Abdominal surgery in infants and children presents a number of unique anesthetic challenges that are reviewed in this chapter. The first section consists of a discussion of anesthetic concerns for intraabdominal procedures, especially in neonates and small infants. This discussion is general in nature, and the reader should remember that there exists a wide spectrum of patient conditions and surgical techniques for which the anesthetic technique is individualized. The second section reviews unique aspects of a number of common pediatric surgical conditions of the abdomen that are of interest to anesthesiologists. Anesthetic considerations for indwelling vascular access placement (e.g., Hickman or Broviac catheters) are also covered.

**GENERAL CONSIDERATIONS**

Intraabdominal procedures in children run the gamut from simple hernia repairs in healthy children to complex bowel resections in extremely ill premature infants (e.g., for necrotizing enterocolitis). Therefore, these general guidelines are intended to be modified for each individual patient, depending on the nature of the surgical procedure and the severity of the illness.

Preoperative assessment should consist of investigation of comorbidities and evaluation of volume resuscitation. Many abdominal diseases will present with vomiting, diarrhea, and sequestration of fluid within the abdominal cavity. Therefore, estimation of volume status is crucial, and preoperative volume resuscitation is often required.

The preoperative physical exam is focused on determination of vital signs, cardiorespiratory stability, and evaluation of the child’s upper airway. Signs of dehydration include dry mucous membranes, poor skin turgor, lethargy, weight loss, tachycardia, cold mottled skin, poor peripheral capillary refill, and a sunken fontanelle in the young infant. Additional systemic findings include metabolic acidosis, oliguria, and hypotension.

Abdominal distension may be caused by bowel edema, accumulation of fluid or air in the bowel, and pneumoperitoneum if intestinal perforation has occurred. It can cause elevation of the diaphragm, which decreases functional residual capacity, and in the small infant can result in alveolar closure during normal tidal breathing, and lead to hypoxemia and respiratory failure.

Small infants with abdominal processes require a full set of preoperative laboratory studies, including a complete blood count with platelets, electrolytes, and coagulation tests. A type-and-crossmatch should be obtained if there is a possibility of blood loss requiring red cell transfusion. When bowel ischemia is likely, such as with necrotizing enterocolitis, a blood gas analysis is indicated to determine the severity of the underlying metabolic acidosis. Liver and kidney function tests are also appropriate in children with abdominal pathology that is likely to cause dysfunction of these organ systems.

Premedication should be administered when indicated for pain, anxiety, or prophylaxis against pulmonary
aspiration of gastric contents. This includes an opioid for pain relief and a benzodiazepine for anxiolysis. Some anesthesiologists may choose to administer a H₂-antagonist to reduce gastric acidity; however, there is no proven benefit to this practice. Metoclopramide, a prokinetic agent, should not be administered if there is the possibility of an intestinal obstruction.

Primary intraoperative anesthetic considerations include management of dehydration, hypovolemia, acidosis, and hypothermia. Standard monitors are usually sufficient but the disease process should determine the need for either direct arterial measurement or central venous access. All measures to ensure normothermia should be used (see Chapter 15). These include core temperature monitoring (esophageal or rectal), warming the operating room (OR), humidification of the breathing circuit, use of an intravenous fluid warming device, and use of a forced warm-air heating blanket underneath and around the child. Overhead radiant heaters can be used for neonates and small infants during placement of monitors and induction of anesthesia. In tiny infants, an esophageal catheter can be advanced too far and into the stomach, where it becomes warm from the OR lights during a laparotomy, thus producing an artificial elevation in temperature. An indwelling urinary catheter is indicated if the procedure will last more than 3–4 hours, or if large intraoperative fluid fluctuations are anticipated. A urinary collection bag is utilized in small neonates or premature infants.

Insensible losses are often high when a large surface area of bowel is exposed (at least 10 mL/kg/h) and will warrant liberal fluid administration. Hypovolemia can occur rapidly from unanticipated bleeding or third-space losses from bowel exposure or edema. Neonates with large abdominal defects such as gastroschisis often require more than 50 mL/kg of isotonic fluid over the duration of the procedure. Many pediatric anesthesiologists will insert two intravenous catheters. Isotonic crystalloid solutions are appropriate for most volume resuscitations; albumin or other colloid solutions are rarely used. Some pediatric anesthesiologists, however, prefer to administer 5% albumin to extremely premature infants undergoing extensive bowel surgery, to maximize the duration that the solution will remain in the vascular space. The occasional child may require inotropic therapy with dopamine (see Chapter 38) if hypotension persists despite seemingly adequate volume resuscitation, especially when there is an intraabdominal process associated with sepsis.

Virtually all infants and children presenting for urgent abdominal surgery are considered to have a full stomach, and thus at increased risk for pulmonary aspiration of gastric contents during the loss of consciousness that accompanies induction of general anesthesia. Decreased gastric emptying in these patients may be caused by the pathologic abdominal process, or administration of medications with anticholinergic effects, such as opioids. Children undergoing elective abdominal procedures that are minor and not associated with pathologic processes that interfere with normal gastric emptying can be managed with normal fasting guidelines (see Chapter 12).

In children presumed to be at risk for pulmonary aspiration of gastric contents during induction of anesthesia, rapid sequence intubation (RSI) with administration of cricoid pressure is indicated. Succinylcholine 2 mg/kg or high-dose rocuronium (1.2–1.6 mg/kg) are both effective for this purpose. A modified rapid sequence induction is preferred in small infants who will likely develop oxyhemoglobin desaturation during brief periods of apnea, and will therefore require assisted ventilation prior to endotracheal intubation. Awake intubations are rarely, if ever, performed on neonates by pediatric anesthesiologists, except during episodes of severe hemodynamic instability.

Many children will present for abdominal surgery with an indwelling nasogastric tube, which should be suctioned immediately prior to induction of general anesthesia. It can then be removed to facilitate airway management, and replaced following insertion of the endotracheal tube.

Maintenance of general anesthesia during abdominal procedures depends primarily on the severity of the child’s illness. For healthy children undergoing procedures that are not expected to require postoperative mechanical ventilation, a balanced technique is chosen, including an inhalational agent and an opioid. In children who are expected to require postoperative mechanical ventilation, an opioid-based technique is preferred, as it has fewer deleterious effects on the cardiovascular system when compared to inhalational agents, and can be continued into the postoperative period to decrease the child’s overall stress response and provide ongoing analgesia and sedation. Small infants and neonates tend to remain hemodynamically stable after relatively large amounts of opioids in the absence of hypovolemia. N₂O is avoided during all but superficial abdominal wall procedures (e.g., simple hernia repair). Regional analgesia via the lumbar or caudal epidural route can be considered when the child is hemodynamically stable and does not demonstrate evidence of bacteremia or sepsis.

Neonates who undergo major abdominal surgery will benefit from postoperative mechanical ventilation for several days. This allows liberal titration of opioids and a decreased stress response without the risk of apnea during this phase of large fluid requirements and intravascular fluid shifts secondary to intestinal “third spacing.”

**ANESTHETIC MANAGEMENT OF INDIVIDUAL PROCEDURES**

**Choledochal Cyst**

A choledochal cyst is an abnormal dilatation of the common bile duct that, when sufficiently large, obstructs the egress of bile from the liver. It is commonly diagnosed
in infants within the first year but may occur in older children. The classic triad of symptoms includes pain, jaundice, and a right upper-quadrant abdominal mass. Chronic biliary obstruction may cause secondary liver damage.

The important aspects of anesthetic management for children undergoing choledochal cyst removal consist of attention to liver function abnormalities and provision of postoperative analgesia. High lumbar or low thoracic epidural analgesia is preferred.

**Congenital Diaphragmatic Hernia**

A congenital diaphragmatic hernia (CDH) is a malformation of the diaphragm that allows the abdominal contents to enter and remain within the thoracic cavity during fetal life (Fig. 28-1). It occurs in approximately 1 of every 2500 live births and is often detected by prenatal ultrasound. The most critical consequence of this anomaly is the prevention of normal prenatal lung growth.
Severe cases cause significant lung hypoplasia that is incompatible with maintenance of normoxemia at birth. Most commonly, CDH occurs on the left side, posteriorly through the foramen of Bochdalek. Right-sided or anterior defects through the foramen of Morgagni occur infrequently, and are not usually associated with severe pulmonary hypoplasia, but rather signs of intestinal obstruction.

Severe defects manifest immediately after birth as respiratory distress. Newborns with CDH will demonstrate chest wall retractions, tachypnea, hypoxemia, absence of breath sounds on the affected side, and the classically appearing scaphoid abdomen that indicates a lack of organs within the abdominal cavity. Diagnosis is confirmed by radiography, which demonstrates bowel in the thoracic cavity and a gasless abdominal cavity. Infants with mild defects and normal lung growth may not be diagnosed until many months after birth, when a chest radiograph is obtained for unrelated reasons.

Pulmonary hypoplasia and hypoxemia trigger a number of deleterious effects in the newborn period, the most critical of which is persistent pulmonary hypertension and failure to transition normally from fetal to adult circulatory function (see Chapter 1). The pressure on the right side of the heart remains high, and right-to-left shunting continues across the ductus arteriosus, which also fails to close secondary to persistent hypoxemia, hypercarbia, and acidosis. Additional right-to-left shunting can occur through a patent foramen ovale or ventricular septal defect, if present. This process sets up a vicious cycle that is difficult to abort in the absence of normoxemia and normal lung function. Concomitant congenital heart disease contributes to the pathologic process and reduces overall survival.

Medical management at birth consists of immediate tracheal intubation and institution of mechanical ventilation. Bag-and-mask positive pressure ventilation should be minimized in an effort to reduce gastric distention since the stomach or small intestine may be contained within the thoracic cavity. A nasogastric tube should be immediately inserted to decompress the upper digestive tract. Until the late 1980s, these infants were rushed to surgery in an attempt to remove the abdominal contents from the thoracic cavity and allow reexpansion of the hypoplastic lung. This practice did not improve survival since the compressed lung is hypoplastic, not atelectatic. Current medical management includes medical stabilization; corrective surgery is performed on a semi-elective basis within the first few weeks of life.

Initial medical management consists of optimization of oxygenation and ventilation, administration of sedatives and neuromuscular blockers, establishment of normothermia, and placement of intravenous and arterial access lines. The goal of ventilatory management is a PaO₂ greater than 60 mmHg and a PCO₂ less than 45 mmHg, to minimize increases in pulmonary arterial pressures. The inability to reduce the PCO₂ or reduce the alveolar-to-arterial oxygen gradient to less than 500 mmHg despite maximal ventilatory techniques (e.g., using the oscillator or jet ventilator) is associated with a poor outcome and is an indication for institution of extracorporeal membrane oxygenation (ECMO). Pulmonary vasodilator therapy with inhaled nitric oxide is infrequently successful.

Surgical correction of CDH occurs in the operating room after medical stabilization, or in the neonatal intensive care unit (NICU), while the patient remains on ECMO life support. The surgery consists of an abdominal or thoracic reduction of the herniated viscera, and placement of an ipsilateral chest tube. Some surgeons will insert a contralateral chest tube to protect against pneumothorax from aggressive ventilator therapy. Unexplained intraoperative decreases in lung compliance, hypoxemia, or hypotension are suggestive of a contralateral pneumothorax and should warrant chest tube placement. The diaphragmatic defect is closed by primary repair or by using a synthetic patch.

Ventilatory management during CDH repair consists of a balance between avoidance of barotrauma and avoidance of factors that increase PVR, such as hypoxemia, hypercarbia, and acidosis. Simultaneous pulse oximetry at preductal (right upper-extremity) and postductal (lower-extremity) sites allows early detection of right-to-left shunting from development of pulmonary hypertension. Cannulation of the right radial artery will allow continuous blood pressure measurement and measurement of preductal oxygenation.

Additional anesthetic priorities during CDH repair include provision of adequate volume expansion, especially when high ventilatory pressures are required, and reduction of sympathetic tone using a high-dose opioid technique to minimize elevations in PVR. Mechanical ventilation is continued in the postoperative period in all but the most minor defects.

### Extrahepatic Biliary Atresia

Extrahepatic biliary atresia describes a congenital malformation of the hepatic ducts between the biliary system of the liver and the duodenum, such that bile cannot be emptied properly from the liver. This disease manifests as direct hyperbilirubinemia within the first several weeks of life. Infants with biliary atresia require a surgical anastomosis between the duodenum and an intrahepatic biliary duct (Kasai procedure). Anesthetic concerns are primarily those of decreased hepatic function and its sequelae, such as clotting factor deficiency, and avoidance of medications that are metabolized in the liver. Postoperative epidural analgesia is preferred in the absence of a coagulopathy. Long-term postoperative complications after the Kasai procedure include recurrent ascending...
Hirschsprung’s Disease

Hirschsprung’s disease (congenital aganglionic megacolon) is defined as the absence of parasympathetic ganglion cells in the lower colon. It is the most common cause of large bowel obstruction in the newborn, and presents in the first few days of life as a failure to pass meconium and abdominal distension. On rare occasions these children may become very ill with toxic megacolon, peritonitis, and colonic perforation. Treatment consists of a colostomy at the time of diagnosis, and definitive therapy (pull-through procedure) some time later in the first year of life, although some surgeons may now choose to perform this procedure in the neonatal period. In many centers, laparoscopy is being utilized during a large part of the intraabdominal resection prior to the perineal repair. During the latter portion of the procedure when the perineum is repaired, the child will be placed at the far end of the OR table in the lithotomy position. The anesthesiologist should anticipate this relocation and adjust the lengths of the monitoring wires, breathing circuit, and IV tubing accordingly.

Imperforate Anus

Imperforate anus (anal atresia) is diagnosed shortly after birth on physical exam, or after an evaluation for failure of the infant to pass meconium in the first days of life. This anomaly ranges in severity from a mild stenosis with a thin obstructive band that is punctured at the bedside, to a more severe atresia that is associated with other anomalies. Anal atresia is a component of the VATER syndrome: Vertebral anomalies, Anal atresia, Tracheo-esophageal fistula, and Renal/gential anomalies. An updated acronym is VACTERL to include Cardiac and Limb anomalies.

Anal atresia is considered an urgent surgical procedure. A colostomy is performed shortly following diagnosis. It is less urgent in female infants with a rectovaginal fistula that allows passage of meconium. The corrective procedure, a posterior sagittal anorectoplasty (Pena procedure), is often performed during the first year of life. Unique anesthetic concerns include the delineation of coexisting anomalies, and assessment of fluid and electrolyte imbalance. The procedure usually begins in the prone position; some surgeons will turn the child and complete the procedure in the supine or lithotomy position.

Indwelling Intravenous Access

One of the most commonly performed surgical procedures in children is the intraoperative placement of an indwelling venous catheter (Broviac, Hickman, Port-a-Cath, etc.) into the central venous system. The catheter is inserted into one of the central veins of the neck or groin, and a portion of it is tunneled underneath the skin for improved stability and to discourage infection at the site of the vein. Children with different types of chronic diseases will require this procedure for long-term parenteral nutrition, administration of antibiotics, or administration of chemotherapy, among many other conditions.

Preoperative evaluation of the patient should consist of complete delineation of comorbidities. A preoperative anxiolytic can be administered orally or intravenously if access has been established. There are no unique considerations for induction and maintenance of general anesthesia. The procedure is performed with the child in the Trendelenburg position, with the head hyperextended and turned to one side. Therefore, airway access is limited, and for this reason all children undergo endotracheal intubation for the procedure.

General anesthesia is also utilized in many children who require removal of their tunneled catheter. The tunneled central catheter can be used to administer intravenous induction agents but should not be removed prior to establishing peripheral venous access. Significant blood loss can occasionally occur from a tear in the vein that contained the tunneled catheter. Endotracheal intubation is not required for this procedure, which often takes less than 10 minutes to perform and in which surgical draping is minimal.

Inguinal Hernia

Inguinal hernia repair is one of the most common surgical procedures in children. A unilateral hernia is usually diagnosed on routine physical exam in healthy school-aged children. Bilateral hernias commonly occur in extremely premature infants and, because of the potential risk of incarceration, will usually be repaired before the child is discharged from the hospital. Therefore, these children will present with all the usual medical problems associated with prematurity (see Chapters 10 and 11).

There are many ways to anesthetize these children. Different factors are taken into consideration, including the health of the child, preference of the surgeon, and the skills of the anesthesiology provider. Older children with uncomplicated unilateral hernias can receive maintenance of general anesthesia by mask or laryngeal mask airway (LMA). When laparoscopic examination of the contralateral side is performed, endotracheal intubation and neuromuscular blockade may be indicated, depending on the preference of the surgeon. Small infants who are at risk for development of postoperative apnea may benefit from spinal anesthesia for inguinal hernia repair (see Chapter 20).
Intussusception

Intussusception is the telescoping of a portion of bowel (usually the distal ileum) into the adjacent more distal portion with subsequent swelling and obstruction. Occasionally, this obstruction may be severe and lead to intestinal ischemia. The cause is largely unknown but is associated with a polyp or enlarged intestinal lymph nodes (Peyer’s patches). These children are usually between the ages of 2 months and 5 years, and present with vomiting, bloody (currant jelly) stools, and abdominal distention. Bowel ischemia and sepsis may be present in severe or protracted cases. The diagnosis is confirmed radiographically. In many cases, the intussusception can be reduced using a barium enema. All others must undergo exploratory laparotomy and manual reduction. The primary anesthetic considerations for this procedure consist of fluid resuscitation, maintenance of normothermia, and provision of postoperative analgesia.

Laparoscopic Surgery

A variety of pediatric abdominal procedures are now being performed through the laparoscope. These include appendectomies, pyloromyotomies, hernias, Nissen fundoplications, and bowel resections, to name just a few. In older children, the laparoscopic methods and anesthetic implications are the same as for adults. In younger children and infants, increases in intraabdominal pressure (IAP) may result in cardiopulmonary compromise. In several studies, an IAP less than 12 mmHg appears to be safe in this young patient population. IAP above 12 mmHg has been associated with hypotension, bradycardia, and difficulty with ventilation secondary to a loss of functional residual capacity (FRC) and a decrease in lung compliance. IAP greater than 6 mmHg may cause increased PVR and result in right-to-left shunting in cyanotic children with congenital heart disease.

Malrotation and Midgut Volvulus

Malrotation is defined as an abnormal twisting of the intestine as it migrates back into the fetal abdominal cavity from its embryonic extraabdominal location during the latter part of the first trimester. When this twisting compromises the blood supply of the intestine (superior mesenteric artery), the condition is known as a volvulus. Infants who develop volvulus from malrotation usually become symptomatic sometime in the first 2 months of life, although mild cases can remain asymptomatic for many years. Symptoms include bilious vomiting or signs of intestinal perforation and ischemia. These infants can present quite ill with a sepsis-like picture; the condition can be fulminant and even fatal. Severely ill children may require fluid and blood resuscitation, and endotracheal intubation in the preoperative period. Children with malrotation often have additional congenital anomalies that should be investigated prior to surgery.

The treatment of volvulus consists of urgent exploratory laparotomy and surgical reduction (Ladd’s procedure). The bowel is untwisted along the mesentry and fixed in an unrotated position. Most children are awakened and extubated in the operating room and require only routine postoperative care. However, depending on the severity of the child’s illness, consideration should be given to leaving the child’s trachea intubated and institution of mechanical ventilation postoperatively, especially if a “second-look” laparotomy is planned to assess bowel viability.

Meckel Diverticulum

A Meckel diverticulum is a persistence of the omphalomesenteric duct after fetal life that presents as painless rectal bleeding sometime in the first few years of life. Definitive treatment is surgical resection via exploratory laparotomy. Clinically significant anemia is uncommon. The major anesthetic consideration is relief of postoperative pain, for which epidural analgesia is recommended.

Necrotizing Enterocolitis

Necrotizing enterocolitis (NEC) is a multifactorial disorder that affects 6–10% of prematurely born infants weighing under 1500 g. Risk factors include administration of hypertonic enteral feedings, decreased bowel perfusion, and infection with enteric organisms (Fig. 28-2). It is a fulminant disease that initially manifests as abdominal distention and bloody stools, and can progress rapidly to severe intestinal ischemia, sepsis, and shock. Additional signs and symptoms include cardiovascular instability, respiratory failure, temperature instability, metabolic acidosis, thrombocytopenia, and disseminated intravascular coagulation (DIC). Mortality ranges between 10% and 50%. Infants who survive an episode of NEC are more likely to suffer from neurodevelopmental morbidity.

Pathologic findings range from mild mucosal ulceration to bowel perforation and severe peritonitis. Bowel ischemia causes damage to the intestinal mucosa, which allows bowel gas to penetrate the submucosal region and enter the mesenteric veins and portal venous system. Diagnosis is usually made on the basis of an abdominal radiograph that reveals pneumatosis intestinalis (air bubbles within the intestinal wall), or free air within the abdominal cavity or portal venous system. Mild cases of NEC can be managed conservatively with medical therapy that consists of gastric decompression, antibiotics, and volume resuscitation with isotonic fluids and blood products. Surgical exploration is indicated for infants with radiographic evidence of intestinal perforation...
Inotropic support may be necessary to support cardiovascular function. Anesthetic considerations include management of acidosis, hypovolemia, anemia, electrolyte imbalance, coagulopathy, and support of cardiovascular function. An arterial line is recommended to monitor blood pressure closely and facilitate frequent collection of blood samples. Central venous cannulation will facilitate volume replacement.

An exploratory laparotomy is performed to examine the bowel in its entirety. Perforations may be repaired or surgically excised. A variable amount of ischemic bowel may be removed. This procedure is associated with large amounts of fluid and possibly blood loss. The anesthesiologist should be prepared to resuscitate the infant with isotonic fluid (normal saline or Lactated Ringers solution) and blood products as needed. Postoperatively these infants remain intubated, sedated, and mechanically ventilated while supportive therapy continues. Recovery and survival are dependent on the extent of bowel ischemia and severity of the underlying disease. Lower birthweight infants have poorer outcomes.

### Omphalocele and Gastroschisis

Although each represents a distinct anatomical defect, omphalocele and gastroschisis are discussed together because their anesthetic considerations are nearly identical. Each is a congenital defect that allows a portion of the intestinal viscera to remain outside the abdominal cavity, and requires surgical repair as soon as possible after birth.

An omphalocele occurs when the visceral organs fail to migrate from the yolk sac back into the abdomen early in gestation; the defect occurs at the insertion of the umbilicus (Fig. 28-3). Gastroschisis is thought to result from an occlusion of the omphalomesenteric artery during early development. As a result, the abdominal viscera herniate through a rent in the abdominal wall, usually to the right of the umbilicus (Fig. 28-4). Omphalocele is more likely than gastroschisis to be associated with prematurity and additional congenital anomalies. It is a component of the Beckwith–Wiedemann syndrome, which consists of hypertrophy of multiple organs. In this syndrome, enlargement of the tongue may compromise the upper airway; and pancreatic enlargement causes hyperinsulinism, which results in hypoglycemia. Infants with gastroschisis are usually born at full term, and it is usually an isolated defect. The major pathophysiological difference between the two defects is that, in omphalocele, the intestinal contents remain covered with the peritoneal membrane which protects the intestinal mucosa from the irritative effects of amniotic fluid, and there is less

(i.e., free air) or rapidly worsening disease. Inotropic support may be necessary to support cardiovascular function.

Anesthetic considerations include management of acidosis, hypovolemia, anemia, electrolyte imbalance, coagulopathy, and support of cardiovascular function. An arterial line is recommended to monitor blood pressure closely and facilitate frequent collection of blood samples. Central venous cannulation will facilitate volume replacement.

An exploratory laparotomy is performed to examine the bowel in its entirety. Perforations may be repaired or surgically excised. A variable amount of ischemic bowel may be removed. This procedure is associated with large amounts of fluid and possibly blood loss. The anesthesiologist should be prepared to resuscitate the infant with isotonic fluid (normal saline or Lactated Ringers solution) and blood products as needed. Postoperatively these infants remain intubated, sedated, and mechanically ventilated while supportive therapy continues. Recovery and survival are dependent on the extent of bowel ischemia and severity of the underlying disease. Lower birthweight infants have poorer outcomes.
Whether diagnosed *in utero* or at birth, management begins immediately after delivery. The extruded abdominal contents are covered with warm saline dressings and are encased in a sterile plastic bag to decrease fluid and temperature loss, and discourage infection. A nasogastric tube is placed for gastric decompression, normovolemia is maintained with intravenous hydration, and associated comorbidities are addressed prior to surgical repair.

Considerations for induction of general anesthesia are similar to those for any newborn infant with a presumed increased risk of a “full stomach” secondary to intestinal obstruction. A modified rapid sequence intubation (RSI) is performed after suctioning the nasogastric tube. Some pediatric anesthesiologists will prefer to temporarily remove the nasogastric tube during endotracheal intubation.

Achieving a primary repair is the major surgical priority, for failure to place all the intestinal contents into the abdominal cavity increases postoperative morbidity significantly. However, in many cases where the abdominal cavity is too restrictive, a partial replacement is performed, and the remaining external viscera is encased in a synthetic silo mesh. Complete repair is accomplished as a staged procedure, allowing for the reduction of intestinal swelling over several days.

A number of intraoperative adverse physiologic derangements may occur when the surgeon attempts to place a large volume of abdominal contents into a restrictive abdominal cavity. Cephalad displacement of the diaphragm evaporative fluid and temperature loss after delivery than with gastroschisis. Because infants with gastroschisis lack this “protective” covering, they are more prone to dehydration, hypothermia, “third-space” fluid accumulation, electrolyte imbalance, acidosis, bleeding, and sepsis.

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**Article To Know**


Few articles exist in the pediatric anesthesia literature that have contributed important information concerning anesthetic management of complex neonatal procedures. This article represents one of those publications. Myron Yaster and his colleagues at Johns Hopkins were interested in predicting the outcome of primary surgical repair of omphalocele and gastroschisis based on the intraoperative abdominal pressure. They expanded upon their own animal experiments which demonstrated that acute elevations in intraabdominal pressure are associated with reductions in cardiac output and regional blood flow. They designed an observational study to determine whether increased gastric pressure at the time of the primary repair is associated with postoperative organ system failure.

The authors studied 11 newborns undergoing primary closure of an omphalocele or gastroschisis within the first 24 hours of life. Intragastric pressure was continuously measured using a fluid-filled 12-French oro gastric tube, and cardiac output indices were measured intraoperatively. Primary repair could not be accomplished in three infants. In the remaining eight infants, four required reoperation within 24 hours (group 1) and four had unremarkable postoperative courses (group 2). Indications for reoperation of the group 1 infants included low or absent urine output, or other evidence of poor cardiac output. Two of these infants were found to have ischemic or necrotic bowel during reoperation. Infants in group 1 who required reoperation had significantly greater increases in intragastric pressure and central venous pressure and decreases in cardiac index during the primary repair than infants who did not require reoperation. In group 1 the intragastric pressures ranged from 6 to 18 mmHg; in group 2 the range was 22–28 mmHg. Furthermore, an increase of central venous pressure (CVP) by 4 mmHg or more predicted reoperation. These results were subsequently confirmed in a prospective management study by the same group, and by a separate study that utilized bladder pressures. The results indicate that intraabdominal pressures greater than 20 mmHg are associated with critical decreases in organ perfusion. Anesthesiologists should use liberal neuromuscular blockade and tailor their ventilatory parameters to remain below this level whenever possible.
can significantly decrease functional residual capacity (FRC) and tidal volume, and lead to hypoxemia. During the repair, the anesthesiologist must frequently use manual ventilation in response to rapid changes in lung compliance and the need for increased inspiratory pressures to maintain adequate tidal volumes. The presence of hypoxemia despite maximal ventilation may preclude completion of a primary repair.

Increased intraabdominal pressure may result in an abdominal compartment syndrome. Venous compression leads to decreased preload and hypotension, and lower-limb venous congestion. Arterial compression causes renal artery compression and oliguria, and decreased perfusion to the lower extremities. Bowel ischemia may also occur. The anesthesiologist must ensure adequate volume and blood replacement, and full neuromuscular blockade must be maintained throughout the procedure. The surgeon is intent on performing a primary repair, but is often limited by respiratory and circulatory compromise, which must be adequately communicated by the anesthesiologist. This procedure provides the anesthesiologist with the opportunity to act in concert with the surgeon as each continually communicates their respective priorities.

All infants, except those with the most trivial repairs, remain intubated and mechanically ventilated in the postoperative period. Abdominal compartment syndrome may continue postoperatively; therefore, paralysis and adequate sedation with an opioid infusion are essential for optimal management.

**Pyloric Stenosis**

Pyloric stenosis describes an abnormality that occurs within the first several weeks of life, in which a hypertrophied pylorus obstructs the passage of food from the stomach to the small intestine. With an incidence of up to 1 in 300 live births, it represents one of the most common procedures requiring general anesthesia within the first weeks of life. Clinical manifestations include projectile nonbilious vomiting after feeds, and when severe or protracted, dehydration and failure to thrive. The diagnosis is confirmed by characteristic findings on physical exam (palpation of the hypertrophied pylorus), barium swallow, or ultrasound examination. Chronic emesis causes loss of hydrochloric acid from the stomach, which leads to a hypochloremic, hypokalemic metabolic alkalosis.

Once the condition is diagnosed, these children should be hospitalized and given intravenous therapy to correct the dehydration and electrolyte abnormalities. A nasogastric tube is inserted and all feedings are stopped. Rehydration consists of normal saline for reestablishment of normovolemia (some infants may require in excess of 50 mL/kg), and maintenance fluids consisting of D5-1/4NS with potassium chloride added. Pyloric stenosis is never considered a surgical emergency. Perioperative morbidity and mortality are associated with surgical correction prior to normalization of fluid and electrolyte derangements. Serum potassium should be in the normal range, and serum chloride should be ≥90 mEq/L prior to surgery. The kidney will retain chloride as a result of volume contraction. A urine chloride >20 mEq/L suggests that volume status has been adequately restored.

Prior to induction of general anesthesia, the infant’s nasogastric tube should be suctioned and removed, and a large-bore suction catheter (e.g., 14-French) is inserted orally into the stomach and suctioned while tilting the infant in all directions to evacuate any remaining gastric contents. This procedure will completely empty the stomach in nearly all infants. The most common anesthetic induction technique at The Children’s Hospital of Philadelphia is a modified rapid-sequence technique that consists of preoxygenation, followed by administration of propofol or thiopental, and a nondepolarizing neuromuscular blocker. Positive-pressure ventilation is provided by mask while an assistant provides cricoid pressure prior to endotracheal intubation. A true rapid-sequence technique using succinylcholine is not often used because oxyhemoglobin desaturation will usually occur prior to intubation, and the incidence of pulmonary aspiration is exceedingly low. “Awake” intubations are no longer performed on children with pyloric stenosis. Maintenance of general anesthesia can consist of any inhalational agent; however, desflurane is preferred because of its ability to be rapidly eliminated. Opioids are not administered, unless a remifentanil infusion is chosen for the duration of the procedure.

Surgical correction consists of a pyloromyotomy, in which the pylorus is partially split lengthwise to loosen the constriction. It is performed as an open procedure or by laparoscopy. Following the myotomy, the surgeon will often request insufflation of the stomach with air via an orogastric tube to test the integrity of the pyloric mucosa. Fluid and blood losses are minimal. Local anesthesia should be administered by the surgeon to the skin and subcutaneous tissues.

Although definitive data are lacking, the clinical experience of many pediatric anesthesiologists has been that these infants take longer than usual to emerge from general anesthesia and will often manifest central apnea in the postoperative period. Some attribute this to the underlying electrolyte imbalance and metabolic alkalosis associated with pyloric stenosis. This author’s practice is to minimize these complications by using short-acting anesthetic agents (e.g., propofol for induction, desflurane for maintenance), and discontinue the anesthetic agent at the time of the myotomy. Mivacurium is used for neuromuscular blockade. Use of continuous remifentanil as the primary maintenance agent has been associated with less postoperative apnea compared to halothane.
A 3-week old, 1.4-kg male infant is scheduled for emergency exploratory laparotomy for NEC. The infant was born at 28 weeks' gestation at a weight of 1.2 kg, and was mechanically ventilated during the first week of life. The infant had been doing well until 2 days ago when he developed abdominal distention and bloody stools. An abdominal radiograph revealed pneumatosis intestinalis and air in the portal system. Antibiotics were begun, enteral feeds were immediately stopped, and a nasogastric tube was inserted for continuous gastric decompression. His current vital signs are: temperature 36.4°C, heart rate 168/min, respiratory rate 54/min, and blood pressure 66/28 mmHg. Recent laboratory findings include: WBC 5.4, Hgb 9.3, and platelets 70,000; electrolytes Na 132, K 5.5, Cl 99, CO2 19; and glucose 77. Arterial blood gas analysis while breathing 1 liter oxygen by nasal cannula revealed pH 7.20, Pco2 36 mmHg, Po2 83 mmHg, and base excess -7.8.

What else would you like to know before proceeding with general anesthesia and the exploratory laparotomy?

This small infant with NEC is teetering on the brink of becoming extremely ill, as evidenced by his low core temperature, anemia, thrombocytopenia, hyponatremia, and metabolic acidosis. There is also a high risk of developing central apnea for which institution of mechanical ventilation will be required. Therefore, surgery should not be delayed for very long. My primary preoperative objectives at this point include volume resuscitation and correction of his anemia. Normal saline boluses, 10 mL/kg, should be administered until urine output reaches at least 1 mL/kg/h. Packed red blood cells should be transfused prior to surgery if time permits. The blood bank should be alerted about this child, and should be asked to prepare packed red cells, platelets, and fresh frozen plasma.

What intraoperative monitors are required for this child?

In addition to standard monitors, I would consider direct arterial cannulation to closely follow blood pressure and facilitate frequent intraoperative blood sampling for hemoglobin, electrolytes, and blood gas analysis. Two free-flowing intravenous lines should be inserted prior to the beginning of the procedure for blood and fluid administration, and provision of a continuous glucose and electrolyte solution. The surgeons may place an indwelling central venous catheter to facilitate postoperative fluid administration and parenteral nutrition.

Hypothermia commonly occurs in small infants with a large amount of skin or intestinal surface exposed. Esophageal or rectal temperature monitoring will closely approximate core body temperature. The OR should be warmed and an overhead radiant heater used during induction of anesthesia and placement of monitors and invasive lines. During the procedure, a forced warm air blanket should be placed underneath and around the infant and should cover all nonoperative exposed body parts, including the face and head. Intravenous fluids should be warmed.

How would you induce anesthesia in this infant?

My primary concerns at induction of general anesthesia include avoidance of pulmonary aspiration of retained gastric contents and hemodynamic deterioration secondary to underlying anemia and possible hypovolemia and sepsis. Previous generations of pediatric anesthesiologists would have performed endotracheal intubation prior to induction of general anesthesia; this is no longer performed in most pediatric centers. The most commonly performed induction technique is a modified rapid sequence induction following administration of intravenous atropine and evacuation of the stomach via the nasogastric tube. Small doses of thiopental or propofol can be administered along with fentanyl that is administered in small amounts and titrated to the infant's blood pressure and heart rate. A nondepolarizing neuromuscular blocker is administered at a sufficiently high dose so as to ensure adequate paralysis and intubating conditions within 1 minute (see Chapter 19). Cricoid pressure can no longer be performed during positive-pressure bag-mask ventilation, with or without the presence of the nasogastric tube (see Chapter 17). A 3.0 styletted endotracheal tube is then inserted when adequate muscular relaxation has been obtained.

How will you maintain general anesthesia in this infant?

Maintenance of general anesthesia will consist primarily of an opioid-based technique with a low-dose inhalational agent, and avoidance of N2O. Small doses of fentanyl (e.g., 1–2 µg/kg) will be administered intermittently throughout the procedure and titrated to the infant's vital signs. The oxygen concentration should be continuously adjusted to maintain the preductal oxyhemoglobin saturation at between 92% and 95%.

What fluids would you administer for this procedure?

One intravenous line will infuse the infant's maintenance solution that contains glucose, potassium, and possibly calcium. Unless the infant demonstrated preoperative hypoglycemia, I will usually halve the usual maintenance rate in an attempt to avoid hyperglycemia related to the intraoperative stress response. This is unlikely in prematurely born infants because of the lack of glycogen stores, which primarily accumulate during the third trimester. Nevertheless, glucose levels will be monitored at least hourly throughout the procedure and the infusion will be adjusted accordingly.
Case Cont’d

The other intravenous line will be used for administration of crystalloid volume replacement (e.g., normal saline) and blood products. Third-space fluid accumulation and evaporative losses usually result in the administration of at least 20 mL/kg/h during the procedure. Red cells should be transfused to maintain the infant’s hemoglobin of at least 10 mg/dL. Additional calcium should be administered along with red cells. Platelets and fresh frozen plasma are indicated for generalized nonsurgical bleeding during the procedure. Sodium bicarbonate is indicated for continuing metabolic acidosis that results in a pH of less than 7.15.

Would you extubate this infant’s trachea at the completion of the procedure?

Postoperatively, a substantial amount of third-space fluid accumulation and fluid shifts are expected. Therefore, this infant should remain sedated and mechanically ventilated for at least several days. This will also facilitate analgesic management with a continuous opioid infusion without risking ventilatory depression. Furthermore, depending on the extent of intestinal ischemia, this infant’s medical condition may worsen over the first several postoperative days and necessitate administration of inotropic agents. In addition, these infants are often returned to the OR for a “second-look” procedure to evaluate ongoing bowel necrosis.

Is there any role for regional analgesia in this infant?

Regional analgesia, in the form of epidural administration of local anesthetics, is not indicated in this infant because of the possibility of bacteremia or sepsis, and will not be necessary in the intubated patient receiving continuous opioids.

ADDITIONAL ARTICLES TO KNOW


