ETT bevel being caught on the right arytenoid, and the proposed solution to minimize this complication is to place the ETT bevel facing down.
- In nasal fiberoptic intubation, the obstruction encountered was the tip of the ETT being caught on the epiglottis, and the proposed solution to minimize this complication is to place the ETT bevel facing up.

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18. ANSWER: C

GlideScope Cobalt® video laryngoscope (GCV; Verathon Medical, Bothell, WA) is a video laryngoscope designed for use in children consisting of a flexible camera baton inserted into a disposable plastic curved blade producing a high-resolution image from the camera on a portable monitor. This video laryngoscope has been useful in teaching novice laryngoscopists and in situations where difficulty with standard direct laryngoscopy may be presumed or actually is difficult. The GlideScope allows for a wider view angle and renders alignment of the oral, pharyngeal, and tracheal axes unnecessary. Most studies to date involving the video laryngoscopes have evaluated manikins or older children. Two randomized large trials in adult patients provided evidence that GlideScope laryngoscopy confers e**qual or superior glottic view** compared to direct laryngoscopy using a Macintosh blade.

One study among the pediatric population involved patients less than 10 years old, ASA Physical Status I-III,

who were not at increased risk of pulmonary aspiration, expected difficult airway, or history of GERD. A total of 60 patients aged 7 months to 10 years were included and were randomly assigned to the Macintosh or the GlideScope group, and every anesthesiologist involved in this study had an experience of at least 100 pediatric Macintosh endotracheal intubations and 20 pediatric GlideScope intubations. Results showed that demographic and airway characteristics by measurement were not statistically different between the groups and GlideScope intubation time was (14 ± 5 seconds), not different from Macintosh intubation time (13 ± 5 seconds). Authors of this study suggested that the GlideScope video laryngoscope is equally suitable to facilitate orotracheal intubation in pediatric patients (but not specifically neonates and infants) compared to the Macintosh laryngoscope with respect to intubation time.

An additional study performed in neonates and infants compared the GlideScope Cobalt® video laryngoscope (GCV) with direct laryngoscopy (DL) using a Miller blade in anatomically normal neonates and infants (<12 months in age). Sixty patients less than 12 months in age undergoing elective surgery were randomly assigned to the GlideScope or DL; data collected included intubation time, time to best view, percentage of glottic opening score, and intubation success. A definition of statistically significant differences in intubation time was classified as 10 seconds. Results showed no difference in overall intubation time between the groups (defined an intubation time difference of less than 10 seconds); GCV median = 22.6 seconds; DL median = 21.4 seconds; $P = 0.24$. GCV yielded faster time to best view (median = 8.1 seconds; DL 9.9 seconds; $P = 0.03$). It is important to note, however, that endotracheal tube passage time was longer for GCV (median = 14.3 seconds; DL 8.5 seconds; $P = 0.007$). The percentage of glottic opening score was improved with GCV (median 100; DL 80; $P < 0.0001$). Results from this population suggest that similar overall intubation times and success rates were achieved in anatomically normal neonates and infants; however, successful passage of ETT took longer among the GCV group and could be a cause for concern in populations where an adequate glottic view can be obtained but significant difficulty placing the ETT is encountered.

KEY FACTS

- The GlideScope allows for a wider view angle (equal or superior glottic view compared to direct laryngoscopy using a Macintosh blade) and renders alignment of the oral, pharyngeal, and tracheal axes unnecessary.
- Studies comparing the use of the GlideScope with either the Macintosh or Miller blade for direct laryngoscopy suggest similar overall intubation times and success rates.

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Redel A, Karademir F, Schlitterlau A, et al. Validation of the Glide Scope video laryngoscope in pediatric patients. *Paediatr Anaesth*. 2009;19:667–71.

19. ANSWER: D

The management of pediatric difficult airway can be quite stressful in those who are not comfortable in the regular management of the pediatric airway. As in adults, a stepwise approach to managing this situation should be present in all practitioners' minds when caring for pediatric patients. The American Society of Anesthesiologists (ASA) has a widely accepted algorithm (see Fig. 23.2) for the management of known and unanticipated difficult airways. The first branch point in this algorithm after failed intubation is whether or not mask ventilation is possible; if mask ventilation is not possible, the next step is **placement of a supraglottic device (SGA),** such as an LMA. If mask ventilation is possible, there is consideration of using alternative approaches to intubation, such as video-assisted laryngoscopy, alternative laryngoscope blades, SGA (e.g., LMA or ILMA) as an intubation conduit (with or without fiberoptic guidance), fiberoptic intubation, intubating stylet or tube changer, light wand, and blind oral or nasal intubation.

In the suggested management of difficult intubation of a pediatric patient (according to the Difficult Airway Society), there are subtle differences between the adult ASA algorithm. As in adults, the first step following difficult attempted laryngoscopy is to insert a **supraglottic device (SGA)** such as an LMA. It is recommended that **no more than four attempts be done via direct laryngoscopy;** and if a poor view is present, one should consider a **bougie, video laryngoscope, or smaller ETT**. Attempted placement of an SGA is not recommended for more than three attempts. If placement of an SGA is not successful, it is then recommended to convert back to face mask ventilation utilizing two providers with additional adjuncts as needed, including nasal or oral airways and/or CPAP. If mask ventilation proceeds to be difficult, another algorithm addressing a "Cannot Intubate Cannot Ventilate" (CICV) situation is proposed, which is available from the Difficult Airway Society.

Two-hand mask ventilation (Answer A) is the third step in the proposed algorithm after attempted placement of a SGA. Video-assisted laryngoscopy (Answer B) is the first step in the algorithm for intubation as long as intubation attempts, all inclusive, are kept to fewer than four total attempts. Fiberoptic intubation (Answer D) is not recommended in the algorithm outside of fiberoptic intubation through a SGA once oxygenation/ventilation is confirmed through that device (see Fig. 23.3).

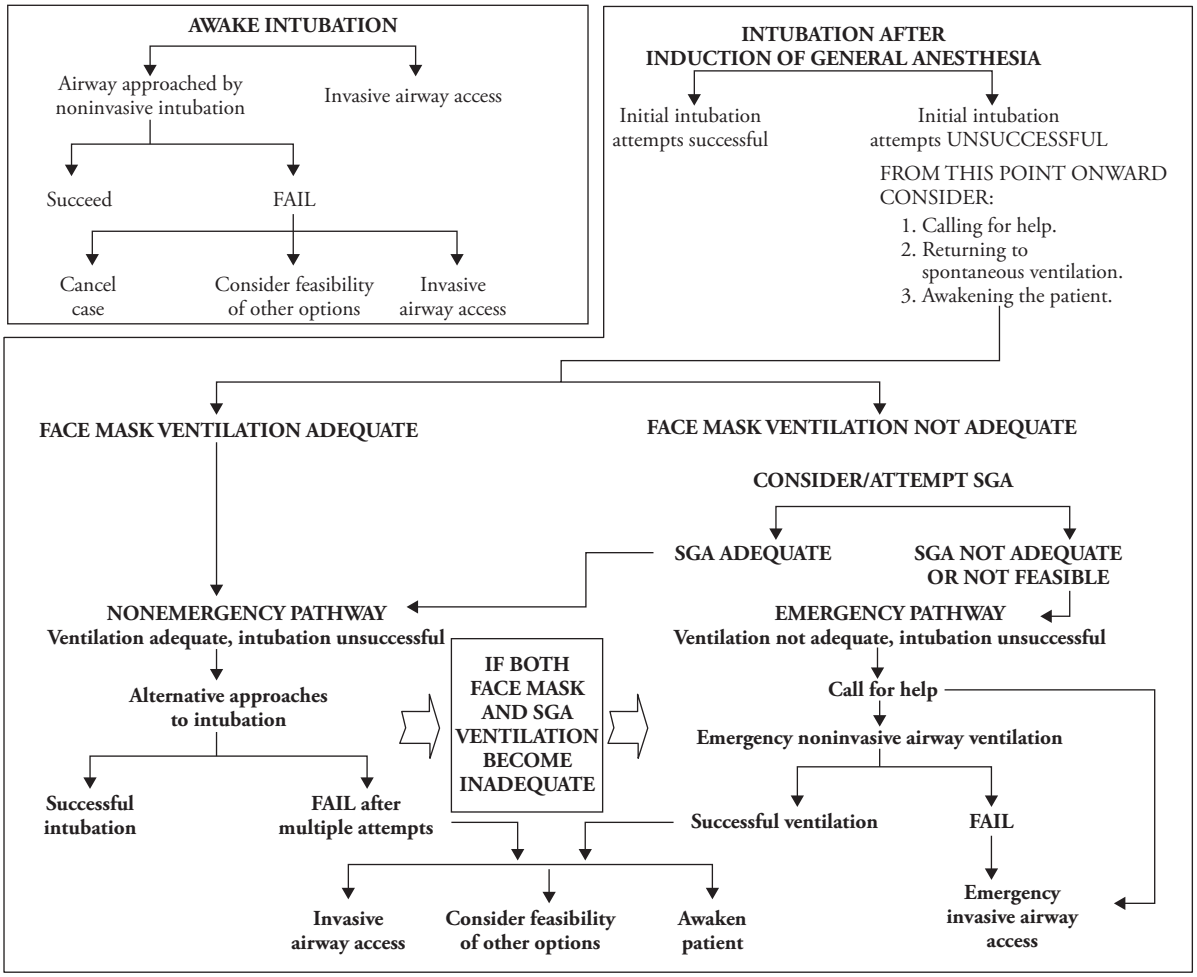

Figure 23.2 ASA algorithm for management of difficult airway. (Reproduced from Apfelbaum JL, Hagberg CA, Caplan RA, et al. Practice guidelines for management of the difficult airway: an updated report by the American Society of Anesthesiologists Task Force on Management of the Difficult Airway. *Anesthesiology.* 2013;118(2):251–70.)

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20. ANSWER: A

There has been increasing interest in using desflurane in the outpatient surgical setting due to its pharmacokinetic properties. Studies have evaluated its use in the adult population when an LMA is used for airway management, but limited data were available for the pediatric population prior to a study published in 2010. This study evaluated postoperative airway responses in children where either mask ventilation or placement of an LMA was used for airway management (chosen by the provider), desflurane or isoflurane was used as the maintenance anesthetic chosen in a randomized fashion (with 3:1 ratio of desflurane to isoflurane), and extubation was chosen by the provider to be done in either a deep plane of anesthesia or when the child was completely awake. Those included in this study were between 2 and 16 years old and did not have a recent history of upper respiratory infection or significant history of reactive airway disease. Results showed that 90% of children received an LMA with a frequency of major airway events after desflurane (9%) similar to that after isoflurane (4%), although the frequency of major events after the LMA was removed during deep desflurane anesthesia (15%) was greater than during awake removal (5%) ($P < 0.006$) and during deep isoflurane removal (2%) (NNH 8) ($P < 0.03$) (Answer B). The frequency of airway events of any severity after desflurane was greater than that after isoflurane (39% vs. 27%) ($P < 0.05$). The frequencies of laryngospasm and coughing of any severity after desflurane were greater than those after isoflurane.

The pathogenesis of desflurane-induced airway irritability in children is poorly understood. Explanations for these findings include the fact that the **presence of**

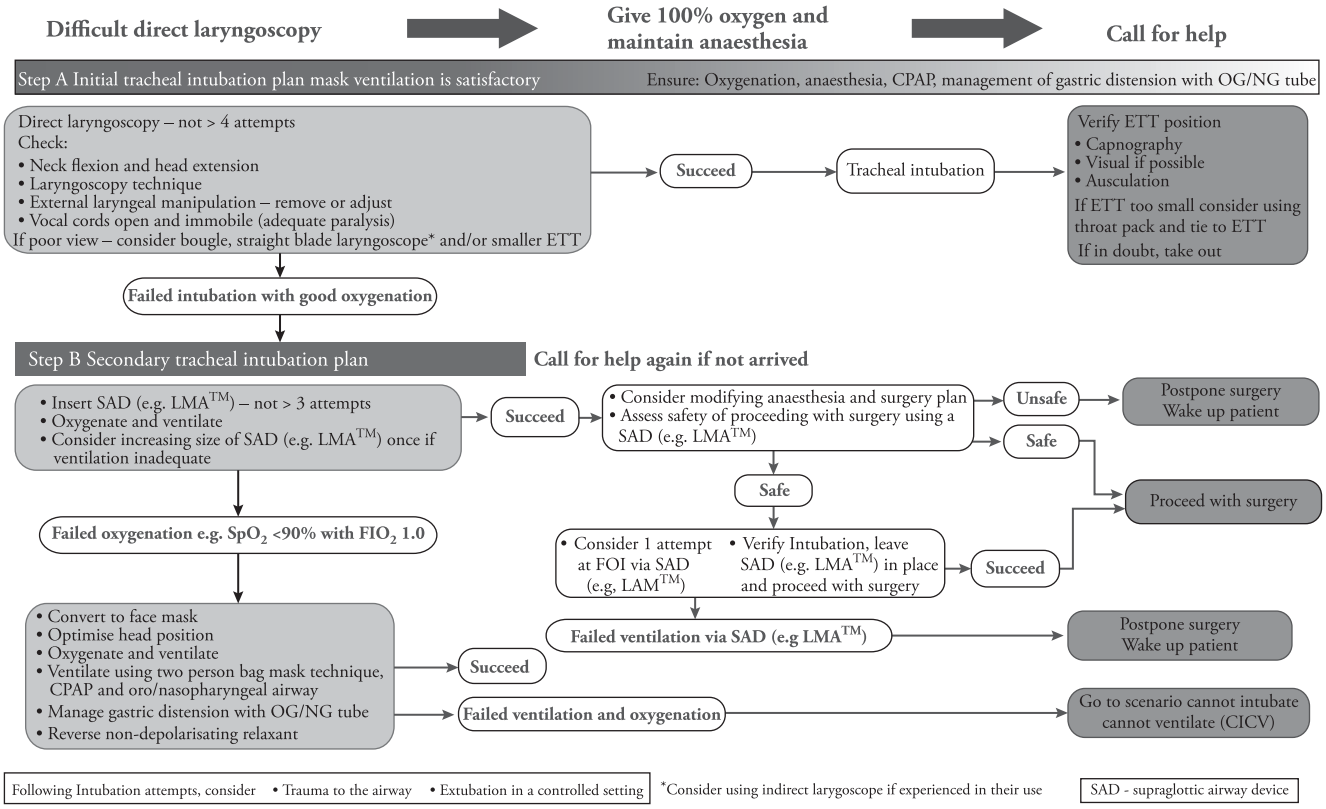

Figure 23.3 Unanticipated difficult tracheal intubation during routine induction of anesthesia in a child aged 1 to 8 years. (Reproduced with permission from Henderson JJ, Popat MT, Latto IP, Pearce AC. Difficult Airway Society guidelines for management of the unanticipated difficult intubation. *Anaesthesia*. 2004; 59: 675–94, with permission from Blackwell Publishing Ltd.)

an LMA may shield the glottic aperture and airway from saliva and blood in the mouth until it is removed during deep anesthesia, after which residual fluids may gravitate toward the larynx and trigger an airway reflex. Also it is possible that the depth of desflurane anesthesia at the time of removing the LMA was insufficient to prevent airway reflex responses. The authors felt this could be a problem since **the ED95 for removing an LMA safely during deep desflurane anesthesia is unknown**, but during deep anesthesia removal of an endotracheal tube during both sevoflurane and desflurane anesthetics, the ED95 was 0.8–0.9 MAC, which was accomplished during this study. Using 1 MAC desflurane in adults has not been shown to alter airway resistance after placement of an endotracheal tube, but with increased levels up to 2 MAC significant increases in airway resistance have been seen, in contrast to decreased airway resistance seen with both 1 and 2 MAC sevoflurane. This could explain **the incidence of bronchospasm during the use of desflurane** and an LMA but does not explain the more common finding in this study of coughing and laryngospasm following the use of desflurane, and in particular following removal during a deep plane of desflurane anesthesia.

Abdominal surgery (Answer C) was not identified as an independent risk factor seen during this study. Concomitant use of opioids (Answer D) should actually decrease risk of adverse events related to airway hyperreactivity as long as apnea or significant depression of respiratory drive is not also present.

KEY FACTS

- The frequency of airway events with deep LMA removal after desflurane use is greater than that after isoflurane.
- The pathogenesis of desflurane-induced airway irritability in children is poorly understood. Explanations for these findings include the fact that the presence of an LMA may shield the glottic aperture and airway from saliva and blood in the mouth until it is removed during deep anesthesia, after which residual fluids may gravitate toward the larynx and trigger an airway reflex.

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21. ANSWER: D

The Pediatric Perioperative Cardiac Arrest (POCA) Registry was founded in 1994. It consisted of a network of both academic and nonacademic institutions that would voluntarily enroll their institution to collect data regarding cardiac arrests occurring in patients <18 years old during the perioperative period. The data collected from each institution were submitted anonymously to the POCA Registry review committee, who classified the arrests as anesthesia related, non anesthesia related, or unknown, and the first set of their findings was published in *Anesthesiology* in 2000, representing findings from 1994 to 1997. The data showed 289 arrests from 63 North American institutions (75% university-affiliated institutions, 40% children's hospitals), with 150 (52%) of those arrests being deemed anesthesia related. The most common cause of **anesthesia-related cardiac arrests** in this study was **medication-related causes**, with halothane being the most commonly involved in these arrests. **Halothane** was involved in 71% of medication-related arrests and in 64% of ASA 1–2 patients. During this time halothane was the preferred agent for inhalational induction with sevoflurane only starting to become more commonly used. These findings showed that in situations where halothane was involved, two additional factors were also associated with increased risk of halothane-related cardiac arrest: ventilation type and difficult IV placement. The explanation of this can be simply described as **increased exposure to potentially much higher concentrations of halothane for longer periods of time** in the peri-induction period (both during inhalational spontaneously breathing inductions or IV inductions followed by halothane administration), leading to greater likelihood of cardiovascular depression and possible cardiac arrest. During controlled ventilation the normal physiologic safety mechanism of decreased respiratory rate with increased blood partial pressure of halothane is lost, suggesting why this **mode of ventilation was likely an additional risk factor** to cardiac arrest when using halothane.

Additional evaluations of the registry in the decade following showed decreased use of halothane and subsequently decreased frequency of medication-related cardiac arrests (when deemed anesthesia related). Data from the 2007 evaluation of the registry showed cardiovascular causes to be the most common factor being associated with deemed anesthesia-related cardiac arrests. In particular, hypovolemia and hyperkalemia were the two most common etiologies within this subgroup, particularly during spinal fusion surgery and craniotomy/craniectomy procedures.

Anesthesia provider experience and nonacademic institutions (Answers A and B) were not shown to be or studied as an independent factor in the initial evaluations. Concomitant administration of succinylcholine (Answer C) could be a possible cause of increased complications if hyperkalemia or bradycardia were to occur, but this was not shown to be as great of a risk factor as controlled ventilation.

KEY FACTS

- The most common cause of anesthesia-related cardiac arrests in the POCA study was medication-related causes, with halothane being the most commonly involved in these arrests.
- During controlled ventilation, the normal physiologic safety mechanism of decreased respiratory rate with increased blood partial pressure of halothane is lost, making it an additional risk factor to cardiac arrest when using halothane.
- Recent data show cardiovascular causes to be the most common factor associated with anesthesia-related cardiac arrests, with hypovolemia and hyperkalemia being the two most common etiologies.

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22. ANSWER: D

Klippel Feil syndrome is characterized by **congenital fusion of any two of the seven cervical vertebrae,** resulting in shortness of the neck, restricted neck movements, and low posterior hairline. Other features included in the syndrome are **congenital heart defect** (e.g., ventricular septal defect) and **hearing loss**. The estimated incidence of this disease is approximately 1:42,000 live births, with females accounting for ~65%; most cases are sporadic in nature but autosomal dominant and autosomal recessive inheritance does occur. The cervical vertebral abnormalities occur due to failure of normal segmentation of cervical somites during the third and eighth week of gestation, resulting in the associated primary or secondary neurologic deficits.

Four subtypes have been described:

- Type I: Extensive cervical and upper thoracic spinal fusion

- Type II: One to two interspace fusions often associated with occipitoatlantal fusion and hemivertebrae
- Type III: Coexisting fusion in the lower thoracic or lumbar spine
- Type IV: Klippel-Feil anomaly associated with sacral agenesis

Diagnosis is made of flexion extension plain X-ray films and should be followed at least annually. The spine abnormalities in the form of **hypermobility** or **spondylosis** places these patients at **higher risk for spinal cord injury** with minor trauma.

The classic triad consists of short neck, restriction of neck movement, and low posterior hairline. Neck restriction is the most common finding and is present in approximately 50% of cases, with the neck actually appearing normal and often going unrecognized until later in life. Patients often present with neurologic deficit that occurs either spontaneously or as the result of minor trauma. **Syncopal episodes** can also occur with sudden movements of the neck. Associated skeletal anomalies include skeletal: cervical vertebral fusion, hemivertebrae, sacral agenesis, scoliosis (up to 60% of cases), spinal canal stenosis, and torticollis. Other findings include webbed neck, Sprengel deformity (small and elevated scapula), genitourinary abnormalities, **congenital heart disease** (particularly VSD), deafness, synkinesia (mirror movements), and rarely hemiplegia or paraplegia. **Cleft palates** are also common with malformation of laryngeal cartilage and mild to severe vocal cord paresis.

Anesthetic considerations in this population include proper preoperative evaluation to assess the **degree of instability** (flexion-extension neck films), and in the clinical scenario described here there is evidence of cervical radiculopathy or myelopathy based on her subjective description of symptoms. Assessment and documentation of **neurological function** or preexisting abnormalities should occur. Careful evaluation of the airway should be performed and **difficult intubation** should be anticipated. There is a high risk of **cervical instability** and patients are at risk for spinal cord injury during direct laryngoscopy, tracheal intubation, and positioning. The utmost care should be taken to protect from injury to the cervical spine, including **inline stabilization and or asleep/awake fiberoptic intubation**. Emergence should be done with the patient in stabilization, and extubation should occur in a fully awake patient.

Clinical exam findings are not suggestive of Marfan syndrome (Answer A); however, aortic dissection is a risk factor with this population.

Oculopharyngeal muscular dystrophy (Answer B) is a disease that affects almost exclusively **males**. However, scoliosis is a feature of this disease, along with the possibility of rhabdomyolysis with administration of volatile anesthetics.

Heterotaxy syndrome (Answer C) can present with conduction defects; however, the clinical description is more suggestive of Klippel-Feil syndrome.

KEY FACTS

- Klippel-Feil syndrome is characterized by congenital fusion of any two of the seven cervical vertebrae, resulting in shortness of the neck, restricted neck movements, and low posterior hairline.
- There is a high risk of cervical instability and patients are at risk for spinal cord injury during direct laryngoscopy, tracheal intubation, and positioning.

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23. ANSWER: B

Treacher Collins syndrome is a syndrome caused by dysmorphogenesis of the **first and second embryonal branchial arch** systems. It has an autosomal dominant transmission with high penetrance and variable expressivity; the protein defect responsible for these abnormalities is called Treacle and affects approximately 1:50,000 live births. The diagnosis can be made prenatally by the 20th week by ultrasound and by molecular biology on chorionic villus sampling.

The clinical diagnosis is based on features including the following:

Eyes: Antimongoloid obliquity of palpebral fissures, coloboma of outer portion of lower lids, with a deficiency of cilia, absence of the lower lacrimal points, microphthalmia, vision loss, strabismus, partial absence of lower eyelashes, and nystagmus

Facies: Flattening of the cheeks, malar hypoplasia, hypoplastic zygomatic arches, antimongoloid slant, lower eyelid coloboma, and choanal atresia

Ears: Atresia of external auditory meatus, microtia, malpositioning or maldevelopment of the pinna, and conductive hearing loss

Mouth: Cleft palate, mandibular hypoplasia, macrostomia, and absence of parotid gland

Miscellaneous: Cardiovascular defects, cervical vertebral malformations, renal anomalies, limb malformations, early failure to thrive, learning disabilities in early life, chronic respiratory insufficiency, sleep apnea syndrome, and sudden death

Severe airway obstruction can be seen during the anesthetic period in these patients, and many must assume positions such as **lateral decubitus or prone** to prevent airway obstruction. Often a tracheostomy will be required in the perioperative and eventual long-term management of these patients.

Mask ventilation and tracheal intubation are **classically difficult** and have been reported to increase in severity over time, particularly due to increasing **basilar kyphosis of the cranial base**, with airway management being difficult at all ages due to high-arched palate and mandibular hypoplasia. It is of the utmost importance to **maintain spontaneous ventilation** in these patients during the induction of anesthesia, with multiple choices available for securing the airway, including sedated fiberoptic intubation, LMA placement, video laryngoscope, or even awake tracheostomy. In patients with Treacher Collins syndrome not undergoing airway or craniofacial surgery, it is critical to **monitor for evidence of airway obstruction postoperatively,** and often these patients may be unsuitable for day surgery procedures. These patients often require **extensive facial reconstruction** and multiple procedures on the orbital, zygomatic, ears, and mandible throughout their lives.

Hypoplastic zygomatic arches (Answer A) is a feature of Treacher Collins syndrome; however, it is not typically thought to be a common cause of difficulty with airway management.

Patients with Treacher Collins syndrome can often have associated cleft palate (Answer C); however, this is the result of mandibular hypoplasia and tongue displacement in utero. Postnatally both of these features can lead to difficult airway management rather than the cleft palate itself.

Glossoptosis (Answer D) can also be seen in Treacher Collins syndrome; however, increasing tongue size with age is typically not a feature of this syndrome.

KEY FACTS

- Severe airway obstruction can be seen during the anesthetic period in these patients.
- Mask ventilation and tracheal intubation are classically difficult.
- It is important to maintain spontaneous ventilation in these patients during the induction of anesthesia.

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24. ANSWER: C

One-lung ventilation (OLV) can be achieved by multiple means; typically, the limiting factor is the size of the patient and the desired location of lung isolation. Various values are used to define appropriate sizing of airway devices for specific patients, and multiple means of achieving lung isolation can be achieved using endotracheal tubes, Fogarty catheters, bronchial blockers (both intra and extraluminal of the ETT), and double-lumen ETT. When performing a left thoracotomy with desired lung isolation, a bronchial blocker can typically be placed intraluminally if the ETT selected for the patient is of adequate size (often recommended >4.0) in order to not impede entrance or egress of gas from the lungs. Once the ETT is placed and confirmed above the carina, a bronchial blocker is placed under direct visualization into the left mainstem bronchus with care to avoid going too distal and either occluding the left upper lobe takeoff or not completely obstructing it, leading to failure of collapse of the left upper lobe. After positioning and during any concern of either ventilation or oxygenation of the patient, the position of the bronchial blocker and ETT should be confirmed, ideally under bronchoscopy.

Troubleshooting bronchial blockers intraoperatively should be done using clear communication with the surgeons. If ventilation or oxygenation is compromised one should first ensure that **100% FiO_2 is being delivered**, then evaluate the surgical field; if the patient is stable, proceed to **bronchoscopy**. If the patient is unstable, and the surgeon is not at a critical point in the operation, the bronchial blocker can be deflated, manual ventilation should commence, and one should ensure that gas exchange is occurring through both lungs. In the scenario described here the decrease in tidal volumes and oxygen desaturation suggests some sort of ETT and/or bronchial blocker malposition, particularly if this is an abrupt change to a previously stable patient. Surgical manipulation of the lungs and operative field can often be the cause of bronchial blocker movement and gas exchange problems. When selectively ventilating the right lung (or nonoperative side in this question) and tidal volumes decrease, the most likely etiologies are either **bronchial blocker migration** into the trachea or **migration of the ETT into the left mainstem bronchus**,

both of which would significantly limit your gas delivery to the nonoperative right lung.

If there was migration of bronchial blocker beyond the left upper lobe takeoff (Answer A), it would make it difficult for the left upper lobe to collapse, but it should not drastically decrease your tidal volumes or cause significant hypoxemia. It would more likely cause a less optimal surgical field due to an uncollapsed left upper lobe.

Deflation of the bronchial blocker (Answer B) would likely cause the lung on the operative side to either not collapse or re-expand during the operation. It would not be likely to cause a decrease in tidal volumes, but it would more likely cause an **increase in tidal volume** if pressure control ventilation was being used. SaO_2 would improve in this situation as well.

Migration of the ETT into the right mainstem bronchus (Answer D) would be unlikely to cause any significant change in tidal volumes or oxygen saturation unless the ETT migrated beyond the right upper lobe takeoff, at which point you would not be oxygenating that portion of the lung as well. It could cause a small decrease in tidal volumes as well, but not as drastic as the ETT migrating down the mainstem bronchus of the operative lung.

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25. ANSWER: A

One-lung ventilation can be achieved by many different means. In young pediatric patients the decision is often limited by patient size and airway dimensions. Most patients under 25 kg are unlikely to accommodate a double-lumen tube for selective lung isolation and are typically managed using a mainstem bronchial intubation with a cuffed ETT, a Fogarty catheter, or a bronchial blocker. In this case it is desired to selectively isolate the right lung in order to adequately expose and surgically remove the right upper lobe of the lung. Placing a bronchial blocker in the right mainstem bronchus can be challenging when trying to ensure a good seal along with adequate deflation of the right upper lobe. Due to the anatomy and rather abrupt takeoff of the right upper lobe from the right mainstem bronchus (in some situations the right upper lobe even coming directly off the trachea itself), the lumen of the right upper lobe can be partially or completely occluding during placement of a bronchial blocker in the right mainstem bronchus. If there is a partial occlusion of the right upper lobe, it will be unlikely to deflate, leading to surgical exposure challenges.

In the case described here, there is abrupt inflation of the lung following surgical stapling, suggesting that **somehow lung isolation was lost**. There have been reports of the bronchial blocker or the distal wire loop of an Arndt blocker being incorporated into the surgical suture line during right upper lobectomy, requiring surgical reexploration after removal of the bronchial blocker after extubation. It is possible to minimize the chance of this happening with close communication during the operation with the surgical team in regard to where the bronchial blocker is located, and paying close attention to the stage of the operation, particularly in the presence of a bronchial blocker on the surgical side. Pulling back the bronchial blocker a few centimeters prior to surgical stapling will also help minimize the chance of this happening during the operation. An additional situation that can lead to acute decompensation in the setting of a bronchial blocker is if the inflated balloon moves out of its position in either mainstem bronchus **into the trachea** above the carina, leading to partial or complete obstruction and subsequent inability to ventilate, hypoxia, and potential cardiac arrest. In the event of any of these concerns with a bronchial blocker in place, typically the safest maneuver is to deflate the bronchial blocker and reassess the ventilation and oxygenation of the patient during two-lung ventilation.

Displacement of the inflated bronchial blocker into the trachea (Answer B) would cause difficulty in ventilation and oxygenation, and it would likely cause both the surgical and nonsurgical lungs to become deflated in the setting of partial or complete obstruction.

Distal advancement of the bronchial blocker into bronchus intermedius (Answer C) could lead to reinflation of the right upper lobe but would be unlikely to cause complete re-expansion of the right lung as the middle and lower lobes would still be obstructed from flow and would be unlikely to re-inflate.

Advancement of the ETT into the left mainstem bronchus (Answer D) would simply be another way to achieve selective lung isolation without use of a bronchial blocker. In this situation, the right lung would likely remain completely deflated.

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24.

COMPLICATIONS OF ANESTHESIA

Andrew Infosino and Marla Ferschl

1. What is the path taken by the afferent and then the efferent limbs of the oculocardiac reflex?

A. Oculomotor nerve → ciliary nerves → ciliary ganglion → dorsal nucleus of vagus nerve → vagus nerve
B. Oculomotor nerve → ciliary nerves → ciliary ganglion → dorsal cardiac ganglion → cardiac nerve
C. Opthalmic nerve → ciliary cerves → ciliary ganglion → dorsal cardiac ganglion → dorsal nucleus of cardiac nerve → cardiac nerve
D. Trigeminal nerve → ciliary nerves → ciliary ganglion → trigeminal ganglion → dorsal nucleus of vagus nerve → vagus nerve

2. A 3-year-old boy is undergoing bilateral strabismus surgery. The boy was induced with sevoflurane, a peripheral intravenous (IV) catheter was introduced, and then a laryngeal mask airway (LMA) was placed. General anesthesia was maintained with inhaled sevoflurane and intravenous fentanyl. During the surgery, the heart rate suddenly drops to 32 beats per minute. What is the most important first step to treat this situation?

A. The ophthalmologist should remove traction on the extraocular muscles of the eye.
B. The anesthesiologist should treat with IV atropine.
C. The anesthesiologist should treat with IV epinephrine.
D. The opthalmologists should infiltrate the extraocular muscles of the eye with local anesthetic.

3. The most common cause of postintubation croup in infants and children is:

A. The use of a nasotracheal tube
B. The use of a cuffed endotracheal tube
C. The use of an endotracheal tube with a leak pressure greater than 40 cm H_2O
D. Being intubated for more than 12 hours

4. A 2-year-old boy was intubated for abdominal surgery that lasted about 4 hours. In the recovery room he was noted to have inspiratory stridor. The oxygen saturation is 95% on room air, his respiratory rate is 24 breaths per minute, and he has mild nasal flaring. The best approach to treating the inspiratory stridor is:

A. Request a consult from otolaryngology and transfer to the floor.
B. Reintubate and transfer to the intensive care unit (ICU) for observation.
C. Treat with humidified oxygen and observe in the recovery room.
D. Administer racemic epinephrine and transfer to the ICU.

5. The best approach to preventing emergence delirium in children is:

A. Parental presence during the induction of anesthesia
B. Intraoperative administration of sevoflurane
C. Intraoperative administration of fentanyl
D. Parental presence in the recovery room

6. Preoperative anxiety in children is associated with which of the following postoperative outcomes?

A. Lower incidence and severity of postoperative anxiety
B. Higher severity of postoperative pain
C. Higher incidence of postintubation croup
D. Higher incidence of postoperative nausea and vomiting

7. A 12-year-old boy is having a general anesthetic for open reduction and internal fixation (ORIF) of an elbow

fracture. He was induced with rocuronium, propofol, and fentanyl and after intubation has been maintained on sevoflurane. Approximately 1 hour later the patient is tachycardic with a heart rate of 133 beats per minute, his end-tidal CO_2 is 84 mm Hg, and his temperature is 39°C. What is the best initial approach to treating this case of suspected malignant hyperthermia?

A. Swtich to another anesthesia machine and administer Dantrolene intravenously.
B. Discontinue inhaled sevoflurane and cool the patient with topical ice.
C. Discontinue inhaled sevoflurane and administer Dantrolene intravenously.
D. Administer IV sodium bicarbonate and cool the patient with topical ice.

8. An 8-year-old is undergoing an ORIF of a supracondylar elbow fracture under sevoflurane anesthesia with an LMA. What is the most reliable early sign of malignant hyperthermia?

A. Increased temperature
B. Cardiac arrhythmias
C. Tachycardia
D. Increased minute ventilation

9. A 14-year-old female patient is scheduled for an elective laparoscopic cholecystectomy for recurrent cholelithiasis. Her family history is significant for an uncle who died during surgery from presumed malignant hyperthermia. What is the best approach for her anesthetic care?

A. Postpone the case and send the patient for a halothane-caffeine contracture test under local anesthesia.
B. Premedicate with Dantrolene 2.5 mg/kg IV and proceed with general anesthesia with IV propofol, fentanyl, rocuronium, and ondansetron.
C. Premedicate with IV midazolam 2 mg and proceed with general anesthesia with IV propofol, fentanyl, rocuronium, and ondansetron.
D. Premedicate with Dantrolene 2.5 mg/kg IV and proceed with general anesthesia with IV ketamine, fentanyl, and ondansetron.

10. The most significant risk factor for laryngospasm is:

A. Male gender
B. Age <5 years
C. History of asthma or reactive airway disease
D. Household exposure to tobacco smoke

11. Perioperative cardiac arrest in infants and children occurs most commonly:

A. During the induction of anesthesia
B. Due to complications from central venous catheterization
C. In neonates undergoing cardiac surgery
D. Due to complications from laryngospasm

12. A 3-year-old boy is scheduled for general anesthesia for surgery. During the inhalational induction with nitrous oxide, oxygen and sevoflurane face mask ventilation becomes difficult, the oxygen saturation drops from 99% to 41%, and the heart rate drops from 116 to 48 beats per minute. You attempt positive-pressure ventilation with bag and mask, but the oxygen saturation and heart rate continue to decrease. What is the best approach to treating this case of laryngospasm?

A. Place an LMA and ventilate with 100% oxygen.
B. Administer intramuscular rocuronium or succinylcholine and then provide positive-pressure face mask ventilation with 100% oxygen.
C. Proceed directly to laryngoscopy and intubation and then provide positive-pressure ventilation with 100% oxygen.
D. Proceed to place a peripheral IV catheter and then administer intravenous succinylcholine.

13. The most likely case of perioperative vision loss is due to:

A. Posterior ischemic optic neuropathy
B. Retinal artery occlusion
C. Cortical blindness
D. Posterior reversible encephalopathy syndrome

14. Which of the following is most likely associated with prolonged/permanent neuropathy due to patient positioning following a general anesthetic?

A. Loss of sensation to multiple nerve distributions
B. Loss of motor as well as sensory function on physical exam
C. Bilateral distribution of symptoms
D. Patient history of chronic pain

15. Which of the following patients is most likely to experience intraoperative awareness under anesthesia?

A. A child
B. An adult
C. A patient with a bispectral index monitor
D. An American Society of Anesthesiologists (ASA) physical status 1 patient

16. You are conducting an anesthetic on a 15-year-old boy who is undergoing a tonsillectomy. He is paralyzed.

Suddenly you notice that you forgot to turn the anesthetic vapor back on after turning it off prior to refilling it. The patient is tachycardia and hypertensive; end-tidal gas sampling measurements suggest he has about 0.5 minimal alveolar concentration (MAC) of volatile anesthetic agent onboard. The most accurate way to assess the occurrence of awareness is:

A. Examine the patient for tearing.
B. Examine the patient for sweating.
C. Place a bispectral index (BIS) monitor and assess a numerical BIS score.
D. Conduct a standardized interview in the postanesthetic care unit (PACU).

17. Which of the following is a most likely cause of intraoperative hypotension due to decreased preload?

A. Sepsis
B. Anaphylactic reaction
C. Surgical bleeding
D. Adrenal insufficiency

18. While administering a general anesthetic to a 15-year-old for a pheochromocytoma resection, the patient's blood pressure acutely increases. The most appropriate drug to give in this situation is:

A. Esmolol
B. Nitroprusside
C. Phenoxybenzamine
D. Fentanyl

19. You are anesthetizing a 1-month-old baby for an eye exam under anesthesia. You suddenly notice that the patient develops a decreased heart rate and hypotension. Which of the following ophthalmic mediations is the most likely cause of the vital sign changes?

A. Pilocarpine
B. Scopolamine
C. Phenylepherine
D. Timolol

20. You are anesthetizing a 5-year-old patient for a tonsillectomy when suddenly the patient develops urticaria and increased peak airway pressures several minutes after antibiotic administration. You are concerned about an anaphylactic reaction. The laboratory test that will be most helpful in determining if this is a true anaphylactic reaction is:

A. Serum tryptase
B. Complete blood count with differential
C. Serum histamine
D. Serum kinin

21. Which of the following is most likely to predict *severe* anaphylaxis?

A. Rapid onset
B. Bronchospasm
C. Tachycardia
D. Cutaneous rash

22. You have administered a general endotracheal anesthetic for a patient undergoing dental restoration. After extubating the patient, you bring him to the PACU. In the PACU, you notice loud inspiratory stridor. Which of the following is the most common cause of inspiratory stridor in infants and children, unrelated to an anesthetic?

A. Underlying laryngomalacia
B. Tonsillar hypertrophy
C. Vocal cord injury
D. Airway foreign body

23. Which of the following infectious diseases is most likely to be transmitted by a blood transfusion?

A. Human immunodeficiency virus (HIV)
B. West Nile virus
C. Hepatitis C virus
D. Hepatitis B virus

24. Which of the following is a hallmark of transfusion-related acute lung injury (TRALI)?

A. Hypothermia
B. Low protein content of pulmonary edema fluid
C. Bilateral infiltrates on chest radiograph
D. Presence of left atrial hypertension

25. The most common complications of umbilical vein cannulation in the neonate is:

A. Increased intracranial pressure
B. Portal vein thrombosis
C. Endocarditis
D. Cirrhosis

26. You are anesthetizing a 5-month-old, 6 kg infant with craniosynostosis for a total cranial vault reconstruction. The child has a starting hematocrit of 38%. You plan to transfuse once the hematocrit drops to 25%. How much blood can the surgeon lose before you begin transfusing?

A. 100 mL
B. 130 mL
C. 160 mL
D. 200 mL

27. You are anesthetizing a child for an exploratory laparotomy who has a history of an astrocytoma. The patient has been on chronic steroids. Which of the following is the most likely sign of an intraoperative adrenal crisis?

A. Hypernatremia
B. Hypertension
C. Hyperglycemia
D. Hyperkalemia

CHAPTER 24 ANSWERS

1. ANSWER: D

The oculocardiac reflex consists of both an **afferent limb that is trigeminal** and an **efferent limb that is vagal**. **Pressure** on the globe, the conjunctiva, or other orbital structures or traction on the extraocular muscles triggers afferent nerve impulses in the **ophthalmic division of the trigeminal nerve,** which is often referred to as V_1. The afferent impulses then travel through the **short ciliary nerves or the long ciliary nerves to the ciliary ganglion and then pass to the trigeminal or gasserian ganglion.** The afferent impulses terminate in the main sensory nucleus of the trigeminal nerve located in the floor of the fourth ventricle.

The efferent limb originates in the dorsal nucleus of the vagus. The **dorsal nucleus of the vagus** is located in the central gray matter of the caudal medulla and is also on the floor of the fourth ventricle. The efferent impulse then travels via the vagus nerve to the sinoatrial and atrioventricular nodes of the heart. The oculocardiac reflex tends to produce **sinus bradycardia** but can also produce a broad spectrum **of dysrhythmias,** including junctional rhythms, atrioventricular block, ventricular bigeminy, idioventricular rhythm, ventricular tachycardia, and asystole.

KEY FACTS

- Afferent limb: opthalmic division of trigeminal nerve → short and long ciliary nerves → ciliary ganglion → trigeminal or gasserian ganglion → trigeminal nerve sensory nucleus
- Efferent limb: dorsal nucleus of vagus nerve → vagus nerve → sinoatrial and atrioventricular nodes of heart
- Results in bradycardia and other dysrhythmias, including junctional rhythms, atrioventricular block, ventricular, bigeminy, idioventricular rhythm, ventricular tachycardia, and asystole

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2. ANSWER: A

The oculocardiac reflex occurs most commonly with traction of the extraocular muscles during strabismus surgery. It occurs more commonly in younger patients. It can occur during **any type of opthalmic surgery** and even during placement of regional anesthesia for the eye such as a **retrobulbar block**. **Hypercarbia, hypoxia, and light anesthesia** all increase the incidence and severity of the oculocardiac reflex. The oculocardiac reflex can occur in the awake patient who may also have symptoms of **somnolence or nausea** as well as **bradycardia and dysrhythmias**. The oculocardiac reflex can also occur from direct pressure on the orbital apex after enucleation.

The oculocardiac reflex should be treated by promptly removing the surgical stimulus, including all pressure on the eye and traction on eye muscles. In the majority of situations, this will be sufficient to treat the oculocardiac reflex. If this does not resolve the bradycardia or dysrhythmia, the oculocardica reflex can be treated with **intravenous atropine or glycopyrolate**. If the oculocardiac reflex recurs, it can be treated by providing a **regional anesthetic** for the eye or infiltrating the extraocular muscles with **local anesthesia**.

The prophylactic use of intramuscular atropine does not reliably prevent the oculocardiac reflex.

KEY FACTS

- The oculocardica reflex is most commonly seen in young patients undergoing strabismus surgery. It can occur during any surgery to the eye or from placement of regional anesthesia to the eye.
- Initial treatment of the oculocardiac reflex is to stop the surgical stimulus. If the bradycardia or dysrhythmia persists, the patient should be treated with intravenous atropine or glycopyrolate. If the oculocardiac reflex recurs, regional or local anesthesia to the eye or extraocular muscles may be necessary. Ensuring the patient is not hypoxic or hypercarbic can also ameliorate the oculocardica reflex.
- Prophylactic intramuscular atropine does not prevent the oculocardiac reflex.

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3. ANSWER: C

Postintubation croup occurs most commonly in children between the ages of 1 and 4 years. The most important **risk factor** for postintubation croup is using an endotracheal tube with a leak pressure >40 cm H_2O. This can occur either with an uncuffed endotracheal tube that is too large or a cuffed endotracheal tube that is either too large or overinflated. The resulting mechanical pressure on the tracheal mucosa can cause venous congestion and edema. The resulting edema can narrow the tracheal lumen significantly enough to cause inspiratory stridor.

Other risk factors include multiple intubation attempts, unusual positioning of the head during surgery usually involving rotation, increased duration of surgery, and procedures involving the upper airway such as rigid bronchoscopy. The use of **cuffed endotracheal tubes** has not been shown to increase the incidence of postintubation croup. The use of **nasal intubation** rather than oral intubation has also not been shown to increase the incidence of postintubation croup.

KEY FACTS

- Postintubation croup is the result of edema of the tracheal mucosa and is most commonly caused by an endotracheal tube that is too large or whose cuff is overinflated so that the leak pressure is >40 cm H_2O.
- Postintubation croup is most commonly seen in children between the ages of 1 and 4 years.
- Risk factors for postintubation croup also include multiple intubation attempts, traumatic intubations, increased duration of surgery, surgical procedures involving the upper airway, and unusual positioning of the head during surgery.
- A history of a recent upper respiratory infection also increases incidence of postintubation croup.

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4. ANSWER: C

The treatment for *postintubation croup* depends on the degree of respiratory distress. **Mild postintubation croup** should be managed with the administration of **humidified oxygen**. **Moderate cases** should also be treated with **aerosolized racemic epinephrine**. If the patient's symptoms do not resolve with humidified oxygen and racemic epinephrine and the patient is in **severe respiratory distress,** he or she may need to be **reintubated** with a smaller endotracheal tube.

Patients with postintubation croup should not be sent to the floor unless their symptoms have resolved. In general, patients with mild postintubation croup can be managed in the recovery room. Patients with severe respiratory distress that require multiple treatments with racemic epinephrine or reintubation should be transferred to the ICU after being stabilized in the recovery room. Steroids such as dexamethasone can be a useful adjunctive therapy.

KEY FACTS

- Mild: humidified oxygen and observation in the recovery room
- Moderate: humidified oxygen in the recovery room, IV dexamethasone, aerosolized racemic epinephrine, and transfer to ICU
- Severe: humidified oxygen, IV dexamethasone, aerosolized racemic epinephrine, reintubation, and transfer to ICU

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5. ANSWER: C

Emergence delirium is also known as emergence agitation. It occurs in the recovery room and can be described as a **dissociated state of consciousness** in which children can be **inconsolable, irritable, uncooperative, incoherent, crying, kicking, thrashing, or combative**. During emergence delirium children do not recognize familiar objects or people, including their parents. Usually emergence delirium is self-limited and resolves in less than 30 minutes.

Emergence delirium occurs more commonly after anesthesia with less soluble inhalational anesthetic agents such as **sevoflurane or desflurane than with halothane**

or isoflurane. Emergence delirium occurs less often after anesthesia with **propofol** than after anesthesia with any of the inhalational agents.

Risk factors that have been identified as increasing the incidence of emergence delirium **include increased preoperative anxiety and increased preoperative parental anxiety**. Emergence delirium occurs in both adults and children, but it occurs most often in children between 2 and 5 years.

Interventions that treat pain also decrease the incidence and severity of emergence delirium. Intraoperative administration of **IV ketorolac or IV fentanyl** decreases the incidence and severity of emergence delirium. Drugs that provide a degree of sedation also decrease the incidence and severity of emergence delirium. **Clonidine** administered either intravenously or caudally and **dexmetomidine** administered intravenously have been shown to be effective in this regard. It is important to note that emergence delirium can occur after anesthesia for both painful surgical procedures and anesthesia for procedures such as magnetic resonance imaging (MRI) that are not painful.

Parental presence during the induction of anesthesia or in the recovery room has not been shown to decrease the incidence or severity of emergence delirium in children.

KEY FACTS

- Emergence delirium is a dissociated state in which children are inconsolable, irritable, uncooperative, and combative. They often do not recognize familiar objects or their parents.
- Emergence delirium occurs more often after sevoflurane or desflurane than halothane or isoflurane.
- Emergence delirium occurs less often after propofol than the inhalational agents.
- IV fentanyl, IV ketorolac, IV and caudal clonidine, and IV dexmetomidine all decrease the incidence of emergence delirium.
- Risk factors for emergence delirium include preoperative anxiety, parental preoperative anxiety, and age between 2 and 5 years.
- Parental presence during the induction of anesthesia or in the recovery room does not decrease the incidence or severity of emergence delirium.

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6. ANSWER: B

Preoperative anxiety in children is a significant issue with at least 50% of children developing significant fear and anxiety before anesthesia and surgery. This preoperative anxiety is characterized by **tension, apprehension, and nervousness**. **Factors contributing** to this anxiety include **separation from their parents, loss of control, and fear of the unknown,** including the induction of anesthesia and surgery.

There are **several risk factors** for preoperative anxiety. **Children between the ages of 1 and 5 years** are at the highest risk. A **history of a previous stressful medical encounter** such as a prior surgery is also a significant risk factor. **Parental preoperative anxiety** is also a significant risk factor for preoperative anxiety in children.

Preoperative anxiety is a significant issue because it results in a more stressful perioperative experience, including the induction of anesthesia. Preoperative anxiety is **also associated with significantly more pain** both during the hospitalization and over the first 3 days after discharge home. Preoperative anxiety is also associated with a **greater incidence of emergence delirium, a greater incidence of postoperative anxiety, and a greater incidence of sleep and other behavioral problems**. Preoperative anxiety is not associated with **a greater incidence of postoperative nausea and vomiting**.

Preoperative anxiety can be **treated pharmacologically** with medications such as oral midazolam. **Parental presence** during the induction of anesthesia has not been shown to reliably decrease preoperative anxiety, especially if the parents also have anxiety. Preoperative anxiety can also be treated with **behavioral modalities** such as child life intervention, music, and video distraction.

KEY FACTS

- Significant preoperative anxiety occurs in at least 50% of children before anesthesia and surgery.
- Risk factors for preoperative anxiety include age between 1 and 5 years, a history of a previous stressful medical encounter, and parental preoperative anxiety.
- Preoperative anxiety results in more stressful induction of anesthesia.
- Preoperative anxiety is associated with greater postoperative pain both during the hospitalization and after discharge home.
- Preoperative anxiety is associated with greater incidence of emergence delirium, postoperative anxiety, and postoperative sleep and behavioral problems.

- Preoperative anxiety can be treated with behavioral modification, such as child life intervention, music, and video distraction.
- Preoperative anxiety can be treated pharmacologically, most commonly with midazolam.

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7. ANSWER: C

Malignant hyperthermia should be treated by immediately **discontinuing the inhalational anesthetic** and administering **100% oxygen** at high flow rates in order to rapidly eliminate the triggering agent. **Minute ventilation** should be increased. The surgeons should be notified so that they can abort or terminate the surgery as quickly as possible. Help should be called for and the malignant hyperthermia cart should be brought to the operating room, and **Dantrolene** should be prepared and then administered at an intravenous dose of 2.5 mg/kg as rapidly as possible. Additional doses of Dantrolene should be administered until there is evidence that the malignant hyperthermia has resolved. Dantrolene should then be continued at a dose of 1 mg/kg IV every 6 hours for 24 to 48 hours.

Additional IV catheters should be placed as well as a Foley catheter to monitor urine output. An arterial line should be placed. Hyperkalemia should be treated with **calcium and glucose-insulin**. Metabolic acidosis should be treated with intravenous bicarbonate. Serum creatinine kinase should be measured and followed as well as urinary myoglobin. If there is any evidence of rhabdomyolysis, the urine should be **alkalinized and mannitol** administered to try to prevent the precipitation of myoglobin in the renal tubules. Multisystem organ failure can result in disseminated intravascular coagulation that should be treated based on the patient's coagulation profile.

KEY FACTS

- Immediately discontinue the inhalational anesthetic and administer 100% oxygen at high flow rates.
- Notify surgeons to abort or terminate surgery.
- Call for help and for the malignant hyperthermia cart.
- Administer Dantrolene 2.5 mg/kg. Repeat until malignant hyperthermia has resolved. Continue Dantrolene 1 mg/kg every 6 hours for another 24–48 hours.
- Place additional IVs, arterial line, and Foley catheter.
- Treat hyperkalemia with calcium and glucose/insulin.
- Follow serum creatinine kinase and urinary myoglobin and treat any rhabdomyolysis with IV bicarbonate and mannitol.
- Monitor coagulation profile and treat DIC with blood products.

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8. ANSWER: D

Malignant hyperthermia is a **hypermetabolic response** to either succinylcholine or one of the inhalational anesthetic agents. The earliest clinical sign of malignant hyperthermia is an **increase in carbon dioxide** production caused by skeletal muscle contraction. In a mechanically ventilated patient this will result in an increase in end-tidal CO_2, and in a patient breathing spontaneously this will result in a rapidly increasing minute ventilation. **Tachycardia** is another early sign, but it is not specific to malignant hyperthermia.

As myoplasmic Ca^{2+} concentrations in the skeletal muscle increase, generalized muscular rigidity develops. Increased anaerobic metabolic activity from the contracting skeletal muscles increases lactate levels. A mixed respiratory and metabolic acidosis develops. **Hyperthermia** is a late sign of malignant hyperthermia and is caused by the heat produced by the continuously contracting skeletal muscles.

Untreated malignant hyperthermia is manifest by uncontrolled temperature elevation. The uncontrolled skeletal muscle contraction results in **severe hypoxia and hypercarbia, significant metabolic acidosis, hyperkalemia, and rhabdomyolysis**. This leads to **hemodynamic instability, ventricular arrhythmias, pulmonary edema, disseminated intravascular coagulation, cerebral hypoxia and edema, and renal failure** from myoglobin deposits in the renal tubules, and eventually death.

KEY FACTS

- Malignant hyperthermia is a hypermetabolic response to either succinylcholine or one of the inhalational agents.
- The earliest reliable sign of malignant hyperthermia is increased carbon dioxide production from the skeletal muscle contraction, which is manifest by either an increase in end-tidal CO_2 in a mechanically ventilated patient or an increase in minute ventilation in a spontaneously ventilated patient.
- Generalized skeletal muscle contraction results in an increase in lactate levels and then a mixed respiratory and metabolic acidosis. Hyperthermia is a late sign of malignant hyperthermia.
- Untreated malignant hyperthermia results in uncontrolled temperature elevations, severe hypoxia, severe hypercarbia, severe metabolic acidosis, hyperkalemia, rhabdomyolysis, ventricular arrhythmias, disseminated intravascular coagulation, cerebral hypoxia and edema, renal failure from myoglobin deposits in the renal tubules, and death.

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9. ANSWER: C

Triggering agents for malignant hyperthermia are only the **inhalational anesthetic agents and succinylcholine**. **Nitrous oxide and xenon** do not trigger malignant hyperthermia. All of the local anesthetics do not trigger malignant hyperthermia. All of the **nondepolarizing muscle relaxants** are safe in patients with malignant hyperthermia. **Ketamine, propofol, opioids, barbiturates, benzodiazepines, clonidine, and dexmetomidine** are all safe in patients with malignant hyperthermia.

Patients with a **family history of malignant hyperthermia or with a history of malignant hyperthermia** with a previous anesthetic are susceptible to malignant hyperthermia.

If a patient is susceptible to malignant hyperthermia, **the anesthesia machine should be prepared by** removing the vaporizers and changing the circuit and the carbon dioxide absorbent. The anesthesia machine should be flushed out for 30 minutes at a flow rate of 10 L/min. Dantrolene should be available, but not given preoperatively. Dantrolene should only be given intraoperatively or postoperatively to treat a case of malignant hyperthermia. A nontriggering anesthetic should be given, avoiding the use of the inhalational agents and succinylcholine. Temperature and end-tidal CO_2 should be monitored. If a patient is susceptible to malignant hyperthermia, he or she should be monitored in the recovery room for a minimum of 4–6 hours after surgery.

KEY FACTS

- The only triggering agents for malignant hyperthermia are succinylcholine and the inhalational anesthetic agents (halothane, isoflurane, sevoflurane, and desflurane).
- Nitrous oxide and xenon are not triggering agents for malignant hyperthermia.
- The nondepolarizing muscle relaxants (e.g., rocuronium, vecuronium) are not triggering agents for malignant hyperthermia.
- Ketamine, propofol, opioids, barbiturates, benzodiazepines, clonidine, dexmetomidine, and the local anesthetics are all not triggering agents for malignant hyperthermia.
- Dantrolene should not be given preoperatively to patients susceptible to malignant hyperthermia. Dantrolene should only be used to treat malignant hyperthermia.
- Preoperative preparation for a patient susceptible to malignant hyperthermia, in addition to a nontriggering anesthetic, includes removing the vaporizers, changing the circuit and carbon dioxide absorbent, and flushing the machine for at least 30 minutes at 10 L/min.

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10. ANSWER: B

Laryngospasm is a relatively frequent complication of anesthesia. The most significant **risk factor** associated with perioperative laryngospasm is **younger age** with the highest incidence of laryngospasm in **children less than 5 years of age**. **Males** have a higher incidence of laryngospasm than females. There is a higher incidence of laryngospasm in patients who have an **upper respiratory infection** or a

history of an upper respiratory infection in the past 2 weeks. There is also a higher incidence of laryngospasm in patients with a history of **eczema** and in patients with a history of **asthma** or reactive airway disease with more than three episodes of wheezing in the past year. A family history of asthma or eczema and household **exposure to tobacco smoking** are also risk factors for perioperative laryngospasm.

Surgery or manipulation of the larynx or pharynx increases the incidence of laryngospasm. Emergency procedures also are associated with a higher incidence of laryngospasm.

Laryngospasm is associated with an **insufficient depth of anesthesia** and is commonly seen during induction and emergence of anesthesia. Triggers of laryngospasm include **blood or secretions in the airway**. **Mechanical stimulation of the oropharynx or larynx** during laryngoscopy or from a bronchoscope, oral airway, or LMA or suction catheter can also trigger laryngospasm.

KEY FACTS

- The most significant risk factor for laryngospasm is younger age.
- Other patient-related risk factors for laryngospasm include male gender, a concurrent or recent upper respiratory infection, a history of eczema, a history of wheezing or asthma, and household exposure to tobacco smoke.
- A family history of asthma or eczema is also associated with an increased incidence of laryngospasm.
- Surgery involving the larynx or pharynx or procedures such as bronchoscopy are also associated with an increased incidence of laryngospasm.
- Laryngospasm is associated with light anesthesia and is commonly seen during induction and emergence.
- Laryngospasm can be triggered by blood or secretions in the airway or direct mechanical stimulation from a laryngoscope, oral airway, LMA, or suction catheter.

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11. ANSWER: C

Perioperative cardiac arrest: Numerous studies have demonstrated that **pediatric patients have a higher incidence of perioperative cardiac arrest than adult patients**. **Infants less than 1 month of age** have the highest incidence of perioperative cardiac arrest. The incidence of perioperative cardiac arrest decreases in older infants and children. Infants and children over 1 year of age have approximately the same incidence of perioperative cardiac arrest as adults.

Infants and children with **congenital heart disease** have a significantly higher incidence of perioperative cardiac arrest than infants and children without congenital heart disease. The incidence of perioperative cardiac arrest is significantly higher in children undergoing **cardiac surgery** than noncardiac surgery.

Approximately 21% of perioperative arrests occurred during **the induction of anesthesia,** and the majority of arrests (67%) occurred during **maintenance of anesthesia**.

Cardiovascular causes accounted for approximately 41% of perioperative arrests. **Respiratory causes** accounted for about 27% and medications accounted for about 18% of perioperative cardiac arrests. The most common cardiovascular cause of perioperative cardiac arrest was **hypovolemia from blood loss,** and the second most common cardiovascular cause was **hyperkalemia from transfusing stored blood**. The most common respiratory cause of perioperative cardiac arrest was from **laryngospasm**. The medication causes of perioperative cardiac arrest included **reactions to the inhalational anesthetic agents succinylcholine and neostigmine**. Approximately 2.5% of perioperative cardiac arrests were due to complications from central venous catheterization.

There is a significant association between surgical procedure and the cause of cardiac arrest. Airway surgery was associated with a respiratory cause in 49% of cardiac arrests and cardiac surgery; neurosurgery and spine surgery were associated with cardiovascular causes in 71% of cardiac arrests.

KEY FACTS

- Infants less than 1 month of age have the highest incidence of perioperative cardiac arrest.
- Infants and children with congenital heart disease undergoing cardiac surgery have the highest incidence of perioperative cardiac arrest.
- The majority of perioperative arrests occur during maintenance of anesthesia.
- Cardiovascular causes account for the most perioperative cardiac arrests, and the most common cause is hypovolemia from blood loss.
- The most common respiratory cause of perioperative cardiac arrest is laryngospasm.

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12. ANSWER: B

Laryngospasm is a relatively frequent complication of anesthesia. The **treatment of laryngospasm** begins with correctly recognizing and diagnosing laryngospasm. Laryngospasm most commonly occurs during the **induction or emergence** phases of anesthesia. Laryngospasm should be suspected when there is **a loss of spontaneous ventilation and an inability to ventilate with positive-pressure ventilation**. The first step to treat laryngospasm is to provide **continuous positive-pressure ventilation with 100% oxygen** via a facemask while applying a chin lift and jaw thrust. The majority of cases of laryngospasm can be treated successfully with this method.

If continuous positive-pressure ventilation is not successful, then treatment depends on whether or not there is intravenous access. If there is intravenous access, laryngospasm can be treated with intravenous **propofol**. If the propofol does not terminate the laryngospasm, then the laryngospasm should be treated with either intravenous **rocuronium** or intravenous **succinylcholine** after intravenous **atropine**. Administering intravenous succinylcholine without atropine in a hypoxic and bradycardic patient may lead to severe bradycardia and cardiac arrest.

If there is no intravenous access, then laryngospasm that is not successfully treated with continuous positive-pressure ventilation with a face mask should be treated with either intramuscular rocuronium or succinylcholine. It is important to treat laryngospasm before the hypoxia causes severe bradycardia and cardiac arrest. Administering intramuscular muscle relaxants will usually resolve the laryngospasm in less than 30 seconds and allow successful positive-pressure ventilation with a face mask. If the laryngospasm occurred during the induction of anesthesia, an intravenous line should be place and the airway should be secured before proceeding with surgery.

KEY FACTS

- Laryngospasm should be initially treated with continuous positive-pressure ventilation with a face mask with 100% oxygen.
- If there is intravenous access, laryngospasm that does not resolve with continuous positive-pressure ventilation should be treated with intravenous propofol. If the laryngospasm does not resolve with propofol, laryngospasm should be treated with intravenous rocuronium. Intravenous succinylcholine can be used instead of rocuronium, but only after intravenous atropine is given to prevent severe bradycardia and cardiac arrest.
- If there is no intravenous access, laryngospasm that does not resolve with continuous positive-pressure ventilation should be treated with intramuscular rocuronium or succinylcholine.

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13. ANSWER: A

Posterior ischemic optic neuropathy is the most common cause of postoperative visual loss. Surgical **risk factors** for postoperative visual loss include **duration of anesthetic, prone positioning, large estimated blood loss, excessive crystalloid use, prolonged hypotension, and direct pressure on the eyes in surgery**, which increases intraocular pressure as well as venous pressure. Patient risk factors include **morbid obesity, hypertension, diabetes mellitus, atherosclerosis, and tobacco use**.

Ischemic optic neuropathy can be anterior or posterior. **Anterior** ischemic optic neuropathy is associated most often with cardiac bypass procedures, spine surgery, and major vascular procedures. **Posterior** ischemic optic neuropathy is associated with procedures that increase venous pressure in the head, such as prone spinal fusion.

Retinal artery occlusion is most often due to either an embolic event or from direct globe compression, resulting in kinking of the central retinal artery. This can occur in prone cases if pressure is placed on the globe.

Cortical blindness is associated with stroke or other embolic phenomena. Interestingly, a recent retrospective review by Shen et al. demonstrated that patients under 18 years old are more likely to have cortical blindness as a cause of postoperative visual loss than patients over 18 years old. The etiology of this is unclear.

Posterior reversible encephalopathy syndrome is a condition associated with variable neurologic findings in

the setting of an acute medical illness, including seizures (88%), visual changes (60%), altered mental status (56%), headaches (52%), nausea and vomiting (28%), brainstem symptoms (12%), and hemiplegia (12%). It is associated with autoimmune disease, hypertensive episodes, malignancy, chemotherapy, immunosuppressive agents, and so on. It is diagnosed by MRI, which reveals vasogenic edema and ischemia on Fluid Attenuated Inversion Recovery (FLAIR) sequences. FLAIR is a method to remove the signal from fluid. Several case reports of posterior reversible encephalopathy syndrome have occurred following the administration of a general anesthetic.

KEY FACTS

- Posterior ischemic optic neuropathy is the most common cause of postoperative visual loss.
- Surgical risk factors for postoperative visual loss include duration of anesthetic, prone positioning, large estimated blood loss, excessive crystalloid use, prolonged hypotension, and direct pressure on the eyes in surgery.
- Anterior ischemic optic neuropathy is associated most often with cardiac bypass procedures, spine surgery, and major vascular procedures.
- Posterior ischemic optic neuropathy is associated with procedures that increase venous pressure in the head, such as prone spinal fusion.

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14. ANSWER: B

Peripheral nerve injuries can be devastating complications of anesthesia. Meticulous attention should be paid to **patient positioning** during an anesthetic to avoid direct pressure or stretch of the nerve. Despite adequate positioning and padding, peripheral neuropathy can still occur, and the mechanism is unknown. The most frequent site of neuropathy is **ulnar** (28%), followed by **brachial plexus** (20%), lumbosacral (16%), and **spinal cord** (13%).

When a patient presents with a neuropathy following a general anesthetic, it is important to do a careful history and physical examination. Frequently, **sensory neuropathies** resolve spontaneously, within 5 days. Any patient with a sensory deficit persisting beyond 5 days should be referred to a neurologist. **Motor deficits** are much more grave. Patients with a motor deficit following a general anesthetic should be referred to a neurologist immediately for an electromyographic study. This study can determine if a preexisting neuropathy was present and determine the exact location of the injury.

Signs of denervation from acute neural injury with resultant motor dysfunction are apparent on electromyography within 3 weeks of the event. Neurapraxia, or demyelenation of the fibers of a nerve trunk, generally recovers within 2 months. More severe injury, such as complete nerve disruption, can cause persistent pain and disability.

Bilateral distribution of symptoms can occur following a centrally mediated neuropathy, such as after a spinal or epidural anesthetic.

A history of **chronic pain** is not the most likely cause of an anesthesia-related neuropathy and may suggest that a preexisting condition has resulted in the complaint.

KEY FACTS

- The most frequent site of neuropathy is ulnar (28%), followed by brachial plexus (20%), lumbosacral (16%), and spinal cord (13%).
- Frequently, sensory neuropathies resolve spontaneously, within 5 days.
- Patients with a motor deficit following a general anesthetic should be referred to a neurologist immediately for an electromyographic study.
- Signs of denervation from acute neural injury with resultant motor dysfunction are apparent on electromyography within 3 weeks of the event.

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15. ANSWER: A

Intraoperative awareness is a serious complication of general anesthesia, with an incidence estimated to be between 0.1% and 0.2%. The incidence of awareness in the **pediatric population is up to 10 times higher**. Besides age, other **risk factors** for intraoperative awareness include patient-related risk factors (history of substance abuse, more comorbid medical conditions/higher ASA PS),

surgical risk factors (emergency surgery, trauma surgery), and anesthetic risk factors (use of muscle relaxants, absence of benzodiazepines).

This **bispectral index** (BIS) is a processed electroencephalogram (EEG)-derived variable that is designed to measure the depth of anesthesia. It is calculated by integrating four different processed EEG descriptors that each perform most accurately at a different stage of anesthesia, into a single variable. These are then integrated to generate a single number, or BIS score. The BIS can range from 0 to 100, with a score of 60 or lower generally thought to confer unconsciousness. **Advantages** of the BIS monitor include more adequate titration of anesthetic agents, faster anesthetic emergence, and probability of recall. It does not, however, prevent **recall**, as it is only a parameter, which must be interpreted by the clinician in conjunction with other signs of light anesthesia. In 2004, Ekman et al. demonstrated a five-fold reduction in the risk on awareness under general anesthesia with the use of a BIS monitor in 4945 patients compared to a historical control group. However, it has also been shown that maintenance 0.75 to 1.3 MAC with a volatile anesthetic was as effective as a BIS monitor in preventing awareness. Additionally, because the incidence of intraoperative awareness is very small, the literature examining the effectiveness of the BIS monitor may be underpowered.

KEY FACTS

- Intraoperative awareness has an incidence estimated to be between 0.1% and 0.2%.
- The incidence of awareness in the pediatric population is up to 10 times higher.
- Besides age, other risk factors for intraoperative awareness include patient-related risk factors (history of substance abuse, more comorbid medical conditions/higher ASA PS), surgical risk factors (emergency surgery, trauma surgery), and anesthetic risk factors (use of muscle relaxants, absence of benzodiazepines).
- Advantages of the BIS monitor include more adequate titration of anesthetic agents, faster anesthetic emergence, and probability of recall.
- BIS does not, however, prevent recall, as it is only a parameter, which must be interpreted by the clinician in conjunction with other signs of light anesthesia.
- It has also been shown that maintenance of 0.75 to 1.3 MAC with a volatile anesthetic was as effective as a BIS monitor in preventing awareness.

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16. ANSWER: D

Awareness under anesthesia is a serious complication of anesthetic practice. **Incidence** is 0.1% to 0.2% but can be up to **10 times higher in children**. When there is concern for awareness under anesthesia, **a standardized interview** of the patient should occur immediately following anesthesia in the recovery room. These questions should ideally be asked again within the next few days.

Standardized interview questions include the following (Modified Brice Questionnaire):

What is the last thing you remember happening before you went to sleep?

What is the first thing you remember happening on waking?

Can you remember anything that happened between these two points? Did you dream or have any other experiences while you were asleep?

What was the worst thing about your operation?

Signs of awareness under anesthesia include patient movement, hypertension, tachycardia, sweating, and tearing. These, however, do not always indicate awareness and may just mark light anesthesia.

The BIS monitor is a processed EEG monitor that is used to assign a numerical value from 0 to 100 to level of consciousness. Though a BIS score correlates with depth of anesthesia, it is most helpful as a trending device and therefore may not be helpful in an acute situation such as this.

Consequences of anesthetic recall include anxiety, flashbacks, and posttraumatic stress disorder. Appropriate referral of these patients to psychiatry should be ensured. Interestingly, children are less likely than adults to have prolonged anxiety or posttraumatic stress disorder following an anesthetic.

If a patient reports intraoperative awareness, details of the event should be obtained and possible reasons should be discussed with the patient. The event should be reported for quality management purposes. Additionally, the patient should be referred to counseling and psychological support.

KEY FACTS

- The incidence of awareness under anesthesia is 0.1% to 0.2%, but it can be up to 10 times higher in children.
- When there is concern for awareness under anesthesia, a standardized interview of the patient should occur immediately following anesthesia in the recovery room.

- Signs of awareness under anesthesia include patient movement, hypertension, tachycardia, sweating, and tearing.
- Consequences of anesthetic recall include anxiety, flashbacks, and posttraumatic stress disorder.

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17. ANSWER: C

Causes of systemic hypotension can be divided into three main categories: preload, pump failure, and afterload.

A frequent cause of intraoperative and postoperative hypotension is **inadequate replacement of fluid losses**. **Surgical bleeding, insensible losses** from exposed body surface area, and bowel exposure contribute to this. A prolonged fasting period prior to surgery may decrease preload. A bowel prep, completed before general or urologic surgical procedures, will decrease intravascular volume. Preload may be decreased by positioning of surgical instruments resulting in pressure on the inferior vena cava and decreasing return from the bowel and lower extremities to the right side of the heart.

A second category of hypotension is due to **decreased cardiac output**. This includes all causes of pump failure, some of which include myocardial ischemia, cardiomyopathy, valvular disease, tamponade, pulmonary embolus, and tension pneumothorax. Cardiac arrhythmias can cause hypotension and may occur secondary to electrolyte abnormalities, anesthetic agents, or surgery.

Finally, hypotension can be due to **decreased afterload**. This is a result of decreased intrinsic vascular tone. Causes include sepsis, allergic reactions, neuraxial anesthesia, and adrenal insufficiency. The most common cause of intraoperative hypotension from reduced afterload is iatrogenic from anesthetic agents, which cause a decrease in the systemic vascular resistance.

Mild hypotension does not typically require treatment. Hypotension generally should be treated if there is **reduction of blood pressure greater than 20%** from baseline. Treatment depends on the cause, which must be first assessed. Intravascular volume assessment can be assessed by a decrease in the central venous pressure, increased systolic or pulse pressure variation on an arterial line tracing, or significant blood in the suction canisters or on drapes and absorbed by surgical sponges. A patient with diabetes insipidus or given lasix or mannitol may have a urine output far in excess of intravenous volume replacement. Patients with severe chronic obstructive pulmonary disease (COPD) may have air trapping if expiratory time is too low, leading to increased intrathoracic pressure and decreased venous return. Elevated positive end-expiratory pressure can have the same result.

KEY FACTS

- Causes of systemic hypotension can be divided into three main categories: preload, pump failure, and afterload.
- Frequent causes of intraoperative and postoperative hypotension are inadequate replacement of fluid losses, surgical bleeding, and insensible losses.
- Decreased afterload results from decreased intrinsic vascular tone, and causes include sepsis, allergic reactions, neuraxial anesthesia, and adrenal insufficiency.
- A second category of hypotension is due to decreased cardiac output.
- Hypotension generally should be treated if there is reduction of blood pressure greater than 20% from baseline.

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18. ANSWER: B

Pheocromocytomas are catecholamine-secreting tumors that most often arise from the adrenal medulla. **Perioperative mortality rates in patients with undiagnosed pheochromocytomas** can be as high as 45%. When a preoperative diagnosis is made, **long-acting oral α-antagonists** such as phenoxybenzamine should be introduced at least 3–5 days prior to surgery; ideally they are given 10–14 days preoperatively. Phenoxybenzamine is long acting (24–48 hours) and works noncompetitively both presynaptically (α2) and postsynaptically (α1). α-adrenergic blockade can also be accomplished with other alpha-blocking agents, such as doxazosin or prazosin. Once alpha blockade is well established, **beta-adrenergic blockade** may be added to correct persistent tachycardia/tachyarrhythmia. **However, it is extremely important to avoid β-blockade until α-blockade is well established, as this may lead to unopposed vasoconstriction.**

Intraoperatively, procedures that cause sympathetic stimulation, such as laryngoscopy or manipulation of the tumor may cause severe hypertension and tachycardia due to excessive catecholamine release. When this occurs, the drugs of choice are sodium **nitroprusside or phentolamine**. Phentolamine is an alpha-antagonist with a duration of action lasting approximately 5 minutes. Short-duration agents are preferred, as once the tumor's blood supply has been ligated, severe hypotension can occur. In the setting of hypotension following tumor removal, the first step is to ensure adequate intravascular volume; if hypotension persists, phenylephrine may be administered.

KEY FACTS

- Pheocromocytomas are catecholamine-secreting tumors that most often arise from the adrenal medulla.
- Perioperative mortality rates in patients with undiagnosed pheochromocytomas can be as high as 45%.
- Long-acting oral α-antagonists such as phenoxybenzamine should be introduced at least 3–5 days prior to surgery.
- Once alpha blockade is well established, beta-adrenergic blockade may be added to correct persistent tachycardia/tachyarrhythmia.

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19. ANSWER: D

Ophthalmic medications can affect a patient's hemodynamics, especially when the patient is a neonate or infant. These medications are given topically but are systemically absorbed in the nasal mucosa or conjunctiva. It is important for the anesthesiologist to understand the hemodynamic effects of each of these medications when they are used by the ophthalmologist during a procedure under general anesthesia. **Pilocarpine** is a direct-acting cholinergic agonist that is used for the treatment of glaucoma. Acute absorption of this medication can lead to **bradycardia**. It also may cause corneal edema or retinal detachment. **Scopolamine** is an antimuscarinic agent that dilates the pupil and paralyzes the cilliary muscle, allowing for retinal evaluation. **Side effects** include photosensitivity and blurry vision; systemic absorption leads to tachycardia and a dry mouth. **Phenylepherine** is the most commonly used medication to induce pupillary dilation. A 2.5% solution is usually used, and especially in neonates and infants, it can be easily systemically absorbed. Signs of phenylephrine toxicity include acute **hypertension**, which, if severe enough, can lead to **bradycardia**. **Timolol** is a β-adrenergic antagonist used to reduce intraocular pressure for glaucoma treatment. Systemic absorption can cause **bradycardia, hypotension, and even bronchospasm**. If toxicity is suspected, directing acting beta-agonists such as epinephrine should be used instead of indirect agents (e.g., ephedrine).

KEY FACTS

- Ophthalmic medications can affect a patient's hemodynamics, especially when the patient is a neonate or infant.
- Pilocarpine is a direct-acting cholinergic agonist that is used for the treatment of glaucoma and can cause bradycardia.
- Scopolamine is an antimuscarinic agent that dilates the pupil and paralyzes the cilliary muscle and can cause photosensitivity and blurry vision, tachycardia, and a dry mouth.
- Phenylepherine induces pupillary dilation and can cause acute hypertension leading to bradycardia.
- Timolol is a β-adrenergic antagonist used to reduce intraocular pressure for glaucoma treatment and can cause bradycardia, hypotension, and even bronchospasm.

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20. ANSWER: A

Anaphylactic reactions can be severe and life threatening and should be immediately recognized by the anesthesiologist. **The most common causes of anaphylaxis during anesthesia include muscle relaxants, latex, and antibiotics**. Clinical severity of anaphylaxis is graded by the Ring and Messmer scale. **Grade 1** involves cutaneous-mucous signs, such as erythema and uticaria. **Grade 2** includes the cutaneous signs as well as hypotension/tachycardia/dyspnea. **Grade 3** has life-threatening signs, such as cardiovascular collapse, cardiac arrhythmias, or severe bronchospasm. **Grade 4** is cardiac arrest. The overall incidence of perioperative anaphylaxis is 1 in 10,000; when neuromuscular blocking agents are used, the incidence climbs to 1 in 6500.

Diagnosis of anaphylaxis relies on clinical history and physical exam, and it can be supported by laboratory investigation. Tryptase is a preformed enzyme contained in mast cell granules. It is released when mast cells are activated and is indicative of an anaphylactic reaction. **Serum tryptase levels** peak 15 minutes to 1 hour after an anaphylactic reaction. Tryptase has a half-life of 2 hours. An elevated serum tryptase (≥ 10 μg/L) is highly suggestive of mast cell activation. Serum tryptase levels should be compared to baseline levels, which can be drawn >24 hours after the suspected anaphylactic reaction. **Histamine** is also stored in mast cell granules, and serum histamine levels may be elevated following anaphylaxis. However, the half-life of histamine is only 15–20 minutes, so any delay in a laboratory draw may miss the presence of serum histamine. Additionally, histamine is released during nonallergic reactions, such as after exposure to common anesthetic medications such as morphine. Therefore, it is not the test of choice to diagnose anaphylaxis. A complete blood count with differential may reveal a **leukocytosis with basophilic or eosinophilic predominance**, but it is not the test of choice in confirming an anaphylactic reaction. Kinins are small peptides present in mast cells and basophils that produce bronchoconstriction and vasodilation. Serum kinin levels cannot be reliably quantified.

KEY FACTS

- The most common causes of anaphylaxis include muscle relaxants, latex, and antibiotics.
- The overall incidence of perioperative anaphylaxis is 1 in 10,000; when neuromuscular blocking agents are used, the incidence climbs to 1 in 6500.
- Serum tryptase levels peak 15 minutes to 1 hour after an anaphylactic reaction.

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21. ANSWER: A

Anaphylaxis is graded by the Ring and Messmer classification system. **Grade 1** anaphylaxis involves cutaneous-mucous signs, such as erythema and uticaria. **Grade 2** includes the cutaneous signs as well as hypotension/tachycardia/dyspnea. **Grade 3** has life-threatening signs, such as cardiovascular collapse, cardiac dysrhythmias, or severe bronchospasm. **Grade 4** anaphylaxis involves cardiac arrest. Severe (grade 3–4) anaphylaxis is associated with rapid onset; in fact, a more rapid onset predicts the severity of the anaphylaxis. By definition, grade 3 and 4 anaphylaxis involves cardiac arrhythmias. Interestingly, **bradycardia** can be seen in severe anyphylaxis. This is a compensatory mechanism, triggered by the Bezold-Jarisch reflex, which occurs in response to severe hypovolemia related to profound systemic vascular dilation. This reflex can be seen up to 10% of the time with anaphylaxis, and it exists to allow the ventricles to fill prior to contraction. In this case, atropine is contraindicated, and instead massive volume resuscitation and epinephrine are the treatment of choice. **Cutaneous manifestations** may be absent in severe, rapidly progressing anaphylaxis, at least initially. This is due to initial superficial vasoconstriction in response to profound hypotension. Once hypotension is corrected, cutaneous signs appear.

KEY FACTS

- Anaphylaxis is graded by the Ring and Messmer classification system.
- Grade 1 anaphylaxis involves cutaneous-mucous signs, such as erythema and uticaria.
- Grade 2 includes the cutaneous signs as well as hypotension/tachycardia/dyspnea.
- Grade 3 has life-threatening signs, such as cardiovascular collapse, cardiac dysrhythmias, or severe bronchospasm.
- Bradycardia can be seen in severe anyphylaxis.
- Grade 4 anaphylaxis involves cardiac arrest.

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Dewachter P, Mouton-Faivre C, Emala CW. Anaphylaxis and anesthesia: controversies and new insights. *Anesthesiology*. 2009;111:1141–50.

Ring J, Messmer K. Incidence and severity of anaphylactoid reactions to colloid volume substitutes. *Lancet*. 1977;1:466–9.

22. ANSWER: A

Stridor is caused by turbulent airflow during respiration. During inspiration, the transmural pressure across the extrathoracic airway causes airway narrowing, as intraluminal pressure is subatmospheric, while extraluminal pressure is nearly atmospheric. Upon exhalation, the opposite occurs, with intraluminal pressure exceeding the extraluminal pressure, causing the airway to open.

Stridor can be caused by fixed or variable lesions that are either intra- or extrathoracic in location. Fixed lesions, whether extra- or intrathoracic, have flattening of both inspiratory and expiratory flow-volume loops. Variable intrathoracic lesions exhibit flattening of the expiratory portion of the flow-volume loop, while variable extrathroacic lesions demonstrate flattening of the inspiratory portion of the flow-volume loop.

Stridor in infants and children is a serious problem, as their airways are smaller and more easily narrowed. When approaching a patient with new-onset stridor, one should consider whether the stridor is inspiratory in nature and thus likely caused by an extrathoracic lesion or expiratory in nature and thus caused by an intrathoracic lesion.

Laryngomalacia is the most common cause of inspiratory stridor in infants and children. It is due to a floppy, immature larynx and is most often outgrown by the age of 2 years. Stridor in patients with laryngomalacia may increase on induction of anesthesia or when the patient is supine.

Tonsillar hypertrophy or other forms of pharyngeal airway obstruction can also cause noisy inspirations, especially during induction or emergence from anesthesia. In these cases, maneuvers that correct upper airway obstruction, such as altering airway positioning or insertion of an oral airway, may relieve the obstruction.

Vocal cord injury from intubation can also cause inspiratory stridor. Stridor most often arises from laryngeal edema; this, in turn, occurs in response to multiple laryngoscopies/intubations during a procedure, placing an endotracheal tube that is too large for the airway, prolonged intubation, and coughing or bucking on emergence with an endotracheal tube in place. Other than edema, intubation can cause aretynoid dislocation or rupture of a vocal cord, also leading to inspiratory stridor.

An airway foreign body can be a cause of expiratory stridor. Usually, stridor is only heard if the foreign body is proximally located in the tracheobronchial tree.

KEY FACTS

- Stridor is caused by turbulent airflow during respiration.
- Fixed lesions, whether extra- or intrathoracic have flattening of both inspiratory and expiratory flow-volume loops.
- Variable intrathoracic lesions exhibit flattening of the expiratory portion of the flow-volume loop.
- Variable extrathroacic lesions demonstrate flattening of the inspiratory portion of the flow-volume loop.
- Stridor in infants and children is a serious problem, as their airways are smaller and more easily narrowed.
- Laryngomalacia is the most common cause of inspiratory stridor in infants and children.
- Vocal cord injury from intubation can also cause inspiratory stridor.

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23. ANSWER: D

Infections acquired from blood transfusion have markedly decreased in the United States. Currently, donated blood is tested for HIV-1, HIV-2, hepatitis B, hepatitis C, human T lymphotrophic virus (HTLV)-1, HTLV-2, West Nile virus, syphilis, and Chagas disease. Other infections that can be transmitted by blood transfusions but are not initially screed for include cytomegalovirus, malaria, and variant Creutzfeldt-Jakob disease. Nucleic acid technology is currently used to screen blood for hepatitis B, hepatitis C, HIV, and West Nile virus. The risk of acquiring HIV or hepatitis C from a blood transfusion is very low, approximately 1 in 2,000,000.

Hepatitis B is an uncommon cause of chronic hepatitis, and only 35% of HBV-exposed patients develop acute disease. Of patients with acute disease, 85% resolves spontaneously. Chronic hepatitis B infection is a risk factor for hepatocellular carcinoma. The current **risk of acquiring hepatitis B from a blood transfusion in the United States** is 1 in 350,000. Risk of hepatitis B infection increases because of the prolonged "window" period: the time between contracting the virus and when it can be detected by nucleic acid screening. The **window period for HIV and hepatitis C** is less than 2 weeks; however, the window period for hepatitis B can be up to 38 days. This, combined with the increased prevalence of hepatitis B in the donor population (compared to hepatitis C and HIV), results in a higher transmission rate of hepatitis B with a blood transfusion. **West Nile virus** has been tested for in donor blood by nucleic acid screening since 2003. It is transmitted by acutely infected but asymptomatic donors; infection rates vary by season.

KEY FACTS

- Currently, donated blood is tested for HIV-1, HIV-2, hepatitis B, hepatitis C, human T lymphotrophic virus (HTLV)-1, HTLV-2, West Nile virus, syphilis, and Chagas disease.
- Hepatitis B is an uncommon cause of chronic hepatitis, and only 35% of HBV-exposed patients develop acute disease.
- The current risk of acquiring hepatitis B from a blood transfusion in the United States is 1 in 350,000.
- The window period for HIV and hepatitis C is less than 2 weeks; however, the window period for hepatitis B can be up to 38 days.
- West Nile virus has been tested for in donor blood by nucleic acid screening since 2003 and is transmitted by acutely infected but asymptomatic donors.

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24. ANSWER: C

TRALI is the leading cause of transfusion-related fatality. It is **defined as** acute lung injury developing within 6 hours of a blood transfusion. Most cases of TRALI develop within minutes of blood administration. **Clinical manifestations** include an increased oxygen requirement, presence of bilateral interstitial infiltrates on chest X-ray, pink/frothy secretions from the endotracheal tube, fever, and hypotension. On **laboratory evaluation** an acute drop in the serum neutrophil count may be seen. When TRALI is suspected, blood product administration should be immediately suspended, and the blood bank physician notified of the possible reaction. TRALI is **more commonly seen in** pooled donor units, such as platelets, plasma containing blood, such as FFP or whole blood, and when the donor is a multiparous female.

TRALI can be difficult to distinguish from transfusion-associated circulatory overload (TACO), especially in small children. **TACO** is more likely to be associated with volume overload: Patients with TACO as opposed to TRALI exhibit **elevated left atrial pressures, elevated levels of brain natriuretic peptide (BNP), and a transudative rather than an exudative pulmonary edema fluid**. TRALI is less responsive to diuretic therapy compared to TACO.

Other transfusion reactions include the following:

Acute hemolytic transfusion reactions. This reaction is due to ABO incompatibility. Many signs of an acute hemolytic transfusion reaction can be masked by anesthesia (back or substernal pain, flushing, fever, and dyspnea); however, the hallmark of a hemolytic transfusion reaction is the appearance of free hemoglobin in urine or plasma. Acute hemolytic transfusion reactions can lead to acute renal failure and disseminated intravascular coagulation.

Delayed hemolytic transfusion reactions. Delayed hemolytic transfusion reactions occur when red blood cells are suddenly hemolyzed days after an ABO compatible cross match. These reactions are usually due to antibodies against Rheuses (Rh), Kell, Duffy, and Kidd antigens. Red blood cell destruction occurs in the spleen and liver. Delayed hemolytic transfusion reactions are much less likely to be fatal.

Allergic reactions. The reactions present with fever, urticaria, and pruitis and are most often due to reactions to proteins in donor plasma.

KEY FACTS

- TRALI is the leading cause of transfusion-related fatality.
- TRALI is defined as acute lung injury developing within 6 hours of a blood transfusion.
- Clinical manifestations include an increased oxygen requirement, presence of bilateral interstitial infiltrates on chest X-ray, pink/frothy secretions form the endotracheal tube, fever, and hypotension.
- TRALI is more commonly seen in pooled donor units, such as platelets, plasma containing blood, such as FFP or whole blood, and when the donor is a multiparous female.
- Patients with TACO as opposed to TRALI exhibit elevated left atrial pressures, elevated levels of BNP, and a transudative rather than an exudative pulmonary edema fluid.

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25. ANSWER: B

Umbilical venous cannulation is used to provide central access in a neonate. These catheters can be used for resuscitation, for delivering vasopressors/ionotropes, for parental nutrition, and for central venous pressure monitoring.

Unfortunately, there are high complication rates with umbilical venous catheters. **An improperly placed catheter can be life threatening**. A **properly placed catheter** ends at the junction of the inferior vena cava and right atrium. A **catheter that fails to cross the ductus venosus** may become stuck in the liver, leading to cirrhosis due to portal necrosis if unrecognized.

Umbilical catheters are associated with a **risk of portal vein thrombosis**. **Risk of thrombosis is increased**

when the catheter is positioned too low, due to a lower venous flow rate resulting in stasis and coagulation. Even with appropriate placement, the incidence of portal vein thrombosis associated with an umbilical venous catheter is 1.3%.

All centrally inserted vascular catheters should be inserted with utmost sterile technique; additionally, they should be assessed on a daily basis. They should be removed as soon as medically possible to reduce the risk of infection. Severe central line infections can lead to sepsis, as well as cause endocarditis.

KEY FACTS

- Umbilical venous cannulation is used to provide central access in a neonate.
- A properly placed catheter ends at the junction of the inferior vena cava and right atrium.
- A catheter that fails to cross the ductus venosus may become stuck in the liver, leading to cirrhosis due to portal necrosis if unrecognized.
- Umbilical catheters are associated with a risk of portal vein thrombosis.

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26. ANSWER: C

In order to **calculate allowable blood loss**, you must first calculate a patient's estimated blood volume (mL/kg). This varies with age. A **preterm neonate** has a blood volume of 95 mL/kg, and **a term neonate** has a blood volume of 85 mL/kg. In the **first year of life**, an infant has a blood volume of about 80 mL/kg. By **adulthood,** the average male has a blood volume of 75 mL/kg, while the average female has a blood volume of 65 mL/kg.

During surgeries where significant blood loss is expected, it is helpful to calculate allowable blood loss, in order to anticipate when packed red blood cell transfusion should begin. A convenient formula to use is as follows:

$$\textbf{Allowable blood loss} = \textbf{Estimated Blood volume} * \left[(\mathbf{Hct}_{\mathbf{initial}} - \mathbf{Hct}_{\mathbf{final}}) / \mathbf{Hct}_{\mathbf{initial}} \right].$$

Of course, frequent laboratory measurements of hematocrit should be performed to validate estimated blood loss, as surgical blood loss can be difficult to quantify. Blood can be hidden in drapes, collected in sterile sponges that are not visible to the anesthesiologist, or spill on the floor.

KEY FACTS

- To calculate allowable blood loss, you must first calculate a patient's estimated blood volume (mL/kg) which varies with age.
- A preterm neonate has a blood volume of 95 mL/kg.
- A term neonate has a blood volume of 85 mL/kg.
- In the first year of life, an infant has a blood volume of about 80 mL/kg.
- By adulthood, the average male has a blood volume of 75 mL/kg, while the average female has a blood volume of 65 mL/kg.
- $\text{Allowable blood loss} = \text{Estimated Blood volume} * \left[(\text{Hct}_{\text{initial}} - \text{Hct}_{\text{final}}) / \text{Hct}_{\text{initial}} \right]$.

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27. ANSWER: D

Adrenal insufficiency is a possible cause of intraoperative hypotension and electrolyte abnormalities in a surgical patient on chronic steroids undergoing anesthesia. **Findings in the pediatric patient** with adrenal insufficiency include hypotension, hyponatremia, hyperkalemia, and hypoglycemia. Metabolic acidosis may also be present. **An awake patient may manifest** abdominal pain, nausea, vomiting, diarrhea, and/or fever.

Although it may be difficult to recognize, prompt treatment of an adrenal crisis is essential to prevent morbidity. **Current recommendations** include stress-dose glucocorticoids—administer hydrocortisone (Solu-Cortef) at the following doses: age 0–3 years 25 mg IV, age 3–12 years 50 mg IV, >12 years 100 mg IV. Steroids should be redosed every 6 hours for a 24-hour period.

Hypoglycemia should be treated with a dextrose-containing intravenous solution. Additional intravenous fluids and/or vasopressors should be used to correct **hypotension**. **Hyperkalemia** should be assessed for and treated rapidly with sodium bicarbonate, calcium

chloride/calcium gluconate, and if necessary insulin/glucose infusion.

Diagnosis of adrenal insufficiency can be accomplished by checking a random plasma cortisol concentration or by performing an adrenocorticotrophic hormone (ACTH) stimulation test following surgery.

KEY FACTS

- Adrenal insufficiency is a possible cause of intraoperative hypotension and electrolyte abnormalities in a surgical patient on chronic steroids undergoing anesthesia.
- Findings in the pediatric patient with adrenal insufficiency include hypotension, hyponatremia, hyperkalemia, and hypoglycemia; metabolic acidosis may also be present.
- An awake patient may manifest abdominal pain, nausea, vomiting, diarrhea, and/or fever.

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25.

SPECIAL TECHNIQUES AND SITUATIONS

Raymond Park and Elizabeth C. Eastburn

1. Laparoscopic surgery is associated with:

A. A linear decrease in cardiac output with increasing intraabdominal insufflation pressure
B. Negligable changes in intracranial pressure
C. Decreased functional residual capacity, lung compliance, and closing volume with unaffected vital capacity
D. A increase in minute ventilation of 50%–100% to maintain pH

2. Ethanol use for embolization and sclerotherapy is associated with:

A. Hemolysis, the severity of which does not correlate with total administered dose
B. Intoxication, the severity of which does not correlate with total administered dose
C. Coagulopathy that frequently requires treatment with fresh-frozen plasma
D. Cardiovascular collapse due to right heart failure

3. A former 31-week premature patient who is now 36 weeks is being brought from the neonatal intensive care unit to the operating room for removal of a tunneled central line. The patient chronically requires 1 L nasal cannula to maintain oxygen saturation greater than 90%. Considerations for the intraoperative care of this patient should include:

A. Liberal fluid hydration
B. Mechanical ventilation with 8–10 mL/kg tidal volume
C. Preoperative echocardiography
D. Permissive hypocapnia

4. A 5-year-old boy in respiratory failure with the onset of 5 days ago, is brought to the interventional radiology suite from the intensive care unit for placement of a peripherally inserted central catheter (PICC) line. He is intubated and his ventilator his ventilator settings are a FiO_2 of 0.5 with a PEEP of 5 cm H_2O. On his last arterial blood gas, his PaO_2 was 90 mm Hg. Based on this information, his lung disease is best characterized as:

A. Mild acute respiratory distress syndrome (ARDS)
B. Moderate ARDS
C. Severe ARDS
D. The diagnosis of ARDS cannot be made without additional information.

5. A 1-year-old, otherwise healthy infant requires monitored anesthesia care for magnetic resonance imaging (MRI) to evaluate a possible tethered spinal cord. Hazards associated with MRI scanning for this patient include:

A. Absorption of radiofrequency energy emitted from the MRI machine
B. Risk of hearing loss if ear protection is not used
C. Systemic fibrosis resulting from intravenous gadolinium contrast
D. Ferromagnetic objects in magnet zone I

6. An otherwise healthy 1-year-old is brought to the operating room for unilateral repair of an inguinal hernia. For this patient, which of the following would be the most effective strategy for maintaining intraoperative normothermia?

A. Fluid warmer
B. Forced air warmer
C. None; under general anesthesia, temperature regulation is well maintained.
D. Heat and moisture exchanger

7. Which patient is most likely to benefit from venous-venous extracorporeal membrane oxygenation?

A. 2-day-old with persistent pulmonary hypertension

B. 8-year-old with cardiovascular collapse from anaphylaxis after administration of vecuronium
C. 3-year-old with ARDS due to influenza A
D. 19-year-old with failure to wean from cardiopulmonary bypass after aortic root replacement

8. Which of the following is most likely needed while anesthetizing a 2.5 kg neonate on ECMO for an open CDH repair?

A. Pressure control ventilation at 7–8 cc/kg at a respiratory rate of 35 breaths per minute
B. Intermittent dosing of 1 μg/kg of fentanyl for intraoperative analgesia
C. Warm ambient temperature in the operating room to maintain patient normothermia
D. Platelet and red blood cell transfusion

9. The organ most often shared by omphalopagus conjoined twins is the:

A. Rectum
B. Brain
C. Heart
D. Liver

10. Which of the following is true regarding intraopertive management for a conjoined twin separation surgery?

A. Cross circulation between may occur between the twins
B. Temperature control is easily managed with controlling the temperature of the operating room
C. One anesthesiologist can care for both patients
D. One central line in Twin A is adequate access for resuscitation of both twins

CHAPTER 25 ANSWERS

1. ANSWER: D

Carbon dioxide is the preferred gas for abdominal insufflation due to the fact that it is not readily combustible, clears quickly from the peritoneum, and does not expand within closed spaces. **Compared with older patients, infants absorb carbon dioxide more quickly from the peritoneum, presumably due to reduced peritoneal fat deposits and a thinner peritoneum.** As a result, during carbon dioxide insufflation, end-tidal and alveolar carbon dioxide increase by up to 20 mm Hg or 20%–50%, necessitating an increase in minute ventilation in order to maintain acid-base homeostasis. If minute ventilation is not adjusted, the subsequent hypercardia can trigger spontaneous respirations in the nonparalyzed patient. **If insufflation pressures exceed venous pressure, massive carbon dioxide embolism can occur with devastating hemodynamic consequences.**

In addition to the effects listed, laparoscopic surgery can have significant impact on many different organ systems.

Pulmonary

- Cephalad displacement of the diaphragm leading to preferential ventilation in the nondependent portions of the lung that may result in V/Q mismatch. The **pneumoperitoneum in conjunction with Trendelenberg positioning may also convert the position of the endotracheal tube (ETT) from being mid-tracheal to a bronchial position**.
- **Decreased pulmonary and thoracic compliance, vital capacity (VC), functional residual capacity (FRC), and closing volume**. This decrement in FRC can also lead to small airway closure and subsequent hypoxemia from V/Q mismatch. The change in pulmonary compliance necessitates higher peak inspiratory pressures. Placing the patient in Trendelenberg will further compromise ventilatory mechanics.
- Potential pneumothorax and pneumomediastinum, especially during surgeries such as fundoplication or hiatal hernia repair where esophageal dissection could result in passages for insufflation gases to cross the diaphragm.

Cardiovascular

- **With abdominal insufflation, there is a biphasic effect on venous return and cardiac output (CO).** At lower insufflation pressures, the splanchnic circulation is compressed, leading to increased venous return while higher pressures lead to inferior vena cava compression and decreased venous return and CO. In children and infants insufflation to pressures of 10–13 mm Hg decreased CO by roughly 13%, although not many changes were noted at intraabdominal pressures of 5 mm Hg.
- Body positioning, particularly head-up positions, can further decrease venous return and CO.

Central Nervous System

- The interaction of increased intraabdominal pressure, hypercarbia, and head-down position can all result in marked increases in intracranial pressure. Therefore, the use of **laparosopy for abdominal surgery should be thoughtfully considered in any patient with elevated intracranial pressure or an existing ventriculoperitoneal shunt.**

Renal Function

- **88% of infants and 33% of children develop oliguria or anuria during laparoscopic abdominal surgery.** The etiology of this phenomenon is multifactorial and includes direct effects of intraabdominal insufflation on kidney perfusion with resultant antidiuretic hormone and endothelin release, both of which lead to decreased urine output. These changes resolve after several hours of desufflation, and fluid loading patients solely on the basis of decreased urine output without any other clinical markers of hypovolemia may result in fluid overload.

KEY FACTS

- Infants absorb carbon dioxide much more readily than older patients from the peritoneum during abdominal insufflation.
- Abdominal insufflation and hypercarbia can have significant effects on multiple organ systems.
  - Decreased pulmonary and thoracic compliance, VC, FRC, and closing volume
  - Biphasic effect on venous return and cardiac output
  - Potential for increased intracranial pressure
  - Oliguria/anuria

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2. ANSWER: D

Although vascular anomalies can be treated with a variety of methods, chemical sclerotherapy is often utilized. The agents commonly used to induce chemical sclerosis include

absolute ethanol (99.9% alcohol), sodium tetradecyl sulfate (STS), doxycycline, and bleomycin. Agents such as **ethanol and STS can result in hemolysis in a dose-dependent manner, and in scenarios that involve treatment of extremities**, **hemoglobinuria manifests only after tourniquet release**. If hematuria is noted, in addition to generous fluid hydration, often a sodium bicarbonate infusion is initiated to alkalinize urine and minimize the potential for hemoglobin to precipitate in the renal tubules.

In addition to development of gradual hemolysis, **with ethanol use there is a rare, but significant risk of cardiovascular collapse**. The mechanism for this sudden collapse is not well elucidated, but it has been reported to occur when there is release of ethanol directly into the systemic venous system and likely involves abrupt increases in pulmonary artery pressure and right heart failure. Ethanol can also be associated with significant nausea and vomiting and can cause dose-related intoxication that is independent of the type or location of the lesion. **Given the potential for intoxication with ethanol treatment, clinicians should be cognizant of the synergistic effects on respiratory depression that ethanol can have with opioid**s.

Though many patients with vascular malformations can have underlying coagulation disturbances, both **ethanol and STS use for sclerotherapy have been associated with the development of coagulation abnormalities**. Patients with preexisting coagulopathy may require a hematology consultation prior to any intervention, while **patients who develop a coagulation abnormality as a result of sclerotherapy rarely require intervention as the coagulopathy is usually self-limited and not clinically relevant**.

It should be noted **that there is the possibility of significant complications with sclerotherapy and embolization procedures,** and there have been reports of highly morbid events such as stroke, cerebral abscess, and pulmonary embolism during the perioperative period. Vascular malformations often involve the face and airway, and **if there is any evidence of undue airway swelling at the conclusion of the procedure despite taking measures to optimize venous drainage (i.e., head-up position, minimizing valsalva), the patient should remain intubated until there is clinical improvement in swelling**. Even when swelling has subsided, if there is any concern that the patient may not be able to maintain airway patency following extubation, the patient should be transferred to the main operating room for extubation.

KEY FACTS

- Ethanol and STS can result in hemolysis in a dose-dependent manner.
- Ethanol use can be associated with rare, but significant risk of cardiovascular collapse.
- Ethanol and STS can be associated with development of coagulopathy that is usually self-limited and not clinically relevant.
- Ethanol treatment can cause intoxication and synergistic respiratory depression with opioids.
- Treatment for vascular anomalies involving the airway can result in significant swelling that may preclude safe extubation at the end of the procedure.

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3. ANSWER: C

This patient meets criteria for bronchopulmonary dysplasia (BPD). **BPD is a form of chronic lung disease associated with many factors, including prematurity, mechanical ventilation, and oxygen toxicity.** BPD is defined in Table 25.1.

Table 25.1 BRONCHOPULMONARY DYSPLASIA (BPD)

Gestational Age	<32 weeks	≧32 weeks
Time of assessment	36 weeks PMA or discharge to home, whichever comes first	>28 days but <56 days postnatal age or discharge to home, whichever comes first
	Treatment with oxygen >21% for at least 28 days **plus**	
Mild BPD	Breathing room air at 36 weeks post-menstrual age (PMA) or discharge, whichever comes first	Breathing room air by 56 days postnatal age or discharge, whichever comes first
Moderate BPD	Need for <30% oxygen at 36 weeks PMA or discharge, whichever comes first	Need for <30% oxygen at 56 days postnatal age or discharge, whichever comes first
Severe BPD	Need for ≥30% oxygen and/or positive pressure (PPV or NCPAP) at 36 weeks PMA or discharge, whichever comes first	Need for ≥30% oxygen and/or positive pressure (PPV or NCPAP) at 56 days postnatal age or discharge, whichever comes first

Prior to the introduction of surfactant therapy, the prominent findings of BPD, also called "old BPD," were airway injury, inflammation, and parenchymal fibrosis due to oxygen toxicity and chronic mechanical ventilation. With the institution of surfactant treatment, the primary pathologic finding of "new BPD" is secondary to disruption of normal lung development, leading to fewer and larger alveoli and reduced surface area for gas exchange. Even with surfactant therapy, patients with severe BPD can manifest signs of "old BPD."

In **BPD patients who require mechanical ventilation, lung-protective ventilation with small tidal volumes, positive end-expiratory pressure (PEEP), and if necessary permissive hypercapnia should be utilized to avoid additional lung injury**. Patients with BPD typically develop obstructive pulmonary disease and airway hyperreactivity that may require a lower I:E ratio and treatment for any acute increases in airway resistance. Ventilatory parameters should also take into account potential chronic hypercapnia and metabolic compensation.

BPD patients are also managed with fluid restriction and diuretics to minimize pulmonary edema and optimize pulmonary compliance. Intraoperative management should avoid excess fluids that could lead to a deterioration in lung function. If the patient is on chronic diuretic therapy, electrolytes should be checked and corrected as needed prior to presenting to the operating room.

Pulmonary hypertension (PH) is often a sequelae of BPD, with a prevalence of up to 25%–35%**,** and is thought to occur as a result of disrupted development of the pulmonary circulation leading to ventilation/perfusion mismatch, hypoxemia, and increased pulmonary vascular resistance and reactivity. In particular, continued need for ventilatory support, oxygen requirement out of proportion to presumed lung disease, cyanotic episodes, failure to thrive, and chronic hypercarbia are often associated with PH; **echocardiography should be performed to assess for PH in BPD patients**.

KEY FACTS

- BPD is a form of chronic lung disease associated with many factors, including prematurity, mechanical ventilation, and oxygen toxicity.
- Mechanical ventilation for patients with BDP should employ lung-protective ventilation with low tidal volumes, PEEP, and permissive hypercapnia.
- PH is often a sequelae of BPD, with a prevalence of up to 25%–35%.
- Echocardiography should be performed to assess for PH in BPD patients.

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4. ANSWER: D

Based on the information given, it is possible that the patient can have other etiologies of respiratory failure than ARDS.

The Berlin definition of ARDS requires that all of the following criteria be present to diagnose ARDS:

1. Respiratory symptoms must have begun within 1 week of a known clinical insult, or the patient must have new or worsening symptoms during the past week.
2. Bilateral opacities consistent with pulmonary edema must be present on a chest radiograph or computed tomographic (CT) scan. These opacities must not be fully explained by pleural effusions, lobar collapse, lung collapse, or pulmonary nodules.
3. The patient's respiratory failure must not be fully explained by cardiac failure or fluid overload. An objective assessment to exclude hydrostatic pulmonary edema is required if no risk factors for ARDS are present.
4. A moderate to severe impairment of oxygenation must be present, as defined by the ratio of arterial oxygen tension to fraction of inspired oxygen (PaO_2/FiO_2).

The degree of hypoxemia defines the severity of ARDS:

- Mild ARDS—The PaO_2/FiO_2 is >200 mm Hg, but ≤300 mm Hg, on ventilator settings that include positive end-expiratory pressure (PEEP) or continuous positive airway pressure (CPAP)
- Moderate ARDS—The PaO_2/FiO_2 is >100 mm Hg, but ≤200 mm Hg, on ventilator settings that include PEEP ≥5 cm H_2O
- Severe ARDS—The PaO_2/FiO_2 is ≤100 mm Hg on a ventilator setting that includes PEEP ≥5 cm H_2O.

This patient would need to also have criteria 2 and 3 present to meet the diagnostic requirements for ARDS. If these two conditions were met, the patient would be classified as having moderate ARDS (PaO_2/FiO_2 = 180 mm Hg on PEEP of 5 cm H_2O).

Perioperative care of patients with ARDS should not only include **continued treatment for the primary etiology for the development of ARDS** (i.e., sepsis, aspiration pneumonitis, trauma, transfusion related, etc.) but also, whenever possible, continue the **supportive care measures initiated in the intensive care unit (ICU)**. These **supportive measures include lung-protective ventilatory strategies, limiting FiO_2 when feasible, conservative fluid**

management in the absence of hypotension or other organ system dysfunction, and glycemic control. In addition, the operating room team should receive structured handover from the ICU care team in order to obtain updated, comprehensive, and individualized goals of care for the patient.

KEY FACTS

- The degree of hypoxemia defines the severity of the ARDS.
- Mechanical ventilation for patients with ARDS should employ lung-protective ventilation with low tidal volumes, PEEP, and permissive hypercapnia.
- Anesthetic care should aim to continue (1) supportive care measures initiated in the ICU and (2) treatment for the primary etiology of ARDS.

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5. ANSWER: B

Due to the inability for many children to cooperate with the need for the degree of immobility necessary for an effective MRI scan, anesthesia is frequently needed to obtain optimal imaging conditions and is fraught with many challenges. The MRI scanners are often far away from the support of the main operating rooms, and **the requirement for an MRI-compatible environment can result in anesthesia equipment and workspace configuration that is significantly different from that of the normal operating room.**

Though **body surfaces absorb radio frequency energy that can result in minimal increases in body temperature, the MRI field is not believed to lead to direct biologic injury**. However, there are many potential dangers for patients and medical personnel while in the active zone of the MRI magnet. Cycling the MRI radiofrequency generators on and off produces noise in excess of 90 decibels, and **all persons within the scanning room are required to wear ear protection.** Due to electromagnetic induction, **monitoring wires can generate heat and lead to potential patient thermal injury.** However, **the gravest risk of the MRI environment is the potential for any ferromagnetic object, including implanted biologic devices, to act as a projectile if placed in close enough proximity to the magnet.** Because of these risks, the MRI work area is typically divided into four zones that serve to restrict access to the magnet room.

Zone I: Freely accessible to the public

Zone II: Typically the interface area between zone I, which is accessible to the public and zone III. Often this is where patient intake, history, and examination are performed. Movement of non-MRI personnel is supervised by MRI personnel.

Zone III: The area within which the introduction of ferromagnetic objects may form a hazard.

Zone IV: The scanner room, which is generally physically separated from zone III. Ferromagnetic objects in this zone have the potential to act as dangerous projectiles.

Regarding Answer C, nephrogenic systemic fibrosis (NSF) is associated with the administration of intravenous gadolinium. The primary risk factor for developing NSF is renal failure.

KEY FACTS

- Anesthesia equipment and workspace configuration in the MRI suite can be significantly different from that of the normal operating room and can complicate patient care.
- The MRI field is not believed to lead to direct biologic injury.
- Patients with renal failure can be at risk for nephrogenic systemic fibrosis with administration of gadolinium contrast.
- Noise from the MRI scanner can lead to hearing damage in the absence of hearing protection.
- The greatest risk of the MRI environment is the potential for any ferromagnetic object to act as a projectile if placed in close enough proximity to the magnet.

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6. ANSWER: B

Normally, core body temperature is maintained within a very narrow range of a few tenths of a degree of normal body temperature. In response to hypothermia, behavioral (putting on extra warm clothing or moving to a warmer environment) or autonomic changes are initiated in an attempt to maintain normothermia. The first autonomic response of the body to hypothermia is to vasoconstrict acral regions of the body (fingers and toes) in order to conserve core heat. If despite vasoconstriction, temperature continues to decline, older children and adults begin to shiver, which can increase basal heat production by 50%–100%. **Neonates**

and infants do not have adequate muscle mass for shivering to result in clinically significant heat production, but instead rely on nonshivering thermogenesis of "brown fat" located in the perirenal and subscapular areas of the body to augment heat production. Nonshivering thermogenesis is not thought to meaningfully contribute to thermoregulation in adults and older children.

Under the influence of general anesthesia, there is a characteristic decline in temperature. Initially, with the induction of anesthesia, vasodilation occurs and with this the central core compartment expands to include parts of the periphery that are at a cooler temperature, resulting in a net decrease in core temperature. In addition, under anesthesia, thermoregulatory defense mechanisms such as behavioral responses and, if muscle relaxants are used, autonomic responses such as shivering are not available. **Further predisposing patients to hypothermia is the fact that in the thermoregulatory mechanisms that remain, the temperature set point at which they are initiated occurs at a lower temperature than in the awake state.**

Even mild hypothermia is associated with adverse side effects. With the return of consciousness, the set point for thermoregulatory mechanisms reverts to those of the normal awake state, and postoperatively hypothermic patients often begin shivering and report significant thermal discomfort. Mild intraoperative hypothermia has also been associated with increased rates of wound infections, impaired wound healing, and increased surgical bleeding due to altered coagulation secondary to hypothermia. Lastly, hypothermia can increase the plasma concentrations of certain intravenous drugs and prolong the action of muscle relaxants.

Though patients are susceptible to intraoperative heat loss, core temperature can be maintained through readily available measures. **The majority of heat transfer from the body is through cutaneous losses and can be greatly decreased by the use of radiant heat warmers, warm blankets, and particularly forced air warmers.** Administering room-temperature fluids and refrigerated blood products can reduce core body temperature, and warming these fluids, as well as fluids used for irrigation and moist packing, to body temperature prior to administration can prevent heat loss. **Children have a much higher minute ventilation/kilogram ratio than adults**, and therefore they lose a higher proportion of heat in humidifying and heating dry-cool air from the anesthesia circuit. Simply **reducing fresh gas flows and utilizing a heat and moisture exchanger (HME) can significantly reduce respiratory heat losses**. Patients also experience radiative, convective, and conductive heat transfer due to the lower temperature of the surrounding operating room environment, and raising the ambient temperature can mitigate these losses.

KEY FACTS

- Neonates and infants rely on nonshivering thermogenesis with "brown fat" rather than shivering to increase heat production.
- Even mild hypothermia is associated with adverse side effects.
- The majority of heat transfer is through cutaneous losses.

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7. ANSWER: C

ECMO can provide long-term cardiopulmonary support. There are two types of ECMO: **venovenous (VV),** which provides only pulmonary support (gas exchange), and **venoarterial (VA),** which provides both pulmonary and hemodynamic support (Table 25.2).

Clinical indications for EMCO include hypoxemic respiratory failure, hypercapnic respiratory failure, refractory cardiogenic shock, cardiac arrest, failure to wean from cardiopulmonary bypass, and as a bridge to longer term support such as lung/heart transplant or placement of a ventricular assist device. **In neonates the following disease states may be treated with ECMO**: meconium aspiration syndrome, respiratory distress syndrome (RDS), sepsis, persistent pulmonary hypertension of the newborn (PPHN), and congenital diaphragmatic hernia.

Answer C is the only instance in which the patient would not require cardiovascular support in addition to pulmonary support.

KEY FACTS

- There are two types of ECMO: VV, which provides only pulmonary support (gas exchange), and VA, which provides both pulmonary and hemodynamic support.
- Clinical indications for EMCO include hypoxemic respiratory failure, hypercapnic respiratory failure, refractory cardiogenic shock, cardiac arrest, failure to wean from cardiopulmonary bypass, and as a bridge to longer term support such as lung/heart transplant or placement of a ventricular assist device.
- In neonates the following disease states may be treated with ECMO: meconium aspiration syndrome, RDS, sepsis, PPHN, and congenital diaphragmatic hernia.

Table 25.2 EXTRACORPOREAL MEMBRANE OXYGENATION (ECMO)

	VA ECMO	VV ECMO
Cannulation site	Vein - Internal jugular - Femoral artery	Single cannulation -Internal jugular - Right atrium
	Axillary: - Right common carotid - Femoral - Aorta	Double cannulation - Jugular-femoral - Femoro-femoral - Sapheno-saphenous
Arterial PaO_2	60–150 mm Hg	45–80 mm Hg
Indicators of O_2 sufficiency	Mixed venous oxygen consumption ($mSvO_2$) PaO_2 Calculated oxygen consumption	SaO_2 and PaO_2 Cerebral venous saturation Pre-membrane saturation trend
Cardiac effects	Preload: decreased Afterload: increased Pulse pressure: lower CVP: varies Coronary O_2: varies LV blood desaturated Cardiac stun syndrome	May reduce RV afterload Rest unaffected
O_2 delivery capacity	High	Moderate
Circulatory support	Partial to complete	No direct support, increased O_2 delivery to coronary and pulmonary circuit → improving cardiac output

ECMO, extracorporeal membrane oxygenation; VA, veno-arterial; VV, veno-venous.
SOURCE: From Chauhan S, Subin S. Extracorporeal membrane oxygenation, an anesthesiologist's perspective: physiology and principles. Part 1. *Ann Card Anaesth*. 2011;14:218–2.

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Chauhan S, Subin S. Extracorporeal membrane oxygenation—an anesthesiologist's perspective—Part II: clinical and technical consideration. *Ann Card Anaesth*. 2012;15:69–82.

Dalton HJ, Menon S. Extracoporeal life support. In: Fuhrman BP, Zimmerman JJ, eds. *Pediatric Critical Care*. 4th ed. Philadelphia, PA: Saunders Elsevier; 2011:717–737.

Mossad EB, Motta P, Rossano J, Hale B, Morales DL. Perioperative management of pediatric patients on mechanical cardiac support. *Paediatr Anaesth*. 2011;21(5):585–93.

8. ANSWER: D

Extracorporeal membrane oxygentation (ECMO) provides long-term mechanical pulmonary and cardiac support.

The major components of an ECMO machine are a roller pump/centrifugal pump, oxygenator, heat exchanger, tubing, and bladder reservoir.

While on ECMO patients need to be **anticoagulated to prevent clotting of the ECMO circuit and also to reduce the risk of thromboembolism**. Therefore, any condition that would be devastating with initiation of anticoagulation such as intracerebral hemorrhage would be a contraindication to ECMO. **Other potential contraindications to ECMO** are irreversible respiratory/cardiac failure where transplant or long-term assist device (VAD) is not possible, extremes in age, significant neurologic dysfunction, or other coexisiting terminal disease. Additionally, **the ECMO circuit activates platelets** leading to thrombocytopenia, usually requiring transfusion.

Since the work of oxygenation and CO_2 removal is being done by the ECMO machine, the goal of patient ventilation should be to provide lung rest. This means that the patient's ventilation should be with low tidal volumes and at low rates.

Fluid management should take into account the additional volume required by the ECMO circuit; for example, the volume of the ECMO circuit in a neonate may be 400–500 mL, which can be 1–2 times the patient's own blood volume. Drug dosing may be challenging due to the increased volume, but there is also variable absorption of drugs by the ECMO tubing. This can lead to altered and

Table 25.3 **FIVE MAJOR CATEGORIES OF ANATOMIC LOCATION OF CONNECTION BETWEEN CONJOINED TWINS**

NAME	ROOT MEANING	POSSIBLE SHARED STRUCTURES
Thoracopagus	"chest"	Pericardium, heart, upper GI tract, liver and biliary system It is common for these patients to have congenital heart defects
Omphalopagus or xiphopagus	"umbilicus"	Liver and biliary system and upper GI tract
Pygopagus	"rump"	Lower GI tract, genitourinary system, nervous system
Ischiopagus	"hip"	Liver and biliary system, upper GI tract, lower GI tract, urogenital system
Craniopagus	"helmet"	Brain and other portions of the nervous system

Note. Thoracopagus and omphalopagus can occur together.

Source: From Spitz L, Kiely EM, Pierro A. Conjoined Twins. In: Coran AG, ed. *Pediatric Surgery*. 7th ed. Philadelphia, PA: Saunders Elsevier; 2012:1725–38.

unpredictable drug pharmacokinetics. Lipophilic drugs such as midazolam and fentanyl seem to have the greatest sequestration by the ECMO circuit.

KEY FACTS

- ECMO provides long-term mechanical pulmonary and cardiac support.
- The major components of an ECMO machine are a roller pump/centrifugal pump, oxygenator, heat exchanger, tubing, and bladder reservoir.
- Any condition that would be devastating with initiation of anticoagulation such as intracerebral hemorrhage would be a contraindication to ECMO.
- Other potential contraindications to ECMO are irreversible respiratory/cardiac failure where transplant or long-term assist device (VAD) is not possible, extremes in age, significant neurologic dysfunction, or other coexisiting terminal disease.

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Dalton HJ, Menon S, Extracoporeal life support. In: Fuhrman BP, Zimmerman JJ, eds. *Pediatric Critical Care*. 4th ed. Philadelphia, PA: Saunders Elsevier; 2011:717–737

Mossad EB, Motta P, Rossano J, Hale B, Morales DL. Perioperative management of pediatric patients on mechanical cardiac support. *Paediatr Anaesth*. 2011;21(5):585–93.

Shekar K, Roberts JA, McDonald CI, et al. Sequestration of drugs in the circuit may lead to therapeutic failure during extracorporeal membrane oxygenation. *Crit Care*. 2012;16(5):R194.

Conjoined twins are named by the **anatomic location** of their connection followed by the Greek suffix *–pagus*, which means fixed or joined. The five major categories are listed in Table 25.3 and listed from **most to least common.**

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9. ANSWER: D

Depending on the connections and shared structures of conjoined twins, the amount of cross circulation that occurs between the two patients will be variable. **Cross circulation can have an impact on fluid management, drug dosing/drug effects, and on hemodynamics**. Prior to undergoing separation, there should be an understanding of cross circulation and also how fluids and medications delivered to one twin will effect the other. During and after separation, **significant hemodynamic alterations may occur as there is less and less cross communication**. Even if there is significant cross circulation, **each twin** requires both arterial and venous access because cross circulation will be variable as the separation progresses and there will likely be significant fluid and blood product requirements throughout the surgery.

Temperature management during conjoined twin separation can be challenging. A large percentage of the patients' body surface area will be exposed. Any surfaces not included in the surgery should be wrapped and insulated as much as possible to prevent heat loss. **Warm fluids and increasing the operating room temperature can also help maintain normothermia**.

Extensive planning should precede the surgical separation. All team members should participate in simulated dry runs of the surgery so that everyone has a clear understanding of the setup and sequence of events. Each twin should have a

complete operating room team assigned to him or her; this includes nurses, anesthesiologists, and after separation, surgeons. Often, assigning a color to each twin helps keep teams, equipment, and medications separate during separation.

KEY FACTS

- Cross circulation can have an impact on fluid management, drug dosing/drug effects, and on hemodynamics.
- Temperature management can be challenging, and warm fluids and increasing the operating room temperature can help maintain normothermia.

REFERENCE

Spitz L, Kiely EM, Pierro A. Conjoined Twins. In: Coran AG, ed. *Pediatric Surgery*. 7th ed. Philadelphia, PA: Saunders Elsevier; 2012:1725–38.

26.

POSTOPERATIVE PERIOD

Laura A. Downey, Herodotos Ellinas, and Aykut Bilge

1. Which patient has the *highest* risk of postoperative nausea and vomiting (PONV)?

A. 3-year-old male for bilateral hernia repair with sevoflurane and caudal block
B. 4-year-old female for laparoscopic appendectomy with sevoflurane
C. 20-month-old female for myringotomy tube placement with sevoflurane
D. 3-year-old male for laparoscopic orchidopexy with sevoflurane

2. The *most* effective prophylaxis for postoperative nausea and vomiting in pediatric patients is:

A. Ondansetron
B. Droperidol
C. Transdermal scopolamine
D. Metoclopramide

3. Which of the following is a discharge criterion for pediatric ambulatory patients?

A. Pain controlled by oral pain medications
B. Blood pressure +/– 30 mm Hg pre-procedure level
C. Able to tolerate PO intake
D. Observation for 60 min after flumazenil administration

4. Which patient is *most* appropriate to undergo bilateral hernia repair under general anesthesia in an ambulatory setting (discharge home after postanesthesia care unit [PACU] stay)?

A. Gestational age 32 weeks, postconceptual age 56 weeks
B. Gestational age 34 weeks, postconceptual age 54 weeks
C. Gestational age 28 weeks, postconceptual age 44 weeks
D. Gestational age 35 weeks, postconceptual age 44 weeks

5. Which risk factor *most l*ikely contributes to postoperative apnea in a preterm infant?

A. Anemia
B. Postconceptual age
C. Type of anesthetic
D. History of lung disease

6. What is the incidence of postintubation stridor in pediatric patients under age 5 years after undergoing a general anesthetic with an endotracheal tube?

A. 1%–5%
B. 8%–12%
C. 16%–20%
D. 24%–29%

7. There is a 2-year-old boy with a history of severe cerebral palsy and developmental delay in the PACU. Which method is the best for appropriately assessing this patient's pain level?

A. Numerical Rating Scale
B. Wong Baker Faces Pain Rating Scale
C. Face, Legs, Activity, Cry, Consolability Scale
D. McGill Pain Scale Tool

8. What age group is at the highest incidence for emergence agitation?

A. 0–1 years
B. 1–3 years
C. 2–9 years
D. 8–14 years

9. Which of the following is *most* likely associated with emergence agitation?

A. Orchidopexy
B. Preoperative anxiety
C. Age <2 years
D. Parent present induction (PPI)

10. Which of the following is *most* likely to reduce the risk of emergence agitation?

A. Ketamine
B. Preoperative midazolam
C. Nitrous oxide
D. Dexmedetomidine

11. Which of the following is a risk factor for postoperative emergence agitation?

A. Fentanyl
B. Sevoflurane
C. Ketamine
D. Nitrous oxide

12. What percentage of children under 6 years old with obstructive sleep apnea (OSA) develops a postoperative respiratory complication?

A. 72%–86%
B. 40%–54%
C. 18%–32%
D. 4%–11%

13. Which feature of children with OSA suggests that they will require a reduction in morphine dose due to increased sensitivity to opiates?

A. Body mass index >30 kg/m^2
B. Apnea-hypopnea index of 5–7 events/hr
C. O_2 desaturation nadir less than 85%
D. Age <3 years old

14. Which of the following patients is eligible for same-day discharge following tonsillectomy?

A. 2-year-old, Apnea-Hypopnea Index (AHI) of 3 events/hour, heterozygous Factor V Leiden
B. 2-year-old, AHI of <3 events/hour, body mass index 30
C. 2-year-old, AHI <3 events/hour, no vomiting for 2 hours
D. 3-year-old, AHI <3 events/hour, family history of von Willebrand's disease

15. What is considered the *most* appropriate treatment for postextubation croup?

A. Administration of antibiotics
B. Administration of racemic epinephrine
C. Reintubation
D. Chest X-ray

16. A 5-year-old child is having a magnetic resonance scan (MRI) scan with a propofol infusion. The child is breathing spontaneously, is not responding to verbal or tactile stimuli, but is purposefully responding to painful stimulation. How would you classify the level of sedation/anesthesia in this child?

A. Minimal sedation
B. Moderate sedation
C. Deep sedation
D. General anesthesia

17. A 5-year-old child is in the state of emergence agitation in the recovery room following a minor procedure. Which of the following management options is *most* likely to prevent emergence agitation?

A. Intraoperative dexmedetomidine
B. Intraoperative sevoflurane
C. Intraoperative desflurane
D. Parental presence in recovery room

18. Which one of the following statements correctly represents the diagnosis?

A. It resolves in 1 to 2 hours with no intervention.
B. It is not associated with any harm.
C. Its highest incidence is between 8 and 12 years of age.
D. Its risk is increased with preoperative anxiety.

CHAPTER 26 ANSWERS

1. ANSWER: D

Incidence of PONV varies between 8% and 50%**.** Eberhart noted the following risk factors for PONV: **surgery lasting longer than 30 minutes, age older than 3 years, family or patient history of PONV, and tonsil or strabismus surgery**. Additionally, the peak incidence of PONV in pediatric patients is between **34% and 50% in school-aged children** as compared with adults, and it can be intractable in up to 3% of pediatric patients. A follow up study, excluding patients undergoing strabismus surgery, by Kranke et al demonstrated the incidence of postoperative vomiting was 3.8%, 11.6%, 28.2%, and 42.3%, respectively if zero, one, two, or three risk factors were present. Additional risk factors related to surgery, anesthesia, and patient factors are listed in Table 26.1. The 3-year-old male undergoing laparoscopic orchidopexy with a volatile anesthetic has four potential risk factors that make him the highest risk for PONV.

KEY FACTS

- Incidence of PONV varies between 8% and 50%.
- Risk factors for PONV: surgery lasting longer than 30 minutes, age older than 3 years, family or patient history of PONV, and tonsil or strabismus surgery.
- The peak incidence of PONV in pediatric patients is between 34% and 50% in school-aged children.

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Polaner D. Anesthesia for same-day procedures In: Davis P, Cladis FP, Motoyama EK, eds. *Smith's Anesthesia for Infants and Children*. 8th ed. Philadelphia, PA: Mosby Elsevier; 2011:1058–76.

Kranke P, Eberhart LH, Toker H, et al. A prospective evaluation of the POVOC score for the pre- diction of postoperative vomiting in children. *Anesth Analg* 2007;105:1592–7.

2. ANSWER: A

The most common medications for treatment and prophylaxis are currently the **HT3-antagonists (ondansetron and granisetron)** and **dexamethasone, especially when used in combination. While as effective as ondansetron,** droperidol should only be used in children if other therapies have failed due to a rare association with torsade de pointes from undiagnosed prolonged QT interval. Dose-response studies of ondansetron suggest that for maximal efficacy, **prophylactic doses of 0.1–0.15 mg/kg** up to 4 mg should be administered. Dexamethasone is effective for PONV prophylaxis, usually at a dose of 0.25 mg/kg. Metoclopramide is a weak anti-emetic and at low doses is not effective at reducing POV. At higher doses, it may be as effective as ondansetron or dexamethasone, but the side effect profile of extrapyramidal effects make this a second-line therapy. **Transdermal scopolamine** is an appropriate prophylactic antiemetic for adult patients or pediatric patients over 12 years old. The transdermal patch is 1.5 mg/disc and as a transdermal medication, it is not approved for patients under 40 kg. For prophylactic antiemetic doses in children, the IV, IM, or subcutaneous scopolamine doses are 6 μg/kg per dose with a maximum of 0.3 mg/dose that can be repeated every 6–8 hours. Side effects of anticholinergics include sedation, blurry vision, constipation, and dry mouth, which may be undesirable.

Current ASA guidelines recommend 1) reducing baseline risks (avoidance/reduction of volatile anesthetics, nitrous oxide and post-op opioids), 2) multimodal approach with more than 2 interventions for high risk pediatric patients, 3) and using a different class of anti-emetic if prophylaxis fails. For patients with multiple risk factors for PONV, several studies suggest that a combination of dexamethasone and ondansetron is the most effective in preventing PONV. Finally, using

TABLE 26.1 **ADDITIONAL RISK FACTORS FOR POSTOPERATIVE NAUSEA AND VOMITING RELATED TO SURGERY, ANESTHESIA, AND PATIENT FACTORS**

SURGICAL FACTORS	ANESTHETIC FACTORS	PATIENT FACTORS
Adenotonsillectomy	Volatile agents	Prior history of PONV
Middle ear surgery	Use of nitrous oxide	History of motion sickness
Testicular surgery	Use of opioids	Age over 2 years
Laparoscopic surgery	Insufflation of the stomach (difficult mask)	Girls > boys (postmenarche)
Insufflation of the bowel (endoscopy)	Reversal of neuromuscular blockade	
Surgery longer than 30 min	Unrelieved pain	

SOURCE: Adapted from Polaner D. Anesthesia for same-day procedures In: Davis P, Cladis FP, Motoyama EK, eds. *Smith's Anesthesia for Infants and Children*. 8th ed. Philadelphia, PA: Mosby Elsevier; 2011:1058–76.

a propofol infusion to avoid volatile anesthetics or as a background low-dose infusion may decrease the incidence of PONV.

KEY FACTS

- The most common medications for PONV treatment and prophylaxis are currently the HT3-antagonists (ondansetron and granisetron) and dexamethasone.
- For patients with multiple risk factors for PONV, several studies suggest that a combination of dexamethasone and ondansetron was the most effective in preventing PONV.

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Rose JB, Watcha MF. Postoperative nausea and vomiting in paediatric patients. *Br J Anaesth*. 1999;83:104–17.

Gan T, Diemunsch P, Habib AS, et al. Consensus guidelines for the management of postoperative nausea and vomiting. *Anesth Anal*. 2014;118(1):85–113.

3. ANSWER: A

Pain controlled by oral medications. Pediatric ambulatory patients must be appropriate to be discharged from the recovery room using several criteria included in the postanesthesia recovery score. **The postanesthesia recovery score** includes evaluation of **motor activity, respiratory status (i.e., respirations and room air saturations), hemodynamic status (i.e., specifically blood pressure), and consciousness** (Box 26.1). Each category is given a score and patients with scores of 9–10 are eligible to be discharged home unless otherwise approved by a physician. Patients who are planning to be discharged home have more strict criteria that include the following: (1) stable cardiovascular and respiratory status, (2) patient is easily arousable and protective reflexes are intact, (3) patient can talk (if age appropriate), (4) patient can sit up if age appropriate, (5) patients with developmental delay should be evaluated based on their preanesthetic abilities and be as close to normal levels as possible, (6) nausea and vomiting are well controlled, (7) hydration state is adequate but does not necessarily mean the patient needs to take oral hydration as this may induce nausea/vomiting, and (8) pain is controlled via oral medications.

KEY FACT

- The postanesthesia recovery score includes evaluation of motor activity, respiratory status (i.e., respirations

Box 26.1 **POSTANESTHESIA RECOVERY SCORE**

Motor Activity

Active voluntary motion on command = 2
Weak voluntary motion on command or any no purposeful motion = 1
No motion = 0

Respiration

Coughing on command or crying = 2
Maintaining good airway = 1
Airway requires maintenance = 0

Blood Pressure

BP ± 20 mm Hg of preprocedure level = 2
BP ± 20–50 mm Hg of preprocedure level = 1
BP ± 50 mm Hg of preprocedure level = 0

Consciousness

Fully awake or easily arousable on calling = 2
Responding to stimuli and presence of protective reflexes = 1
Not responding or absence of protective reflexes = 0

Room Air Saturation

100%–98% = 2
97%–95% = 1
<95% = 0

Maximum Score Equals 10

SOURCE: Modified from Blum RH. *Discharge Guidelines for Ambulatory Surgery Patients Post Anesthesia Care Unit*. Children's Hospital Practice Guideline; 2004.Discharge Criteria (Inpatients)

1. Recovery of airway and respiratory reflexes adequate to support gas exchange and to protect against aspiration of secretions, vomitus, or blood.
2. Stability of circulation and control of any surgical bleeding.
3. Absence of anticipated instability in above categories 1 and 2.
4. Reasonable control of pain and vomiting.
5. Appropriate duration of observation after narcotic or naloxone/flumazenil administration (a minimum of 60 minutes after intravenous naloxone and up to 2 hours following flumazenil).

Additional Criteria (Outpatients)

1. Cardiovascular function and airway patency are satisfactory and stable.

2. The patient is easily arousable, and protective reflexes are intact.
3. The patient can talk (if age appropriate).
4. The patient can sit up unaided (if age appropriate).
5. For a very young or handicapped child, incapable of the usual expected responses, the preanesthetic level of responsiveness, or a level as close as possible to the normal level for that child should be achieved unless the child is to be transferred to another monitored location.
6. The state of hydration is adequate.
7. It may be permissible for parents to carry their children without full recovery of gait (parents must be advised that the child is at risk of injury if improperly supervised).
8. Control of pain to permit adequate analgesia via the oral route thereafter.
9. Control of nausea and vomiting to allow oral hydration. Oral hydration is not absolutely required and forcing fluids may result in increased vomiting in the PACU or on the way home.

and room air saturations, hemodynamic status (i.e., specifically blood pressure), and consciousness.

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4. ANSWER: A

Premature and former premature infants are at risk for developing **postoperative apnea** after elective surgery, and most centers agree that **preterm patients born at less than 36 weeks gestational age should be admitted overnight for observation** if the postconceptual age (PCA = gestational age + postnatal age) is **<56 weeks**. Postoperative apnea is defined as cessation of breathing for **20 seconds** or more. Prematurity is defined as **birth before 37 weeks gestation**. While there appear to be several contributors to postoperative apnea, including **hypoglycemia, hypoxia, hypothermia, anemia, and hypocalcemia**, it is thought that preterm infants have a **less developed central nervous system** that is more susceptible to residual anesthesia in the postoperative period. Several studies have sought to elucidate a clear time point when preterm patients are beyond the risk for postoperative apnea. Most studies have found an inverse relationship between postconceptual age and the incidence of apnea. A meta-analysis to stratify the postoperative apnea risk, found that PCA required to reduce the risk to less than 1% with 95% confidence was **54 weeks in infants born at 35 weeks gestational age and 56 weeks for preterm infants born before 32 weeks gestation**. While this is somewhat dependent on the type of surgery, the patient's gestational age and postconceptual age, hematocrit, and current cardiorespiratory function, it is felt that preterm infants (gestational age <36 weeks) who are less than postconceptual age of 56 weeks should be observed for 12–24 hours postoperatively.

KEY FACTS

- Preterm patients born at less than 36 weeks gestational age should be admitted overnight for observation if the postconceptual age (gestational age + postnatal age) is <56 weeks.
- Risk factors for postoperative apnea includle hypoglycemia, hypoxia, hypothermia, anemia, and hypocalcemia.

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Polaner D. Anesthesia for same-day procedures In: Davis P, Cladis FP, Motoyama EK, edd. *Smith's Anesthesia for Infants and Children*. 8th ed. Philadelphia, PA: Mosby Elsevier; 2011:1058–76.

5. ANSWER: A

As discussed in the answer to question 4, ex-premature infants are at increased risk for postoperative apnea after general anesthesia. While there are many factors that may contribute to the postoperative apnea, including **hypoxia, hypothermia, anemia, hypocalcemia, cardiopulmonary respiratory status, and neurologic status**, it has been demonstrated that there is **an inverse relationship** between **postconceptual age and incidence of apnea**. However, it is thought that sedative medications used during anesthesia may cause further central nervous system depression in an immature neurologic system that includes the respiratory center. Low dose halothane has been shown to **depress the chemoreceptors to hypoxia**. Volatile anesthetics may lead to prolonged periods of post-operative apnea as they 1) depress normal respiratory response to hypoxia and hypercarbia, 2) impair intercostal muscle

function and 3) reduce the functional residual capacity. As the risk of apnea is likely related to an interaction between **the immaturity of the respiratory center in the brainstem and medications**, any sedative-hypnotic agents such as narcotics and IV anesthetics (i.e., propofol, ketamine) are associated with similar risks of postoperative apnea.

KEY FACTS

- Factors that may contribute to the postoperative apnea include hypoxia, hypothermia, anemia, hypocalcemia, cardiopulmonary respiratory status, and neurologic status.
- There is an inverse relationship between postconceptual age and incidence of apnea.

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6. ANSWER: A

Pediatric patients requiring an endotracheal tube (ETT) during surgery may develop postoperative stridor. Depending on the paper examined, the rate of **postintubation stridor** in pediatric patients under age 5 years with an endotracheal tube is estimated between **1% and 5%.** Controversy remains whether pediatric patients should be intubated with a cuffed or uncuffed ETT. Traditionally, patients were intubated with uncuffed ETTs to achieve an appropriate seal to allow ventilation, but with a **leak at peak inspiratory pressures >25 cm H_2O**. In many cases this required multiple laryngoscopies and tube changes. However, with improvements in low-pressure cuffed ETTs, many practitioners believe that it is less traumatic to place a cuffed ETT and inflate the pilot balloon to achieve an appropriate seal as long as the cuff pressure is <20 cm H_2O. A study published in the BJA (2009) found no difference in postoperative stridor in a study of 2246 children (1119 cuffed/1127 uncuffed). Postextubation stridor was noted to be 4.4% in patients with cuffed ETTs and 4.7% in uncuffed ETTs. Of note, 2.1% of patients with cuffed tubes require a tube change, while 30.8% of patients with uncuffed tubes required a tube change.

KEY FACTS

- Incidence of postintubation stridor in pediatric patients under age 5 years with an endotracheal tube is between 1% and 5%.
- ETT tube size should ensure that there is a leak present at peak inspiratory pressures >25 cm H_2O.

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Weiss M, Dullenkopf A, Fischer JE, Keller C, Gerber AC. Prospective randomized controlled multi-centre trial of cuffed or uncuffed endotracheal tubes in small children. *Br J Anaesth*. 2009;103(6):867–73.

7. ANSWER: C

Assessing pain in pediatric patients can be challenging as pediatric patients can have different cognitive, verbal, and emotional responses depending on the patient age and the individual patient. Using a patient-appropriate pain assessment tool is important in both assessing and treating pain. Several pain assessment tools have been used in pediatric hospitals and often rely on a combination of self-report, behavioral, and physiologic assessments. The most common self-report tool is the **Numerical Rating Scale, a self-report pain assessment best used in patients at least of school age, where 0 = no pain and 10 = the worst pain you can imagine** (Figs. 26.1–26.3). The **Wong-Baker Faces Pain Rating Scale** can be used in younger children **(3–7 years of age)** by asking the patient to point to one of the faces that

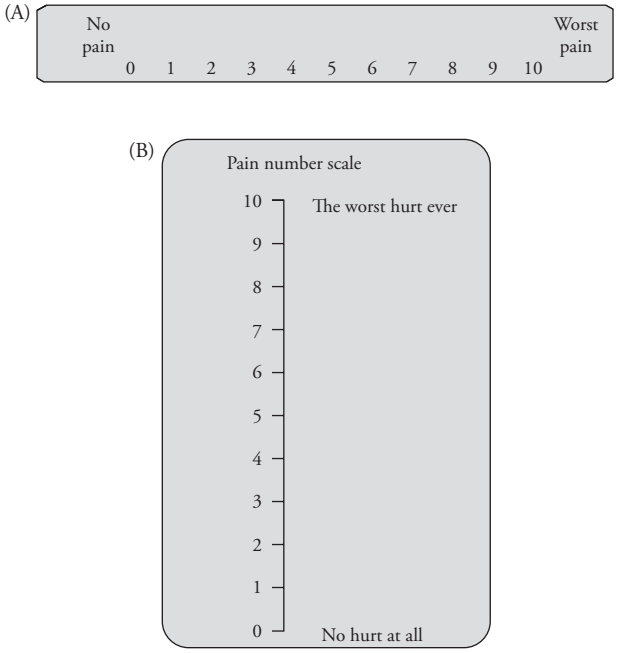

Figure 26.1 Numerical self-report scales. (A) Horizontal Visual Analog Scale. (B) Vertical Visual Analog Scale. (From Malviya, Shobha. In: Cote CJ, Lerman J, Anderson B, eds. *A Practice of Anesthesia for Infants and Children*. 5th ed. Philadelphia, PA: Saunders Elsevier; 2013.)

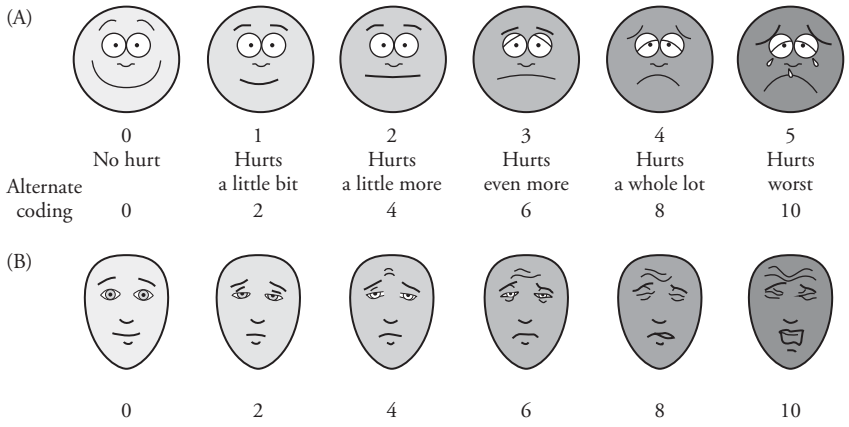

Figure 26.2 (A) The Wong-Baker Faces Pain Scale. (B) The Bieri Faces Pain Scale. (B modified from Bieri D, Reeve RA, Champion GD, et al. The Faces Pain Scale for the self-assessment of the severity of pain experienced by children: development, initial validation, and preliminary investigation for ratio scale properties. *Pain* 1990;41:139–150.)

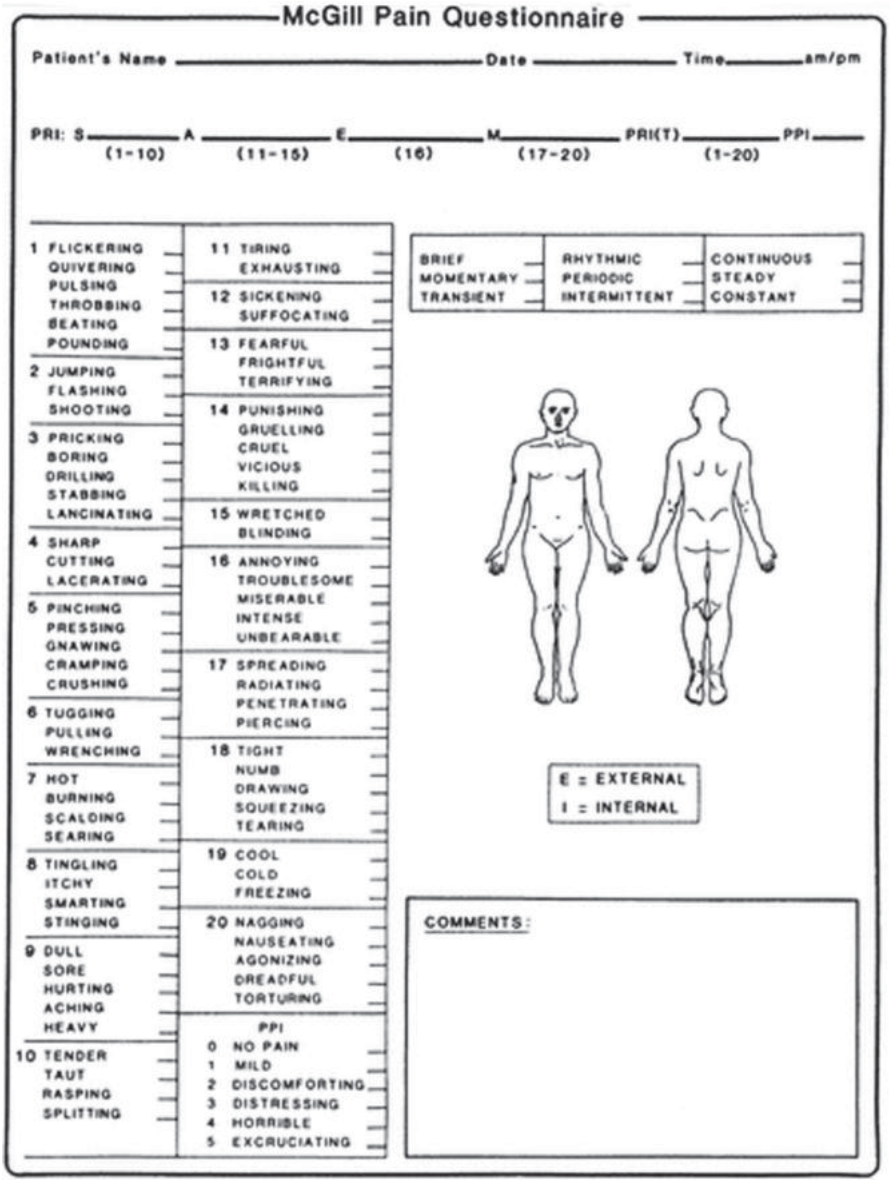

Figure 26.3 Acute Pain. (From Malviya, Shobha. Practice of Anesthesia for Infants and Children, A, 43, 909–950.) Copyright © 2013, 2009, 2001, 1993, 1986 by Saunders, an imprint of Elsevier Inc.

reflects his or her pain. For infants, young toddlers and cognitively impaired children who cannot communicate, it is necessary to use a scale, such as the **FLACC score**, which assesses behavioral and physiologic parameters. The FLACC score assesses the following: face, legs, activity, cry, and consolability. The **McGill Pain Questionnaire** is a list of words grouped together to describe pain. The person ranks the words in each group and then the evaluator assigns a numerical score based on the rankings, called a Pain Rating Index. In this question, the patient is likely unable to verbally communicate his pain level due to developmental delay and severe cerebral palsy. Therefore, it would be necessary to assess his pain using a pain scale tool that does not require patient participation and instead uses objective behavioral and physiologic parameters (FLACC).

8. ANSWER: C

Emergence agitation (EA), also called emergence delirium, is a common problem seen in pediatric anesthesia. Depending on the inclusion criteria and particular study, the incidence has been reported as high as 50% of patients under 10 years of age. EA is defined as a **"state of nonpurposeful restlessness and inconsolability that is often accompanied by thrashing, screaming, prolonged crying, and disorientation."** EA places patients at risk for harming themselves, recovery room staff, or caregivers. EA often prolongs the PACU stay and may tie up staff to care for these patients. Several factors have been identified that increase a patient's risk for developing EA, including **age, surgery type, anesthetic technique, preoperative anxiety, and time to awakening**. Patients under 10 years of age have reported incidence of EA as high as 46% compared with <15% for patients over 10 years. The **highest incidence of EA** is between **2 and 9 years of age**.

KEY FACTS

- EA is defined as a "state of nonpurposeful restlessness and inconsolability that is often accompanied by thrashing, screaming, prolonged crying, and disorientation."
- Risk factors for EA include age, surgery type, anesthetic technique, preoperative anxiety, and time to awakening.

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Voepel-Lewis T, Malviya S, Tait AR. A prospective cohort study of emergence agitation in the pediatric postanesthesia care unit. *Anesth Analg*. 2003;96:1625–30.

9. ANSWER: B

Emergence agitation is a common problem seen in pediatric anesthesia, with reported incidence between 10% and 50% **in patients under 10 years of age**. As noted earlier, many studies have sought to delineate risk factors associated with EA. These risk factors include patient factors, anesthetic technique, and surgical procedure. These are listed in Table 26.2. **Surgical procedures associated with higher incidences of EA are usually ophthalmologic and ENT procedures**. Orchidopexy does not have a particular association with EA. While patients under 2 years may develop EA, the **greatest incidence is seen in patients** 2–9 **years of age**. Having a parent present during induction in itself is not a risk factor for EA. However, preoperative anxiety of the parents may contribute to EA. Of those factors listed, preoperative anxiety in both parents and children, as well as maladaptive behaviors, is most likely associated with EA.

KEY FACTS

- Surgical procedures associated with higher incidences of EA are usually ophthalmologic and ENT procedures.
- Greatest incidence of EA is seen in patients 2–9 years of age.

REFERENCES

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TABLE 26.2 FACTORS THAT INCREASE THE RISK OF POSTOPERATIVE EMERGENCE DELIRIUM

PATIENT FACTORS	ANESTHESIA TECHNIQUE	SURGERY TYPE
Age 2–9	Volatile anesthetics	Otorhinolaryngology
Preoperative anxiety	Sevoflurane	Tonsillectomy
Maladaptive behaviors	Desflurane	Adenoidectomy
Prior history of emergence agitation	Isoflurane	Ophthalmologic procedures
	Time to awakening	Strabismus
	Pain	

Eckenhoff JE, Kneale DH, Dripps, RD. The incidence and etiology of postanesthetic excitement: a clinical survey. *Anesthesiology*. 1961:22:667–73.
Grundmann U, Uth M, Eichner A, et al. Total intravenous anaesthesia with propofol and remifentanil in paediatric patients: a comparison with desflurane-nitrous oxide inhalation anaesthesia. *Acta Anaesth Scand*. 1998;42:845–50.
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Voepel-Lewis T, Malviya S, Tait AR. A prospective cohort study of emergence agitation in the pediatric postanesthesia care unit. *Anesth Analg*. 2003;96:1625–30.

10. ANSWER: D

Preoperative midazolam has conflicting data with some studies demonstrating a decrease in emergence agitation (EA), while other demonstrated an increase in EA. While studies looking at EA in patients undergoing nonpainful procedures (MRI) have demonstrated that these patients also develop EA, Kain et al. found that patients with **higher pain scores tended to have a much higher incidence of EA**. Therefore, narcotics or regional anesthesia is likely to reduce the risk of pain-associated EA. Used intraoperatively, fentanyl (2.5μg/kg) significantly decreased EA in adenoidectomy patients. As mentioned earlier, a total TIVA or propofol anesthetic significantly reduces the risk of EA. Studies have compared propofol and fentanyl as treatment for EA with similar success rates. Patients treated with **fentanyl were more likely to have associated PONV**, while patients who received **propofol were more likely to have a prolonged PACU stay from sedation**. Nitrous oxide does not appear to be a risk factor for emergence delirium, but it has not been shown to significantly reduce the risk of EA. Finally, **dexmedetomidine** has been shown to **significantly reduce the risk of EA**. Patients receiving 0.5–1 μg/kg intravenously for tonsillectomy and adenoidectomy demonstrated significantly reduced incidence of EA and pain scores. Lower doses of dexmedetomidine (0.15 μg/kg) have also been shown to decrease the incidence of EA in patients undergoing other procedures.

KEY FACTS

- Patients with higher pain scores tended to have a much higher incidence of EA.
- Dexmedetomidine has been shown to significantly reduce the risk of EA.

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Weldon BC, Bell M, Craddock T. The effect of caudal analgesia on emergence agitation in children after sevoflurane versus halothane anesthesia. *Anesth Analg*. 2004;98:321–6.

11. ANSWER: B

Emergence agitation (EA) has been described extensively in the pediatric anesthesia literature. It has been defined as **crying, sobbing, thrashing and disorientation in patients after anesthesia**, most often seen in pediatric patients in the recovery room. Several factors have been attributed to patients developing EA, including **age, previous surgery, ophthalmology and ENT procedures, inhaled anesthetics, pain, time to awakening, and preoperative anxiety levels**. While some studies initially found that inhaled agents with lower solubility, such as sevoflurane and desflurane, increased the risk of EA, later studies have demonstrated that isoflurane has a similar profile risk. While studies looking at EA in patients undergoing nonpainful procedures (MRI) have demonstrated that these patients also develop EA, Kain et al. found that patients with **higher pain scores** tended to have much higher incidence of EA. Intraoperative narcotics have been shown to reduce the pain-associated EA. **Although nitrous oxide increases the risk of nausea and vomiting**, it does not appear to be a risk factor for emergence delirium.

KEY FACTS

- Several factors have been attributed to patients developing EA, including age, previous surgery, ophthalmology and ENT procedures, inhaled anesthetics, pain, time to awakening, and preoperative anxiety levels.
- Patients with higher pain scores tended to have a much higher incidence of EA.

REFERENCES

Cole JW, Murray DJ, McAllister JD, Hirshberg GE. Emergence behaviour in children: defining the incidence of excitement and agitation following anaesthesia. *Paediatr Anaesth*. 2002;12:442–7.
Eckenhoff JE, Kneale DH, Dripps, RD. The incidence and etiology of postanesthetic excitement: a clinical survey. *Anesthesiology*. 1961:22:667–73.
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Voepel-Lewis T, Malviya S, Tait AR. A prospective cohort study of emergence agitation in the pediatric postanesthesia care unit. *Anesth Analg*. 2003;96:1625–30.

12. ANSWER: D

Children with obstructive sleep apnea (OSA) are at increased risk of developing postoperative respiratory complications. These types of complications include

oxygen desaturations <90%, apnea, increased work of breathing, pneumothorax, and pulmonary edema. PACU interventions may include insertion of an oral or nasopharyngeal airway, continuous positive-pressure ventilation (CPAP), or reintubation with an endotracheal tube. In a study of pediatric patients undergoing tonsillectomy and adenoidectomy for OSA, 6.4% (149/2315) of patients younger than 6 years old developed a respiratory complication based on the criteria listed earlier. For patients younger than 3 years of age, the risk was even greater—9.8% in children less than 3 versus 4.9% in children ages 3–6 years. Other factors that increase the risk of postoperative respiratory complications include patient factors and anesthetic technique. Underlying comorbidities that increase the risk of postoperative complications **include neuromuscular or neurologic disease, chromosomal abnormalities, craniofacial abnormalities, severe OSA, obesity, echocardiographic evidence of pulmonary hypertension, or an upper respiratory tract infection within 4 weeks of surgery**. Anesthetic factors that may include risk include deep extubation for patients with severe upper airway obstruction and the use of long-acting medications that may depress respiratory drive, such as narcotics.

KEY FACTS

- Postoperative respiratory complications in patients with OSA include oxygen desaturations <90%, apnea, increased work of breathing, pneumothorax, and pulmonary edema.
- Underlying comorbidities that increase the risk of postoperative complications include neuromuscular or neurologic disease, chromosomal abnormalities, craniofacial abnormalities, severe OSA, obesity, echocardiographic evidence of pulmonary hypertension, or an upper respiratory tract infection within 4 weeks of surgery.

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Statham MM, Elluru RG, Buncher R, Kalra M. Adenotonsillectomy for obstructive sleep apnea syndrome in young children: prevalence of pulmonary complications. *Arch Otolaryngol Head Neck Surg*. 2006;132:476–80.

13. ANSWER: C

O_2 desaturation nadir less than 85%. On polysomnography, severe OSA is diagnosed by the following criteria: **apnea-hypopnea index (AHI) > 10 events/hr, oxygen desaturation nadir less than 80%, or both**. Recurrent hypoxemia in children is known to be associated with an increased sensitivity to opiates. While a BMI >30 kg/m^2 may increase the risk of OSA and postoperative airway obstruction, BMI does not independently increase the risk of sensitivity to opiates. Children with a polysomnography study showing an **AHI of 5–7events/hr** is characteristic of a patient with **moderate OSA.** Patients with mild and moderate OSA have the same opiate requirements as otherwise healthy patients without OSA. Age does not determine sensitivity to opiates, unless the child is a neonate or premature with an immature central respiratory center. Patients with **severe hypoxemia preoperatively (nadir <85%)** have been noted to have a **50% reduction in morphine requirements** compared with patients with nadir oxygen saturations >85%. A study by Raghavendran in 2010 showed that when a lower morphine-equivalent dose is administered to tonsillectomy patients with preoperative severe hypoxemia, the number of postoperative medical interventions was significantly decreased (29.6% vs. 11.3%). Medical interventions included bag/mask ventilation, intubation/oral/nasopharyngeal airway insertion, or reversal medication by a physician.

KEY FACTS

- Severe OSA is diagnosed by the following criteria: AHI > 10 events/hr, oxygen desaturation nadir less 80%, or both.
- Patients with severe hypoxemia preoperatively (nadir <85%) have been noted to have a 50% reduction in morphine requirements.

REFERENCES

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14. ANSWER: A

2-year-old, Apnea-Hypopnea Index (AHI) of 3 events/hour, Heterozygous for Factor V Leiden. Tonsillectomy and adenoidectomy is one of the most common

pediatric surgical procedures. The recommendations for T&A include nocturnal upper airway obstruction with or without obstructive sleep apnea (OSA) and chronic tonsillitis. The diagnosis of obstructive sleep apnea syndrome (OSAS) is based on history and physical exam, as well as sleep studies, when indicated. Symptoms include **snoring, increased respiratory efforts, periodic obstructive apnea, and oxygen desaturation while asleep**. While not all patients undergo polysomnography, the severity of the sleep apnea may be ascertained from these results. On polysomnography, **severe OSA** is diagnosed by the following criteria: **apnea-hypopnea index (AHI) > 10 events/hr, oxygen desaturation nadir less than 80%, or both**. Based on the American Academy of Pediatrics clinical practice guidelines, children with OSAS are at high risk for postoperative complications after tonsillectomy and adenoidectomy. The following factors place patients in a high-risk category for postoperative complications and should be used to determine if a patient should be admitted for overnight monitoring:

1. Severe OSAS (AHI > 10 events/hr, oxygen nadir 80%)
2. Age <3 years
3. Craniofacial disorders
4. Neurologic/neuromuscular disorders
5. Cerebral palsy
6. Down syndrome
7. Failure to thrive
8. Morbid obesity
9. Prematurity
10. Cardiac complications of OSAS (right ventricle hypertension)
11. Central hypoventilation syndrome
12. Genetic/metabolic/storage disease
13. Chronic lung disease
14. Bleeding diathesis that may lead to coagulopathy

Based on these criteria, the 2-year-old patients should be admitted for overnight monitoring based on age. While each of the 3-year-old patients do not have severe OSA by polysomnography criteria, the patient with von Willebrand's factor has a risk for bleeding postoperatively. Heterozygous for Factor V Leiden does not confer any increased risk for coagulopathy postoperatively.

KEY FACTS

- Symptoms of OSA include snoring, increased respiratory efforts, periodic obstructive apnea, and oxygen desaturation while asleep.
- The factors listed herein place patients in a high-risk category for postoperative complications and should be a consideration for overnight admission and monitoring.

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15. ANSWER: B

Administration of racemic epinephrine. The incidence of **postoperative croup** is reported to be around 1%–4%. Postextubation stridor was noted to be 4.4% in patients with cuffed ETTs and 4.7% in uncuffed ETTs. The most common cause is the result of an endotracheal tube that is too tight. An **appropriate leak should be less than 25 cm H_2O**. An ETT leak is tested by placing a stethoscope over the larynx until the circuit is slowly pressurized. The pressure at which the leak is auscultated (appropriate is 10–25 cm H_2O) is the "leak." A leak less than 10 cm H_2O suggests that the ETT is too small. A leak greater than 25–30 cm H_2O suggests that the ETT is too tight. Other factors associated with **postintubation croup include traumatic or repeated intubations**, **duration of surgery, movement of the head or neck, or head and neck surgery**. Accepted treatments include cool, **humidified** mist after extubation. For more severe cases, **racemic epinephrine** (0.5 mL of 2.25% solution) delivered by nebulizer helps reduce swelling of mucosa by vasoconstriction. However, a rebound effect can be seen and therefore these patients should be observed for at least 4 hours after treatment. Additionally, treatment with **dexamethasone** has been found to be effective in reducing swelling and postextubation croup, especially in patients intubated longer than 48 hours. Postextubation croup is not related to infections and does not required antibiotic treatment. Usually, postextubation croup does not require reintubation unless the patient is at risk for airway compromise. A chest X-ray is not usually needed because the postextubation croup is related to upper airway swelling. The treatments listed earlier should not be delayed for getting a chest X-ray.

KEY FACTS

- Appropriate ETT leak should be less than 25 cm H_2O.
- Risk factors for postintubation croup include traumatic or repeated intubations, duration of surgery, movement of the head or neck, or head and neck surgery.
- Treatments include humidified mist, racemic epinephrine, and dexamethasone.

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16. ANSWER: C

Definitions of "levels of sedation" have been proposed by the American Academy of Pediatrics (AAP), the American Society of Anesthesiologists (ASA), and the Joint Commission on Accreditation of Healthcare Organizations (JCAHO). Older terminology like "conscious sedation" was confusing and is not used anymore. Current definitions of "levels of sedation" are as follows:

Minimal sedation (anxiolysis)—A drug-induced state during which patients respond normally to verbal commands. Ventilatory and cardiovascular functions are unaffected though cognitive function and coordination are impaired.

Moderate sedation ("conscious sedation")—A drug-induced depression of consciousness during which patients respond purposefully to verbal commands either alone or accompanied by light tactile stimulation. No airway interventions are required for a patent airway, and spontaneous ventilation is adequate. Cardiovascular function is usually maintained.

Deep sedation—A drug-induced depression of consciousness during which patients cannot be easily aroused but respond purposefully after repeated or painful stimulation. Reflex withdrawal is not considered a purposeful response. At this level of sedation airway intervention may be required and spontaneous ventilation may be inadequate. Cardiovascular function is usually maintained.

General anesthesia—A drug-induced loss of consciousness during which patients are not arousable even with painful stimulation. The response may be nonpurposeful reflex withdrawal. Airway intervention is often required to maintain a patent airway, often with positive-pressure ventilation. Cardiovascular function may be impaired.

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17. ANSWER: A

Emergence delirium (ED) or agitation (EA) is a **dissociative state of consciousness** in which children are irritable, uncooperative, inconsolable, and incoherent. The highest incidence of emergence agitation occurs in children **<6 years of age**. It has been reported in adults as well as infants. It presents as crying, moaning, kicking, and thrashing. Many times, effected children do not recognize and respond appropriately to their parents. The episodes are usually **short (5–45 minutes)** and **resolve spontaneously**. Several factors have been implicated in the etiology of emergence agitation. These include **use of less soluble inhaled agents (sevoflurane, desflurane), pain, hypoxia, hypercarbia, and anxiety**. However, the exact mechanism is unknown. Emergence agitation has been seen even following pain-free procedures such as MRI scans.

Several preventive measures have been used, and the most effective ones are usually pharmaceutical. **Avoiding the use of sevoflurane/desflurane and the intraoperative administration of dexmedetomidine, clonidine, or fentanyl has been shown to be effective**. Parental presence in the recovery room does not have any effect on the incidence and duration of emergence agitation.

KEY FACTS

- Highest incidence of emergence agitation occurs <6 years of age.
- Factors associated with development of EA include use of less soluble inhaled agents (sevoflurane, desflurane), pain, hypoxia, hypercarbia, and anxiety.

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18. ANSWER: D

This question describes emergence delirium (ED) or emergence agitation (EA). Although its mechanism of action is unknown, it has been thought to be related to both nonpainful and painful procedures alike. Possible **etiologies have included pain, metabolic changes, neurologic abnormalities, awakening in a strange environment, separation anxiety, and airway obstruction with hypoventilation and hypoxia**. Children who exhibit **preoperative anxiety** or who have **anxious parents** are at a higher risk for perioperative ED. The highest incidence of ED is in children younger than 5 years of age, and it tends to be self-limiting, **lasting less than 20 minutes**. It has been associated with specific types of surgery such as ENT/eye procedures, mainly because of their quick turnover and use of potent volatile anesthetics. The harmful effects of emergence agitation can occur perioperatively both to the child (i.e. surgical site) and to the providers (i.e., physical injury). **There is a Pediatric Anesthesia Emergence Delirium Scale** (PAEDS) that provides a valid and reliable tool to identify ED. It uses five criteria: **eye contact, purposeful movements, awareness of environment, restlessness, and inconsolability**. Pharmacologic options for prevention include propofol (1 mg/kg) at the end of the surgery, intravenous dexmedetomidine (0.15 μg/kg), intranasal fentanyl (1 μg/kg), and oral clonidine (4 mg/kg).

KEY FACTS

- Possible etiologies have included pain, metabolic changes, neurologic abnormalities, awakening in a strange environment, separation anxiety, and airway obstruction with hypoventilation and hypoxia.
- The Pediatric Anesthesia Emergence Delirium Scale (PAEDS) provides a valid and reliable tool to identify ED. It uses five criteria: eye contact, purposeful movements, awareness of environment, restlessness, and inconsolability.

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SECTION V

SPECIAL PROBLEMS OR ISSUES

27.

PROFESSIONAL ISSUES

Solmaz P. Manuel and Christine L. Mai

1. During a multiple-hour hand reconstruction surgery on an otherwise healthy teenager, the operating room nurse expresses concern that you may have had a microsleep episode. Which of these is an effective fatigue countermeasure?

A. Strategic caffeine consumption
B. Eating a large meal 1 hour before bedtime
C. Napping between cases at work
D. Prescription methylphenidate use

2. Which of the following is required to prove a case of clinical negligence in civil litigation?

A. Money was exchanged for services.
B. Injury or damages were suffered.
C. The provider was not forthcoming about a medical error that occurred.
D. An intentional breach of duty took place.

3. Which of the following is one of the Accreditation Council for Graduate Medical Education (ACGME) core educational competency areas?

A. Critical evaluation and decision making
B. Practice-based learning and improvement
C. Technical skill
D. Personal effectiveness

4. Which of the following is an example of practice-based learning and improvement?

A. Submission of a case for M&M conference
B. Participation in a patient's family meeting to discuss goals of medical care
C. Conducting a controlled pharmacologic experiment
D. Demonstrating cost-awareness in the clinical setting

5. Your team is conducting a research study that involves bispectral index (BIS) monitoring during anesthesia in 8- to 12-year-old children. The research protocol approved by your institutional review board (IRB) includes obtaining assent of children who participate in the study. A 9-year-old boy who is very upset about coming to the hospital that day adamantly refuses to participate in the study. Which of the following describes the most appropriate action to be taken?

A. Honor the child's decision and exclude him from the study.
B. Review the consent form with one of the parents and obtain consent from him or her instead.
C. Review the consent form with both of the parents and obtain consent from them instead.
D. Because this imposes minimal risk to the child, it is acceptable to perform BIS monitoring without consent.

6. A 5-year-old boy has been declared brain dead after suffering a traumatic brain injury last week. You are asked to assist with organ harvesting. Prior to transporting him to the operating room, you review his chart for documentation of brain death criteria. Which of the following fulfills one requirement for the diagnosis of brain death?

A. Hypocarbia
B. Burst suppression on electroencephalogram
C. Hypothermia
D. Atropine resistance

7. A 16-year-old patient is scheduled for excision of an arm lesion. You receive a call from the preoperative nurse that her urine pregnancy test is positive. The patient is currently waiting in the holding area with her parents, who are her surrogate decision makers and the anesthesia consent has already been signed. How will

you notify the patient and her parents about her test results?

A. Tell both the patient and the parents about the positive pregnancy test.
B. Tell only the parents about the positive pregnancy test.
C. Ask to speak privately to the patient and relay the results. Encourage the patient to share the information with her parents.
D. Contact risk management and have them disclose the results to the patient and her parents.

8. A 16-year-old girl with cholelithiasis presents for a laparoscopic cholecystectomy. She is in the holding area with her husband and their 1-year-old daughter. When asked if her parents are with her, she states that her father is deceased and her mother is at work. After multiple attempts at trying to get in touch with her mother, it is deemed that she is unavailable to give phone consent. How will you proceed with this case?

A. Call the social worker and get consent from the patient with the social worker as a witness.
B. Call the legal counsel at your hospital to help verify that the patient can sign her own consent since she is an emancipated minor.
C. Cancel the case since there is no parental consent.
D. Waive the consent since it is assumed that the surgeon's consent covers the risks and benefits, including the anesthesia consent.

9. While obtaining consent for a Nuss procedure on a 12-year-old boy, his parents inform you that they are Jehovah's Witnesses and will not consent for their child to receive any blood products. You inform them that the likelihood of a blood transfusion is very low but reaffirm that in an emergency you are obligated to act in the best interest of the child. After much discussion, the parents reluctantly give you consent for anesthesia and the case proceeds. One hour into the procedure, you notice an increased amount of blood in the suction canister. The surgeon thinks that he has perforated the right ventricle and will need to do an open thoracotomy, and possibly a sternotomy. Despite several crystalloid, colloid, and vasopressor boluses, the patient becomes hypotensive with a blood pressure of 40/20, tachycardic, and the surgeons are struggling to control the bleeding. What is your next step?

A. Call the parents in the waiting room and request verbal permission to emergently give a blood transfusion.
B. Call the hospital's legal counsel and request an emergency court order to bypass the parents' wishes so that you can give a blood transfusion.
C. Respect the parents' wishes and start a phenylephrine infusion with epinephrine boluses until the surgeon gains hemostasis.
D. Call the blood bank to release emergency blood products that you can administer immediately to the patient.

10. A 1-year-old boy presents for a circumcision. You are planning a general anesthetic with a caudal block. The risks and benefits of the caudal block are discussed with the parents and they agree to proceed. Immediately after induction, the caudal block was placed smoothly without incident. The surgeon proceeds with the prep and drape and asks if you can give a dose of cefazolin. When you retrieve the cefazolin that you had predrawn before the start of the case, you notice that a syringe labeled bupivacaine 0.25% with 1:200 000 epinephrine is on your cart. The syringe in the sharps container is labeled cefazolin. In this case of medication error, what is the *best* approach?

A. Meet the parents with the surgeon and discuss the event. Avoid apologizing or talking about blame because this might be used against you in a lawsuit.
B. Write a note in the medical record about the event and have the surgeon relay the event to the parents. Contact risk management at the end of the case.
C. Notify risk management and meet with the parents in order to explain the event, the consequences to the patient, and the plans of patient care and management for the medication error. Apologize for the error and explain what investigation will be performed in order to prevent such an event from occurring to other patients in the future.
D. Call risk management and the lawyer to discuss your next steps. Have the surgeon relay the events to the parents because this concerns his patient.

11. A 5-month-old infant is brought emergently from the emergency room to the operating room for a craniotomy. The mother reports that the infant rolled off the couch and hit her head on the hardwood floor. On examination, the infant is crying and agitated, she has a large hematoma on her occiput, and bruises on her upper arms and legs. Which of the following sign is *most* suggestive of child abuse?

A. Height and weight in the 10th percentile
B. Bruises on the upper arms
C. Cuts on the knees and shin
D. Scratches on the face

12. A 5-year-old girl presents to the operating room with tonsillar bleeding that started 8 hours prior to the hospital admission. She is listless, hypotensive, and

tachycardic in the preoperative holding area. In the patient's chart, you noted that she is an adopted child and her foster mother is present with her. The nurse tells you that the foster mother is not legally able to sign her consent, the child is still in custody of Department for Children and Families (DCF), and that a representative from DCF needs to legally sign the consent. After multiple unsuccessful attempts at contacting the DCF representative, how will you proceed with this case?

A. Call the PICU and transfer the patient to the PICU for supportive management with fluids and blood products until the DCF representative is contacted.
B. Call the hospital's legal office and explain to the foster mother that this is an emergency that needs to be attended to prior to the DCF consent. Obtain consent from the foster mother and proceed with the case.
C. Proceed with the case and attempt to call the DCF office later to explain the situation.
D. Manage the patient in the recovery room with fluid and vasopressor boluses while continuing to contact the DCF representative.

13. What are the six dimensions of quality in health care as defined by the Institute of Medicine (IOM)?

A. Professionalism, efficiency, equity, cleanliness, patient safety, and patient-centered care
B. Professionalism, efficiency, equity, timeliness, patient safety, and patient-centered care
C. Effectiveness, efficiency, equity, timeliness, patient safety, and patient-centered care
D. Effectiveness, autonomy, equity, timeliness, patient safety, and patient-centered care

14. According to The Institute of Medicine's (IOM) 1999 report, "To Err Is Human: Building a Safer Health System," where are the most preventable medical errors in US hospitals likely to occur?

A. Ambulatory care clinics
B. Operating rooms, emergency departments, and intensive care units
C. Urgent care clinics and emergency departments
D. Operating rooms and postanesthetic care units

CHAPTER 27 ANSWERS

1. ANSWER: C

The performance of anesthesiologists can be greatly impacted by **sleep deprivation and fatigue**. Sleep is a basic physiologic requirement and is necessary to maintain alertness, performance, and overall health and well-being.

Sleep debt is a common problem for anesthesiologists due to their long duty-hour periods and shift work. Disruption of circadian rhythm and sleep fragmentation further exacerbate chronic sleep deprivation, fatigue, and decreased mental and physical performance.

Microsleep events are the **most serious manifestation of fatigue** and indicate that **longer periods of sleep are imminent**. Microsleep events are thought to contribute significantly to single-vehicle car crashes and aviation accidents. Although the exact incidence among fatigued anesthesiologists is unknown, such complete lapses in vigilance seriously threaten patient safety.

Good sleep hygiene is important to maximize available sleep time. Good sleep habits include **regular bedtime and wake-up time; sufficient time for adequate sleep; a dark and quiet area for sleep; and avoidance of caffeine, alcohol, nicotine, or heavy meals before bedtime**.

Rest breaks can prevent decrements in vigilance of anesthesiologists. Short breaks improve job satisfaction, increase productivity, and reduce boredom.

Strategic naps from 10 minutes (power napping) to 90 minutes (allowing a full sleep cycle) improve alertness and performance, and is a useful countermeasure to fatigue. Optimal timing and frequency of breaks are unknown, but breaks should be taken when possible.

Caffeine and other stronger stimulants can also **reduce nighttime sleep quantity and quality**. Stimulant medications are not an appropriate fatigue countermeasure for health care providers: after temporary increase in alertness, the individual must undergo a substantial recovery sleep.

Light therapy, timed cycles of bright light and darkness, can be used to reset the circadian pacemaker and help adapt to shift work. Though likely impractical for many anesthesiologists, research continues in this promising area.

KEY FACTS

- Microsleep events are the most serious manifestation of fatigue.
- Good sleep habits include regular bedtime and wake-up time; sufficient time for adequate sleep; a dark and quiet area for sleep; and avoidance of caffeine, alcohol, nicotine, or heavy meals before bedtime.

REFERENCE

Miller R, Eriksson L, Fleisher L, Wiener-Kronish J, Young W, eds. *Miller's Anesthesia*. 7th ed. Philadelphia, PA: Churchill Livingstone; 2010:113–21.

2. ANSWER: B

The most common medical malpractice claim is that of **professional negligence**: an **unintentional act or omission by a health care provider** in which the treatment provided falls below the accepted standard of practice in the medical community and causes injury or damages to the patient.

In order to bring a successful case of negligence to civil courts, four separate elements must be proven. The elements that must be established in every negligence case include **duty, breach of standard of care, causation, and injury or damage**.

Duty of Care: First, a plaintiff (typically a patient or the patient's family) must establish that the defendant (typically the physician or health care institution) had a **legal duty to the plaintiff**. Generally, a legal duty exists whenever a hospital or health care provider **undertakes care or treatment of a patient**. The exchange of money is not necessary to establish duty of care.

When a physician–patient relationship is established, the physician has a duty to exercise the **degree of care, diligence, and skill** that physicians of reasonable and ordinary prudence would exercise under the same or similar circumstances.

Breach of Standard of Care: With the existence of the physician's duty of care comes responsibility to conform to the relevant standard of care. In a medical negligence case the plaintiff must establish that the health care provider breached that standard of care: he or she undertook a **form of treatment that a reasonable, prudent member of the medical profession** would not have taken under the same or similar circumstances.

Damage: The plaintiff must also establish that a "**compensable**" injury was suffered. A compensable injury is one for which it is **possible to be compensated for the actual harm suffered**, including **pain and suffering, with a monetary award**. Without injury, there is no basis for a claim, regardless of whether a medical provider was negligent. Likewise, damage can occur without negligence and does not create a presumption of negligence.

Causation: Finally, the plaintiff must establish that the **defendant's breach of standard of care was the direct and proximate cause of the injury**.

KEY FACTS

- The most common medical malpractice claim is that of professional negligence.

- The elements that must be established in every negligence case include duty, breach of standard of care, causation, and injury or damage.

REFERENCE

Motoyama EK, Davis P, eds. *Smith's Anesthesia for infants and children*. 8th ed. Philadelphia, PA: Mosby Elsevier; 2011:1309–14.

3. ANSWER: B

The Accreditation Council for Graduate Medical Education (ACGME) has defined six educational areas for which all residents and fellows must demonstrate competency. These areas are also required for Maintenance of Certification in Anesthesiology.

The **six core competencies** are as follows:

Patient care—Residents must be able to provide patient care that is compassionate, appropriate, and effective for the treatment of health problems and the promotion of health.

Medical knowledge—Residents must demonstrate knowledge of established and evolving biomedical, clinical, epidemiologic, and social-behavioral sciences, as well as the application of this knowledge to patient care.

Practice-based learning and improvement—Residents must demonstrate the ability to investigate and evaluate their care of patients, to appraise and assimilate scientific evidence, and to continuously improve patient care based on constant self-evaluation and lifelong learning.

Interpersonal and communication skills—Residents must demonstrate interpersonal and communication skills that result in the effective exchange of information and collaboration with patients, their families, and health professionals.

Professionalism—Residents must demonstrate a commitment to carrying out professional responsibilities and adherence to ethical principles.

Systems-based practice—Residents must demonstrate an awareness of and responsiveness to the larger context and system of health care, as well as the ability to call effectively on other resources in the system to provide optimal health care.

KEY FACT

- The six ACGME core competencies include patient care, medical knowledge, practice-based learning and improvement, interpersonal and communication skills, professionalism, and system-based practice.

REFERENCE

Accreditation Council for Graduate Medical Education. Common program requirements. Section IV.A.5.C. Available at: https://www.acgme.org/acgmeweb/tabid/429/ProgramandInstitutionalAccreditation/CommonProgramRequirements.aspx. Accessed June 19, 2014.

4. ANSWER: A

Practice-based learning and improvement is one of the Accreditation Council for Graduate Medical Education (ACGME) core educational competency areas. This competency requires trainees to develop skills of lifelong learning through a review of their own practices. Trainees must demonstrate the ability to investigate and evaluate their care of patients, to appraise and assimilate scientific evidence, and to continuously improve patient care based on constant self-evaluation and lifelong learning.

Suggested opportunities for **practice-based learning and improvement** include the following:

Submitting cases for M&M conference

Participating in quality and safety projects

Participating in journal clubs

Requesting and accepting feedback

Changing behavior based on feedback and reflection

Using medical literature to direct patient care

Demonstrating cost awareness in the clinical setting (an example of systems-based practice competency)

KEY FACTS

- Practice-based learning and improvement: Trainees must demonstrate the ability to investigate and evaluate their care of patients, to appraise and assimilate scientific evidence, and to continuously improve patient care based on constant self-evaluation and lifelong learning.

REFERENCE

Accreditation Council for Graduate Medical Education. Common program requirements. Section IV.A.5.C. Available at: https://www.acgme.org/acgmeweb/tabid/429/ProgramandInstitutionalAccreditation/CommonProgramRequirements.aspx. Accessed June 19, 2014.

5. ANSWER: A

Children, though legally minors and socially subject to the authority of guardians, often have decision-making capacity that is undervalued by parents and physicians.

It is important that children are not completely excluded from the consent process, and they should not be coerced in most circumstances. **Assent**—an agreement to treatment by **children** who do possess legal adult rights—should be obtained from any child who is able to **participate in a discussion about his or her care**.

US federal law specifically requires **assent of minors 7 years and older to participate in medical research**. Medical ethicists agree that especially for research that offers no real individual benefit, **a child's dissent must always be honored**.

KEY FACT

- Assent—an agreement to treatment by children who do possess legal adult rights; minors older than 7 years of age must assent prior to participation in medical research.

REFERENCES

Motoyama EK, Davis P, eds. *Smith's Anesthesia for Infants and Children*. 8th ed. Philadelphia, PA: Mosby Elsevier; 2011:1309–14.

Waisel DB, Truog RD, Todres ID. Ethical issues in pediatric anesthesiology. Cote CJ, Lerman J, Todres ID, eds. *A Practice of Anesthesia for Infants and Children*. 4th ed. Philadelphia, PA: Saunders Elsevier; 2009:71–87.

6. ANSWER: D

The diagnosis of **brain death** in neonates, infants, and children is made by clinically demonstrating **absence of cortical activity and brainstem reflexes**, identifying an **irreversible cause**, and ensuring reversible conditions that mimic loss of brain function are absent.

In children, **two examinations**, both including **apnea testing**, are required. The examinations should be performed by two different physicians and separated by an observation period. The recommended observation period is **24 hours for neonates and 12 hours for infants and children**.

The neurologic exam of a brain-dead individual should show no clinical evidence of brain function, including **no response to pain and no cranial nerve reflexes**. Common reflexes tested include **pupillary response (fixed pupils), oculocephalic reflex, and corneal reflex**. There is also **atropine resistance** (failure of heart rate to increase with atropine 40 μg/kg given intravenously).

Apnea testing requires documentation of an **arterial $PaCO_2$ ≥60 mm Hg** (and to ≥20 mm Hg above the baseline $PaCO_2$ level for children with chronic respiratory disease), **with no respiratory effort**. If apnea testing cannot be performed due to hemodynamic instability or rapid desaturation, ancillary tests may be performed to help confirm diagnosis of brain death. Electroencephalogram will show **electrocortical silence**, and a radionuclide study will show **absence of cerebral blood flow**.

Reversible conditions that must be corrected prior to examination for brain death include **hypotension, hypothermia, hypoglycemia, and metabolic disturbances**. Sedatives, analgesics, neuromuscular blockers, and anticonvulsant agents should be discontinued for a reasonable time period prior to the neurologic examination. Evaluation should be deferred for at least 24–48 hours after cardiopulmonary resuscitation or other severe acute brain injuries (events that can confound the neurological examination).

Before assuming care of a brain-dead organ donor, anesthesiologists are obligated to **review the chart for clear documentation** of the criteria used to declare brain death.

KEY FACTS

- Brain death in neonates, infants, and children is made by clinically demonstrating absence of cortical activity and brainstem reflexes, identifying an irreversible cause, and ensuring reversible conditions that mimic loss of brain function are absent.
- Two examinations are required, separated by an observation period of 24 hours for neonates and 12 hours for infants and children.

REFERENCES

Nakagawa TA, Ashwal S, Mathur M, et al. Guidelines for the determination of brain death in infants and children: an update of the 1987 Task Force recommendations. *Crit Care Med*. 2011;39(9):2139–55.

7. ANSWER: C

Even though the patient is a minor and lacks the legal ability to provide informed consent, she has the rights to **physician–patient confidentiality**. The obligation to maintain confidentiality requires physicians to protect patient information. This confidentiality is important for the development of a patient–physician relationship that supports open communication and sharing of information. A trusting alliance is important in the care of adolescents who are more likely to defer treatment because they are concerned about confidentiality.

Emancipated and mature minors have a right to complete confidentiality. For all other adolescents, if

maintaining confidentiality is of minimal harm, the physician should encourage the patient to share the information with parents. However, if maintaining confidentiality can cause harm to the patient (i.e., when a teenager is suicidal), then the physician may be **ethically justified in notifying the parents.**

Given the principles of confidentiality, in the case of a positive preanesthetic pregnancy test, it is ethically appropriate to inform only the adolescent patient of the results. Although the anesthesiologist can encourage the patient to share this information with her parents, **adolescents have the legal right to keep this information private**. Anesthesiologists and surgeons must be careful in their deliberation and the subsequent postponing of the surgery and anesthesia if the patient chooses to not inform her parents of the positive pregnancy test.

KEY FACT

- Emancipated and mature minors have a right to complete physician–patient confidentiality.

REFERENCE

Waisel DB, Truog RD, Todres ID. Ethical issues in pediatric anesthesiology. Cote CJ, Lerman J, Todres ID, eds. *A Practice of Anesthesia for Infants and Children*. 4th ed. Philadelphia, PA: Saunders Elsevier; 2009:71–87.

8. ANSWER: B

An **emancipated minor is a person who is under the age of 18 years** but who has been given the right to make his or her own global decision to consent to treatment. Status of emancipated minor is given to adolescents who are **married, parents, in the military, and economically independent**. Minors who are currently pregnant may also be considered emancipated. A court must grant emancipation of a minor; a minor patient presenting with criteria for emancipation remains a minor until the court amends this status. The mature minor doctrine holds that **adolescents be at least 14 years old** and must have decision-making capacity in order to be deemed legally and ethically capable of giving informed consent in certain situations determined by a court.

KEY FACT

- An emancipated minor is a person who is under the age of 18 years who is married, a parent, in the military, and economically independent.

REFERENCE

Waisel DB, Truog RD, Todres ID. Ethical issues in pediatric anesthesiology. Cote CJ, Lerman J, Todres ID, eds. *A Practice of Anesthesia for Infants and Children*. 4th ed. Philadelphia, PA: Saunders Elsevier; 2009:71–87.

9. ANSWER: D

Jehovah's Witnesses believe that the Bible prohibits blood transfusions because blood holds the "life force" and anyone who takes blood will be "cut off from his people" and not earn eternal salvation. The courts have **allowed nonpregnant adults to refuse blood transfusions** when making decisions about their own medical care. However, under the legal doctrine of *parens patriae*, the courts have mandated that the **obligation of the state is to protect the interests of incompetent patients such as children and minors**. When Jehovah's Witnesses parents refuse blood transfusions on behalf of their children in both emergent and elective cases, a physician can seek the hospital's legal counsel to obtain a court order to circumvent the parents' wishes and legally administer blood.

In a life-threatening condition when there is a sudden need for a blood transfusion because of massive hemorrhage, the physician has the **obligation to protect the child** and should take legally correct and ethically appropriate actions to transfuse the life-saving blood without the court order. Waiting for the court order may inappropriately result in functionally honoring the parents' wishes but result in permanent harm to the child.

KEY FACT

- Courts have mandated that the obligation of the state is to protect the interests of incompetent patients such as children and minors.

REFERENCE

Waisel DB, Truog RD, Todres ID. Ethical issues in pediatric anesthesiology. Cote CJ, Lerman J, Todres ID, eds. *A Practice of Anesthesia for Infants and Children*. 4th ed. Philadelphia, PA: Saunders Elsevier; 2009:71–87.

10. ANSWER: C

It is in the best interest of all parties involved that the parents of the child receive **full disclosure of the medical error**. The physician who is responsible (not the surgeon or other surrogate) should do his or her best to disclose the reason for the error and **apologize for the unintended outcome**. Medication error is one of the leading, preventable

causes of death in the United States. The natural inclination of physicians is to avoid disclosing the medical error to patients and family members due to fear of litigation and blame for unintended outcomes. Studies have shown that **patients are less likely to file a malpractice claim if medical errors are fully disclosed and the physician apologizes for the error**.

Full disclosure involves the following:

- Disclosure of all error(s)
- Discussion as to why the error(s) occurred
- Ways in which the patient will be managed now that the error(s) has occurred
- Explanation of how the physician and organization will assess the incident and make changes to prevent a recurrence of the error

Notifying the hospital's risk management is also important and should occur as soon as possible or before speaking to the parents in order to get guidance or counseling as to how to approach the family.

KEY FACT

- Full disclosure of medical error includes disclosure of all error(s), discussion as to why the error(s) occurred, ways in which the patient will be managed now that the error(s) has occurred, and explanation of how the physician and organization will assess the incident and make changes to prevent a recurrence of the error.

REFERENCES

Mazor KM, Reed GW, Yood RA, Fischer MA, Baril J, Gurwitz J. Disclosure of medication errors. *J Gen Int Med*. 2006:704–10.

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11. ANSWER: B

Child abuse includes **physical abuse, sexual abuse, emotional abuse, and neglect**. An anesthesiologist is in a position to recognize some of the signs of physical abuse since there is more attention to hands, feet, ankles, and faces. Careful attention should be noted for bruises or burn marks in the shape of objects, injuries to soft tissue on **arms**, injuries **to mouth and dentition**, **fractures in infants**, and height and weight less than the **5th percentile**. Children with **physical and mental disabilities are particularly prone to abuse**. Anesthesiologists, as well as all physicians, are legally required to report suspicion of child abuse or neglect to appropriate hospital authorities. To help physicians identify child abuse, the American Academy of Pediatrics states that "**child abuse should be considered as the most likely explanations for inflicted skin injuries if they are non-accidental and there is any injury beyond reddening of the skin.**" Other physical signs of abuse to consider include injuries that are **developmentally not appropriate**, injuries that leave a **biomechanical mark (i.e., handprint)**, injuries that are not explained by the offered history, and injuries that do not appear accidental. Physicians can be criminally prosecuted if they fail to report suspected child abuse.

KEY FACT

- Child abuse should be considered as the most likely explanation for inflicted skin injuries if they are nonaccidental and there is any injury beyond reddening of the skin.

REFERENCES

Newberger EH. Child physical abuse. *Primary Care*. 1993;20:317–27.

Waisel DB, Truog RD, Todres ID. Ethical issues in pediatric anesthesiology. Cote CJ, Lerman J, Todres ID, eds. *A Practice of Anesthesia for Infants and Children*. 4th ed. Philadelphia, PA: Saunders Elsevier; 2009:71–87.

Wissow LS. Child abuse and neglect. *N Engl J Med*. 1995;332:1425–31.

12. ANSWER: B

In an emergency situation, the presumption is that **necessary treatment is desirable and should be given** even if informed consent from legal guardians is unattainable. While it is reasonable to attempt to contact the parents to obtain informed consent, these attempts should not delay necessary therapy. In the case of a guardian who is not able to sign informed consent and a legal entity such as the Department for Children and Families is involved, it is prudent to have a discussion with the hospital's legal counsel and the surrogate guardian to explain the emergency nature of the case and **proceed in the best interest of the child**. Delaying the case for formal consent and permission could result in death, disability, and increased risk of further complications.

KEY FACT

- Necessary treatment is desirable and should be given even if informed consent from legal guardians is unattainable.

REFERENCES

Waisel DB. Ethical and legal considerations in pediatric anesthesia. Holzman RS, Mancuso TJ, Polaner DM, eds. *A Practical Approach to Pediatric Anesthesia*. Philadelphia, PA: Lippincott, Williams & Wilkins; 2008:74.

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13. ANSWER: C

The Institute of Medicine's (IOM) 1999 report, "To Err Is Human: Building a Safer Health System," brought attention to the problem of preventable medical errors occurring in US hospitals each year. These errors resulted in up to 98,000 patient deaths and were more likely to occur in operating rooms, emergency departments, and intensive care units. The report called for a comprehensive effort by health care providers, government, and consumers to make drastic reductions in these errors.

To measure health care quality, the IOM identified *Six Dimensions of Quality*. The Six Dimensions of Quality are **effectiveness, efficiency, equity, timeliness, patient safety, and patient-centered care**.

Health care needs to be **effective**, meaning health care services should result in beneficial outcomes. Health care services also need to be **efficient**: providers should avoid waste and improve system cost-efficiencies. Health care should be delivered in an **equitable** manner: variations due to ethnicity, gender, geographic location, and socioeconomic status should be minimized. Health care services must be **timely**, emphasizing the need for appropriate access to care. Health care should **improve patient safety**. Finally, health care should be **patient-centered**: each individual patient's needs, preferences, and values should be identified and incorporated into clinical decision making.

The IOM emphasizes that all Six Dimensions of Quality need to be met for high-quality health care to be achieved. The evolving health care system in the United States is now requiring physicians, health care providers, health care organizations, and hospitals to partner together to measure, demonstrate, and improve the overall quality of care to the patients they serve.

KEY FACT

- The Six Dimensions of Quality are effectiveness, efficiency, equity, timeliness, patient safety, and patient-centered care.

REFERENCES

Kliegman RM, Stanton BF, St. Geme JW, Schor NF, Behrman RE, eds. *Nelson Textbook of Pediatrics.* 19th ed. St. Louis, MO: Mosby Elsevier; 2011:13.

Kohn L, Corrigan J, Donaldson M, eds. *To Err Is Human: Building a Safer Health System*. Washington, DC: Committee on Quality of Health Care in America, Institute of Medicine, National Academies Press; 1999.

14. ANSWER: B

The Institute of Medicine's (IOM) 1999 report, "To Err Is Human: Building a Safer Health System," brought attention to the problem of preventable medical errors occurring in US hospitals each year. These errors resulted in up to 98,000 patient deaths and were more likely to occur in **operating rooms, emergency departments, and intensive care units**. The report called for a comprehensive effort by health care providers, government, and consumers to make drastic reductions in these errors.

To measure health care quality, the IOM identified *Six Dimensions of Quality*. The Six Dimensions of Quality are **effectiveness, efficiency, equity, timeliness, patient safety, and patient-centered care**.

Health care needs to be effective, meaning health care services should result in beneficial outcomes. Health care services also need to be efficient: providers should avoid waste and improve system cost-efficiencies. Health care should be delivered in an equitable manner: variations due to ethnicity, gender, geographic location, and socioeconomic status should be minimized. Health care services must be timely, emphasizing the need for appropriate access to care. Health care should improve patient safety. Finally, health care should be patient centered: each individual patient's needs, preferences, and values should be identified and incorporated into clinical decision making.

The IOM emphasizes that all Six Dimensions of Quality need to be met for high-quality health care to be achieved. The evolving health care system in the United States is now requiring physicians, health care providers, health care organizations, and hospitals to partner together to measure, demonstrate, and improve the overall quality of care to the patients they serve.

KEY FACT

- Errors were more likely to occur in operating rooms, emergency departments, and intensive care units.

REFERENCES

Kliegman RM, Stanton BF, St. Geme JW, Schor NF, Behrman RE, eds. *Nelson Textbook of Pediatrics.* 19th ed. St. Louis, MO: Mosby Elsevier; 2011:13.

Kohn L, Corrigan J, Donaldson M, eds. *To Err Is Human: Building a Safer Health System*. Washington, DC: Committee on Quality of Health Care in America, Institute of Medicine, National Academies Press; 1999.

28.

PRINCIPLES OF BIOSTATISTICS AND STUDY DESIGN

Herodotos Ellinas and D. John Doyle

1. A researcher is evaluating the feasibility or the success of a screening program. The clinician working with her poses the question: If my patient's test is negative, how reassured should he be that he does not have the disease in question? What statistical value is she referring to?

A. Test sensitivity
B. Positive predictive value (PPV)
C. Test specificity
D. Negative predictive value (NPV)

2. A physician scientist is trying to evaluate the effect of fatigue among residents. She is testing three groups of residents after an 8-hour, a 16-hour, and a 24-hour shift. Which of the following is the appropriate statistical procedure to analyze the data obtained from this study?

A. Analysis of variance (ANOVA)
B. Repeated-measures t statistic
C. Independent-measures t statistic
D. Chi-square statistic

3. What methods can increase the power of a hypothesis test?

A. Decrease alpha (α) level
B. Increase population variability
C. Decrease sample size
D. Increase the difference between treatments

4. After reviewing hospital charts, a researcher collects data from a group of patients who suffered an acute stroke during coiling in interventional radiology (IR). Another group of patients with similar age, gender, and comorbidity characteristics is also chosen but with no complications during the same procedure. The two groups were then compared for the use or not of nitroglycerin infusion intraoperatively.
What kind of an example of research design is this study?

A. Observational
B. Case-control
C. Cohort
D. Cross-sectional

5. A researcher obtains the following weights (in kilograms) in nine consecutive study subjects: 4, 6, 7, 8, 9, 3, 4, 8, and 5. What are the mean and median values for this group of study subjects?

A. Mean 5, median 9
B. Mean 9, median 5
C. Mean 7, median 4
D. Mean 6, median 6

6. A researcher obtains the following weights (in kilograms) in nine consecutive study subjects: 4, 6, 7, 8, 9, 3, 4, 8, and 5. What is the range in weights for the study subjects?

A. 5
B. 1
C. 6
D. 7

7. The numbers of central line placement in a group of six anesthesiology residents are as follows: 10, 12, 13, 16, 12, and 14. The mode for the study subjects is:

A. 12.8
B. 12
C. 10
D. 12.5

8. The mean of the normal IQ population distribution is known to be 100 ($\mu = 100$) and the standard deviation is 15 ($\sigma = 15$). What percentage of data lies between 85 and 115?

A. 68%
B. 34%

C. 99%
D. 95%

9. Which of the following is the correct definition of a null hypothesis?

A. It is the hypothesis being tested.
B. It is the hypothesis being rejected.
C. It is the hypothesis that is accepted when it is false.
D. It is the hypothesis that is rejected when it is true.

10. Which of the statements about confidence intervals is correct?

A. The larger the sample size, the larger the confidence interval.
B. Confidence intervals can be used to indicate the reliability of an estimate.
C. A confidence interval predicts where a population parameter should be.
D. A confidence interval is an interval estimate of a sample statistic.

11. Which of the following statements about analysis of variance (ANOVA) is correct?

A. H_1 (alternative hypothesis) for an ANOVA states that all population means are different.
B. The results for the ANOVA test are depicted on a contingency table.
C. It is an independent t-test for more than two groups.
D. The variances for the populations tested should not be equal.

12. A pharmaceutical company has proposed a new study to compare a new medication compared to standard current therapy. The hypothesis is that the new medication will improve treatment by 20% compared to standard current management. The study is powered to 0.8. Which is the correct statement regarding this study?

A. There is an 80% chance that the study will accept the null hypothesis when it is false.
B. Increasing the power decreases the chance for type II error.
C. Increasing the sample size decreases the power of the study.
D. Increasing the power decreases the chance for type I error.

13. Which of the following statements about statistical errors is correct?

A. A type II error is a false positive.
B. A type II error accepts the null hypothesis when it is false.
C. A type I error rejects the null hypothesis when it is false.
D. A type I error is a false negative.

14. Randomization of study subjects:

A. Increases the power of a study
B. Introduces bias
C. Balances confounders
D. Controls for placebo effects

15. A random selection of 400 children participate in a study of the effects of a newly released drug. They are followed prospectively for 3 years to see if there is an association between the incidence of cardiac arrhythmias and the use of the drug. This type of study is a:

A. Crossover study
B. Randomized controlled clinical trial
C. Case-control study
D. Cohort study

16. A researcher plans to compare the frequency of postoperative apneic events in children who undergo surgery for tonsillectomy against similar children undergoing strabismus surgery. This type of study is a:

A. Crossover study
B. Cross-sectional study
C. Case-control study
D. Cohort study

17. If a test was very difficult, although a few students still obtained very high scores, then the distribution of scores would be:

A. Positively skewed
B. Negatively skewed
C. Normally distributed
D. Symmetric

18. Which of the following statements about causation and correlation is correct?

A. Correlation implies causation.
B. Correlation depends upon the study sample size.
C. Causation is determined by the statistical test chosen.
D. Causation must be decided by the research team.

19. Which of the following measures of central tendency is most likely influenced by an extreme score?

A. Mean
B. Mode

C. Median
D. Standard deviation

20. A researcher determines the best-fitting straight line for two variables: y = 2x + 25. Which of the following statements is correct?

A. The line crosses the y-axis at x = 2.
B. The dependent variable is x.
C. The independent variable is y.
D. The value of y increases by 2 for each unit increase in the value of x.

21. A researcher wishes to compare two unpaired groups whose data are not normally distributed. Which test would be most appropriate in this setting?

A. Paired t-test
B. Mann-Whitney test
C. Kruskal-Wallis test
D. Kolmogorov-Smirnov test

22. A researcher wishes to compare the means for two unmatched groups. Prior research data suggested that the mean of the experimental group will be larger than the mean for the control group. Which statistical test would be most appropriate to analyze the data?

A. One-sided paired t-test
B. Two-sided paired t-test
C. One-sided independent measures t-test
D. Two-sided independent measures t-test

23. Which of following variables is an example of a nominal (categorical) variable?

A. Height
B. Weight
C. Gender
D. Class rank

24. A new treatment for malignant melanoma significantly extends the life span of the patient but does not prevent the disease or lead to its cure. Given this scenario, which of the following statements about malignant melanoma is correct?

A. Its incidence will decrease.
B. Its prevalence will decrease.
C. Its incidence will increase.
D. Its prevalence will increase.

25. Two physiologic parameters are plotted as noted in the figure. Which of the following statements describes this figure?

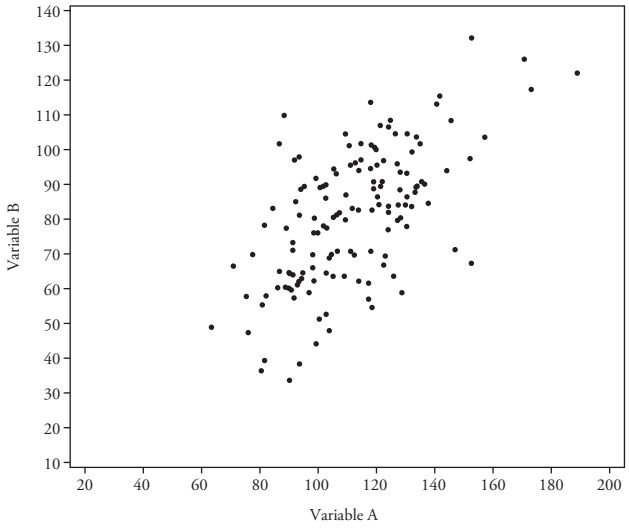

Figure 28.1 Two physiologic variables.

A. Linear regression determines correlation between variables A and B.
B. This figure is a histogram.
C. Variables A and B are negatively correlated.
D. There is a causal relationship between variables A and B.

26. Which of the following statements about crossover studies is correct?

A. In a crossover study each subject acts as his or her own control.
B. A crossover study is one in which interventions are applied sequentially to different groups.
C. Crossover studies generally require more subjects than do noncrossover designs.
D. Crossover studies achieve better results if the sequence of treatments is immediate with no waiting period.

CHAPTER 28 ANSWERS

1. ANSWER: D

This question outlines important differences among statistical values. **Sensitivity and specificity of a screening test refer to values that do not depend on the population tested. Sensitivity** refers to the percent of subjects with the disease who test positive for a given test. **Specificity** refers to the percent of subjects without the disease who test negative for a given test. In both cases, the numbers outline the ability of a test to identify correctly either patients who have or patients who do not have the disease.

On the other hand, the **positive predictive value** (PPV) is the probability that patients with a positive test truly have the disease. The **negative predictive value** (NPV) is the probability that patients with a negative test really do not have the disease (the answer to our question). These values depend on the prevalence of the disease. For example, if the disease is highly prevalent, then the PPV would be close to 1; if the disease is very rare, the NPV would be close to 1.

Sensitivity = TP/TP + FN
Specificity = TN/TN + FP
PPV = TP/TP + FP
NPV = TN/TN + FN

Table 28.1 TRUE DISEASE STATUS

TEST RESULTS	POSITIVE	NEGATIVE
Positive	True positives	False positives
Negative	False negatives	True negatives

KEY FACTS

- Sensitivity and specificity of a screening test refer to values that do not depend on the population tested.
- Sensitivity refers to the percent of subjects with the disease who test positive for a given test.
- Specificity refers to the percent of subjects without the disease who test negative for a given test.
- Positive predictive value (PPV) is the probability that patients with a positive test truly have the disease.
- Negative predictive value (NPV) is the probability that patients with a negative test really do not have the disease.

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2. ANSWER: A

This question addresses different statistical methods in analyzing sample data.

Scientists use sample data to evaluate hypotheses about populations. **The four steps of hypothesis testing include the following:**

1. State a hypothesis about a population; for example, Americans spend an average of $500 during the holiday season.
2. Set criteria for decision making.
3. Collect data and calculate sample statistics.
4. Make a decision.

The hypothesis statement usually comes from either prior published research, from pilot studies the researcher might have already completed, or from an instinct that the scientist may have regarding the particulars of the study. The **null hypothesis** (H_0) refers to no change or no relationship between the variables tested. Instead, the alternative hypothesis (H_1) refers to a change, an effect present between the independent variable (treatment) and the dependent variable.

Once the hypothesis is set, the researcher tests whether the data support the null hypothesis or not. In order to do so, he or she needs to define boundaries that separate the high-probability from low-probability samples. These boundaries are delineated by the level of significance or α level chosen. Usually **the probability α is either 0.05 (5%), separating the 5% extreme sample means from the more likely 95% sample means, or 0.01 corresponding to the 1% extreme values**. Depending on the statistic used, the researcher will then turn to a statistical table (e.g., z-distribution, t-distribution) to determine the critical region (boundaries).

Collecting the data and analyzing them is the next logical step. Although the population mean is known, usually the **population standard deviation** (spread) is unknown and therefore a **t-statistic** is used (instead of a **z-statistic** used when the population mean and standard deviation are both known). When the same group of persons is tested in either two different conditions or before and after treatment, the **repeated-measures design model** is used for analysis. When two different groups of individuals or two different conditions are tested, the **independent-measures t-test** is used. **ANOVA** is used to evaluate significance when two or more treatments/conditions/groups are tested (just like our study). It can be used both for repeated and independent design models. **Chi-square** hypothesis testing method is used for nonnumerical data.

Once the statistic has been calculated, based on the critical region already identified, the scientist has to either declare the null hypothesis true or reject it. A rejection of the null hypothesis means that there is a significant difference between the tested sample means, inferring to a significant difference between population means. (Remember the goal of testing samples is to infer to populations because it is difficult and expensive to test entire groups of individuals.)

KEY FACTS

- t-statistic is used when the population standard deviation is unknown.
- z-statistic is used when the population mean and standard deviation are both known.
- When the same group of persons is tested in either two different conditions or before and after treatment, the repeated-measures design model is used for analysis.
- When two different groups of individuals or two different conditions are tested, the independent-measures t-test is used.
- ANOVA is used to evaluate significance when two or more treatments/conditions/groups are tested. It can be used both for repeated and independent design models.
- Chi-square hypothesis testing method is used for nonnumerical data.

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3. ANSWER: D

This question outlines the different mechanisms for increasing the power of a test. **Power of a testing hypothesis is the probability that a test will reject the null hypothesis when it is false.** For every study, it is calculated in advance in order to assure an adequate number of data collected.

Power depends on four factors:

1. **Alpha (α) level,** type I error: to reject the null hypothesis when it is true; the smaller this error, the lower the risk to reject the null hypothesis when it is true (larger type II error) and the smaller the power of a hypothesis test. The researcher will need more evidence to reject the null.
2. **Population variability**: the greater the variability, the greater the chance for type II error (accept the null hypothesis when it is false) and therefore the smaller the power.
3. **Sample size**: by decreasing the sample size, researchers will have a bigger type II error and therefore power will decrease.
4. **Magnitude of difference between experimental conditions**: the larger the magnitude, the easier it is to find a difference between the samples tested and by extrapolation the populations in question (smaller type II error) and therefore the power of a test goes up.

KEY FACTS

- Power of a testing hypothesis is the probability that a test will reject the null hypothesis when it is false and it is defined as $1 - \beta$.
- Power depends on four factors: alpha level, population variability, sample size, and the magnitude of difference between experimental conditions.

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4. ANSWER: B

This question discusses different research design methods. **The classification of research design divides them first in longitudinal and cross-sectional studies.** The former refers to a study performed over time, whereas the latter describes an experiment at a certain point in time (reliance on existing differences). **Longitudinal designs** are subsequently separated into **prospective or retrospective**. Prospective are also known as **cohort studies** with study subjects monitored before an intervention occurs and thus allowing information about the natural history of a condition. **Cohort studies** can have controls that are either concurrent (parallel groups or self-control/cross over groups) with the study or historical. **Retrospective designs are also known as case-control studies** because they compare outcomes between a group after a condition/intervention has occurred, with a control group.

Observational studies are ones where data are collected but either no intervention has occurred or more important the researcher had no control over that intervention. Differences can be revealed with observational studies, but

clear distinction of what caused these differences is unclear (intervention vs. other internal or external processes).

The gold standard of experimental designs is a randomized, controlled double-blind study. It is randomized because the subjects are assigned by a random process and double blind because neither the researcher nor the subjects know in which group they have been assigned. Although these studies provide the most information, they are both expensive and labor intensive.

KEY FACTS

- Longitudinal studies are performed over time.
- Cross-sectional studies are from a certain point in time.
- Longitudinal studies are separated into prospective and retrospective.
- Prospective are also known as cohort studies with study subjects monitored before an intervention occurs and thus allowing information about the natural history of a condition.

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5. ANSWER: D

This question outlines differences between central tendency measures in descriptive statistics. Statistics are methods to organize, summarize, and interpret data. We refer to a population as the total number of individuals, that is, the US population. A characteristic that describes the population is known as the parameter (usually denoted in Greek letters, mean = μ). When we take a sample of a larger group (i.e., the population of WI), we have a characteristic that describes it and is referred to as the statistic (usually denoted in English letters, mean = X bar).

In an attempt to describe a distribution, we look for a single data point that can define its center. **The mean is calculated as the arithmetic average of a set of scores, that is, summing up all the scores and dividing them with the total number of subjects (ΣX/n, where × are the individual scores, weights, and measurements, and n is the total number of individuals.** In our case:

$$(4 + 6 + 7 + 8 + 9 + 3 + 4 + 8 + 5) = 54$$

$$n = 9$$

$$54/9 = 6$$

The median is the middle of a distribution of data (50% of the scores lie below this score/value). The scores have to be arranged from smallest to largest. If n is odd, the median is the middle score. If n is even, the median is the average of the middle scores. In our case, scores arranged from smallest to largest (3, 4, 4, 5, 6, 7, 8, 8, 9, n = 9) are an odd number; therefore, the median is the midpoint of the scores (i.e., 6). If there was an additional score, 3, 4, 4, 5, 5, 6, 7, 8, 8, 9 with n = 10, the median would be the average of the middle two numbers, 5 + 6/2 = 5.5.

Although the mean is the preferred measure of central tendency, the median is used when we have outlier scores (extreme values) or when we have an undetermined value (a subject did not complete the test; therefore, there is no score; ΣX cannot be calculated).

KEY FACTS

- The mean is calculated as the arithmetic average of a set of scores; that is, summing up all the scores and dividing them with the total number of subjects.
- The median is the middle of a distribution of data (50% of the scores lie below this score/value).

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6. ANSWER: C

This question describes range as a measure of variability. **We refer to a population as the total number of individuals** (i.e., the US population). A characteristic that describes the population is known at the parameter (usually denoted in Greek letters, mean = μ). When we take a sample of a larger group (i.e., the population of WI), we have a characteristic that describes it and is referred to as the statistic (usually denoted in English letters, mean = X bar). Variability is a way to describe a distribution by evaluating each individual score and its spread within the distribution. It helps us decide what kind of error we should expect if we take a sample from a given population.

We use three different measures of variability: the range, standard deviation, and variance. **The *range* is the difference between the largest and the smallest value in a set of data.** First, we order the data from smallest to largest and then we subtract the numbers. In our case,

Scores arranged from smallest to largest: 3, 4, 4, 5, 6, 7, 8, 8, and 9.

Range = 9 – 3 = 6.

The standard deviation (population denoted by σ, sample denoted by s) is a measure of the average distance of each score from the mean and since the mean provides the balance point of the distribution, the sum of all deviations equals zero. The variance (population denoted by σ^2, sample denoted by s^2) is the mean squared distance from the mean and since most of the times it is in squared units it is not as meaningful of a value.

The *mean* is calculated as the arithmetic average of a set of scores; that is, summing up all the scores and dividing them with the total number of subjects (ΣX/n where × are the individual scores, weights, and measurements and n is the total number of individuals. The calculations are as noted in the following chart. In order to calculate the standard deviation, we square the deviations, divide them with the number of scores (population) or number of scores minus 1 (sample), and then take the square root:

$$\sigma^2 = \Sigma(X - \mu)^2/n \text{ or } s^2 = \Sigma(X - Xbar)^2/n - 1 \text{ and } s = \sqrt{\Sigma(X - Xbar)^2/n - 1}$$

Scores	X-Xbar	(X-Xbar)²
3	–3	9
4	–2	4
4	–2	4
5	–1	1
6	0	0
7	1	1
8	2	4
8	2	4
9	3	9
SUM = 54	0	36
Mean = 54/9 = 6		S^2 = 36/8 = 4.5
n = 9		s = √4.5 = 2.12

KEY POINTS

- We refer to a population as the total number of individuals.
- The *range* is the difference between the largest and the smallest value in a set of data.
- The standard deviation (population denoted by σ, sample denoted by s) is a measure of the average distance of each score from the mean and since the mean provides the balance point of the distribution, the sum of all deviations equals zero.

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7. ANSWER: B

This question describes mode as another measure of central tendency. Although the mode is the score with the absolute highest frequency, sometimes a distribution may have two high-frequency data points and is called bimodal or more than two and is called multimodal. The mode is the measure of central tendency that corresponds to an actual score in the distribution.

KEY POINT

- The mode is the score with the absolute highest frequency; sometimes a distribution may have two high-frequency data points and is called bimodal or more than two and is called multimodal.

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8. ANSWER: A

This question describes the normal distribution and the proportions described by the area under the curve. Based on a normal distribution the mean (μ), median, and mode all lie in the middle and correspond to the peak of the curve. The sections on one side of the mean are exactly equal to the ones on the other side of the mean. In our scenario, **one standard deviation from the mean** corresponds to scores between 85 and 115 (100 ± 15) and therefore the **proportion is 34.1% × 2 (68%)** or the probability of 0.34 × 2 (0.68). If we want to know what percentage of the data lies within **two standard deviations of the mean**, the answer will be **(34.1% × 2) + (13.6% × 2) = 95%** (0.95). The data that lie within **three standard deviations of the**

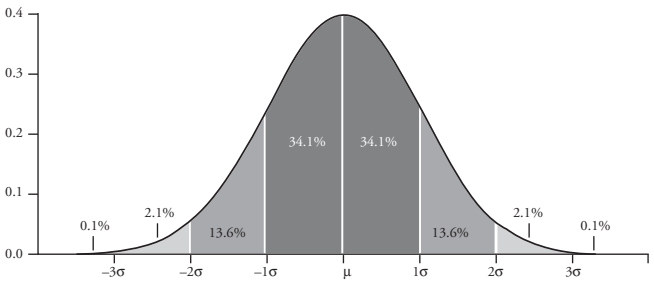

Figure 28.2 Normal (Gaussian) distribution.

mean are about (**34.1 % × 2**) + (**13.6% × 2**) + (**2.3% × 2**) = **99%** (0.99). The advantage of knowing the approximate percentage of data within standard deviations from the mean is that it allows you to determine extreme values based on results (i.e., if someone's IQ is 130, we presume based on the normal IQ distribution that this person falls into a group of only 2.3% of the population with that high of an IQ).

KEY POINTS

- The normal (or Gaussian) distribution is a very commonly occurring continuous probability distribution.
- In Gaussian distribution, one standard deviation from the mean corresponds to a proportion of 34.1% × 2 (68%) or the probability of 0.34 × 2 = 0.68.
- Two standard deviations of the mean correspond to (34.1% × 2) + (13.6% × 2) = 95% with a probability of 0.95.
- Three standard deviations of the mean correspond to (34.1% × 2) + (13.6 % × 2) + (2.3 % × 2) = 99% with a probability of 0.95.

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9. ANSWER: A

The null hypothesis (H0) refers to a no change or no relationship between the variables tested. Instead, the alternative hypothesis (H1) refers to a change, an effect present between the independent variable (treatment) and the dependent variable. The null hypothesis is assumed true until there is evidence to reject it based on the data obtained. If the null hypothesis is rejected (not true), then the ***alternative hypothesis (H1)*** is accepted. A ***type I error*** occurs when the null hypothesis is rejected but it is actually true. A ***type II error*** occurs when the null hypothesis is accepted but it is actually false.

When we are testing a hypothesis, we set a criterion for decision making, the so called level of significance (α). By convention, α is either set at 0.05 (5%) or 0.01 (1%). This level is the probability to define samples that are extremely unlikely to be obtained if the null hypothesis is true.

		No effect	Rx effect
		H_0 True	H_0 False
	Reject H_0	α=Type I error, FP	CORRECT
DECISION			
	Reject H_0	CORRECT	β=Type II error, FN

KEY POINTS

- The null hypothesis (H0) refers to a no change or no relationship between the variables tested.
- Instead, the alternative hypothesis (H1) refers to a change, an effect present between the independent variable (treatment) and the dependent variable.
- The null hypothesis is assumed true until there is evidence to reject it based on the data obtained.
- A type I error occurs when the null hypothesis is rejected, but it is actually true.
- A type II error occurs when the null hypothesis is accepted, but it is actually false.
- When we are testing a hypothesis, we set a criterion for decision making, the so-called level of significance (α). By convention, α is either set at 0.05 (5%) or 0.01 (1%).

REFERENCES

GraphPad Software. *GraphPad statistics guide*. Available at: http://www.graphpad.com/guides/prism/6/statistics. Accessed December 15, 2014. (A free instructional material on basic statistics)

Gravetter F, Wallnau L. *Statistics for the Behavioral Sciences*. 9th ed. Independence, KY: Cengage Learning; 2013:233–6, 244–6.

10. ANSWER: B

Statistics are methods to organize, summarize, and interpret data. We refer to a population as the total number of individuals (i.e., the US population). A characteristic that describes the population is known at the parameter (usually denoted in Greek letters, mean = μ). When we take a sample of a larger group (i.e., the population of WI), we have a characteristic that describes it and is referred to as the statistic (usually denoted in English letters, mean = X bar). **A confidence interval is an interval estimate of a population parameter rather than a sample statistic. Confidence intervals are used to indicate how reliable an estimate is but do not predict where a population parameter should be.** For example, a 95% confidence interval for a mean indicates that we are 95% confident that the calculated interval encompasses the population mean. With hypothesis testing, we reject the null hypothesis if the confidence interval does not include zero.

The larger the level of confidence, the wider the interval we expect. To have more precise interval, you have to give up confidence. The opposite is seen with sample size. **The larger the sample size, the smaller the confidence interval.** Once you have a larger sample size, it is easier to get population information and allow for a better, more precise estimate (narrowed interval).

KEY POINTS

- A confidence interval is an interval estimate of a population parameter rather than a sample statistic.
- Confidence intervals are used to indicate how reliable an estimate is but do not predict where a population parameter should be.
- The larger the sample size, the smaller the confidence interval.

REFERENCES

GraphPad Software. *GraphPad statistics guide*. Available at: http://www.graphpad.com/guides/prism/6/statistics. Accessed December 15, 2014. (A free instructional material on basic statistics)

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11. ANSWER: C

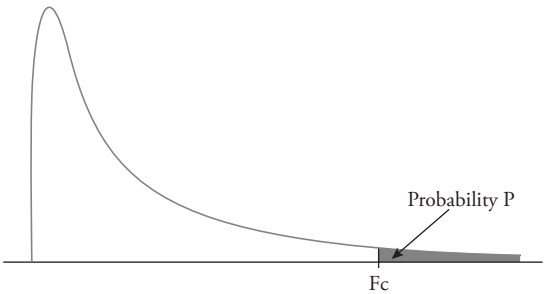
This question describes the analysis of variance (ANOVA). **ANOVA is a statistical hypothesis technique to evaluate mean differences between two or more groups/treatments/conditions.** It is essentially the same test as the independent t-test for two groups. The calculations can be cumbersome when large amounts of data are involved but with the advent of computers, software programs such as SPSS and SAS have made the analysis much easier.

The test statistic for ANOVA is the F-test; it is a ratio of the between treatment variability divided with the within treatment variability and follows the F-distribution. The ANOVA testing questions a null hypothesis H_0: all the means of the populations tested are the same. The alternative hypothesis H_1 states that *at least one* of the means is different but not all.

The assumptions that should be obeyed for the ANOVA testing include the following:

1. Independent observations within each sample
2. Samples obtained from populations that are normally distributed
3. Samples obtained from populations with equal variances

The results of an ANOVA test are resulted on an ANOVA summary table as shown below (hypothetical results). The larger the F, the more likely for a significant difference between treatment groups.



ANOVA Summary

SOURCES	SS	df	MS	
Between Rx	30	2	15	F = 15/1.67 = 8.98
Within Rx	20	12	1.67	
TOTAL	50	14		

df, degrees of freedom; MS, mean square or mean of squared deviations; S, sum of squares.

KEY POINTS

- Analysis of variance (ANOVA) is a statistical hypothesis technique to evaluate mean differences between two or more groups/treatments/conditions.
- The test statistic for ANOVA is the F-test; it is a ratio of the between treatment variability divided with the within treatment variability and follows the F-distribution.

The assumptions that should be obeyed for the ANOVA testing include the following:

1. Independent observations within each sample
2. Samples obtained from populations that are normally distributed
3. Samples obtained from populations with equal variances

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12. ANSWER: B

Power of a testing hypothesis is the probability that a test will reject the null hypothesis when it is false and it is defined as $1 - \beta$ (β = type II error). In our case, power is 0.8, which means that there is a 20% chance that the study will accept the null hypothesis when it is false and an 80% chance that it will reject it when it is false.

For every study, power is calculated in advance in order to assure an adequate number of data collected. A type II error (β) is the probability of failing to reject the null hypothesis when it is false; in other words, no real treatment effect was detected.

Power depends on four factors:

1. Alpha (α) level, type I error; to reject the null hypothesis when it is true; the smaller this error, the

lower the risk to reject the null hypothesis when it is true (larger type II error) and the smaller the power of a hypothesis test. The researcher will need more evidence to reject the null.
2. Population variability; the greater the variability, the greater the chance for type II error (accept the null hypothesis when it is false) and therefore the smaller the power.
3. Sample size; by decreasing the sample size, researchers will have a bigger type II error and therefore power will decrease.
4. Magnitude of difference between experimental conditions; the larger the magnitude, the easier it is to find a difference between the samples tested and by extrapolation the populations in question (smaller type II error) and therefore the power of a test goes up.

KEY POINTS

- Power of a testing hypothesis is the probability that a test will reject the null hypothesis when it is false and it is defined as $1 - \beta$ (β = type II error).
- Power depends on four factors: alpha (α) level, type I error; population variability; sample size; and magnitude of difference between experimental conditions.

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13. ANSWER: B

The null hypothesis (H_0) refers to a no change or no relationship between the variables tested. Instead, the alternative hypothesis (H_1) refers to a change, an effect present between the independent variable (treatment) and the dependent variable. The null hypothesis is assumed true until there is evidence to reject it based on the data obtained. A type I error (α) also known as a false positive, is the probability of rejecting the null hypothesis when it is true; in other words, the researcher finds effect when there is none. **A type II error (β) also known as a false negative, is the probability of failing to reject the null hypothesis when it is false;** the data show that there is no real treatment effect when there is.

KEY POINTS

- The null hypothesis (H_0) refers to a no change or no relationship between the variables tested.
- Instead, the alternative hypothesis (H_1) refers to a change, an effect present between the independent variable (treatment) and the dependent variable.
- The null hypothesis is assumed true until there is evidence to reject it based on the data obtained.
- A type I error (α), also known as a false positive, is the probability of rejecting the null hypothesis when it is true.
- A type II error (β), also known as a false negative, is the probability of failing to reject the null hypothesis when it is false.

		No effect	Rx effect
		H_0 True	H_0 False
	Reject H_0	α=Type I error, FP	CORRECT
DECISION			
	Reject H_0	CORRECT	β=Type II error, FN

REFERENCES

GraphPad Software. *GraphPad statistics guide*. Available at: http://www.graphpad.com/guides/prism/6/statistics. Accessed December 15, 2014. (A free instructional material on basic statistics)

Gravetter F, Wallnau L. *Statistics for the Behavioral Sciences*. 9th ed. Independence, KY: Cengage Learning; 2013:244–5.

14. ANSWER: C

Randomization serves to balance potential confounding factors between treatment groups, not to control for placebo effects. It has no effect on the power of the study or on the number of study subjects that are necessary. Although randomization may decrease certain biases in a study, only appropriate study design can decrease the types of bias in a study.

KEY FACT

- Randomization serves to balance potential confounding factors between treatment groups, not to control for placebo effects.

REFERENCES

GraphPad Software. *GraphPad statistics guide*. Available at: http://www.graphpad.com/guides/prism/6/statistics. Accessed December 15, 2014. (A free instructional material on basic statistics)

Gravetter F, Wallnau L. *Statistics for the Behavioral Sciences*. 9th ed. Independence, KY: Cengage Learning; 2013:244–5.

15. ANSWER: D

The classification of research design divides them first into longitudinal and cross-sectional studies. Longitudinal studies refer to a study performed over time, whereas **cross-sectional studies describe** an experiment at **a certain point in time** (reliance on existing differences). Longitudinal designs are subsequently separated into prospective or retrospective. **Cohort studies** can have controls that are either concurrent (parallel groups or self-control/crossover groups) with the study or historical. The randomization of children in this study allows for decrease of bias from confounding factors. The researcher can add a similar random group of children with the same disease process but not on this new medication to serve as a control group. Perhaps the best-known example of a cohort study is the Framingham Heart Study (www.framinghamheartstudy.org), which began in 1948 with about 5000 adult subjects and is now on its third generation of participants. **Retrospective designs are also known as case-control studies** because they compare outcomes between a group after a condition/intervention has occurred, with a control group.

Observational studies are ones where data are collected but either no intervention has occurred or more important the researcher had no control over that intervention. Differences can be revealed with observational studies but clear distinction of what caused these differences is unclear (intervention vs. other internal or external processes). The gold standard of experimental designs is a **randomized, controlled double-blind study**. Randomized because the subjects are assigned by a random process and double blind because neither the researcher nor the subjects know in which group they have been assigned. Although these studies provide the most information, they are both expensive and labor intensive.

KEY POINTS

- A longitudinal study refers to a study performed over time, whereas the cross-sectional study describes an experiment at a certain point in time (reliance on existing differences).
- Prospective studies are also known as cohort studies with study subjects monitored before an intervention occurs and thus allowing information about the natural history of a condition.
- Cohort studies can have controls that are either concurrent (parallel groups or self-control/cross over groups) with the study or historical.
- Observational studies are ones where data are collected but either no intervention has occurred or more important the researcher had no control over that intervention.
- The gold standard of experimental designs is a randomized, controlled double-blind study.

REFERENCES

Experimental design and statistics. In: Barash PG, Cullen BF, Stoelting R, eds. *Handbook of Clinical Anesthesia*. 5th ed. Philadelphia, PA: Lippincott Williams & Wilkins; 2005:65–6.

Rosenbaum SH. Statistical methods in anesthesia. In: Miller RD, Eriksson LI, Fleisher LA, Wiener-Kronish JP, Young WL, eds. *Miller's Anesthesia*. 7th ed. Philadelphia, PA: Churchill Livingstone; 2010:3080–1.

16. ANSWER: C

Case-control studies are used to identify factors that may contribute to a medical condition (such as postoperative apnea) by comparing a group of patients of interest with a set of control patients. They **are observational studies** in which two existing groups differing in outcome are identified and compared on the basis of some supposed causal attribute. Case-control studies require fewer resources but provide less evidence for causal inference than a randomized controlled trial.

KEY POINT

- Case-control studies are used to identify factors that may contribute to a medical condition (such as postoperative apnea) by comparing a group of patients of interest with a set of control patients.

REFERENCES

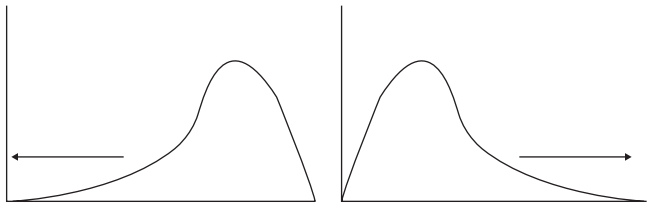
Experimental design and statistics. In: Barash PG, Cullen BF, Stoelting R, eds. *Handbook of Clinical Anesthesia*. 5th ed. Philadelphia, PA: Lippincott Williams & Wilkins; 2005:65–6.

Rosenbaum SH. Statistical methods in anesthesia. In: Miller RD, Eriksson LI, Fleisher LA, Wiener-Kronish JP, Young WL, eds. *Miller's Anesthesia*. 7th ed. Philadelphia, PA: Churchill Livingstone; 2010:3080–1.

17. ANSWER: A

Skewness **is a measure of the asymmetry of the probability distribution of a real-valued random variable.** The skewness value can be positive or negative, or even undefined.

Qualitatively, **a negative skew** indicates that the **tail on the left side of the probability density function is longer than the right side and the bulk of the values** (possibly including the median) **lie to the right of the mean**. A **positive skew** indicates that the **tail on the right side is longer than the left side and the bulk of the values lie to the left of the mean.** A zero value indicates that the values are relatively evenly distributed on both sides of the mean, typically but not necessarily implying a symmetric distribution (Fig. 28.3).



Negative Skew

Elongated tail at the **left**
More data in the left tail than would be expected in a normal distribution

Positive Skew

Elongated tail at the **right**
More data in the right tail than would be expected in a normal distribution

Figure 28.3 Skewness.

KEY POINTS

- Skewness is a measure of the asymmetry of the probability distribution of a real-valued random variable.
- Skewed distributions are ones where data are accumulated on one side.
- A negative skew indicates that the tail on the left side of the probability density function is longer than the right side and the bulk of the values (possibly including the median) lie to the right of the mean.
- A positive skew indicates that the tail on the right side is longer than the left side and the bulk of the values lie to the left of the mean.

REFERENCE

Groeneveld RA, Meeden G. Measuring skewness and kurtosis. *The Statistician*. 1984;33(4):391–9. doi:10.2307/2987742. JSTOR 2987742.

18. ANSWER: D

There are three characteristics of a relationship and correlation, the number that describes and measures it and provides us with detailed information.

1. The relationship has directionality; the correlation number is either positive or negative, implying that either the two variables change in the same direction (positive) or change in the opposite direction (negative). For example, the higher the education levels, the higher the income (positive correlation). The higher the temperature, the fewer hot drinks purchased.
2. The relationship has a form; the most common one is a linear type. Pearson correlation (r) is a measure of the degree and the direction of the linear relationship between two variables.
3. The relationship has a strength or consistent pattern; perfect correlation is 1.00. Zero corresponds to data with no clear trend but rather random propensity.

Correlations allow us to predict values. Assuming we have a linear equation representing two variables, once we know one of the two variables, we can predict the other (GPA and SAT scores). The linear equation is represented by $Y = bX + a$, where b is the slope of the line and a is the Y-intercept ($X = 0$). The statistical method for fitting the best straight line for a set of data is called regression.

Although the Pearson coefficient can be negative or positive, this does not correspond to a good or poor strength of a correlation. A −0.90 is as strong of a negative correlation as a +0.90 of a positive correlation.

Cautions interpreting correlations:

1. A correlation does not imply causality; the researcher will have to perform a study/an experiment with one variable being manipulated and the other being controlled, in order to show a causal link.
2. Correlation coefficients can be influenced by extreme data (outliers).

Causation implies that an action or occurrence is caused by something else (i.e., smoking causing lung cancer). **Causation is decided by the research team and cannot be determined by statistical analysis alone.**

Correlation should not be generalized beyond the range of the data obtained.

KEY POINTS

- Correlations allow us to predict values. Assuming we have a linear equation representing two variables, once we know one of the two variables, we can predict the other.
- Correlation should not be generalized beyond the range of the data obtained.
- Causation implies that an action or occurrence is caused by something else.
- Causation is decided by the research team and cannot be determined by statistical analysis alone.

REFERENCES

GraphPad Software. *GraphPad statistics guide*. Available at: http://www.graphpad.com/guides/prism/6/statistics. Accessed December 15, 2014. (A free instructional material on basic statistics)

Gravetter F, Wallnau L. *Statistics for the Behavioral Sciences*. 9th ed. Independence, KY: Cengage Learning; 2013:510–4, 519–22.

19. ANSWER: A

Measures of central tendency include the mean, the median, and the mode. The *mean* is calculated as the arithmetic average of a set of scores; that is, summing up all the scores and dividing them with the total number of subjects

(ΣX/n, where × are the individual scores, weights, and measurements, and n is the total number of individuals). The *median* is the middle of a distribution of data (50% of the scores lie below this score/value). The scores have to be arranged from smallest to largest. If n is odd, the median is the middle score. If n is even, the median is the average of the middle scores. Although the mean is the preferred measure of central tendency, the median is used when we have outlier scores (extreme values) or when we have an undetermined value (a subject did not complete the test; therefore, there is no score; ΣX cannot be calculated).

For example, scores 4, 6, 7, 8, 9, 3, 10, 8, and 5, arranged smallest to largest: 3, 4, 5, 6, 7, 8, 8, 9, and 10.

Mean is calculated as follows: (3 + 4 + 5 + 6 + 7 + 8 + 8 + 9 + 10) = 60, n = 9, MEAN = 60/9 = 6.7.

If we change the last score to a 50, then the mean will be (3 + 4 + 5 + 6 + 7 + 8 + 8 + 9 + 50) = 100, MEAN = 100/9 = 11.1.

The median will still remain the middle of the distribution and therefore 7.
The mode will still remain the score with the highest frequency and therefore still 8.

The *mode* is the score or grouping with the highest frequency and can be used with any scale of measurement. It can be used when we have nominal data (data only identified by name) and when we are describing a distribution (mode is the highest peak). Although the mode is the score with the absolute highest frequency, sometimes a distribution may have two high-frequency data points and is called bimodal or more than two and is called multimodal. The mode is the measure of central tendency that corresponds to an actual score in the distribution.

The standard deviation (population denoted by σ, sample denoted by s) is influenced by extreme scores, but it is a measure of variability and not of central tendency. It is defined as the average distance of each score from the mean and since the mean provides the balance point of the distribution, the sum of all deviations equals to zero. The variance (population denoted by σ^2, sample denoted by s^2) is the mean squared distance from the mean and since most of the times it is in squared units it is not as meaningful of a value.

KEY POINTS

- Measures of central tendency include the mean, the median, and the mode.
- The mean is calculated as the arithmetic average of a set of scores.
- The median is the middle of a distribution of data.
- The mode is the score or grouping with the highest frequency and can be used with any scale of measurement.
- The standard deviation (population denoted by σ, sample denoted by s) is influenced by extreme scores, but it is a measure of variability and not of central tendency.

REFERENCES

GraphPad Software. *GraphPad statistics guide*. Available at: http://www.graphpad.com/guides/prism/6/statistics. Accessed December 15, 2014. (A free instructional material on basic statistics)

Gravetter F, Wallnau L. *Statistics for the Behavioral Sciences*. 9th ed. Independence, KY: Cengage Learning; 2013:72–92.

20. ANSWER: D

This question describes regression and best-fitting lines for regression analysis. Correlations allow us to predict values. Assuming we have a linear equation representing two variables, once we know one of the two variables we can predict the other (GPA and SAT scores). The linear equation is represented by Y = bX + a, where b is the slope of the line and a is the Y-intercept (X = 0). The value of × where the line crosses the y-axis is 0 and is called the y-intercept (y = 25 in our case). The value of y where the line crosses the x-axis is 0 and is called the x-intercept (x = −12.5 in our case). The dependent variable is y and the independent variable is × (each × change makes a change in the y value). Since the slope of the line in our case is +2, for each unit change of x, the y value will increase by 2 points as noted in the chart.

X	Y
0	25
1	27
2	29
3	31

The statistical method for fitting the best straight line for a set of data is called regression.

The Pearson correlation is a method to describe a linear relationship between two parameters. This coefficient can be negative or positive, but this does not correspond to a good or poor strength of a correlation. A −0.90 is as strong of a negative correlation as a +0.90 of a positive correlation.

KEY POINTS

- The statistical method for fitting the best straight line for a set of data is called regression.
- The Pearson correlation is a method to describe a linear relationship between two parameters. This coefficient can be negative or positive, but this does not correspond to a good or poor strength of a correlation.
- A correlation does not imply causality; the researcher will have to perform a study/an experiment with

one variable being manipulated and the other being controlled, in order to show a causal link.
- Correlation coefficients can be influenced by extreme data (outliers).
- Correlation should not be generalized beyond the range of the data obtained.

REFERENCES

GraphPad Software. *GraphPad statistics guide*. Available at: http://www.graphpad.com/guides/prism/6/statistics. Accessed December 15, 2014. (A free instructional material on basic statistics)

Gravetter F, Wallnau L. *Statistics for the Behavioral Sciences*. 9th ed. Independence, KY: Cengage Learning; 2013:558–66.

21. ANSWER: B

The ***Mann-Whitney test*** allows a comparison of unpaired groups for differences in mean when the variables do not follow a normal (Gaussian) distribution. It can also be used for ranked data. Where the data are known to follow a normal (Gaussian) distribution, a simple unpaired t-test can be used.

Paired samples t-tests typically consist of a sample of matched pairs of similar units, or one group of units that has been tested twice (a "repeated measures" t-test). The Kruskal–Wallis one-way analysis of variance by ranks is a nonparametric method for testing whether samples originate from the same distribution. It is used for comparing two or more samples that are independent, and that may have different sample sizes, and extends the Mann–Whitney U test to more than two groups.

The Kolmogorov–Smirnov test is a nonparametric test of the equality of continuous, one-dimensional probability distributions that can be used to compare a sample with a reference probability distribution (one-sample K–S test) or to compare two samples (two-sample K–S test). The Kolmogorov–Smirnov statistic quantifies a distance between the empirical distribution function of the sample and the cumulative distribution function of the reference distribution, or between the empirical distribution functions of two samples.

KEY FACTS

- The Mann-Whitney test allows a comparison of unpaired groups for differences in mean when the variables do not follow a normal (Gaussian) distribution.
- Where the data are known to follow a normal (Gaussian) distribution, a simple t-test can be used.

REFERENCE

Gravetter F, Wallnau L. *Statistics for the Behavioral Sciences*. 9th ed. Independence, KY: Cengage Learning; 2013:284–8, 291–2, 317–21.

22. ANSWER: C

The student t-test is one of the most commonly used techniques for testing a hypothesis on the basis of a difference between two sample means. A two-sided or two-tailed test, using a significance level of 0.05, allots half of alpha to testing the statistical significance in one direction and half of alpha to testing statistical significance in the other direction. This means that 0.025 lies in each tail of the distribution of the test statistic. When using a two-tailed test, regardless of the direction of the relationship, one tests for the possibility of the relationship in both directions. If one cannot indicate the direction of any group mean difference in advance, then a two-sided t-test is more appropriate. If in doubt, a two-sided t-test should be used because it is more conservative and reduces the probability of rejecting the null hypothesis when it is true (a type I error = α).

A one-sided or one-tailed test, using a significance level of 0.05, allots all of alpha to testing the statistical significance in the one direction of interest. This means that 0.05 is in one tail of the distribution of the test statistic. When using a one-tailed test, one tests for the possibility of the relationship in one direction and completely disregards the possibility of a relationship in the other direction. The one-tailed test provides more power to detect an effect in one direction by not testing the effect in the other direction. A one-sided t-test is appropriate when one is certain that there either will be no difference between the two group means or that the difference will go in a direction you can specify in advance. If you consider the consequences of missing an effect in the untested direction and conclude that they are negligible and in no way irresponsible or unethical, then you can proceed with a one-tailed test. Choosing a one-tailed test for the sole purpose of attaining significance is not appropriate. Choosing a one-tailed test after running a two-tailed test that failed to reject the null hypothesis is not appropriate, no matter how "close" to significant the two-tailed test was. Because the groups in the example above are unpaired or unmatched, an unpaired or independent t-test is most appropriate.

KEY POINTS

- The student t-test is one of the most commonly used techniques for testing a hypothesis on the basis of a difference between two sample means.
- A two-sided or two-tailed test, using a significance level of 0.05, allots half of alpha to testing the statistical significance in one direction and half of alpha to testing statistical significance in the other direction.
- A one-sided or one-tailed test, using a significance level of 0.05, allots all of alpha to testing the statistical significance in the one direction of interest.

- The one-tailed test provides more power to detect an effect in one direction by not testing the effect in the other direction.

REFERENCES

GraphPad Software. *GraphPad statistics guide*. Available at: http://www.graphpad.com/guides/prism/6/statistics. Accessed December 15, 2014. (A free instructional material on basic statistics)

Gravetter F, Wallnau L. *Statistics for the Behavioral Sciences*. 9th ed. Independence, KY: Cengage Learning; 2013:284–8, 291–2, 317–21.

23. ANSWER: C

This question describes classification of statistical data. Data are classified into four categories also known as scales of measurements: nominal, ordinal, interval, and ratio. **Nominal data, data relating to name, describe data only in a qualitative way.** They differentiate measurements, but they do not give direction or size of a difference between them. Examples include gender, occupation, marital status, and ethnicity. **Ordinal data represent data in an organized ranked pattern.** They allow for distinction between observations and provide direction; for example, 1st, 2nd, 3rd or small, medium, and large or class rank. **The interval and ratio measurements still differentiate measurements, and they rank them, but in addition they allow for both a size and a direction of the difference between measurements.** The interval scale has an arbitrary zero (zero Celsius temperature does not mean there is no temperature), but the ratio scale has an absolute zero and allows for comparisons between ratios (a test taker took 2 hours to complete a test and another one took 4 hours, so we can say that the second tester took 2x the time compared to the first one).

Height and weight are also ratio scales. They have absolute zeroes and provide comparisons between measurements. A 200 lb patient is 2x heavier than an 100 lb patient and a 6 ft tall man is 2x taller than a 3 ft boy.

The important distinction between all the scales of measurements is that nominal and ordinal are not numerical and require different statistical methods for analysis such as chi-square testing, whereas interval and ratio scales use most statistical applications because they deal with numerical computations.

KEY POINTS

- Nominal data, data relating to name, describe data only in a qualitative way.
- Ordinal data represent data in an organized ranked pattern.
- The interval and ratio measurements still differentiate measurements, and they rank them, but in addition they allow for both a size and a direction of the difference between measurements.

REFERENCES

GraphPad Software. *GraphPad statistics guide*. Available at: http://www.graphpad.com/guides/prism/6/statistics. Accessed December 15, 2014. (A free instructional material on basic statistics)

Gravetter F, Wallnau L. *Statistics for the Behavioral Sciences*. 9th ed. Independence, KY: Cengage Learning; 2013:23–5, 30–1.

24. ANSWER: D

Prevalence and incidence are very different epidemiologic measures. **The *prevalence* of a condition is the number of people who currently have the condition; the *incidence* refers to the number of people per year who acquire the condition.** A chronic disease like diabetes can have a low annual incidence but a high prevalence. By contrast, a short-duration condition such as the common cold may have a high incidence but low prevalence.

KEY FACTS

- The prevalence of a condition is the number of people who currently have the condition.
- The incidence refers to the number of people per year who acquire the condition.

REFERENCE

Experimental design and statistics. In: Barash PG, Cullen BF, Stoelting R, eds. *Handbook of Clinical Anesthesia*. 5th ed. Philadelphia, PA: Lippincott Williams & Wilkins; 2005:65–6.

25. ANSWER: A

This question describes a **scatter plot** and correlation as a method of describing relationships between two variables. A scatter plot provides **visual representation of data and allows for a concise description of a relationship between two parameters**. There are three characteristics of a relationship and the correlation, the number that describes and measures it and provides us with detailed information.

1. The relationship has directionality; the correlation number is either positive or negative, implying that either the two variables change in the same direction (positive) or change in opposite directions (negative). For example, the higher the education levels, the higher the income (positive correlation). The higher the temperature, the fewer hot drinks purchased.
2. The relationship has a form; the most common one is a linear type. Pearson correlation (r) is a

measure of the degree and the direction of the linear relationship between two variables.
3. The relationship has a strength or consistent pattern; perfect correlation is 1.00. Zero corresponds to data with no clear trend but rather random propensity.

Correlations allow us to predict values. Assuming we have a linear equation representing two variables, once we know one of the two variables we can predict the other (GPA and SAT scores). The linear equation is represented by Y = bX + a, where b is the slope of the line and a is the Y-intercept (X = 0). The statistical method for fitting the best straight line for a set of data is called regression.

Although the Pearson coefficient can be negative or positive, this does not correspond to a good or poor strength of a correlation. A −0.90 is as strong of a negative correlation as a +0.90 of a positive correlation.

Cautions interpreting correlations:

1. A correlation does not imply causality; the researcher will have to perform a study/an experiment with one variable being manipulated and the other being controlled, in order to show a causal link.
2. Correlation coefficients can be influenced by extreme data (outliers).
3. Correlation should not be generalized beyond the range of the data obtained.

A histogram is a type of graph that allows depiction of interval or ratio scale measurements.

KEY POINTS

- A scatter plot provides visual representation of data and allows for a concise description of a relationship between two parameters.
- Although the Pearson coefficient can be negative or positive, this does not correspond to a good or poor strength of a correlation.

REFERENCES

Gravetter F, Wallnau L. *Statistics for the Behavioral Sciences*. 9th ed. Independence, KY: Cengage Learning; 2013:510–4,519–22.

GraphPad Software. *GraphPad statistics guide*. Available at: http://www.graphpad.com/guides/prism/6/statistics. Accessed December 15, 2014. (A free instructional material on basic statistics)

26. ANSWER: A

Crossover studies are longitudinal designs in which subjects receive a sequence of different interventions/treatments/exposures. Although they can be observational studies, the majority are controlled experiments. Each subject acts as his or her own control since the subjects are used twice and subjected to the different interventions. Therefore, fewer numbers are needed to perform the study.

Table 28.3

GOAL	TYPE OF DATA: MEASUREMENT (FROM GAUSSIAN POPULATION)	TYPE OF DATA: RANK, SCORE, OR MEASUREMENT (FROM NON-GAUSSIAN POPULATION)	TYPE OF DATA: BINOMIAL (TWO POSSIBLE OUTCOMES)	TYPE OF DATA: SURVIVAL TIME
Describe one group	Mean, SD	Median, interquartile range	Proportion	Kaplan Meier survival curve
Compare one group to a hypothetical value	One-sample t-test	Wilcoxon test	Chi-square or binomial test	
Compare two unpaired groups	Unpaired t-test	Mann-Whitney test	Fisher test (chi-square for large samples)	Log-rank test or Mantel Haenszel
Compare two paired groups	Paired t-test	Wilcoxon test	McNemar test	Conditional proportional hazards regression
Compare three or more unmatched groups	One-way ANOVA	Kruskal-Wallis test	Chi-square	Cox proportional hazard regression
Compare three or more matched groups	Repeated-measures ANOVA	Friedman test	Cochrane Q	Conditional proportional hazards regression
Quantify association between two variables	Pearson correlation	Spearman correlation	Contingency coefficients	
Predict value from another measured variable	Simple linear regression or nonlinear regression	Nonparametric regression	Simple logistic regression	Cox proportional hazard regression
Predict value from several measured or binomial variables	Multiple linear regression or multiple nonlinear regression		Multiple logistic regression	Cox proportional hazard regression

Source: From Motulsky H. *Intuitive Biostatistics*. New York, NY: Oxford University Press; 1999.

To minimize the effect of interactions between treatments, a "washout" period between interventions may be required.

KEY POINTS

- In crossover studies subjects receive a sequence of different interventions/treatments/exposures.
- Each subject acts as his or her own control.

REFERENCES

Experimental design and statistics. In: Barash PG, Cullen BF, Stoelting R, eds. *Handbook of Clinical Anesthesia*. 5th ed. Philadelphia, PA: Lippincott Williams & Wilkins; 2005:65–6.

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