# Thoracoabdominal and General Surgery

10

Kate Cross, Jonathan Smith, and Isabeau A. Walker

## Introduction

Provision of anesthesia for thoracoabdominal surgery in the neonate presents a number of specific challenges to the anesthesiologist. Many neonates are born at term in good condition, with or without an antenatal diagnosis, but many others are born premature and/or of low birth weight with associated cardiac abnormalities, pulmonary hypertension, and/or complications relating to the specific surgical diagnosis. Many of the principles of neonatal surgery are discussed elsewhere—this chapter considers specific conditions that require thoracic or abdominal surgery in the neonatal period, and the anesthetic and surgical requirements for each. There are very few randomized controlled trials to guide management. Most management strategies are based on retrospective case reviews or expert opinion. The use of minimally invasive techniques is becoming increasingly common and these approaches are also discussed.

## General Considerations

Anesthesia complications are more common in the neonatal period, so only essential surgery should be carried out in this period [1–4]. Conditions range from minor elective procedures such as neonatal inguinal hernia repair to emergency lifesaving procedures such as repair of abdominal wall defect or esophageal atresia. The anesthesiologist, surgeon, and neonatologist must collaborate to ensure that the neonate is optimally prepared for surgery, that every member of the team understands the surgical/anesthetic plan, and that the neonate is returned to the neonatal intensive care unit (NICU) in stable condition with appropriate IV access and monitors in place.

K. Cross, FRACS
Great Ormond Street Hospital NHS Foundation Trust, Institute of Child Health, Unversity College London, Great Ormond Street, London WC1N 3JH, UK

J. Smith, FRCA • I.A. Walker, FRCA (✉)
Portex Department of Paediatric Anaesthesia, Great Ormond Street Hospital NHS Foundation Trust, Institute of Child Health, University College London, Great Ormond Street, London WC1N 3JH, UK
e-mail: isabeauwalker@mac.com

## Preoperative Assessment and Preparation

Anesthetic evaluation includes a detailed history of the presenting condition and the current status, the birth history, gestational age, physical examination, and assessment of laboratory investigations and imaging. Cardiac defects are commonly associated with several congenital defects. A preoperative echocardiogram should be performed if a cardiac defect is possible or present, e.g., in esophageal atresia/tracheoesophageal fistula (EA/TEF) or omphalocele. A renal ultrasound should also be performed in neonates with abnormalities such as EA/TEF, and preoperative cranial ultrasound in those at risk of intraventricular hemorrhage, such as premature infants. For the acutely unwell neonate, or the extreme premature infant, it is useful to assess how the neonate responds to handling, in order to assess its physiological stability during transport to the operating room (OR).

Preoperatively, the anesthesiologist should review the coagulation profile to ensure that it is within normal limits for the local laboratory standards for age and for neonates and that vitamin K was administered postdelivery. Thrombocytopenia is common, particularly in neonates with sepsis, and should be corrected before undertaking surgery. Platelet concentrations <150,000/mm$^3$ are considered abnormal in neonates in many centers, but surgical bleeding is uncommon when the count is >50,000/mm$^3$ [5]. A platelet transfusion consisting of 10–20 ml/kg should be considered if the platelet count is $<100 \times 10^9$/l before surgery, although in the case of necrotizing enterocolitis (NEC), the platelet count is often <100,000/mm$^3$ preoperatively and platelet transfusions have not been shown to be beneficial in the absence of bleeding [6]. Few would hesitate to transfuse platelets if the

J. Lerman (ed.), *Neonatal Anesthesia*, DOI 10.1007/978-1-4419-6041-2_10,

platelet count was <50,000/mm$^3$ preoperatively. Prothrombin time (PT) and partial thromboplastin time (APTT) vary during the neonatal period, being prolonged immediately after birth due to reduced procoagulants and then decrease toward normal childhood values throughout the neonatal period [5]. Fresh frozen plasma (FFP) 15 ml/kg is recommended if the prothrombin time (PT) or activated partial thromboplastin time (APTT) ratio is >1.5 times normal. These indices should be rechecked once corrective actions are completed. One adult unit of CMV-negative leukodepleted blood should be crossmatched for all but minor procedures. Where possible, the mother's blood should be screened for atypical red cell antibodies; alternatively, the neonate's serum should be screened for antibodies of maternal origin [7, 8].

Sedative premedication is not required, but atropine or glycopyrrolate may be used to blunt vagal responses to intubation and to dry secretions if a bronchoscopy is planned. The plan for anesthesia and perioperative analgesia should be discussed with the parents, and informed consent for anesthesia and surgery obtained. All members of the theater team should be fully briefed before the start of surgery, and appropriate safety checks undertaken according to international recommendations [9].

## Anesthesia Techniques

The anesthesia technique should be chosen with reference to the condition of the neonate, the surgical requirements, and postoperative management. For instance, epidural analgesia reduces the stress response to surgery, provides excellent analgesia, and reduces postoperative ventilatory requirements, whereas an opioid-based technique with fentanyl 10–50 mcg/kg may be more appropriate for the neonate who requires paralysis and controlled ventilation for 5 days after repair of a long-gap esophageal atresia [10]. Spinal anesthesia may reduce the need for postoperative ventilation in a premature neonate, but is not a suitable technique if the child is undergoing laparoscopic surgery.

The choice between inhalational and intravenous induction of anesthesia depends on personal preference and the condition of the neonate. Inhalational inductions are suited for neonates undergoing elective surgery or in those with poor venous access [11]. However, most surgeries in neonates are emergencies and/or involve a full stomach, both of which favor an IV induction of anesthesia. Propofol 2–3 mg/kg or ketamine 1–2 mg/kg may be used to induce anesthesia intravenously, with the latter preferred for cardiovascular stability. For the sick neonate with NEC, many prefer IV fentanyl. A nasogastric tube should be in place if there is a risk of aspiration and suctioned (and possibly removed) before induction of anesthesia. The debate to remove the nasogastric tube before induction or leave it in situ here favors the former, primarily to provide a clear view of the larynx with less concern for incompetence of the lower esophageal junction and potential regurgitation. A classic rapid sequence induction (RSI) is eschewed in neonates because desaturation is very common after even a brief apnea between induction of anesthesia and tracheal intubation and in spite of optimal preoxygenation [12]. In place of the classic RSI, a "modified" RSI is widely practiced. This differs from the classic RSI in that gentle mask ventilation (at the smallest peak inspiratory pressures possible) that continues after induction of anesthesia and paralysis until the airway is secured [13, 14]. Traditionally, cricoid pressure has been an essential element of the RSI, although recent evidence has cast doubts on its effectiveness [15]. Furthermore, the cricoid ring may be difficult to identify in neonates, the appropriate force is rarely applied, cricoid pressure may distort the airway, and tracheal intubation may be more difficult to perform [16, 17]. As a consequence, it is not used routinely by many anesthesiologists [13] (see Chaps. 4 and 5).

Secure vascular access should be obtained using an aseptic technique, including central access if required, with the aid of ultrasound guidance (4Fr or 5Fr catheter, internal jugular or femoral vein) (see Chap. 7). Arterial access is indicated for major surgery (22G or 24G cannula, with radial or femoral artery). An umbilical arterial catheter (UAC) or umbilical venous catheter (UVC) may be used for short-term access (<5 days). The tip of the UAC should ideally end in the thoracic region (above the diaphragm at the level of T6–T10), and the tip of the UVC or central line at the junction of the superior vena cava and right atrium. A peripherally inserted central line (PICC) or tunneled central line should be considered if total parenteral nutrition is required, for instance, after closure of gastroschisis.

Monitoring during anesthesia should be in accordance with international standards (see Chaps. 6 and 7). Invasive monitoring is indicated for major surgery and neonates with significant comorbidity such as congenital heart disease. Pre- and post-ductal oxygen saturation may be useful in the neonate at risk of pulmonary hypertensive crisis (saturation probe on right hand and either foot). Although transcutaneous $CO_2$ monitoring is commonplace in the NICU, it does not respond as rapidly as end-tidal $pCO_2$ monitoring on a breath-to-breath basis [18]. Provided non-HFOV ventilation strategies are used and the lung disease is not severe, capnography should be employed to monitor ventilation in preterm and full-term neonates [19–21]. Great care should be taken when removing adhesive ECG electrodes (and adhesive drapes) to avoid removing a layer of epidermis, particularly in very premature neonates.

Neonates are poikilotherms. They have limited ability to generate heat in a cold stress situation and as such should be maintained in a thermoneutral environment, 36.3–37.3 °C [22]. The neonate generates heat when stressed primarily using nonshivering thermogenesis via brown fat. To prevent hypothermia in the operating room, the temperature of the

operating theater should be increased to 25–28 °C before the neonate enters the room to minimize radiation (39 %) and convective (34 %) heat losses. The other mechanisms for heat loss are evaporative (24 %) and conduction (3 %). A forced air-warming blanket should be placed on the operating room table and preheated before the neonate arrives [23]. Humidified gases and warmed fluids should be used intraoperatively. The temperature of surgical irrigation fluids should also be warmed, and exposed bowel covered to reduce evaporative losses. To monitor the effectiveness of these heating strategies, core temperature should be measured continuously from one of several sites. We recommend the mid-esophagus, immediately retrocardiac. Rectal temperature is not commonly used as it lags behind the central core temperature during changes in temperature and is best avoided in neonates with anal anomalies. Nasopharyngeal temperature may be cooled by ventilation gas and axillary temperature is often skewed by the temperature of the forced air warmer.

## Fluid Management (See Chap. 8)

In the first few days of life, the serum concentrations of antidiuretic hormone (ADH) are increased, and fluid maintenance requirements are small (60 % of normal). Sodium requirements are small; hence, hyponatremic solutions are commonly used for maintenance. To prevent hypoglycemia, 10 % dextrose is commonly infused in neonates on the first day of life, and sodium should be added and fluids liberalized after the first few days when the postnatal diuresis occurs. It is important to monitor the serum electrolyte and glucose concentrations so that the fluid composition can be adjusted to suit the neonate. The volume of maintenance fluids is greater in premature neonates to compensate for their large insensible fluid losses.

Fluid management during surgery depends on the clinical condition of the child and the procedure. For example, the fluid requirements during elective inguinal hernia repair are vastly different from those in the neonate undergoing laparotomy for NEC. In both cases, there are limited studies to guide practice. Maintenance fluids should be continued at the same rates as preoperatively using isotonic fluids to replace intraoperative fluid losses [24, 25]. The aim of intraoperative fluid management is to replace preexisting fluid deficits and ongoing losses and to maintain cardiovascular stability. Modern fasting regimens before elective surgery minimize the preoperative deficit: no formula milk for 6 h, no breast milk for 4 h, and free clear fluids up to 2 h preoperatively [26]. Neonates scheduled for emergency surgery should be actively resuscitated with 10–20 ml/kg IV balanced salt solution preoperatively. Fluid replacement during surgery includes a balanced salt solution such as Ringer's lactate or PlasmaLyte, blood or colloid such as 5 % albumin, gelatin, or a third-generation starch solution, although the safety of starches in the neonatal population has not been fully established [25, 27]. Our practice is to give fluid boluses of 10–20 ml/kg lactated Ringer's solution, or an appropriate volume of albumin (or blood), and monitor fluid losses and clinical parameters such as heart rate, blood pressure, filling pressure, and capillary refill. Laboratory testing of hemoglobin, base excess, serum lactate, electrolytes, and blood glucose concentrations and the coagulation status is essential.

The volume of fluid required intraoperatively varies with the clinical condition of the child, from 10 to 20 ml/kg for a child undergoing an uncomplicated EA/TEF repair to 50–100 ml/kg for a critically ill neonate with NEC or ischemic gut due to malrotation/volvulus. 5 % albumin is commonly used in the septic neonate. The trigger for blood transfusion depends on the age of the neonate; a trigger of 12 g/dl on day 1 of life has been recommended due to the presence of fetal hemoglobin, 11 g/dl in a neonate with chronic oxygen dependency, and 7 g/dl in a stable neonate with chronic anemia in early infancy [7]. If blood is required, an infusion of 4 ml/kg of packed red blood cells increases the hemoglobin concentration by 1 g/dl (as an infusion of 6 ml/kg of whole blood increases the hematocrit 3 gm%); a generous target for the hemoglobin concentration should be set to minimize donor exposure. Neonates are susceptible to hypothermia and hyperkalemia after a rapid transfusion; all blood should be warmed and fresh and the neonates should be closely monitored. Clotting factors should be considered in large-volume blood transfusion (e.g., one circulating blood volume).

The question of intraoperative dextrose is controversial; some units suggest maintenance fluid with low-dose (0.9 %) dextrose in a balanced salt solution at 4 ml/kg/h (<10 kg) to maintain the blood sugar concentration and avoid lipid mobilization [9]. This fluid should not be used for volume replacement. Lactated Ringer's or PlasmaLyte solution should be used intraoperatively to maintain fluid homeostasis. If a child requires a dextrose-containing fluid to maintain blood sugar preoperatively, or is receiving TPN, this infusion should not be stopped; rather, it should be maintained at the same rate as preoperatively throughout the perioperative period and serial serum glucose concentration measured. Although some reduce the preoperative infusion rate of dextrose-containing solutions intraoperatively, such a strategy must account for the possibility that the increased insulin levels may lead to hypoglycemia. In such cases, the serum glucose concentrations should be monitored intraoperatively whenever the preoperative glucose infusion is manipulated. Some neonates such as those with Beckwith–Wiedemann syndrome are at risk for hypoglycemia.

## Surgery in the Neonatal Intensive Care Unit

Most elective and major neonatal surgery is performed in the OR, but transfer from the NICU to the OR carries particular risks for critically ill neonates who require inotropic

support or high-frequency oscillatory ventilation (HFOV) (see Chap. 12 Anesthesia Outside the Operating Room). Surgery can also be performed successfully in the neonatal intensive care unit (NICU) without an increase in infective or other complications, particularly for very low-birth-weight infants (<1,500 g) with NEC or intestinal perforation [28]. The use of a surgical headlight, thermal mattress, and transparent drapes improves operating conditions for the surgeon and access for the anesthesiologist. Total intravenous anesthesia (TIVA) and analgesia techniques are required (fentanyl or remifentanil, ± ketamine), although the need for a hypnotic agent in this age group has been questioned [29]. Most NICUs do not use end-tidal $pCO_2$ monitoring but prefer transcutaneous $pCO_2$ monitoring. To ensure rapid responses to changes in ventilation (provided the ventilation is not HFOV), a capnograph monitor may be transferred from the OR to the NICU. Portable screens should be in place to cordon off the surgical area and visitors should be excluded from the immediate vicinity in the NICU during surgery. Complex, endoscopic, or airway procedures are more appropriately performed in the OR, as are most procedures in neonates whose lungs are not ventilated before surgery.

## Minimally Invasive Surgery

The benefits of minimally invasive surgery (MIS) are well known, and with improvements in technology, MIS is increasing in popularity in neonatal practice. There is a significant surgical and institutional learning curve to neonatal MIS, but it does speed recovery after procedures such as pyloromyotomy, accomplishes the surgery for reduced cost, and may reduce complications such as chest wall deformity after EA/TEF repair [30–33]. In expert hands, surgical complication rates are comparable to open surgery, although cardiac arrest has occurred in neonates [31, 34–37]. Thoracoscopy has been steadily gaining popularity as the approach for congenital thoracic lesions. A recent review of the published studies determined that thoracoscopic surgery is a reasonable alternative to thoracotomy in neonates [38].

It is essential that the anesthesiologist and surgeon work closely together to minimize complications during MIS. The physiological changes associated with laparoscopic surgery in neonates are substantive and depend on several variables including the intra-abdominal insufflation pressure, the neonate's position, and its fluid status. The physiological changes associated with a pneumoperitoneum in laparoscopic surgery in neonates and children are addressed in detail elsewhere [39]. Neonates with congenital heart defects, such as aortic stenosis and cyanotic heart disease, may experience very serious complications including cardiac arrest during laparoscopic surgery [40, 41]. These neonates should be screened preoperatively and only anesthetized by those with a thorough understanding of the cardiac pathophysiology and in an institution with adequate support [40–42]. Anesthetic complications relate to positioning, reduced access, and the effects of the pneumoperitoneum or pneumothorax. The neonate may be positioned head up, head down, or semiprone and will be surrounded by equipment and monitors, with limited access to intravenous lines or the tracheal tube after the surgical drapes are in place. It is essential that the tube and lines are checked and securely fixed at the start of the procedure.

Specific complications from MIS in neonates relate to hypercarbia, desaturation, hypotension, metabolic acidosis, and hypothermia and are seen more often during thoracoscopic procedures [43]. During laparoscopic surgery, the pneumoperitoneum or pneumothorax is created and maintained by insufflating carbon dioxide ($CO_2$), which results in significant absorption of $CO_2$ into the circulation. Insufflated $CO_2$ may contribute up to 30 % of the exhaled $CO_2$ during thoracoscopic procedures and up to 20 % during laparoscopic surgery [43]. As a result, high levels of arterial $CO_2$ may be reached [44–47]. End tidal $CO_2$ measurement does not give an accurate measurement of arterial $CO_2$ and it is important to monitor $CO_2$ absorption accurately with transcutaneous carbon dioxide monitoring or arterial blood gases, rather than end tidal measurements [13, 19]. The significance of severe hypercarbia in this context is unclear, but specific adverse effects have not been reported to date, although respiratory acidosis and cerebral oxygen desaturation have been demonstrated, and concerns remain about neuronal apoptosis in animal models [44, 45].

The $CO_2$ insufflation pressure should be limited to 8 mmHg and operative time to <100 min to minimize the adverse cardiorespiratory sequelae from insufflation [48–50]. Isolated cardiac arrests have occurred in several neonates undergoing abdominal insufflation with carbon dioxide. This should be suspected if sudden hemodynamic instability occurs during insufflation of the abdomen. Augmenting the preload with 10 ml/kg IV balanced salt solution before insufflation of the abdomen preserves circulatory homeostasis. Minute volume should be increased to compensate for increased arterial carbon dioxide ($PaCO_2$) [46, 51]. A range of procedures are now performed using MIS, although some, including repair of a congenital diaphragmatic hernia (CDH), have a high rate of conversion to open surgery [31, 34, 52, 53].

## One-Lung Ventilation

One-lung ventilation (OLV) may be required for thoracic surgery in neonates. There are few absolute indications for OLV as the lung is generally easy to compress during open thoracotomy, and gentle insufflation of $CO_2$ is used to compress the lung and maintain the artificial pneumothorax

during thoracoscopic surgery. Some authors recommend OLV for surgery for congenital thoracic malformations involving a bronchial connection, for instance, in congenital lobar emphysema (CLE) [54–56].

Double-lumen tubes are not available for neonates, and OLV is obtained by either selective endobronchial intubation or the use of a bronchial blocker [54–56].

Selective endobronchial intubation is relatively easy, although more so on the right than the left. The disadvantage is that tube must be withdrawn at the end of surgery to ventilate both lungs and check for air leaks, and there is a risk of accidental extubation at this time. Fiberoptic bronchoscopes with an external diameter as small as 2.0 mm are available, suitable for a 2.5 mm ID tracheal tube [57]. The following techniques have been described to achieve one-lung ventilation [54]:

### Endobronchial Intubation

- Intubate the trachea in the normal way, check for bilateral breath sounds, and note the depth of the tracheal tube at the alveolar ridge.
- Selectively intubate the bronchus using a fiberoptic bronchoscope threaded through the tracheal tube. Advance the tube over the bronchoscope and withdraw the scope. Check if breath sounds have disappeared on the contralateral side. Note the depth of the tube. If the right bronchus was intubated, check for the presence of breath sounds in the right upper lobe. If not, withdraw the tube until the right upper lobe is ventilated. Although it may be more difficult to pass the tracheal tube into the left bronchus, there is no concern that a bronchus will be blocked inadvertently.
- At the end of surgery, carefully withdraw the tube to the original position to allow bilateral air entry (note length), and secure.

### Bronchial Blocker

A balloon-tipped 3Fr Fogarty embolectomy catheter, atrioseptostomy catheter, pulmonary artery catheter, or 5Fr Arndt endobronchial blocker may be used to occlude the lung on the operative side. The last two have the advantage of a central lumen to decompress the lung. The bronchial blocker is placed alongside the tracheal tube, as the tracheal tube in a neonate is too small to accommodate the blocker within the lumen of the tube:

- Perform direct laryngoscopy; place the bronchial blocker into the lumen of the trachea.
- Intubate the trachea with the bronchial blocker alongside the tracheal tube, on the operative side.
- Place a fiberoptic bronchoscope into the lumen of the tracheal tube and advance the bronchial blocker into the bronchus on the operative side under direct vision.
- Inflate the balloon of the bronchial blocker with saline and check if breath sounds are absent on the operative side.

The primary disadvantage of the bronchial blocker is that it requires experience and expertise to place and is particularly difficult if the neonate has any degree of respiratory compromise. Another concern relates to the bronchial blocker becoming displaced during surgery and causing complete tracheal obstruction. This is thought to be less likely if the balloon is inflated with saline [54]. Oxygen saturation, arterial $pCO_2$, breath sounds, and airway pressures should be monitored continually during the surgery.

## Specific Conditions

### Congenital Thoracic Malformations

There are a number of congenital thoracic malformations that may require surgical intervention in the neonatal period. The three most common lesions described may represent a spectrum of disease rather than true separate entities [57].

### Congenital Cystic Adenomatoid Malformation

This rare congenital lung lesion that occurs in 1:25–30,000 live births is the most common of the congenital thoracic malformations [58]. Congenital cystic adenomatoid malformation (CCAM) is a multicystic pulmonary mass usually affecting only one lobe of the lung, more commonly on

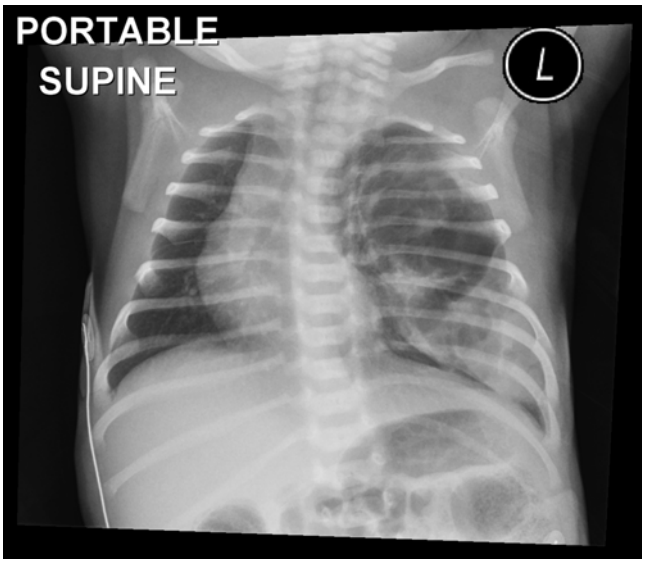


**Fig. 10.1** Congenital cystic adenomatoid malformation. Chest radiograph in a neonate with a left-sided amorphous cystic mass filling most of the left hemithorax. The cardiac silhouette is shifted to the right. The right hemithorax is slightly opacified

**Table 10.1** The Stocker classification of congenital cystic adenomatoid malformation (CCAM)

| |
|---|
| Stocker type 0 (rare). This is a fatal defect in which the lungs do not develop beyond the pseudoglandular level, resulting in small hypoplastic lungs bilaterally with a bronchial airway. Also known as acinar dysplasia |
| Stocker type I (macrocystic adenomatoid malformation) (60–70 %). Single or multiple large "cysts" (>2 cm diameter) are present, which communicate with the proximal airways and distal lung parenchyma. The lesion is relatively localized and most infants have a good prognosis after cyst resection. Good prognosis |
| Stocker type II (microcystic adenomatoid malformation) (10–15 %). Multiple small spongelike cysts (<1 cm) replace the distal lung parenchyma. This has a worse prognosis and is more commonly associated with other anomalies, such as renal agenesis and cardiac and chromosomal abnormalities |
| Stocker type III (solid cystic adenomatoid malformation) (5 %). The abnormality represents a severe end of the spectrum with multiple airless cysts involving an entire lobe or even lung. This has a poor prognosis, more commonly reported in stillbirths with CCAM |
| Stocker type IV (rare). This is an entirely alveolar pulmonary defect in which large cysts replace the numerous alveoli in the periphery of the lung. Good prognosis |

the left, but may occur bilaterally in 5–15 % (Fig. 10.1). The etiology is unknown, although it may represent a hamartomatous process, focal pulmonary dysplasia, or a bronchiolar developmental anomaly [22]. Associated anomalies occur in up to 18 % of cases, involving renal agenesis and cardiac defects (see type II below) [58]. The prognosis depends on the size of the CCAM; small lesions may be asymptomatic, but large lesions may be associated with hypoplasia of the normal lung and pulmonary hypertension and, in severe cases, mediastinal shift causing cardiac compromise and nonimmune fetal hydrops [59, 60]. Fetal hydrops is the most serious harbinger of death [61]. The ratio of the CCAM volume to the head circumference on the first antenatal ultrasound predicts the fetus' perinatal course: a ratio <0.56 is consistent with a good postnatal outcome, whereas a ratio >1.6 is consistent with developing hydrops [62].

## Classification of CCAM

Stocker originally classified CCAM based on cyst size and postnatal histology, yielding three types. Subsequently type 0 (tracheobronchial defect with small firm lungs and a bronchial airway) and type 4 (an entirely alveolar defect) were added to complete the current classification. Since types 1–3 are usually adenomatoid and types 1, 2, and 4 are cystic, Stocker proposed a broader term for these defects: congenital pulmonary airway malformations (CPAM) [58, 63]. However, CCAM remains the primary acronym for these defects. A simpler classification for this defect was proposed: macrocystic or microcystic (solid), based on anatomy and appearance on antenatal ultrasound, but Stocker's classification has persisted [58, 59, 63–65] (Table 10.1).

## Diagnosis of CCAM

The diagnosis is usually made by antenatal ultrasound at approximately 20 weeks gestation [66–70]. The lesions are monitored throughout gestation following one of three courses: increase in size, remain unchanged, or undergo spontaneous resolution. In aggressive disease, the lesion may respond to maternal steroids. A few specialist centers offer fetal interventions for high-risk cases causing hydrops including thoracoamniotic shunt for isolated cysts, open fetal surgery, or an EXIT procedure at delivery (ex-utero intrapartum treatment), depending on gestational age, the size of the cyst, and the health of the mother [59, 68, 70].

Infants present with symptoms of respiratory distress in the neonatal period, with tachypnea, increased work of breathing, and desaturation in 30 % of cases, or occasionally with hyperinflation on the side of the CCAM. Some infants may appear to be relatively asymptomatic. Ten percent of the cases present with recurrent pneumonia or pneumothorax in later childhood. A significant number of infants remain asymptomatic and are only detected incidentally.

CCAM is evident on chest X-ray, especially if it is large. Microcystic lesions may be fluid filled, but macrocystic lesions are usually aerated and may be difficult to visualize. A CT scan with contrast is usually performed to delineate the limitations of the lesion. Ultrasound may be used to identify the blood supply and exclude an anomalous systemic artery.

## Management of CCAM

Initial management involves respiratory support as needed and imaging to confirm and define the extent of the lesion. Neonates with hydrops have a very high perioperative mortality as a result of the pulmonary hypoplasia and pulmonary hypertension. These neonates should be medically stabilized before embarking on surgical interventions [61, 70]. Surgery may be beneficial for neonates with significant respiratory signs and symptoms and/or compression of adjacent cardiac or major vascular structures. Controversy exists regarding the appropriateness and timing of surgery in asymptomatic or smaller lesions [60, 71–74]. Resection in infancy or early childhood is increasingly advocated to preclude infectious complications and malignant transformation (rhabdomyosarcoma, squamous cell carcinoma, bronchoalveolar carcinoma, and pleuropulmonary blastoma in 2–4 % of cases) and to encourage compensatory lung growth. If surgery is not undertaken, ideally these neonates should be followed into

adulthood to ensure a timely intervention should the lesion turn malignant [74].

### Surgical Considerations

The aim of surgery is to preserve viable lung tissue and reduce the mediastinal shift. The standard approach is posterolateral thoracotomy and lobectomy. Segmental resection may be used for small lesions or multilobular disease but is associated with a greater incidence of postoperative air leak. Thoracoscopic resection can be performed but access may be difficult with large cystic lesions.

### Anesthetic Considerations

Thoracotomy and lung resection are generally well tolerated in neonates; blood transfusions are not usually required. Full invasive monitoring should be used. CCAM are connected to the bronchial tree, and preoperative hyperinflation resulting in ball-valve effect is a possibility, although one-lung ventilation is not usually required. Nitrous oxide is best avoided.

Infants with severe respiratory distress may require HFOV preoperatively, but it is usually possible to wean to conventional ventilation in the early postoperative period [70]. Analgesia may be provided by intravenous opioids such as fentanyl or remifentanil or thoracic epidural analgesia with the catheter inserted via the caudal route [75, 76]. Most neonates require only a brief period of postoperative ventilation, although ventilation may be extended if pulmonary hypoplasia and/or pulmonary hypertension is present.

## Lung Sequestration

This lesion consists of nonfunctioning lung tissue that does not have a tracheobronchial communication. There is anomalous systemic arterial supply, usually directly from the aorta, with more than one vessel in 15 % of lesions. Sequestrations may have a patent or non-patent connection to the gastrointestinal tract (bronchopulmonary foregut malformations) [70].

### Classification of Lung Sequestration

- Intralobar sequestration (ILS) (75 %): the abnormal tissue is contained within normal lung predominantly within the lower lobes (often left sided). The child is generally asymptomatic but may present with hemoptysis, pneumothorax, or recurrent infections in later childhood. The venous drainage is often via the pulmonary veins. Right-sided ILS may be associated with anomalous pulmonary venous drainage characteristic of scimitar syndrome; care must be taken not to ligate pulmonary veins during surgical resection.
- Extralobar sequestration (ELS) (25 %): the sequestration is completely separated from the lung by visceral pleura. There is an infradiaphragmatic arterial supply in 20 % and the lesion itself is infradiaphragmatic in 3 % of cases. Venous drainage is to the azygous system in the majority. ELS affects males four times more commonly than females and is more often associated with other anomalies such as congenital diaphragmatic hernia (CDH) (16 %), CCAM (15 %), congenital heart disease, chest wall abnormalities, and hindgut duplications.

### Diagnosis of Lung Sequestration

These lesions may be detected on antenatal ultrasound or postnatal chest X-ray. The systemic blood supply must be delineated using ultrasound, CT, or MRI.

ELS is generally asymptomatic but is often detected earlier than intralobar sequestrations. Both ILS and ELS may be detected antenatally and may resolve. Symptomatic infants with large sequestrations may present with respiratory distress, feeding difficulties, or cardiac failure if the sequestered lobe is associated with significant arteriovenous or left-to-right shunting [70]. Hydrops may result from severe cardiac failure in utero, and pulmonary hypoplasia and pulmonary hypertension may be associated with large lesions, as in CCAM.

### Management of Lung Sequestration

Respiratory support should be instituted as required, and the systemic blood supply defined on imaging as the first step. Surgical excision is generally advocated. The timing of surgery depends on the clinical situation. Complications such as infection and cardiovascular compromise due to shunting should be treated before resection.

### Surgical Considerations

As for CCAM, thoracotomy is the standard approach for pulmonary sequestrations. Thoracoscopic resection is a viable alternative due to the relatively smaller size of the lesions. A laparotomy or laparoscopic approach is required for infradiaphragmatic lesions. Additional therapeutic interventions have been reported anecdotally including radiofrequency ablation and coil embolization [77].

The anomalous systemic vessels can be fragile elastic vessels with significant blood flow. Careful dissection and meticulous control are required to prevent hemorrhage. Control of the systemic blood supply during surgery is critical especially when the origin of the vessel is on the opposite aspect of the diaphragm to the operative field (infradiaphragmatic vessel for intrathoracic lesions). A loss of control can result in retraction of the vessel out of the operative field and catastrophic hemorrhage. A crossmatch should be available for all of these neonates.

### Anesthetic Considerations

These are similar to CCAM. Neonates with severe pulmonary hypertension should be optimized medically before surgery.

## Congenital Lobar Emphysema

Congenital lobar emphysema (CLE) is an obstructive overinflation disorder, which may be due to defective bronchiolar development. The affected lobe is hyperinflated and compresses the adjacent normal lung. Hyperinflation becomes progressive after birth, although neonates usually present with respiratory distress in the first few days of life. Males are more commonly affected than females (3:1). The left upper lobe is involved in almost 50 % of cases followed by the right middle lobe (28 %) and the right upper lobe (20 %); bilateral involvement is rare (Fig. 10.2). Cardiac anomalies are present in 20 % of neonates with CLE [70].

### Diagnosis of CLE

CLE may be detected antenatally but is difficult to distinguish from CCAM. Postnatally there is often early respiratory distress and clinical signs suggestive of pneumothorax. A CXR may show lobar hyperinflation, mediastinal shift, and flattening of the ipsilateral diaphragm. Ultrasound can help distinguish from a tension pneumothorax, or if stable enough, CT or MRI scan will confirm the diagnosis. If the neonate is stable, then a preoperative echocardiogram should be also performed.

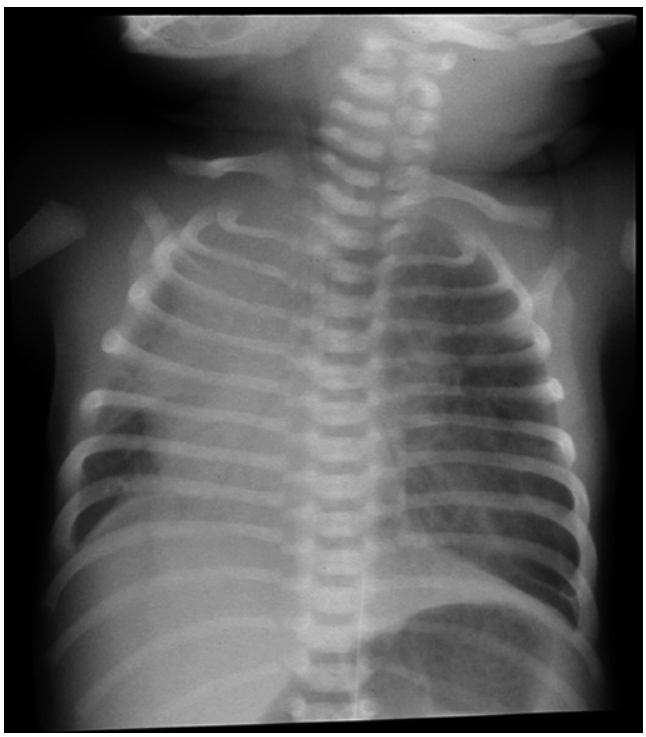

**Fig. 10.2** Congenital lobar emphysema. Chest radiograph with hyperinflation of the left chest and displacement of the cardiac silhouette toward the right chest. A large gastric air bubble is present

### Management of CLE

The primary treatment is lobectomy, which may be required on an emergent basis before a full preoperative workup can be performed. More recently, segmental lung resection has proven successful in preserving lung without an increased incidence of a recurrence [78]. Positive pressure ventilation worsens the hyperinflation, and if respiratory support is required preoperatively, then HFOV may be preferred. A chest drain should never be inserted as it may cause preferential ventilation of the abnormal lung leading to respiratory failure.

### Surgical and Anesthetic Considerations

Induction of anesthesia with positive pressure ventilation may cause rapid deterioration due to air trapping. If possible, spontaneous ventilation should be maintained until one-lung ventilation has been achieved or until the chest is opened. Anesthesia should be introduced by inhalation, and lines placed while spontaneous ventilation is maintained. Muscle relaxants may be administered, but in these neonates, the inspiratory pressure should be minimized [79]. Alternatively, muscle relaxants may be avoided and intubation achieved using a combination of inhalational anesthesia, intravenous propofol with topical lidocaine (3 mg/kg) administered to the cords [54, 80]. The thoracotomy instruments and the surgeon must be ready in the event that urgent thoracotomy and decompression become necessary.

## Esophageal Atresia/Tracheoesophageal Fistula

Esophageal atresia (EA) and tracheoesophageal fistula (TEF) occur in 1:3,000–1:4,500 live births [81–83]. The etiology is believed to be due to a defect in the separation of the trachea and esophagus from a common foregut, which normally occurs after 4 weeks gestation. The etiology and exact embryology remain unclear, although the theories put forth include failure of fusion of lateral tracheoesophageal folds or the tracheoesophageal septum, imbalance in epithelial proliferation and apoptosis, trifurcation of the lung bud, and a possible role of the notochord. Animal evidence suggests that a greater developmental role of the foregut in this defect as the fistula and distal esophagus may be respiratory in origin [58]. There is also evidence that specific targets in the molecular mechanisms responsible for complete separation of the trachea and the esophagus may be responsible for EA/TEF defects [84].

### Classification

First classified in 1929, and modified in 1953, five common types of EA/TEF have been described, although it is probably more appropriate to describe the conditions anatomically [81, 82, 85] (see Fig. 10.3) (Table 10.2).

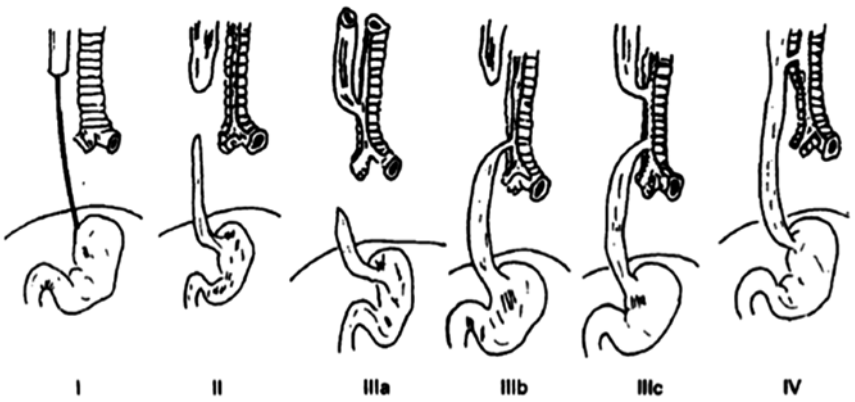


**Fig. 10.3** Classification of esophageal atresia and tracheoesophageal fistula according to Vogt. Type 1: Obliteration of the esophagus. Type II: Atresia without fistula. Type IIIa: Atresia with proximal fistula. Type IIIb: Atresia with distal fistula. Type IIIc: Atresia with proximal and distal fistula. Type IV: Tracheoesophageal fistula (H-type fistula). *Adapted from: HolzKi J. Pediatric Anaesthesia 1992; 2: 297–303*

**Table 10.2** EA/TEF classification and incidence in neonates

| |
|---|
| EA with distal TEF (80–85 %) |
| Pure EA (5–7 %) |
| Isolated TEF ("H"-type fistula) (3–6 %) |
| EA with proximal and distal TEF (3–5 %) |
| EA and proximal TEF (2 %) |

The length of the gap between proximal and distal esophagus is variable, as is the position of fistula (or fistulae) within the trachea. These anatomical variations have important implications for surgical strategy and anesthesia management. In one series, the fistula was mid-tracheal in 61 %, at or just above the carina in 33 %, cervical in 8 %, and bronchial in 1 %. There was more than one fistula in 3 % of patients [85, 86]. In the "H"-type TEF, the fistula is typically in the cervical region, whereas in EA with a proximal fistula, the fistula is usually 1–2 cm from the blind-ending upper pouch [83].

Neonates with EA/TEF are often born premature, with low birth weight (Fig. 10.4) [82]. Approximately 50 % of neonates with EA/TEF have associated anomalies, an incidence that increases with decreasing birth weight (<2,500 g) and with pure EA. In contrast, anomalies are less common in those with an isolated H-type fistula [82, 83, 87, 88]. The most common anomalies associated with EA/TEF are cardiac anomalies (29 %), followed by duodenal atresia and anorectal anomalies (14 %), genitourinary anomalies (14 %), intestinal malrotation (13 %), chromosomal abnormalities (trisomies 21, 18, and 13q deletion) (4 %), vertebral and skeletal anomalies (10 %), and specific-named associations (see below). The most common cardiac defects are atrial or ventricular septal defects or tetralogy of Fallot [88, 89] (Fig. 10.5) [90]. A right-sided aortic arch is present in 2.5–5 % of infants with EA/TEF [91].

Several disorders have been associated with EA/TEF [82]. The VATER/VACTERL association, an association of unknown etiology, is defined by the presence of at least three of the following congenital malformations: *v*ertebral defects, *a*norectal anomaly, *c*ardiac defects, *T*EF, *r*enal anomalies, and *l*imb (radial) abnormalities [90, 92, 93]. Approximately 47 % of neonates with EA have VACTERL anomalies.

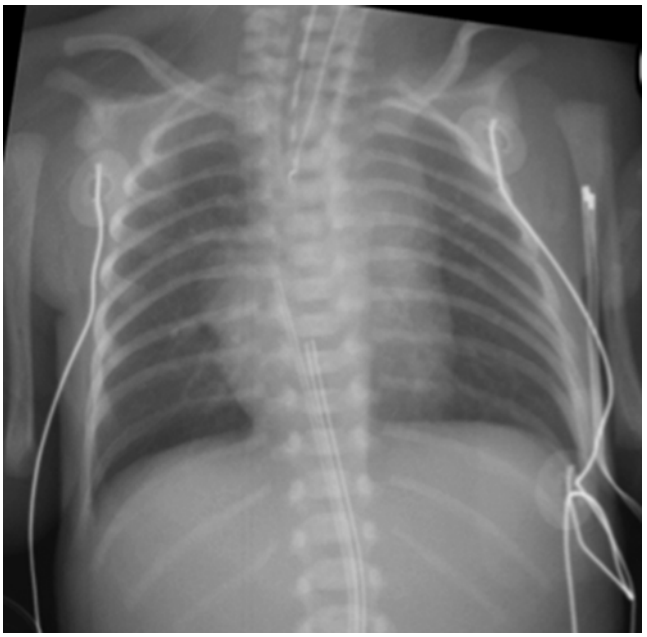

**Fig. 10.4** Esophageal atresia in a neonate. This chest radiograph depicts a multi-orifice orogastric tube (with side holes) ending at the mid-thoracic level. A tracheal tube ends at the thoracic inlet. Umbilical vein and artery catheters enter radiograph from below; one terminates at T6–T7 and a second at T8–T9. A gastric air bubble is not visible here

VACTERL-H association is the VACTERL association with hydrocephalus, although hydrocephalus is often listed as a non-VACTERL anomaly (see above). CHARGE syndrome is an autosomal dominant disorder caused by a mutation on chromosome 7. It is associated with TEF, coloboma, cardiac defects, choanal atresia, neurocognitive and growth impairment, and genital, ear, and cranial nerve defects. Potter's syndrome, which is associated with renal agenesis, pulmonary hypoplasia, dysmorphic facies, and Schisis association, which is associated with omphalocele, cleft lip and/

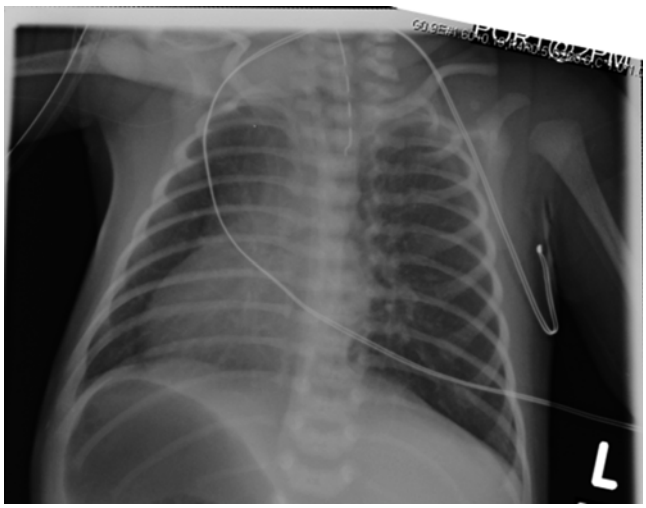

**Fig. 10.5** EA/TEF with situs inversus. Chest radiograph of a neonate with EA/TEF. The multi-orificed orogastric tube (with side orifices) ends at T3–T4 reflecting EA. The cardiac silhouette and gastric bubble are reversed, present on the right side. Echocardiogram verified the presence of a ventricular septal defect. The large gastric air bubble is consistent with a distal tracheoesophageal fistula

or palate, and genital hypoplasia, may also be associated with EA/TEF. EA/TEF is also associated with CATCH syndrome (22q deletion that includes cardiac defects, abnormal facies, thymic aplasia, cleft palate, and hypocalcaemia). Of the trisomy syndromes [13, 20], EA/TEF is most often associated with Edwards syndrome (trisomy 18). Feingold syndrome (dominant inheritance) is similar to VACTERL syndrome but features microcephaly and learning difficulties [82]. Other syndromes associated with EA/TEF include DiGeorge sequence, Pierre Robin sequence, Fanconi syndrome, and polysplenia [58].

Non-VACTERL anomalies are being reported in association with EA/TEF with increasing frequency. Such anomalies include single umbilical arteries, genital defects, digital defects, neurologic anomalies, and respiratory tract defects [90, 94].

## Diagnosis

EA may be suspected antenatally in the presence of polyhydramnios with a small or absent gastric bubble or associated abnormalities present in the fetus. Most cases, however, present after birth. A history of polyhydramnios should prompt the pediatrician to pass a size 8–10 Fr orogastric tube immediately after birth. The tube cannot pass the upper esophagus (EA). The diagnosis is strongly suspected in the first few hours after birth if an orogastric tube cannot be passed and mucous that accumulates in the upper airway cannot be cleared by swallowing. The neonate chokes or becomes cyanosed if it attempts to feed. Aspiration pneumonia due to delayed diagnosis was common decades ago but is quite uncommon in modern medicine.

The diagnosis of EA/TEF should be confirmed on plain X-ray of the chest and abdomen. A coiled nasogastric tube will be identified in the upper third of the esophagus (level T2–T4); air in the gastrointestinal tract indicates the presence of a distal TE fistula. A gasless gastrointestinal tract suggests the absence of a distal fistula, although a proximal fistula remains a possibility. Other abnormalities such as vertebral anomalies (usually in the lower thoracic region) or the "double bubble" of duodenal atresia can also be detected on preoperative films. A thorough clinical examination is important to exclude associated anomalies and the presence of coexisting problems, such as respiratory distress syndrome in premature infants. An echocardiogram is strongly recommended before surgery to identify cardiac defects and the position of the aortic arch. If the neonate has passed urine (thus excluding bilateral renal agenesis), then a renal US can be delayed until after surgery.

An H-type TEF is infrequently detected in the neonatal period but should be suspected with a history of recurrent chest infection due to repeated aspiration.

## Risk Stratification

It is helpful to stratify neonates with EA/TEF according to risk. The original stratification by Waterson was based on birth weight, associated anomalies, and the presence of pneumonia [83]. Neonatal care has improved leading to a current risk stratification that is based solely on birth weight and the presence of cardiac anomalies [88, 89, 95]. Improved outcomes have resulted in survival rates exceeding 98 % in neonates with birth weights >1,500 g and without major cardiac anomalies, 82 % with birth weights <1,500 g or major cardiac anomalies, and 50 % with birth weights <1,500 g and major cardiac anomalies [95]. A four-part classification has been suggested more recently, with prediction of 100 % survival in neonates with birth weights >2,000 g without cardiac anomalies and 40 % survival in high-risk neonates with birth weights <2,000 g with major cardiac anomalies [89]. The premature infant with a major cardiac anomaly remains a high risk. Parents of infants with bilateral renal agenesis or major complications of prematurity such as grade IV intraventricular hemorrhage should be given the option of nonoperative treatment.

## Medical Management

Initial management of neonates with EA/TEF is to prevent aspiration of oral secretions before definitive surgery. A 10Fr double-lumen oro-esophageal Replogle tube should be inserted into the upper pouch and placed on continuous suction, or secretions should be cleared frequently by naso-esophageal tube suction. The neonate should be given maintenance intravenous fluids and nursed 30° head up or in the decubitus position. Blood should be crossmatched and available for surgery. If preoperative ventilation is required,

inspiratory pressures should be kept to a minimum, if possible placing the tip of the tracheal tube distal to the fistula (see below). Premature infants should receive surfactant according to standard protocols.

### Surgical Considerations

The aim of surgery is to restore continuity of the esophagus and ligate the TE fistula, if present. Surgery is usually performed on the first or second day of life if the neonate is stable and does not require respiratory support. Primary esophageal anastomosis is usually possible in EA with distal TEF, although it may be preferable to divide the fistula and place a feeding gastrostomy in a neonate with severe comorbidities such as a duct-dependent cardiac anomaly. Primary esophageal repair can be performed 6–12 weeks after cardiac surgery.

Emergency surgery may be required if the child requires preoperative ventilation, as in the case of the preterm neonate with respiratory distress syndrome. If the lung compliance is poor, gas from the ventilator may preferentially enter the gastrointestinal tract via the fistula. This may lead to gastric distension, deteriorating cardiorespiratory status, and possible gastric rupture. Inadvertent intubation of the fistula must be excluded in cases of severe gastric distention with cardiorespiratory instability [96]. To prevent gastric distention from ventilation via the fistula, some have recommended clamping the distal esophagus as soon as the chest is opened [97]. Decompressive gastrostomy should not be undertaken as a primary intervention as it will lead to a torrential gas leak via the gastrostomy and worsening minute ventilation. The child should undergo emergency transpleural ligation of the fistula, with delayed division of the fistula and possible repair of EA at 8–10 days [83].

Neonates with pure EA or EA with a proximal TEF often have a long gap between proximal and distal ends of the esophagus. A feeding gastrostomy is inserted and the length of the gap estimated radiographically at the time of surgery. If the gap is greater than the vertical height of three vertebral bodies, upper pouch suction is continued postoperatively and delayed primary closure is usually possible by about 12 weeks of age; if the gap is greater than six vertebral bodies, a cervical esophagostomy is often fashioned and the esophagus repaired at a later date. Esophageal replacement surgery is occasionally required [83].

An esophagoscopy or bronchoscopy is often performed at the start of surgery to provide absolute confirmation of the diagnosis, to assess the position of the fistula if present, and to exclude multiple fistulae [86]. A variety of techniques have been described to identify fistulae in neonates: rigid bronchoscopy, esophagoscopy, or flexible fiberoptic bronchoscopy via the tracheal tube. The advantage of using a small flexible bronchoscope is that the scope may also be used to assess the position of the tip of tracheal tube, to pass through the fistula to assist the surgeon in identifying the fistula during surgery, and to assess the airway at the end of surgery to exclude a residual blind-ending tracheal pouch and the severity of the tracheomalacia near the fistula [98].

The traditional approach to repair of EA/TEF is extrapleural via a right posterolateral thoracotomy with the neonate placed in the lateral decubitus position with a roll under the chest to facilitate surgical access. The posterior mediastinum is approached via the 4th and 5th intercostal spaces and the extrapleural route, gently compressing the right lung. The approach is delicate and time consuming but reduces morbidity from an anastomotic leak, should one occur. If a right arch is confirmed on preoperative echo, a left-sided approach should be considered and a double aortic arch may be approached via the standard right thoracotomy [91]. If the child becomes unstable, a transpleural approach may be used.

Thoracoscopic repair has become popular in specialist centers in recent years and, in expert hands, has the same complication rate as open techniques, with comparable blood gases, operating times, and reduced time in intensive care postoperatively [99–101]. Currently recommendations are based on large case series, since no randomized controlled trials have compared the two techniques [34, 35, 102]. For thoracoscopic repair, the child is placed semiprone with the right side of the chest elevated at 45° so that the structures may be easily visualized. Lung deflation is produced by $CO_2$ insufflation, and care should be taken to minimize hypercarbia, as described previously.

Major concerns during open or thoracoscopic surgery include accurate identification of anatomical structures and cardiorespiratory instability due to OLV and distortion of the trachea. The anesthesiologist may be asked to push on the Replogle tube to help identify the proximal esophageal pouch. Test occlusion of the fistula is good practice to ensure that the right lung can still be inflated and that a vital structure (e.g., the pulmonary artery or main bronchus) has not been clamped in error. If the neonate does not tolerate OLV, surgery may have to proceed with intermittent two-lung ventilation once the neonate recovers. This requires good communication between the anesthesiologist and surgeon. Increased $FiO_2$ and hand ventilation may be required, but respiratory compromise usually improves after ligation of the fistula. The integrity of tracheal repair can be checked by instilling warm saline in the chest during a sustained inflation to identify an air leak by the presence of air bubbles. The lower esophagus should not be aggressively mobilized in order to avoid devascularization, as this may cause later problems with esophageal motility. A gas leak from the upper pouch during esophageal anastomosis should raise suspicion of an upper pouch fistula. Dissection of the upper pouch helps to identify a proximal fistula, if one is present, and allows mobilization of the esophagus to minimize

tension of the repair. If there is significant tension at the anastomosis, the neonate should remain paralyzed and the lungs ventilated mechanically for approximately 5 days postoperatively [83]. A transanastomotic tube (TAT tube) placed under direct vision before the anastomosis is completed facilitates early feeding and should be clearly marked to preclude accidental removal postoperatively.

Early complications at EA/TEF repair include tracheobronchomalacia (20–40 %), anastomotic leak (15–20 %), anastomotic stricture (30–50 %), and recurrent fistula (10 %) [103]. Tracheomalacia is due to abnormal cartilage in the region of the fistula and often produces a typical barking cough. In severe cases, the child may develop recurrent chest infections or "near death" episodes due to acute airway collapse, and emergency aortopexy may be required in the first few months after repair [83]. An early anastomotic leak may cause a tension pneumothorax; a chest drain should be inserted and the leak explored and repaired. Late complications include gastroesophageal reflux (severe reflux in 40 %) and recurrent chest infections, probably related to gastroesophageal reflux [82]. Long-term respiratory complications including bronchiectasis may result from aspiration, GERD, and chest wall abnormalities [104]. Both the parents and their neonate are at risk for psychological and traumatic stress (including post-traumatic stress disorder) [105]. These are long-term issues centered around feeding difficulties, multiple painful procedures and surgeries, feeding, and airway issues.

## Anesthetic Considerations

Anesthetic considerations include general factors relating to the thoracotomy or thoracoscopic surgery in neonates and the high incidence of comorbidity. Specific considerations include airway management and positioning the tracheal tube in the presence of a tracheal fistula. Selective OLV is not usually required as the surgeon can easily compress the lung to access the fistula. Every neonate should have a preoperative echocardiogram to identify the presence of a congenital heart defect that may range from a patent ductus arteriosus or ASD/VSD to a hypoplastic left heart. Failure to be aware of the presence of a congenital heart defect during one-lung anesthesia for an EA/TEF repair could lead to catastrophic complications including hypoxia, hypotension, and cardiac arrest.

The main anesthesia complications relate to inadvertent intubation of the fistula or preferential ventilation of the fistula causing gastric distension and desaturation [95, 106, 107]. As described above, the fistula may vary in position; two-thirds occur in the mid-trachea and one-third occur at or near the carina. The majority of complications have been described with large fistulae, particularly when they occur near the carina.

The traditional technique to secure the airway in these neonates has been to intubate the trachea while the neonate remains awake and maintain spontaneous respiration until the fistula was controlled. However, this is no longer recommended. A variety of anesthetic techniques and techniques of airway management have been described [82, 98, 106–109]. Most advocate inhalational or intravenous induction, according to personal preference, with muscle relaxant and gentle mask ventilation before intubating the trachea [98, 106–108].

Several approaches have been popularized to position the tracheal tube while avoiding intubating the tracheoesophageal atresia. One popular technique is to deliberately intubate the right main bronchus after general anesthesia is induced and then withdraw the tube until bilateral air entry is confirmed. This ensures the tracheal tube is below the fistula but does not prevent intubation of a large fistula at the carina [96]. Alternatively, rigid bronchoscopy (or flexible bronchoscopy after intubation) may be used to demonstrate the precise level of the fistula (or exclude multiple fistulae) and then plan the intubation strategy. If the fistula is mid-tracheal, the tip of the tracheal tube is ideally positioned just below the fistula, with the bevel facing anteriorly (to avoid ventilating the fistula since the origin of the fistula is the posterior tracheal wall) and gentle positive pressure ventilation used. If the fistula is at the carina, the tracheal tube may still be placed at the mid-tracheal level, provided the fistula is small. The tracheal tube should be fixed carefully and the position of the tube checked again after positioning for surgery to make sure that the dependent lung remains ventilated.

In the unusual situation of a large fistula at the level of the carina resulting in preferential gastric ventilation, some authors suggest passing a 2 or 3Fr Fogarty embolectomy catheter through the fistula into the stomach via the rigid bronchoscope; the balloon of the Fogarty catheter is then inflated to occlude the fistula. The tracheal tube is positioned alongside the Fogarty catheter [106]. This may not be a suitable technique if the child is very small or unstable. In such a case, the surgeon should proceed directly to thoracotomy to ligate the fistula as quickly as possible. Alternately, the chest may be opened rapidly and the distal esophagus ligated below the fistula [97]. If the stomach becomes very distended before the fistula is occluded, the tracheal tube should be disconnected intermittently to decompress the stomach via the airway.

Analgesia may be managed using an opioid-based technique such as fentanyl or remifentanil intraoperatively and morphine IV postoperatively, particularly for the child with long-gap EA who will remain ventilated postoperatively. Regional techniques using caudal catheters have been described and are most suitable for low-risk infants who are likely to be extubated in the immediate postoperative period. Many pediatric surgeons prefer a controlled extubation by anesthesia immediately postoperatively to reduce the risk/need for emergency reintubation that may damage the surgical closure.

Blood loss during surgery is usually minimal; intravenous crystalloid such as Ringer's is ideal and fluid volume of 10–20 ml/kg is usually required. The blood glucose concentration should be measured [24]. Broad-spectrum antibiotics should be given before skin incision and continued postoperatively. Secure intravenous access should be obtained, and some prefer arterial access to monitor blood pressure beat to beat and to sample the blood gases during one-lung ventilation, particularly in infants with significant comorbidity. Neonates with cardiac disease have a greater incidence of critical events such as desaturation or the need for new inotropic support compared with those without cardiac disease as well as a 57 % mortality during the hospitalization for those with ductal-dependent congenital heart disease [87]. These data underscore the need for a preoperative echocardiogram to identify a possible cardiac defect in all neonates with EA/TEF and, if a heart defect is present, to discuss the need for central venous access. Phenylephrine should be prepared to treat a "tet spell" in a neonate with an unrepaired tetralogy of Fallot.

## Congenital Diaphragmatic Hernia

Congenital diaphragmatic hernia (CDH) occurs in 1:2,500 live births, with a slight predilection for males. There are two major types: Bochdalek (posterolateral defect) (Fig. 10.6a, b) and Morgagni (anterior) (Fig. 10.7a, b) [110]. The posterolateral defect accounts for 85–95 % cases of CDH and most are diagnosed antenatally. CDH is associated with herniation of the abdominal viscera into the affected hemithorax, with displacement of the mediastinum to the contralateral side (Fig. 10.6a, b). The lung on the side of the hernia is hypoplastic, whereas the lung on the contralateral side is usually normal (if survival is likely) or hypoplastic (if survival is unlikely). The degree of lung hypoplasia and associated pulmonary hypertension are the major determinants of outcome; surgical repair of the diaphragm has a relatively minor contribution to the long-term outcome. Anomalies occur in 40–60 % of neonates with CDH. These include cardiac, neural tube, chromosomal, renal, and genital anomalies and pulmonary sequestrations, as well as malrotation and duodenal atresia [111, 112]. The anterior (Morgagni) defect accounts for only 2 % of diaphragmatic hernias, located retrosternal (at the level of the xiphoid) or anteromedially in the diaphragm (Fig. 10.7a, b). These are often asymptomatic and may not be detected until adulthood [113].

### Embryology

The diaphragm develops during weeks 4–8 from four embryological elements. A Bochdalek hernia results from failure of closure of the pleuroperitoneal canals during early embryonal life, often with early in-growth of the liver through the defect. The exact cause for CDH remains unknown but may be associated with genetic factors that lead to failure in cell migration, myogenesis and formation of connective tissue, or abnormalities of the retinoid signaling pathway, which is important in the development of the diaphragm. CDH may

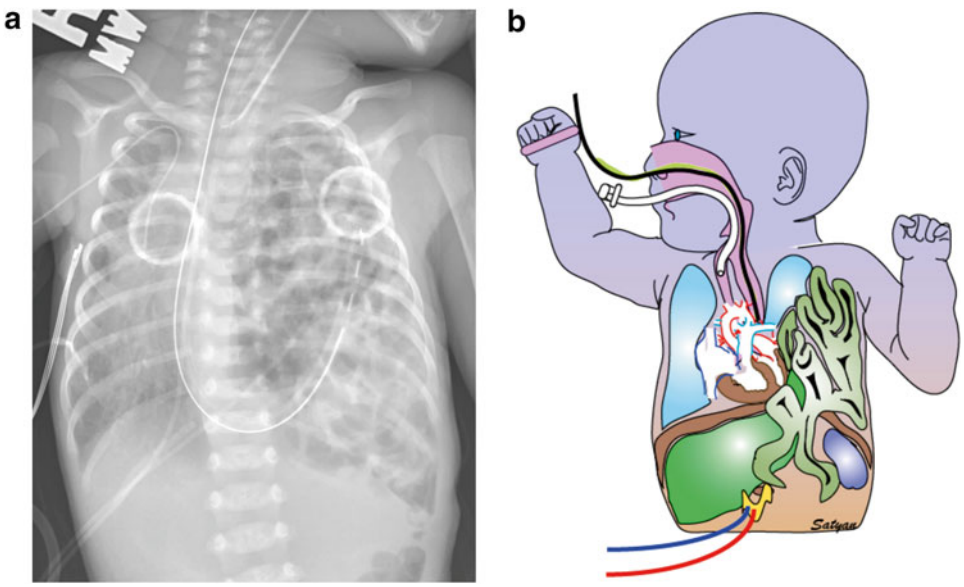


**Fig. 10.6** Congenital diaphragmatic hernia (CDH): foramen of Bochdalek defect. (**a**) This chest radiograph depicts a neonate with congenital diaphragmatic hernia in the left (classic Bochdalek defect) chest with stomach and bowel in the chest, displacing the heart to the right chest. Note the multi-orificed orogastric tube (with side holes) in the esophagus, curving up and across the diaphragm and terminating in the stomach in the left chest. The tracheal tube ends at the thoracic inlet. PICC line enters the right chest and ends in the superior vena cava. (**b**) A schematic of a neonate with a CDH with bowel present in the left chest; the right lung is compressed and the heart is deviated toward the right chest (Courtesy of Dr. Satyan Lakshminrusimha, Division of Neonatology, Women and Children's Hospital of Buffalo, Buffalo, NY)

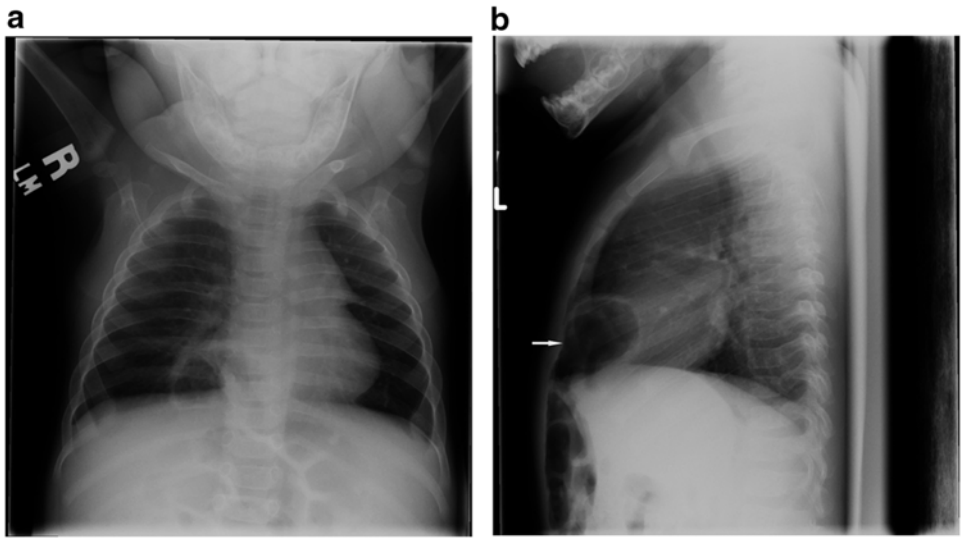


**Fig. 10.7** (**a**, **b**). Congenital diaphragmatic hernia. Foramen of Morgagni defect. (**a**) This AP chest radiograph depicts a neonate with congenital diaphragmatic hernia with a loop of bowel that herniated through a defect in the anteromedial (retrosternal) area of the diaphragm (foramen of Morgagni). (**b**) This lateral chest radiograph depicts a loop of bowel in the immediate retrosternal space (see *arrow*), rising above the anterior aspect of the diaphragm (Courtesy of Dr. K. Valle, Division of Pediatric Surgery, Women and Children's Hospital of Buffalo, Buffalo, NY)

occur as an isolated abnormality (often associated with a mutation on chromosome 15q26) or occasionally associated with syndromes such as Pallister-Killian, Fryns syndrome, Cornelia De Lange, or Edwards syndrome [111]. Abnormal karyotyping has been reported in 16 % of neonates with CDH, in 4 % of those without anomalies, and 39 % of those with anomalies [114, 115].

## Diagnosis

The diagnosis of CDH is made by antenatal ultrasound in ~70 % of cases, due to the presence of intrathoracic bowel loops or stomach, often signaled by a history of maternal polyhydramnios [114, 116]. All cases should be referred to a specialist center. The fetus should be screened for associated anomalies and the family provided with antenatal counseling, particularly if there are features associated with a poor prognosis (see below) [117, 118]. Antenatal MRI scans may provide further prognostic information about lung volume, liver herniation, left ventricular mass, and pulmonary diameter, but is not routine [111].

Postnatally, the neonate may present with an exacerbation of their respiratory distress. Symptoms may range from mild to severe, depending on severity of the CDH. The abdomen is scaphoid as the intestine is in the chest, and breath sounds are reduced on the affected side. The diagnosis is confirmed by X-ray of the chest and abdomen, which helps differentiate from other chest pathologies such as CCAM. A nasogastric tube should be placed before imaging as this may lie or curl above the diaphragm if the stomach is in the chest. An echocardiogram should be sought to delineate associated cardiac abnormalities and to estimate the severity of the pulmonary hypertension [119]. Serial cranial ultrasound should be performed to exclude an intracranial bleed.

## Outcomes

Despite the advances in the medical and surgical management of this condition, the overall mortality remains at 21–48 %. However, specialist centers with a large number of cases have better survival rates of up to 80 % live births [120]. Mortality in nonsyndromic infants is primarily related to pulmonary hypoplasia and pulmonary hypertension and, as surrogate markers of severity, the need for ECMO/HFOV or for patch repair [121]. Right-sided, bilateral, or large defects, a lung to head ratio of 1.0 or less, and the presence of the liver in the chest portend worse outcomes, as do prematurity, chromosomal anomalies, severe cardiac defects (particularly transposition of the great arteries or single ventricle physiology), and spinal anomalies [122, 123]. In an effort to establish a standardized scoring system, an international consensus concluded that the size of the diaphragmatic defect (as a surrogate for the severity of pulmonary hypoplasia and hypertension) and the severity of the cardiac defect may predict outcome [124]. ECMO required for more than two weeks or associated with renal complications, or persistent pulmonary hypertension for more than 3 weeks are also associated with high mortality [117, 118, 120, 121].

Morbidity associated with CDH in the longer term includes ongoing respiratory problems with recurrent infections and reduced exercise capacity compared with age-matched peers, neurocognitive defects secondary to neonatal hypoxia or intracranial hemorrhage, and visual impairment and deafness, possibly related to intensive care management.

Gastroesophageal reflux is common and may require medical or surgical intervention. Recurrence rates of up to 50 % are reported in CDH especially if an initial patch repair is required. Scoliosis and chest wall deformity may also occur [111].

### Prenatal Treatment

Prenatal treatment for CHD has been trialed with varying success. The most promising treatment is fetal endoscopic tracheal occlusion (FETO) with a balloon for babies with poor prognosis based on lung measurements. FETO prevents the egress of lung fluid from the fetal lung and improves lung growth and reduces vascular resistance. The tracheal balloon is either removed before delivery, by ex-utero intrapartum treatment (EXIT), or punctured immediately after delivery by tracheoscopy or percutaneous puncture [125, 126]. Promising results have been reported, but the complication rate is relatively high and may include previously unrecognized conditions such as tracheomegaly or bronchomegaly [127]. Premature delivery contributes to the poor outcomes of FETO [125]. In a randomized controlled trial of FETO, survival in neonates with isolated severe CDH is improved [125, 126, 128].

### Medical Management

Medical management of CDH has changed dramatically over the last two decades, from a strategy of early emergency surgery with aggressive hyperventilation to reduce pulmonary hypertension to optimizing the cardiorespiratory status using a "gentle ventilation" strategy to minimize barotrauma that includes minimum peak inspiratory pressures, maintaining spontaneous ventilation and permissive hypercarbia followed by a planned, surgical intervention [129].

Delivery should be planned at or near a center with pediatric surgical and NICU expertise so that the optimal postnatal respiratory support and timely surgical intervention can be provided. The neonate should be allowed to mature to term to permit maximum maturation of the lung. A nasogastric tube should be passed after delivery to decompress the stomach, central and arterial access obtained, and the warming strategies commence with minimal handling. Pulmonary surfactant has not been shown to be beneficial [130].

Since most neonates require some level of ventilatory support after birth, it seems prudent to intubate their tracheas at delivery. The initial ventilation strategy (conventional or high-frequency oscillation) varies among centers in the absence of randomized controlled trials [131]. The aim should be to achieve pre-ductal $SpO_2$ 85–95 %, post-ductal $SpO_2$ >70 %, arterial $pCO_2$ 45–60 mmHg, and pH > 7.25. If a conventional ventilation strategy is used, the initial settings should include a peak inspiratory pressure (PIP) 20–25 $cmH_2O$, positive end-expiratory pressure (PEEP) 2–5 $cmH_2O$, and a frequency 40–60 breaths per minute with minimum required inspired oxygen to maintain the threshold oxygen saturation. Prolonged use of muscle relaxants is ideally avoided, and the neonate should be allowed to breathe spontaneously between assisted breaths. If HFOV is used, the initial settings should include a mean airway pressure 13–17 $cmH_2O$, frequency 10 Hz, amplitude (ΔP) 30–50 $cmH_2O$, and I:E ratio 1:1. Hyperinflation of the lungs should be avoided (<8 ribs on unaffected side on chest X-ray).

Echocardiography should be performed to estimate the pulmonary artery pressure, direction of shunting across the arterial duct/foramen ovale, myocardial contractility, the presence of a congenital heart/vascular defect, and the response to treatment. The oxygenation index (OI) should be calculated (OI = mean airway pressure ($cmH_2O$) × $FiO_2$ × 100/$PaO_2$ (mmHg)). Inhaled nitric oxide (iNO) 10–20 ppm may be indicated if the OI is >20 or the pre-post-ductal oxygen saturation difference is >10 %. The use of iNO is controversial and response should be assessed using echocardiography. Prostacyclin or prostaglandin E1 (PGE1) should be considered if there is no response to iNO. Many units use PGE1 routinely to prevent closure of the arterial duct and to off-load the right ventricle. Sildenafil or milrinone may be indicated if pulmonary hypertension is refractory to treatment or persistent [132], but may cause systemic hypotension [130]. Endothelin receptor antagonists (bosentan) and tyrosine kinase inhibitors (imatinib) are currently under investigation. Fluid boluses may be required if peripheral perfusion is poor or hypotension is present. If cardiovascular instability persists, inotropes may be required to increase the mean arterial pressure to the upper normal range in order to reduce right to left shunting across the arterial duct.

Venoarterial extracorporeal membrane oxygenation (ECMO) may be offered in some centers as temporary stabilization and support in cases of severe cardiorespiratory failure. Specific ECMO criteria vary between centers; current European criteria for ECMO include inability to maintain pre-ductal saturation >85 % or post-ductal saturation >70 %, respiratory or metabolic acidosis with a pH < 7.15, need for aggressive ventilation, or refractory systemic hypotension [133]. The neonate should be >2 kg and >35 weeks gestation, have no lethal congenital abnormalities, have no irreversible organ dysfunction (including neurological injury), and have no contraindication to systemic anticoagulation.

### Surgical Considerations

The objectives of surgery in the management of CDH are to reduce the herniated contents safely into the abdomen and repair the defect. Ideally, surgery should be delayed until the neonate is stable, that is, off inotropes (with the possible exception of dopamine) for 24 h. Some have used "stability" criteria to determine the neonate's eligibility for surgery; however these criteria may be more appropriate for determining the timing, rather than eligibility, for surgery [134]. Surgical

intervention is possible while the neonate is on ECMO, although early studies suggested that the mortality was increased because of a greater risk of bleeding. Many centers undertake surgery only after weaning the neonate from ECMO, although some have achieved acceptable mortality rates repairing CDH on ECMO by limiting the use of anticoagulants and using antifibrinolytics [135]. For large defects, a patch repair may be required as a dome shape rather than a flat repair. Surgery may be performed by using an open technique (usually laparotomy) or a minimally invasive technique.

Laparotomy via an upper abdominal transverse incision allows good access to the length of the diaphragm and can be extended easily if further access is required. The abdominal contents are reduced into the abdomen and the defect is identified. The spleen may require gentle finger reduction rather than simple traction on the gastric and colonic attachments, to avoid damage and bleeding. A hernial sac, which is present in 10–20 % of cases, is usually excised during surgery. Pulmonary sequestrations may also be found, either supra- or subdiaphragmatic, and these are also excised. The hypoplastic ipsilateral lung may be seen via the defect in the chest. The diaphragmatic rim should be mobilized and, if possible, a primary repair performed without tension using nonabsorbable interrupted sutures. If the diaphragm is deficient laterally, then the sutures should incorporate a large bite of rib or muscle to prevent recurrence. If the defect cannot be closed without tension or is very large, a patch repair is required, although this technique is associated with worse short-term and long-term outcomes. A variety of nonabsorbable materials have been used, including Gore-Tex®, Marlex®, Dacron®, and Silastic®. Nonabsorbable materials have the advantage of cost, reduced bleeding, and easy handling; however they do not grow with the child and may actually shrink over time. These materials are associated with adhesions, increased recurrence, gastroesophageal reflux, and chest wall deformities [135]. Newer biosynthetic patch materials such as collagen lattices with embedded growth factors (Surgisis®, AlloDerm®) are under investigation, although they may increase the risk of postoperative small bowel obstruction. Techniques that involve muscular flaps have been described, but they are time-consuming and may be associated with increased bleeding and abdominal wall deformity. Myogenic patches may be developed in the future [135]. A chest drain is not used routinely as the underwater drain may cause overdistension of the hypoplastic lung. Such a drain may be inserted at a later date if a clinically significant effusion develops. The advantage of the abdominal approach is that a Ladd's procedure can be performed at the same time if the position of the duodenojejunal (D-J) flexure is consistent with malrotation and there is the potential for malrotation.

MIS for CDH has been reported using both laparoscopic and thoracoscopic approaches. The laparoscopic approach enables better instrument handling for the diaphragmatic repair. Reduction of contents against the pneumoperitoneum and the subsequent lack of intra-abdominal space after reduction can be challenging. The thoracoscopic approach is preferred by many and has the advantage that the pneumothorax encourages reduction and there is an excellent view of the diaphragm after reduction. The lateral suture placement can be very difficult due to the rigidity and shape of the thoracic cavity. Initial reports of thoracoscopic repair also suggested an early higher recurrence rate [136]. Right-sided CDH, CDH-associated liver herniation, and the need for patch closure may be better suited for an open procedure. As for thoracoscopic repair, carbon dioxide absorption and acidosis can be problematic during MIS [101]. For this reason, an open surgical approach is probably preferred for neonates with CDH and congenital heart disease, for those who required ECMO, or for those who have continuing systemic right ventricular pressures or require significant inotropic support [137].

It is important to avoid a "flat" diaphragmatic repair during primary or domed patch repair. When the herniated chest contents are reduced into the abdomen, the intra-abdominal pressures may increase to cause abdominal compartment syndrome. If there is evidence of significant venous congestion of lower limbs after closure, then an abdominal wall silo should be left as a laparotomy at the site of the abdominal incision, as for gastroschisis repair. This may be closed a few days later.

## Anesthetic Considerations

Management of pulmonary hypertension and pulmonary insufficiency and the timing of surgery are primary considerations in these neonates. Surgical repair should only be performed in physiologically stable neonates, ideally when inotropic support is no longer required and the neonate has been weaned off ECMO, usually at 2–6 days after birth [120]. If the child becomes unstable on transfer to or in theater before surgery begins, then surgery should be postponed. Some units perform surgery in the NICU, but it remains a contentious issue (see Chap. 13) [135].

A balanced anesthesia technique that includes opioids such as high-dose fentanyl 20–50 mcg/kg [10], muscle relaxants, and an inhalational anesthetic should be used to preclude a pulmonary hypertensive crisis. Nitrous oxide should be avoided. The ventilatory strategy should be the same as in NICU; an intravenous technique will be required if the child is receiving HFOV or remains dependent on ECMO. Invasive monitoring should be continued from the NICU, with transcutaneous carbon dioxide monitoring to supplement direct measurement of arterial $PaCO_2$, particularly in MIS.

Surgical repair is usually uneventful and blood loss usually limited (special precautions are required if the child

remains on ECMO). Hypotension usually responds to fluid boluses of 10–20 ml/kg balanced salt solution or an increase in the infusion rates of inotropes. Hypotension in the presence of an increasing difference between the pre- and postductal $SpO_2$ values may indicate an intraoperative pulmonary hypertensive crisis. Simple interventions include increasing $FiO_2$, increasing depth of anesthesia, opioid administration, and correction of the acidosis that are usually effective. iNO should be available in the event of a pulmonary hypertensive crisis unresponsive to these measures. If oxygenation deteriorates intraoperatively, a pneumothorax on the contralateral (good lung) side and an endobronchial intubation must be excluded. At the conclusion of surgery, the neonate should be transferred back to the NICU; the duration of postoperative ventilation is determined by the severity of pulmonary hypoplasia and pulmonary hypertension.

## Abdominal Surgery

### Inguinal Hernia

Inguinal hernias occur commonly with a childhood incidence of 0.8–4.4 %. Males are affected 8–10 times more than females. Premature infants have an increased risk of hernias with an incidence of 13 % in neonates born at <32 weeks gestational age (GA) and 30 % in infants <1 kg birth weight [138]. This group also has an increased risk of complications such as obstruction and incarceration. Inguinal hernia is also associated with cystic fibrosis, connective tissue disorders, and abdominal wall defects.

#### Pathophysiology

Inguinal hernias result from the failure of obliteration of the patent processus vaginalis (PPV), which develops during testicular descent. Up to 50–80 % of neonates may have a PPV and remain asymptomatic until bowel or other intra-abdominal contents enter this sac. When that occurs, it is classified as an inguinal hernia. The right side is more frequently affected (60 %) than the left, with 10–15 % of cases occurring bilaterally (with a greater incidence in infants).

#### Diagnosis

An inguinal hernia is diagnosed clinically with the history or presence of a groin swelling (Fig. 10.8). This may extend into the scrotum on the ipsilateral side. The testis should also be palpated during examination, separate to the groin swelling. The hernia may contain bowel, omentum, or the ovary in females. Examination should ensure that the hernia is reducible; if the hernia is irreducible (i.e., incarcerated), then the hernia immediately becomes a surgical emergency. The majority (60 %) of incarcerated inguinal hernias occur in the first 6 months of life.

**Fig. 10.8** Inguinal hernia in a neonate. Close-up of a right inguinal hernia (Courtesy of Dr. YH Lee, Division of Pediatric Surgery, Strong Hospital, University of Rochester, Rochester, NY)

#### Surgical Management

Inguinal hernias require surgical closure of the PPV. In many centers, hernia repair is performed as an open procedure via an inguinal incision with ligation of the sac after separating it from the vas and testicular vessels. Care must be taken to fully mobilize and ligate the sac to prevent recurrence, while preserving the vas and vessels with minimal surgical trauma. The duration of anesthesia and surgery for inguinal hernia repair in neonates is greater than in older children. The risks of recurrence or testicular atrophy are greater in neonates, particularly if the hernia has become incarcerated.

Laparoscopic repair may also be performed with closure of the internal ring with a nonabsorbable suture. This technique allows assessment of the contralateral side and bilateral repair if indicated, which may be particularly beneficial in infants as there is a 60 % incidence of bilateral hernia or contralateral PPV in infants. There is less dissection of the cord structures, which may result in less damage; laparoscopic hernia repair in infants is a safe procedure with a small complication rate, although long-term outcomes are not yet available [139]. The laparoscopic approach is feasible even in very small neonates, although the ability to tolerate carbon dioxide insufflation is an important factor, and the procedure may be more challenging technically in the very premature or low-birth-weight neonates. Instead of carbon dioxide insufflation, some advocate gasless laparoscopy in

neonates thereby obviating the cardiorespiratory effects of a carboperitoneum [140].

### Anesthetic Management

The timing of surgery in neonates who require hernia repair remains controversial, particularly in premature neonates; the younger the neonate, the more susceptible they are to postoperative apneas as well as surgical complications. This has to be balanced with the risk of incarceration if surgery is delayed. Many centers plan surgery for premature infants near the time of discharge from the hospital, and others delay surgery until after discharge to reduce the potential for postoperative apnea and the need for prolonged postoperative ventilation [141].

An analysis of data from prospective studies of former preterm infants undergoing hernia repair under general anesthesia in the mid-1980s and late 1990s suggested that the probability of postoperative apnea in premature infants was <1 % at PCA 56 weeks, with negligible risk of postoperative apnea at 60 weeks PCA. The risk factors for postoperative apnea were gestational age at birth, postconceptional age, ongoing preoperative apneas, and anemia (hematocrit<30 %) [142]. Factors that may reduce the frequency of apneas in premature infants after general anesthesia include regional block (spinal anesthesia) without sedation, an ilioinguinal/iliohypogastric nerve block, administration of intravenous caffeine 10mg/kg, and the avoidance of neuromuscular blockade or potent opioids [143, 144]. Respiratory events after sevoflurane and desflurane anesthesia occur with similar frequencies in premature neonates [145]. Current practice guidelines recommend postoperative apnoea monitoring for neonates/infants who are full term but less than 44 weeks PCA and infants who were premature at birth (e.g., ≤37 weeks gestation) and who are less than 60 weeks PCA, although it has been suggested that this guidance could be relaxed to 46 weeks for former preterm infants without other risk factors for postoperative apnea [146].

Spinal or caudal epidural anesthesia as a sole technique may be associated with fewer postoperative respiratory complications than general anesthesia but has a significant failure rate [146, 147]. The GAS study (general anesthesia versus spinal anesthesia for infants undergoing hernia repair) may yield further evidence to support the choice of anesthesia for hernia repair in this vulnerable group of infants [148].

## Pyloric Stenosis

Pyloric stenosis occurs in 1–3:1,000 births and is four to five times more common in males than females and more commonly in firstborn males. The etiology of pyloric stenosis has been elusive, although there is some evidence for a genetic basis for the disease, feeding practices, erythromycin exposure postnatally (or prenatally), sleeping position (prone increases the risk), and possibly infectious moieties [149–152]. The age at which pyloric stenosis presents has been gradually decreasing. Currently, most cases present at 2–5 postnatal weeks, after several days of projectile vomiting [153–155]. Pathological hypertrophy of the inner layer of smooth muscle in the pylorus results in gastric outlet obstruction, which leads to the projectile nature of the vomiting.

Pyloric stenosis is usually an isolated defect. However, in many cases, it is associated with genetic syndromes including Cornelia de Lange and Smith–Lemli–Opitz syndromes as well as chromosome 8 and 17 translocations and (partial) trisomy 9 [150].

### Diagnosis of Pyloric Stenosis

The classic symptom of pyloric stenosis is non-bilious projectile vomiting. Term infants are predominantly affected, although pyloric stenosis does occur in premature infants. The diagnosis may be confirmed by clinical examination with visible gastric peristalsis and a palpable pyloric "tumor." These signs may be more clearly demonstrated with a "test feed." The classical biochemical picture is one of dehydration with hypochloremic metabolic alkalosis due to loss of gastric acid. Total body potassium may be depleted due to the renal compensation and tubular reabsorption of hydrogen and sodium ions and water in exchange for potassium. However, mounting evidence suggests that neonates with pyloric stenosis present earlier in their disease process, resulting in less severe electrolyte imbalance in the past decade [155, 156]. As a result of the less severe electrolyte imbalance and the increasing reliability of ultrasound to delineate both the thickness and length of the pylori (with a sensitivity of 100 % and specificity of 98 %), ultrasound has supplanted the electrolyte panel as the cardinal criterion for diagnosis of pyloric stenosis [153–155, 157].

### Medical Management

This disorder is a medical, not surgical, emergency. Initial management consists of rehydration and correction of any electrolyte imbalance. Depending on the severity of the fluid and electrolyte derangements, 24–48 h preparation may be required, although affected neonates are reaching pediatric surgeons earlier in the disease process currently, reducing the time required to correct electrolyte disturbances [155, 156]. Surgical intervention should not be undertaken until the neonates have been stable medically and the plasma bicarbonate is <28 mmol/l and plasma chloride >100 mmol/l. Infants with severe dehydration may require an initial fluid bolus of 20 ml/kg 0.9 % saline, followed by maintenance fluid with 5–10 % dextrose and 0.45 % saline, provided the plasma sodium is in the normal range. The stomach should be decompressed with a nasogastric tube, and gastric losses replaced ml for ml

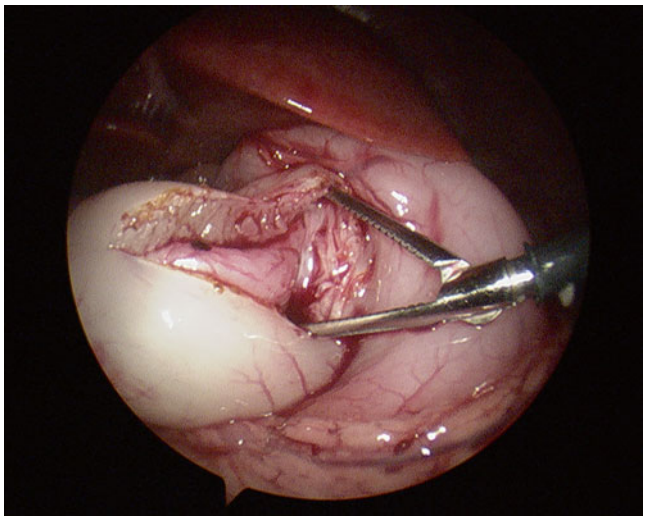

**Fig. 10.9** Pyloromyotomy. The thickened muscle layer of the pylorus can be seen, incised down to the mucosa. To ensure the muscle has been completely incised, laparoscopic alligators distract the walls of the muscle layer. Note the very thick muscular wall that has been peeled off the pylorus. The liver edge is present immediately above the pylorus at the top of the figure (Courtesy of Dr. K. Bass, Division of Pediatric Surgery, Women and Children's Hospital of Buffalo, Buffalo, NY)

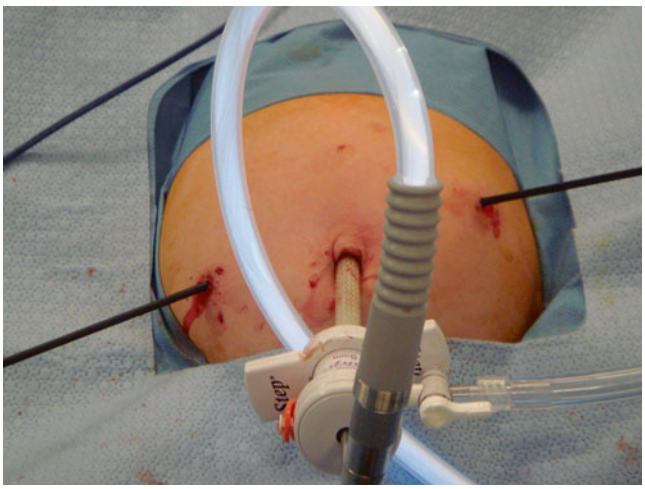

**Fig. 10.10** Laparoscopic insufflation of the abdomen. The neonate's head is at the top of the figure and the legs are at the bottom. During laparoscopic pyloromyotomy, three ports are placed: the largest trocar (5 mm Mini Step) is inserted through the umbilicus, whereas the two smaller graspers are passed laterally through simple skin incisions. The peritoneal cavity is insufflated with carbon dioxide to ~8 mmHg pressure

with intravenous 0.9 % saline and 10 mmol KCL per 500 ml. Potassium should be added to maintenance fluids only after the child begins to pass urine [153].

## Surgical Management

The traditional operation for pyloric stenosis is Ramstedt's pyloromyotomy, an extramucosal longitudinal splitting of the hypertrophied muscle (Fig. 10.9). This was originally described using an upper midline incision but many centers now use a supraumbilical approach to provide better cosmesis. Laparoscopic pyloromyotomy is also widely performed, and a recent randomized controlled study and meta-analysis have demonstrated some benefits from this approach (reduced time to full feed and length of stay), without an increase in postoperative complications although the debate continues regarding the superiority of the laparoscopic over the open approach for pyloric stenosis [158] (Fig. 10.10) [30]. Whether laparoscopic approach includes multiple incisions, a single incision, or a microlaparoscopic (<2 mm diameter instruments) approach [159], it would appear to be the evolving standard for pyloromyotomy.

## Anesthetic Considerations

Surgery should only be scheduled after the fluid status and electrolyte concentrations (including pH) have been normalized; otherwise, the child will be at increased risk of postoperative apnea, arrhythmias, and circulatory instability. A nasogastric tube will be in situ before induction of anesthesia. After administering atropine 0.02 mg/kg IV, the nasogastric tube is replaced with a large red rubber catheter in some centers to suction the gastric contents in the supine and decubitus positions, before induction of anesthesia. When complete, the red rubber catheter is removed. The traditional induction technique for pyloromyotomy is a modified RSI, in which cricoid pressure is avoided after consciousness is lost, but gentle mask ventilation continues with 100 % oxygen until laryngoscopy begins. Surveys of experienced pediatric anesthesiologists reveal that fewer than 50 % apply cricoid pressure to infants with pyloric stenosis [160, 161]. In fact, cricoid pressure is difficult to apply correctly in young infants and may distort the airway, complicating laryngoscopy and tracheal intubation [16, 162, 163]. The modified RSI as described is commonly practiced in neonates and young infants with full stomachs to prevent desaturation during the interval between loss of consciousness and securing the airway.

The anesthetic regimen for pyloric stenosis in the neonate presents two offsetting conditions: to facilitate rapid tracheal intubation and recovery from anesthesia in ~30 min, the duration of surgery. IV induction of anesthesia is usually accomplished with IV propofol using a dose that depends on adjunctive medications. If succinylcholine (2 mg/kg) (preceded by atropine) is included in the regimen, then a dose of 2 mg/kg propofol may be used. Following the black box warning by the Food and Drug Administration, many clinicians in the US avoid succinylcholine in young males, so use either a non-depolarising muscle relaxant or other medications to facilitate intubation of the airway. If a nondepolarizing relaxant is used (most commonly rocuronium), then a

small dose should be used to preclude difficulty antagonizing its effects after the brief surgery [164, 165]. Suggamadex may be effective for terminating the action of the relaxant, but it is expensive and not available in every country.

Faced with a male with pyloric stenosis, a fast surgeon, and reluctance to use a nondepolarizing muscle relaxant, several other regimens may be used. Some administer a short-acting IV opioid such as fentanyl 1–2 μg/kg or remifentanil followed by a large dose of propofol (3–5 mg/kg) to induce anesthesia and secure the airway. Alternately, others administer sevoflurane in oxygen while preoxygenating the neonate [166], judiciously timing a bolus of IV propofol (2–4 mg/kg) ± a short-acting opioid, to provide optimal intubating conditions.

In preparation for tracheal intubation, a hockey-stick curve to the tracheal tube (a 3.5 uncuffed or 3.0 Microcuff® tube) molded with a stylet to maintain its shape ensures a rapid and successful tracheal intubation, particularly in the absence of a muscle relaxant. Once the airway is secured, a gastric tube may be reinserted with a stopcock attached to permit inflation of the pylori with 20 ml boluses of air to test the integrity of the underlying mucosa.

Delayed emergence after pyloric stenosis is a common and perplexing problem. This has been attributed to several causes including the use of intraoperative opioids. Infiltration of the wounds with local anesthetic is usually sufficient to control the pain after pyloromyotomy, obviating the need for any opioid intraoperatively, although some prefer a short-acting opioid such as fentanyl or remifentanil [167]. Others advocate a regional block such as a rectus sheath block or epidural, depending on the surgical approach [168, 169]. IV or rectal acetaminophen may also provide mild pain relief intraoperatively and postoperatively, without slowing emergence [28]. However, despite avoiding opioids entirely, many continue to experience a very slow to emerge from anesthesia after this surgery. Some have attributed the slow emergence from anesthesia to the use of nondepolarizing muscle relaxants, although one retrospective study disputed this claim, noting that 0.7 mg/kg rocuronium minimally delayed the time to transport to recovery compared with succinylcholine, after a propofol/sevoflurane anesthetic [164, 165, 170]. Insufflating the abdomen in neonates and infants does not mandate the need for a nondepolarizing muscle relaxant. If relaxants were not used for tracheal intubation and are not part of the anesthetic regimen for surgery, then insufflation requires a deep level of anesthesia and controlled ventilation. This usually involves large concentrations of inhalational anesthetics, which could delay emergence unless the least soluble anesthetics, desflurane and nitrous oxide, were used for maintenance. At least one MAC of desflurane is required during insufflation, which corresponds to an end-tidal desflurane concentration of 9.6 % in this age group [171]. To reduce the concentration of inhalational anesthetic required, remifentanil may be added [167]. Antiemetics are not indicated in neonates as the incidence of postoperative vomiting in this age group is very small and surgeons may use ongoing vomiting as a sign of an incomplete repair or complication [172]. As soon as the surgeon desufflates the peritoneum, the inspired concentration of desflurane is reduced to 3 %. When the skin incisions are closed and dressed, all anesthetics are discontinued.

## Intestinal Atresias

Congenital intestinal atresia or stenosis can occur at any point along the gastrointestinal tract. The neonate presents with intestinal obstruction, the timing and specific presenting features relating to the level of the obstruction [173, 174, 265].

## Pyloric Atresia

Pyloric atresia is an extremely rare condition (1:100,000 live births) representing 1 % of intestinal atresias. Up to 30 % of patients have other associated anomalies including epidermolysis bullosa, aplasia cutis congenita, and esophageal atresia. Presentation is with non-bilious vomiting with a single gastric bubble on abdominal X-ray and no distal gas. Surgery involves a laparotomy to either excise the obstructing membrane or perform a bypass procedure (gastroduodenostomy or gastrojejunostomy) to restore intestinal continuity. The practical considerations are similar to those for duodenal atresia.

## Duodenal Atresia

Duodenal atresia or stenosis occurs in 1:5,000–1:10,000 live births with a male preponderance. Half of the patients have associated anomalies, commonly trisomy 21 (30–40 %), malrotation (30–40 %), and cardiac anomalies (20 %). Anorectal and genitourinary anomalies, esophageal atresia, and Meckel's diverticulum are also associated with duodenal atresia and, more rarely, biliary anomalies. Up to 45 % of babies are born prematurely [173]. Duodenal atresia may be classified as follows (Table 10.3).

### Embryology

Duodenal atresia may be due to abnormal embryological development of the duodenum, pancreas, and biliary tree.

**Table 10.3** Classification of duodenal atresia

| |
|---|
| Type I—mucosal diaphragmatic membrane |
| Type II—short fibrous cord connecting two ends of the atretic duodenum |
| Type III—complete separation of the two ends of the duodenum |

Proposed mechanisms include failure of recanalization of the duodenum during the 8–10th week and altered rotation of the ventral analogue of the pancreas resulting in an annular pancreas. The obstruction is distal to the ampulla in the majority of patients (60–85 %). An alternative theory common to all atresias is the possibility of a vascular accident (see jejunoileal atresia below).

### Diagnosis

Polyhydramnios occurs in 33–60 % of pregnancies and antenatal ultrasound may demonstrate a "double bubble." Cardiac abnormalities may also be detected at this time. Postnatally the baby develops bilious vomiting in the majority, although vomiting may be non-bilious if the atresia is proximal to the ampulla. Abdominal X-ray shows the characteristic double bubble with an absence of gas distally. Distal gas may occasionally be seen if the atresia is periampullary with the main pancreatic and accessory duct opening on either side. Gas can then travel via the biliary tree into the distal intestine. The antenatal and abdominal X-ray findings are less clear in duodenal stenosis, which may present later depending on the degree of obstruction. The differential diagnosis of duodenal atresia is malrotation and volvulus, which can have catastrophic consequences if not detected. If there is any doubt about the diagnosis, for instance, if there is distal gas or no antenatal history, an urgent upper gastrointestinal contrast study should be performed to exclude malrotation. If doubt still remains, then an urgent laparotomy should be performed.

### Management

Ultimate management is surgical; however the patient should be resuscitated and stabilized as required. A nasogastric tube should be passed with replacement of losses and maintenance fluids given intravenously. Preoperative workup includes a thorough clinical examination and echocardiography to exclude associated anomalies.

### Outcomes

There is low reported mortality and morbidity associated with duodenal atresia. Early operative mortality is less than 5 %, predominantly due to complex cardiac anomalies, and long-term survival is 90 %. Morbidity associated with this condition includes gastroesophageal reflux disease, delayed gastric emptying, peptic ulcer disease, duodenal stasis and blind loop syndrome or megaduodenum, and adhesive small bowel obstruction. These complications may not be apparent until much later in life.

### Surgical Considerations

A laparotomy and duodenostomy (either end-to-side or Kimura diamond anastomosis) are the primary procedures performed. Access is via a supraumbilical transverse or umbilical (Bianchi) incision. The minimally invasive laparoscopic approach is feasible and safe and is being introduced in some centers, although liver retraction and exposure of the duodenum can be difficult especially in a small infant or in the presence of hepatomegaly. It is important to check that a second duodenal web is not present (seen in 1–3 % of cases), and there are no distal atresias. Intestinal rotation should be checked and malrotation corrected if present. The gall bladder should be visualized for bile. Some surgeons choose to leave a transanastomotic tube in situ although full enteral feeds are usually achieved without this maneuver.

### Anesthetic Considerations

Anesthetic considerations relate mainly to anesthesia for laparotomy in the presence of upper gastrointestinal obstruction and coexisting abnormalities, especially complex cardiac anomalies, and prematurity. If the child is otherwise well, the aim should be to extubate at the end of the procedure.

## Jejunal/Ileal Atresia

Small bowel atresia or stenosis is a common cause of neonatal intestinal obstruction occurring in 1:3,000 live births [80]. A stenosis is due to a localized narrowing of the lumen without loss of continuity in the intestine or mesentery (Fig. 10.11). Small bowel atresias are classified into four major types [175, 176] (Table 10.4).

Types II and IIIa occur most commonly. There may be a family history especially in type IIIb atresia. Multiple atresias are not uncommon, with up to 67 % of jejunal atresias and 25 % of ileal atresias having further distal atresias. Chromosomal abnormalities are much less common in the

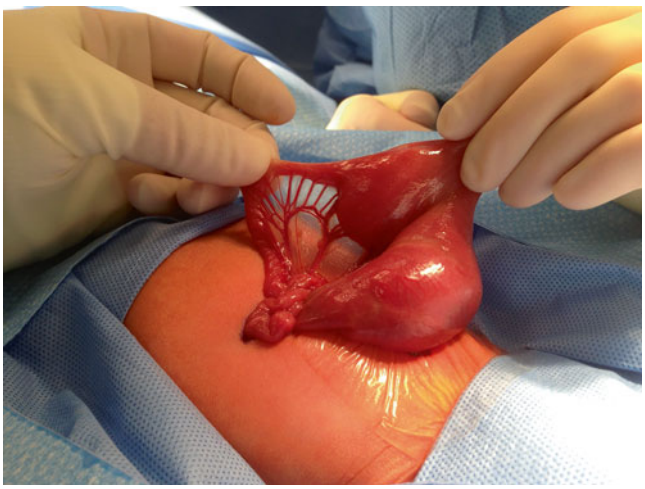

**Fig. 10.11** Jejunal atresia. At laparotomy, normal jejunum is held up on the right side of the photo. The jejunal lumen narrows at the atresia in the middle of the photograph, with a very small lumen thereafter. The mesentery, which supplies blood to the bowel, is intact (Courtesy of Dr. YH Lee, Division of Pediatric Surgery, Strong Hospital, University of Rochester, Rochester, NY)

**Table 10.4** Classification of small bowel atresias [175]

| |
|---|
| Type I—a membrane or web |
| Type II—blind ends separated by a fibrous cord |
| Type IIIa—disconnected blind ends |
| Type IIIb—absence of the superior mesenteric artery resulting in the "apple peel," "Xmas tree," or "Maypole" abnormality |
| Type IV—multiple segment atresia ("string of sausages") |

more distal atresias compared to duodenal atresia although 12 % of patients with ileal atresia will also have cystic fibrosis. These patients should have genetic screening and a sweat test performed at an appropriate time postoperatively. There is an association between gastroschisis and small bowel atresias.

### Embryology

The most popular theory is that the atresia is a result of an intrauterine "vascular accident." Interruption of the blood supply results in sterile necrosis and resorption of affected segments. Multiple causes of vascular interruption have been proposed including fetal intussusceptions, midgut volvulus, thromboembolic occlusions, transmesenteric internal hernias, and incarceration as the result of an abdominal wall defect. The use of methylene blue in amniocentesis for twin pregnancies has also been implicated. The insult is felt to occur late (after week 11), and this is supported by the findings of bile, lanugo hair, and squamous epithelial cells from swallowed amniotic fluid distal to the atresia.

### Diagnosis

Polyhydramnios may be present prenatally although less common the more distal the obstruction. Dilated bowel lops may be seen on antenatal scans. Presentation after birth is with signs of intestinal obstruction including vomiting (usually bilious), abdominal distension, and failure to pass meconium. Respiratory compromise may occur if the distension is severe, and the baby may require preoperative respiratory support (and hence postoperative support). A plain abdominal X-ray will show dilated bowel loops (number depending on the level of the obstruction). A contrast enema may be performed preoperatively to exclude the differential diagnoses of meconium ileus, Hirschsprung's disease, and coexisting more distal atresias. Ten percent of neonates present with meconium peritonitis due to antenatal perforation; calcification or meconium pseudocyst may be seen on abdominal X-ray.

### Outcomes

The long-term survival for patients with jejunoileal atresia is 84 %. The primary cause of morbidity and mortality is short bowel syndrome or intestinal failure requiring total parenteral nutrition, with associated risk of sepsis and liver disease.

### Medical Management

As with all neonatal intestinal obstruction, the initial goal is to stabilize the neonate with nasogastric decompression, nil by mouth, intravenous resuscitation, and maintenance fluids. Investigations should be performed as above.

### Surgical Considerations

The most common surgical procedure to localize the atresia is a laparotomy. Once it has been identified, the atresia is excised with a primary anastomosis. There may be significant discrepancy in size between the proximal and distal ends of the atresia, making an end-to-end primary anastomosis challenging. Despite this, a 7:1 discrepancy can be accommodated with meticulous technique and 7-0 suture material. If bowel length is not a problem, then the dilated bowel can be resected back to a more reasonable caliber. If a type IIIb "apple peel" atresia is discovered, particular care must be taken to avoid compromising the retrograde vascular supply from the marginal colic arteries to the remaining distal small bowel. Problems with absorption of feed and short bowel syndrome are also more common with this type of atresia. This has been attributed to the severity of the vascular insult. Given the high risk of multiple atresias, the continuity of the distal bowel should be confirmed by passing a small balloon catheter through the lumen and flushing with either air or saline before the anastomosis is performed. If the neonate is unstable or the distal bowel is significantly compromised, then a proximal stoma and mucous fistula are preferred as a temporizing measure, with restoration of bowel continuity restored when the neonate has fully recovered. The remaining length of small bowel should be measured and documented to help predict and manage neonates with possible short bowel syndrome.

### Anesthetic Considerations

These are the same as for any neonate undergoing laparotomy. However, postoperative ventilation may be required after prolonged laparotomy and a significant fluid shift. Long term vascular access may be required for parenteral nutrition.

## Colonic Atresia

This is a very rare cause of intestinal obstruction and represents <10 % of all intestinal atresias. A vascular insult is the likely cause of these atresias. These occur when closing abdominal wall defects especially gastroschises secondary to localized vascular interruption. Applying the Grosfeld classification, most are type IIIa or type I. Associated proximal atresias are common (22 %), and right-sided atresias are associated with Hirschsprung's disease.

### Diagnosis

Colonic atresia presents with symptoms of distal obstruction, including abdominal distension, failure to pass meconium, and bilious vomiting. Multiple loops of distended bowel on plain abdominal X-ray confirm the presence of distal bowel obstruction. A hugely distended loop of bowel is often

present because of the closed loop obstruction in the presence of a competent ileocecal valve. Contrast enema confirms the location of the most distal atresia.

### Management

Preoperative management is the same as for all neonates with intestinal obstruction. This has been discussed above. Early surgical intervention is essential, as the mortality from perforation may reach 100 % if surgery is delayed for more than 4 days.

### Surgical Considerations

Surgical options are laparotomy with either formation of decompressing colostomy or primary anastomosis. Although a high incidence of anastomotic leakage and sepsis has been reported previously in neonates undergoing primary anastomosis, more recent reports support this approach. Hirschsprung's disease should be considered if an anastomotic leak is detected. A stoma is preferred to direct anastomosis, if resection to bowel with a more appropriate caliber results in short bowel syndrome. As per jejunal/ileal atresias, the proximal bowel must be assessed intraoperatively by flushing with air or fluid to identify additional atresias.

## Meconium Ileus

Meconium ileus results from the obstruction of the distal small bowel due to thick inspissated meconium. The majority (90 %) are due to intestinal and pancreatic dysfunction secondary to cystic fibrosis (CF). Up to 25 % of neonates with underlying cystic fibrosis will present with meconium ileus. Once the obstruction has been successfully treated, the infant must be tested for CF. The presence of meconium ileus does not predict a worse, long-term outcome from CF, although almost all children with meconium ileus develop pancreatic insufficiency and will require pancreatic enzyme replacement when feeds are introduced [177]. It is important to involve the respiratory physicians early, even though clinical lung disease is very uncommon in neonates.

### Diagnosis

Simple meconium ileus presents with distal intestinal obstruction. Plain abdominal X-ray shows multiple loops of dilated bowel with a "soap bubble" appearance in the right lower quadrant (Neuhauser's sign). This results from the mixing of air and the tenacious meconium. A contrast enema will show a microcolon with pellets of meconium in the terminal ileum.

Complications occur in 50 % of cases. Perforation may occur in the antenatal period if the proximal bowel becomes ischemic or perforates secondary to a volvulus. This will lead to meconium peritonitis and possibly a giant pseudocyst. The neonate may present with a large abdominal mass or meconium may be passed vaginally or be evident in a patent processus vaginalis in the scrotum. Calcification is often evident on a flat plate (X-ray) of the abdomen. Intestinal volvulus or atresias may also occur.

### Outcomes

Outcomes are slightly more favorable in simple meconium ileus with a 1-year survival of 92 % compared with 89 % in complicated meconium ileus [177].

### Management

The usual resuscitative measures should be performed in conjunction with broad-spectrum intravenous antibiotics, and the neonate should remain nil by mouth. If the diagnosis is consistent with simple meconium ileus, the obstruction may be relieved by nonoperative measures using a hyperosmolar contrast enema (Gastrografin® or Omnipaque®), which may be repeated. Operative intervention is indicated for enema failures and complicated meconium ileus.

### Surgical Considerations

Surgical options include manual disimpaction at laparotomy either via a proximal enterotomy or with the intraluminal injection of 4 % *N*-acetylcysteine. A combination of these two may be required to fully clear the impacted plugs. If this is not possible, a distal loop or double-barreled stoma should be performed, although this is rarely required. Primary laparotomy is performed in complicated meconium ileus; the options are resection and anastomosis or, alternatively, stoma formation. It is essential to ensure that the obstruction into the microcolon is relieved completely if a stoma is not performed. Additional *N*-acetylcysteine via a nasogastric tube is sometimes advocated. The stoma should be closed as soon as possible to avoid excessive sodium losses from the gastrointestinal tract and from sweat.

### Anesthetic Considerations

Management is the same as for any neonatal laparotomy including fluid resuscitation and respiratory support according to clinical requirements. Hypertonic enemas increase the risk of hypovolemic shock in neonates as fluid becomes sequestered in the gut. Fluid may need to be replaced throughout the intra- and postoperative periods to replace the preoperative and intraoperative fluid losses. A sweat test should be performed early in the postoperative period to establish the diagnosis of cystic fibrosis. Fortunately, respiratory complications are uncommon in the neonatal period.

## Malrotation and Volvulus

Malrotation is a congenital anomaly of the bowel in which an abnormal position and fixation of the midgut shortens the mesenteric base, predisposing to a volvulus [178]. The incidence

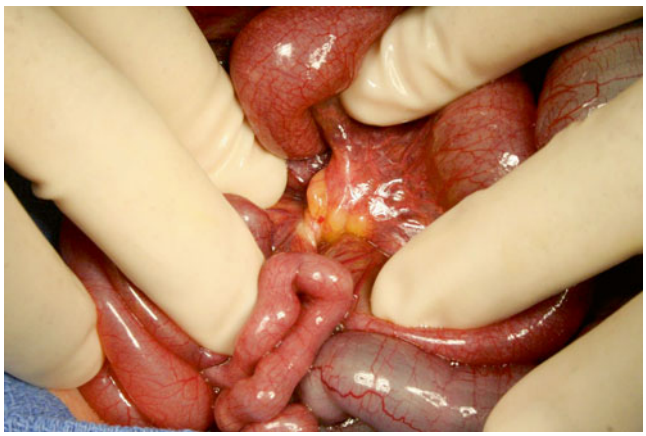

**Fig. 10.12** Midgut volvulus. At the ends of the gloved fingers (center of the photo), a tightly twisted midgut (covered in yellow fat) volvulus is evident (Courtesy of Dr. YH Lee, Division of Pediatric Surgery, Strong Hospital, University of Rochester, Rochester, NY)

is 1:500–1:1,000 based on postmortem studies. The incidence based on symptomatic presentation is 1:6,000 live births or may be discovered incidentally. Other anomalies associated with malrotation include intestinal atresias, such as duodenal web, abdominal wall defects, congenital diaphragmatic hernia, imperforate anus, cardiac abnormalities, Meckel's diverticulum, and trisomy 21. Males are twice as likely to present in the neonatal period as females. Malrotation with midgut volvulus constitutes a true surgical emergency as the consequences are potentially catastrophic with loss of the entire small intestine (Fig. 10.12).

## Embryology

The traditional theory of intestinal development has the small bowel undergoing a counterclockwise 270° rotation during the 6th–10th week of gestation as it returns to the abdomen from the physiological hernia. During weeks 10–12, the bowel undergoes fixation. Failure of these processes is termed "malrotation." This anomaly results in a shortened mesenteric base with the D-J flexure in an abnormal right-sided and low position, with a high position of the cecum, and a tendency of the small bowel to twist around the mesenteric base (volvulus). This causes obstruction of the blood supply and lymphatic drainage to the small bowel (as well as luminal bowel obstruction), which can lead to ischemia to ischemia with necrosis of the entire midgut. It is imperative that malrotation with volvulus is identified in a timely manner and corrected before necrosis of the bowel occurs.

## Diagnosis

The majority of neonates with malrotation present in the first month of life (50–75 % of cases). The most common presenting symptom is bilious vomiting, although some may have non-bilious vomiting. Other signs including abdominal tenderness or distension, diarrhea or constipation, and lethargy present less commonly. Systemic compromise and blood in the stools are later signs of volvulus in which significant ischemia has already occurred. Abdominal X-ray may be deceptively normal. The gold standard for diagnosis is an upper GI contrast study, which demonstrates duodenal obstruction when volvulus has occurred. The appearance is that of a "bird's beak," coiled, or "corkscrew." The normal position of the D-J flexure is to the left of the midline, at or above the level of the pylorus. For uncomplicated malrotation in the absence of a volvulus, the contrast study demonstrates the abnormal position of the D-J flexure to the right of the midline. The position of the cecum is variable, rendering it an unreliable sign of a malrotation. CT or ultrasound may demonstrate reversal of the normal position of the superior mesenteric artery (SMA) relative to the superior mesenteric vein (SMV), with spiraling of these vessels if volvulus has occurred. Ultrasound can be used to track the course of the duodenum and D-J flexure. Urgent laparoscopy or laparotomy is required if the diagnosis remains in doubt [179].

## Outcomes

Malrotation with volvulus may lead to ischemic necrosis of the entire midgut. Accordingly, it is essential that a pediatric surgeon assess all neonates with bilious vomiting in a timely manner to prevent ischemia of the bowel. The mortality rate is ≤10 %. Short bowel syndrome (see Gastroschisis for further discussion) occurs in 18 % of neonates with volvulus. Complications of surgery include adhesive bowel obstruction in up to 20 % and recurrent volvulus in 6 % of neonates. Those with a malrotation may develop intestinal dysmotility at a later date.

## Management

A high level of clinical suspicion must be present when a neonate presents with bilious vomiting. The outcome after volvulus is time dependent so early diagnosis and intervention are critical. Initial resuscitation should be undertaken before an urgent upper GI contrast study. Immediate surgical intervention is indicated if a malrotation with volvulus is diagnosed. For those in whom a malrotation without volvulus is confirmed or suspected, the optimal management is controversial. Knowing there is a substantive risk for future volvulus, many surgeons advocate a semi-urgent surgical procedure to assess the mesenteric base and proceed to correction, if appropriate.

## Surgical Considerations

The classic surgical approach is Ladd's procedure with derotation of the volvulus. In this procedure, the duodenum is mobilized, the mesenteric base is widened, and the D-J flexure and the small bowel are mobilized to the right of the abdomen and

the cecum and large bowel to the left. If obstructing peritoneal bands (Ladd's bands) are identified, they are divided. Many surgeons also perform an appendicectomy as the cecum is abnormally located in the left upper quadrant. Ladd's procedure has been classically performed via laparotomy or more recently by laparoscopy, the latter providing a potentially less invasive means to assess the stability of the mesentery. If technical factors preclude the latter approach, then early conversion to an open technique must occur. The role of laparoscopy for correction of a volvulus in a neonate remains controversial: some do not endorse this approach, whereas others suggest it as not appropriate in an unstable neonate in whom necrotic bowel is likely [179, 180]. The long-term outcomes for the laparoscopic approach remain unclear. Despite a reduced risk of future adhesive bowel obstruction, the risk of recurrent volvulus remains uncertain.

Derotation of the bowel is often sufficient to restore the blood supply to the midgut and the viability of the bowel. However, if the diagnosis is delayed, the bowel may remain ischemic after derotation, possibly the result of vascular thrombosis in the mesenteric vessels. The surgical options to address the ischemic/necrotic bowel include excision of the necrotic segment, with or without anastomosis, or conservative management with a "second look" laparotomy after 36–48 h to determine whether perfusion of the ischemic bowel has improved. A technique that involves massage of the mesenteric vessels after derotation (to break up clot), and systemic thrombolysis using tissue recombinant tissue-type plasminogen activator (tPA), has recently been described in two neonates with severe intestinal ischemia due to thrombosis. This resulted in dramatic restoration of bowel perfusion, with subsequent complete recovery of bowel function [181]. If the small bowel is completely necrotic, then withdrawal of care should be explored with the parents.

### Anesthetic Considerations

These cases are critical surgical emergencies that must be given priority over all other cases. Surgery must not be delayed. Preoperatively, the status of the neonate may range from relatively healthy to hypovolemic and/or septic shock. In the latter condition, preoperative resuscitation should occur concurrently with preparation and transfer of the neonate to the operating theater. Group "O"-negative blood should be available if necessary. A nasogastric tube should be passed to decompress the abdomen, and ventilatory support provided as required. If the neonate is in shock or extremis, then anesthesia should be induced using IV ketamine, fentanyl, and/or remifentanil and the airway secured after either rocuronium or atropine/succinylcholine [11]. Coagulopathy is common in the presence of necrotic bowel requiring platelets and fresh frozen plasma. Inotropic support with dopamine and/or adrenaline may be required. Invasive monitoring is very useful during this initial resuscitation phase.

If the neonate is stable, maintenance of anesthesia can include fentanyl or remifentanil or a low dose of inhalational anesthesia. Deep inhalational anesthesia must be avoided in critically ill neonates. The surgeon should inform the anesthesiologist when the volvulus is about to be reduced because derotation may lead to acute cardiovascular instability due to release of lactic acid and other vasoactive compounds. The anesthesiologist should be prepared to manage transient acidosis and hyperkalemia with IV calcium chloride (10–30 mg/kg), bicarbonate, and occasionally salbutamol.

Reperfusion of the bowel is the primary goal. Adequate fluid resuscitation with warmed boluses of lactated Ringer's solution, albumin, or packed red cells is required based on clinical assessment and monitoring. Fluid requirement may be substantial at this juncture; volumes as great as 50–100 ml/kg may be required. Inotropic support may also be required at this time to support the circulation, active warming of the neonate, and patience and time to assess recovery of the bowel.

If malrotation is identified early, and the child is in good condition preoperatively, it is reasonable to consider extubating the trachea at the end of surgery. The late-presenting infant with necrotic bowel may remain critically ill even after derotation, requiring full support in the intensive care unit until perfusion is restored. Long-term parenteral nutrition may be required in some cases to bridge until the bowel regains full functionality.

## Hirschsprung's Disease

Hirschsprung's disease is congenital aganglionosis of the bowel of variable length extending from the anus proximally [182]. This results in a lack of propagation of the intestinal propulsive waves, failure of relaxation of the internal anal sphincter, and functional bowel obstruction. It occurs in 1:4,500–5,000 live births with males affected more than females. 80–90 % of those with Hirschsprung's disease present in the neonatal period.

### Embryology

Hirschsprung's disease is one of the neurocristopathies with presumed failure of the craniocaudal migration of the neural crest-derived neuroblasts, which form the myenteric and submucosal enteric plexuses (which should reach the rectum by week 12 of development). Other theories include failure of neuroblast differentiation, defects in function, or cell death. Varying lengths of bowel are affected, the most frequent pattern being short-segment disease affecting the rectosigmoid region (80 %). Long-segment disease occurs when aganglionosis extends proximal to the rectosigmoid region,

with total colonic disease in 3–8 % of cases. Total intestinal involvement is rare.

## Genetics

Hirschsprung's disease is a multigenic disorder with ten different genes and five chromosomal loci currently implicated [183]. There appears to be a dysfunction in one of two signaling pathways, which are critical in the development of the enteric nervous system. There is low and sex-dependent penetrance, with variable phenotypic expression. 10 % of patients have a family history (more common in long-segment disease). The RET (receptor tyrosine kinase) proto-oncogene mutation 10q11.2 is involved in 50 % of familial and 15–20 % of sporadic cases and 70–80 % of long segment and up to 38 % of short-segment disease [182]. Currently, genetic profiles are not widely available to assess the disease risk in individuals.

Hirschsprung's disease occurs in isolation in 70 % of cases, but it may be associated with trisomy 21 (5–15 % of cases of Hirschsprung's disease), other neurocristopathies (Waardenburg–Shah syndrome (SW4), congenital central hypoventilation syndrome, multiple endocrine neoplasia (MEN) type 2, neuroblastoma, and neurofibromatosis I), other syndromes such as Shprintzen-Goldberg and Smith-Lemli-Opitz, and congenital anomalies such as cardiac, genital, gastrointestinal anomalies, facial dysmorphism, and cleft palate [182].

## Diagnosis

In neonates, the most common presenting symptoms are bile-stained vomiting with failure to pass meconium in the first 24 h of life (94 % of normal term infants pass meconium <24 h). This may be associated with poor feeding, abdominal distension, and vomiting. Rectal examination may result in explosive stool and may temporarily relieve the symptoms. Signs of enterocolitis (fever, abdominal distension, and diarrhea) may also be present. Differential diagnoses include the other causes of neonatal distal bowel obstruction discussed in this chapter. Abdominal X-ray may show dilated loops of bowel with an absence of air in the rectum. A distal contrast study may show dilatation of the proximal colon with a change in caliber (transition zone) to normal bowel, but this is not reliable. Rectal biopsy provides a definitive diagnosis for Hirschsprung's disease when it fails to demonstrate ganglion cells, with altered acetyl cholinesterase staining with hypertrophied nerve trunks. It is performed using a suction rectal biopsy in the neonatal period or open biopsy in older children. Anorectal manometry is not usually performed in neonates.

## Management

Initial management aims to relieve the functional bowel obstruction either with warm saline washouts or a defunctioning stoma into ganglionic bowel. A stoma is indicated if the neonate is unwell or has developed enterocolitis and perforation and has a grossly dilated colon or suspected long-segment disease. Hirschsprung's enterocolitis is a potentially fatal complication that must be identified early and managed aggressively to reduce the risk of sepsis, intestinal necrosis, and perforation. Treatment with fluid resuscitation and broad-spectrum antibiotics is required.

Definitive surgery consists of resection of the aganglionic segment, either after initial stoma formation or ideally as a primary procedure. Several "pull-through" techniques have been described, usually performed when the infant is approximately 3 months of age, 5–6 kg weight [184]. The timing and exact procedure performed varies among centers and according to the length of abnormal bowel. Each technique can be performed completely open, or with laparoscopically assisted intra-abdominal dissection and biopsies, or entirely laparoscopically [184, 185].

## Surgical Procedures

The first surgical procedure described to address Hirschsprung's disease was the Swenson procedure. This procedure is a low anterior resection of the rectum and aganglionic bowel, with a low anastomosis performed by prolapsing the bowel outside the anus.

The Duhamel procedure was the first alternative operation proposed in which the native rectum remains unchanged and a side-to-side anastomosis is stapled to the ganglionic bowel, which is mobilized and brought down to the presacral space. This requires less rectal dissection and offers a better chance of continence in the long term. It is often the preferred technique for long-segment disease. A retrospective review of open and laparoscopic approaches yielded similar operative time and outcomes [185].

The Soave procedure further minimizes rectal dissection by performing a mucosal dissection in the rectum and leaving a rectal muscular cuff. The original description has been modified to include a formal anastomosis just above the level of the dentate line.

A pure anal pull-through without a laparotomy or laparoscopy has also been reported for Hirschsprung's disease but may not be appropriate for longer-segment disease. Long-segment disease is not always suspected preoperatively potentially complicating this approach. Other operations have been described, although less frequently reported.

## Outcomes

Appropriately managed, Hirschsprung's disease is associated with low mortality, although up to 50 % of patients undergoing surgery develop a complication such as constipation, fecal incontinence, or enterocolitis. Enterocolitis,

the most severe complication, can occur in all patients with Hirschsprung's disease, both before and after surgery. It occurs more frequently in those with long-segment disease and those with trisomy 21. Enterocolitis is the primary cause of mortality in children with Hirschsprung's disease and must be identified and managed aggressively. Constipation occurs more frequently after the Duhamel pull-through, whereas incontinence occurs more frequently after the Soave and Swenson procedures. To date, there are no prospective randomized controlled trials that compare the outcomes from the different surgical techniques, although overall complication rates appear to be similar among all approaches.

### Surgical Considerations

The transition zone between ganglionic (normal) and aganglionic (abnormal) bowel can vary in length (up to 10 cm) and demonstrate an irregular margin. It is important to perform an anastomosis between bowel segments with adequate ganglion cells without tension or vascular compromise. Time must be allowed regardless of procedure for intraoperative frozen section results of serial biopsies at ascending levels to accurately assess the extent of affected bowel. If long-segment disease is discovered unexpectedly, then many recommend that the pull-through procedure be delayed until formal histology is available.

### Anesthetic Considerations

A complete preoperative history should be completed including a history of existing syndromes and anomalies that are associated with Hirschsprung's disease. Definitive surgery, either open or laparoscopic, may take 1.5–4 h in experienced hands [185]. The anesthetic prescription should be designed to ensure tracheal extubation at the end of surgery. After anesthesia is induced, the trachea is intubated and the lungs are ventilated with positive pressure and positive end-expiratory pressure. For the laparoscopic approach, the neonate is supine but positioned in steep Trendelenburg. All of the airway fittings should be manually tightened and IV access points extended such that they are reachable once the neonate is draped. Blood loss is usually minimal obviating the need for blood transfusion. Caudal/epidural regional analgesia is well suited for perioperative analgesia after this surgery. Postoperatively, rectal analgesia is contraindicated.

## Anorectal Anomalies

Anorectal anomalies occur on 1:4,000–1:5,000 neonates with a slight male preponderance. Associated abnormalities are present in 30–60 % of cases; the most common associations are listed below (Table 10.5).

**Table 10.5** Conditions associated with anorectal anomalies

| |
|---|
| Genitourinary (renal dysplasia, vesicoureteric reflux, undescended testes, vaginal abnormalities) |
| Spinosacral (sacral agenesis, vertebral anomalies, tethered cord) |
| Cardiac (septal defects and tetralogy of Fallot) |
| Gastrointestinal (esophageal atresia, intestinal atresias, Hirschsprung's disease) |
| Chromosomal (trisomy 21, VACTERL association, Currarino triad) |

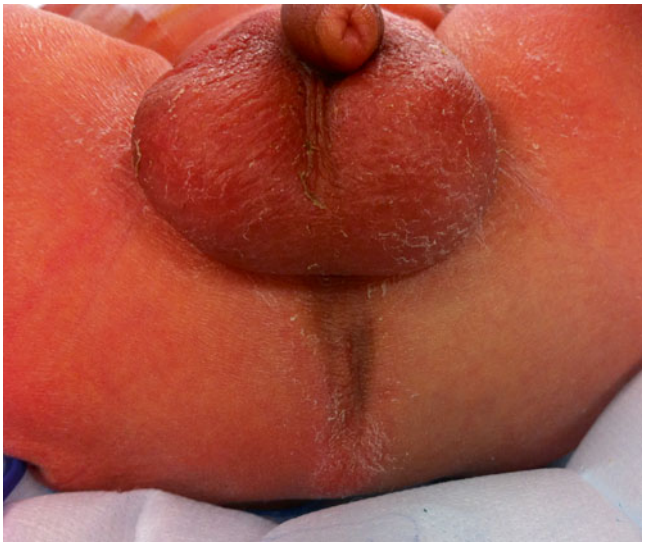

**Fig. 10.13** Imperforate anus. A closeup photograph of the perineum in a male. Note that immediately inferior to the normal penis and scrotum, one observes the outline and pigmentation of the imperforate anus (Courtesy of Dr. YH Lee, Division of Pediatric Surgery, Strong Hospital, University of Rochester, Rochester, NY)

### Embryology

During weeks 4–6, the pouch at the caudal end of the hindgut (the cloaca) is separated into the urogenital sinus (bladder, urethra, vagina) and rectum. Anorectal anomalies occur as the result of failure of this separation and usual subsequent degeneration (apoptosis of the membrane) resulting in a wide range of clinical abnormalities.

### Classification

The Krickenbeck classification of anorectal anomalies is shown in Table 10.6 [186]. In males, imperforate anus with rectourethral fistula is the most common defect followed by rectoperineal fistulae (Fig. 10.13). In females the most common defect is imperforate anus with rectovestibular fistula [187].

### Diagnosis

Anorectal anomalies are diagnosed clinically, requiring a thorough inspection of the perineum, sacrum, and buttocks to identify the anatomy. If the neonate's clinical condition permits, it is important to wait 16–24 h after birth to diagnose a fistula, especially in males, as it may take this time for meconium to reach the rectum [188].

**Table 10.6** Krickenbeck classification of anorectal anomalies [186]

| |
|---|
| Major clinical groups |
| • Perineal (cutaneous) fistula |
| • Rectourethral fistula (prostatic, bulbar) |
| • Rectovesical fistula |
| • Vestibular fistula |
| • Cloaca |
| • No fistula |
| • Anal stenosis |
| Rare/regional variants |
| • Pouch colon |
| • Recta atresia/stenosis |
| • Rectovaginal fistula |
| • H fistula |
| • Others |

Associated anomalies should be sought and further investigations may be required such as an echocardiogram, abdominal X-ray, and renal ultrasound. An "invertogram" was previously advocated, but this is not routinely performed in many centers.

### Outcomes

Short-term complications after reconstructive surgery include anal stenosis, which may require repeated dilatation or formal revision and wound infection. Pelvic sepsis can occur as a life- and continence-threatening early complication of surgery, especially if a diverting stoma has not been performed.

Constipation is the most common long-term complication of anorectal surgery, occurring in 18–62 % of infants. Fecal incontinence is a second long-term complication, occurring in 25 % of infants. Social continence can often be achieved with a combination of modalities including antegrade enemas via an antegrade colonic enema (ACE) stoma. Urinary dysfunction may also occur, being attributable to the underlying urinary tract anomaly rather than the surgery.

### Management

Initial management is supportive with intravenous fluids and gastric decompression with a nasogastric tube. Associated anomalies should be excluded and time allowed to detect a fistula, if clinically appropriate. Surgical decompression and reconstruction is required. Depending on the anatomy and associated anomalies, the neonate may undergo a primary anoplasty ("low" anomalies) with or without a diverting colostomy and distal mucous fistula or formation of colostomy/mucous fistula with later reconstructive surgery at 1–2 months of age ("high" anomalies). Several operative approaches have been proposed for reconstruction including posterior sagittal anorectoplasty (PSARP), an anterior sagittal approach, sacroperineal procedure, abdominosacral pull-through, abdominoperineal pull-through, and laparoscopic-assisted pull-through techniques. PSARP is the most common procedure, suitable for most females and 90 % of males. In the remaining males, a combined abdominal approach is required to mobilize the rectum.

### Surgical Considerations

It is important to avoid damage to pelvic structures and their innervation during surgery. A muscle stimulator is essential to identify the sphincter complex and ensure correct placement of the neo-anus. For muscle function to be stimulated, muscle relaxants are avoided after induction of anesthesia. Dissection should be adequate to bring the rectum to the perineum without tension in order to minimize retraction after the repair and anal complications.

### Anesthetic Considerations

An understanding of the associated anomalies, particularly cardiac and spinal anomalies, is important. Stoma formation is a relatively minor procedure in the neonatal period, and a single-shot caudal epidural provides excellent perioperative analgesia for primary anoplasty (provided there are no sacral abnormalities). Reconstructive surgery is usually performed in the prone position (PSARP) or occasionally as a combined abdominoperineal or laparoscopically assisted procedure. Intravenous access should be placed in the upper extremities to ensure that the fluids are infused into the circulation, not the surgical field. Blood transfusion is rarely required for this surgery. These reconstructive surgeries are usually several hours in duration, with the neonates in the Trendelenburg position. As a result, tracheal intubation is usually required. The anesthetic prescription should be designed to extubate the trachea at the end of surgery. Perioperative analgesia can be achieved with a continuous caudal/epidural infusion of local anesthetics (e.g., bupivacaine) [189] or IV morphine infusion [190–192].

## Cloaca

This type of anorectal anomaly is uncommon, occurring in 1:50,000 live births.

### Diagnosis

Careful clinical examination will reveal a single perineal opening. Further imaging studies such as contrast studies and CT scan with reconstruction can be very useful, as well as assessment of the common channel and structure via cystoscopy.

### Management

Initial management is supportive as for other anorectal anomalies. Of note, hydrocolpos can result in urinary obstruction and pyocolpos can result in perforation. Both of these conditions may require urgent drainage.

### Outcomes

The long-term results for cloacal repair in terms of continence are worse than for lower anorectal anomalies. Only 10 % of neonates with a common channel >3 cm in length will be continent.

### Surgical Considerations

Recognition of the anomaly is important as a more proximal transverse colostomy is required to allow for adequate length for the reconstruction procedure. Assessment of the length of the common channel before reconstructive surgery is important for both prognostic reasons and to assess the need for a combined intra-abdominal approach.

## Abdominal Wall Defects

### Gastroschisis

Gastroschisis occurs in 1:4,000 live births, affecting males and females equally. The incidence of gastroschisis, which is increasing, is strongly associated with maternal age <20 years, smoking, use of recreational drugs, low maternal weight, maternal genitourinary infection, and low socioeconomic status [193–196].

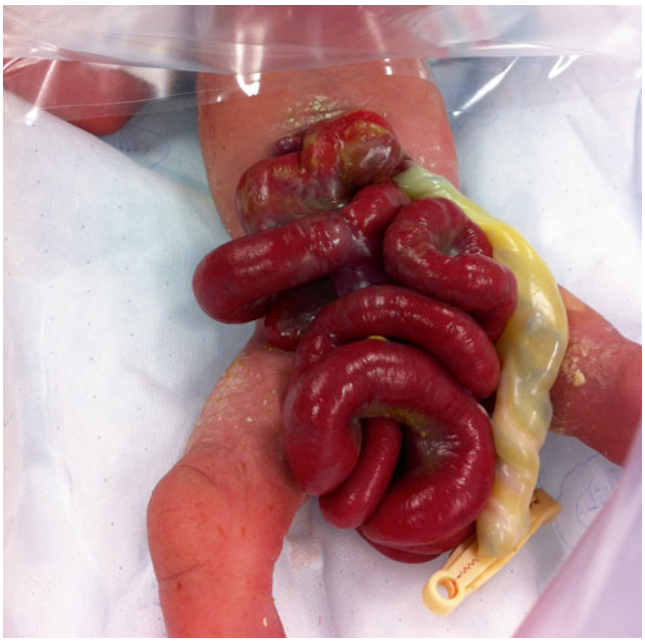

**Fig. 10.14** Gastroschisis. In this preterm neonate, the thickened, red bowel from a gastroschisis lays open and exposed. Note that the gastroschisis arises from an anterior abdominal wall defect on the right side, lateral to the intact umbilical cord (Courtesy of Dr. YH Lee, Division of Pediatric Surgery, Strong Hospital, University of Rochester, Rochester, NY)

### Pathophysiology

Gastroschisis is usually a small, right-sided (<10 % left) defect in the abdominal wall lateral to the intact umbilical cord, through which the intestines protrude, uncovered, and unprotected (Fig. 10.14). The exact embryological mechanism for this anomaly is still unclear. In utero, the eviscerated bowel floats uncovered and exposed in the amniotic fluid. This may contribute to thickening of the bowel wall and fibrinous "peel" that is often present on the bowel at delivery. The abdominal wall defect can narrow later in pregnancy, resulting in obstruction and ischemic changes to the gut. Associated anomalies are infrequent with this defect, but when they occur, they are usually gastrointestinal in origin. For example, intestinal atresias occur in 10–15 % of cases. The liver rarely herniates.

### Diagnosis

The majority of neonates with gastroschisis are diagnosed on routine antenatal ultrasound. Blood testing shows increased maternal serum concentrations of alpha-fetoprotein in the absence of a myelomeningocele. "Complicated gastroschisis," as in the case of gastroschisis with intestinal atresia, may be predicted by the presence of dilated bowel on antenatal ultrasound [197]. Approximately 30–70 % of neonates have intrauterine growth retardation or small for gestational age. The mechanism for this latter effect is unclear but may be due to enteric loss of proteins or inadequate supply of fetal nutrients [198]. After delivery, the laterality of the defect, the absence of a sac, and an intact umbilical cord differentiate gastroschisis from omphalocele.

### Management

Antenatal diagnosis allows prenatal planning and transfer of the parturient to a center where surgical management of the gastroschisis and a level-3 nursery are available [199]. There is insufficient evidence to determine the optimal management of these fetuses, for example, the age at which the fetus should be delivered and the delivery technique [200]. A survey of maternal-fetal medicine practitioners in Canada suggested that preterm (<36 weeks) delivery of fetuses with gastroschisis was associated with more complications, i.e., greater time requiring parenteral nutrition and greater length of stay in NICU, whereas delivery of fetuses ≥38 weeks was associated with increased bowel matting [201]. There is no evidence that cesarean section improves neonatal outcomes, although early induction of labor (from gestational week 36) may avoid the unexplained late fetal deaths that can occur with this condition.

Initial management at delivery is supportive, avoiding hypothermia, hypovolemia, and sepsis. The exteriorized bowel should be wrapped in clear plastic film and supported in the midline to minimize venous engorgement or placed in a preformed silo. Above all, care must be taken to avoid damaging the exposed bowel. A servo-controlled warm

incubator should be used. Large volumes of intravenous fluids may be required to offset the large evaporative fluid loss from the exposed bowel. Broad-spectrum antibiotics should be given. A nasogastric tube should be placed to decompress the stomach and bowel.

## Outcomes

Survival with gastroschisis is reported to be 90–95 %, with the majority of deaths due to massive bowel resection or necrosis [202]. Intestinal function may be slow to recover after closing the defect necessitating a long period of parenteral nutrition. A review of a gastroschisis database indicated that the time to achieve independence from parenteral nutrition, reduce length of stay, and achieve freedom from infection was optimized when enteral feeds were withheld for at least 7 days after closure of the defect [203]. However, these findings should be interpreted in the context of the neonate's status. Intestinal dysfunction and short bowel syndrome complicate gastroschisis. Gastroschisis accounts for approximately 20 % of the cases of short bowel syndrome, with the incidence of the latter inversely proportional to birth weight [204]. Surgical short bowel syndrome is defined as the need for parenteral nutrition for >3 months. Current advances in management strategies that involve a multidisciplinary team approach, parenteral nutrition, prophylaxis from infection, and ongoing surgical consultation have dramatically improved bowel function and survival in these neonates [204].

## Surgical Considerations

The primary objective of surgery is to cover and protect the bowel. The secondary objective is to effect a staged return of the bowels to the abdomen, without causing an abdominal compartment syndrome. The latter is often identified by the onset of respiratory distress, ischemic or necrotic bowel, and renal insufficiency. For monitoring strategies to identify abdominal compartment syndrome, see Anesthetic Considerations below.

The surgical treatment of gastroschisis remains controversial. Primary closure may be undertaken in neonates with small-size gastroschises using general anesthesia in the operating theater. Complications such as intestinal atresia, perforation, necrosis, or volvulus may be addressed at the same time. Before attempting a primary closure, rectal decompression with possible rectal washouts may decrease intraluminal contents and facilitate a smooth reduction. Good long-term outcomes have also been reported using a "sutureless ward reduction" protocol with morphine sedation for carefully selected neonates with uncomplicated gastroschisis. The bowel is inspected carefully for intestinal anomalies and the neonate remains conscious during the procedure. The reduction should be abandoned if the neonate develops respiratory distress or the surgeon perceives the abdominal pressure is excessive [205].

A staged closure is required if primary closure is not appropriate or possible. This may be performed by surgical application of a hand-sewn Prolene mesh silo under general anesthesia or using a preformed spring-loaded silo. For neonates with uncomplicated gastroschisis who do not have significant viscero-abdominal disproportion, the preformed silo can be applied on the neonatal unit without the need for general anesthesia or routine intubation [206]. These techniques allow gradual compression of the bowel into the abdomen over a period of days and facilitate early extubation. The neonate undergoes planned surgical closure 3–5 days later, or closure of the defect using adhesive strips once the bowel is fully reduced, depending on the silo technique used [207]. Use of the preformed silo may be associated with reduced ventilator days in the NICU [97], but this approach may also be associated with specific technical complications leading to venous congestion of the intestine and bowel ischemia [208].

## Anesthetic Considerations

Some centers do not use anesthesia for closure of gastroschisis if a sutureless or preformed silo technique is used, although others recommend routine anesthesia with paralysis to facilitate every attempt to reduce the bowel. An operative technique is required for complicated gastroschisis. A combination of general anesthesia with epidural anesthesia provides good postoperative analgesia and may reduce the need for postoperative ventilation [209]. The child must be kept warm and well hydrated with fluid blouses of 20 ml/kg Ringer's or albumin. Arterial access is useful for monitoring complex procedures. In neonates with otherwise uncomplicated gastroschisis, enteral feeding usually begins 7–10 days after delivery. In those who require long-term parenteral nutrition, it is important to preserve veins for chronic catheters for long-term parenteral feeding. Some units advocate placement of a tunneled feeding line at the time of initial surgery [210].

The major concern during closure is the development of abdominal compartment syndrome. If the reduction is performed under general anesthesia, care should be taken during face mask ventilation to avoid gaseous distention of the gastrointestinal tract and nitrous oxide should be avoided. Intra-abdominal pressures should be maintained <20 mmHg during primary closure of the defect [210]. Some centers advocate the use of a balloon-tipped catheter in the bladder or stomach, central venous pressure, or $P_{ET}CO_2$ to track changes in intra-abdominal pressure during the closure [211, 212]. The ventilator settings should be noted at the start of the procedure and followed throughout to identify any decreases in tidal volume due to upward movement and splinting of the diaphragm. If these occur, the reduction must stop and the approach reassessed. During closure the bowel must be constantly assessed for signs of venous congestion. Urine output can be used to reflect the adequacy of renal perfusion after completing the surgery. After closure but before leaving the operating room, the lower limbs should be examined for evidence of venous compromise and pulses.

## Exomphalos (Omphalocele)

Exomphalos occurs in 1:4,000 live births, affecting males 1.5 times more frequently than females. It can be classified as major, minor, or giant, depending on the size of the defect and the presence of liver herniation. Major defects are greater than 4 cm in diameter or contain a herniated liver. Giant defects are greater than 6 cm in diameter or contain a herniated liver. Associated anomalies are common, occurring in more than 50 % of neonates, particularly those with a minor defect. Anomalies associated with exomphalos include chromosomal abnormalities (30 %) such as trisomies 13, 18, and 21, other midline defects (pentalogy of Cantrell, bladder and cloacal anomalies), and cardiac and musculoskeletal abnormalities. Beckwith–Wiedemann syndrome, an abnormality found on chromosome 11 associated with gigantism, macroglossia, exomphalos, pancreatic islet cell hyperplasia with hyperinsulinism, organomegaly, and hemihypertrophy, occurs in 12 % of cases. Pulmonary hypoplasia is associated with exomphalos major.

### Pathophysiology

Exomphalos is a central defect of the umbilical ring. The herniated organs are covered with a membrane (sac) continuous with the umbilical cord (Fig. 10.15). This is thought to represent failure of the intestines to retract into the abdominal cavity from the umbilical stalk after the period of rapid growth of the intestines early in embryogenesis.

### Diagnosis

As in gastroschisis, the diagnosis of exomphalos is confirmed antenatally using ultrasound imaging. Exomphalos is a midline abdominal wall defect with a sac that contains the herniated visceral contents. Antenatal chromosome testing is recommended. After delivery, the defect in the umbilical ring is visible, usually with an intact sac. It can be difficult to visualize externally whether the liver is herniated.

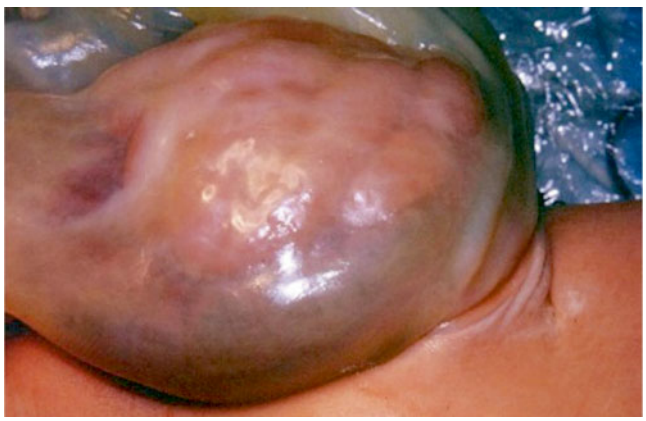

**Fig. 10.15** Omphalocele. In this midline defect, the herniated bowels are covered by a thick membrane (Courtesy of Dr. YH Lee, Division of Pediatric Surgery, Strong Hospital, University of Rochester, Rochester, NY)

### Outcomes

The mortality rate in neonates with exomphalos, 10–30 %, is substantively worse than it is for gastroschisis. However, unlike gastroschisis in which the severity of the bowel dysfunction and ischemia determines the morbidity and mortality in that condition, the severity of the associated anomalies determines the morbidity and mortality in exomphalos.

### Management

Supportive management is the initial priority. If the sac remains intact, then the bowels are protected and urgent surgical intervention is unnecessary. The sac and its contents should be supported depending on its size. Time can be taken to delineate and stabilize the associated anomalies before proceeding with reduction. If the sac has ruptured, then surgical intervention becomes more urgent as in the case of gastroschisis.

### Surgical Considerations

Primary reduction of the contents with excision of sac is usually achievable for small defects, but a staged closure is generally required for larger defects. A hand-sewn surgical silo is placed under general anesthesia, leaving the sac intact, with serial reductions performed in the neonatal unit, including after extubation. Once the visceral contents have been reduced, then the silo can be removed and the defect formally closed in theater. The likely success of primary closure should be assessed by gentle compression before excising the sac. If not favorable, then the sac should be left intact for silo placement. If the sac is excised, care must be taken superiorly to avoid damaging the hepatic veins, which may cause significant haemorrhage. Neonates with giant exomphalos are occasionally treated conservatively, particularly if there is marked disproportion between the viscera and the size of the abdominal cavity (typical "scaphoid" abdomen). The intact sac is allowed to epithelialize, with topical application of antibacterial sclerosing agents such as povidone-iodine or silver sulfadiazine, although systemic absorption of iodine or silver may themselves create a problem [213].

### Anesthetic Considerations

The preoperative assessment should include an echocardiogram and appropriate investigations to fully define the severity of any other anomalies present. Otherwise, the anesthetic prescription is similar to that for gastroschisis repair. Neonates with exomphalos major are particularly at risk for abdominal compartment syndrome. Reduction of the liver into the abdomen can compress the inferior vena cava, acutely decreasing venous return and cardiac output. Intra-abdominal pressure

can be monitored using either a bladder or gastric pressure transducer (see above) to provide an objective metric upon which to stage the reduction. As in the gastroschisis, close and clear communication between the surgeon and anesthesiologist will ensure a successful reduction.

## Bladder Exstrophy/Cloacal Exstrophy

Bladder exstrophy occurs in 1:30–50,000 live births affecting males four times more frequently than females. Antenatal diagnosis occurs in only 25 % of cases [214]. This defect in the anterior bladder and abdominal wall exposes the bladder and urethra as part of the exstrophy–epispadias complex (Fig. 10.16).

Cloacal exstrophy occurs four to five times less frequently than bladder exstrophy, 1:200,000 live births. It occurs equally in both males and females. Cloacal exstrophy is a lower abdominal wall defect with two hemibladders separated by a midline cecum, exomphalos, and imperforate anus. Spinal malformations such as myelomeningocele may occur as part of the omphalocele–exstrophy–imperforate anus-spinal defects (OEIS) complex.

### Outcomes

Optimal outcomes for these rare conditions are obtained by centralizing the care to specialist centers, with the involvement of a multidisciplinary team. Previously a commonly fatal condition, the dramatic advances in neonatal care have transformed the outcome from this defect to almost 100 % survival beyond the neonatal period, although long-term issues relating to function and psychological outcomes remain.

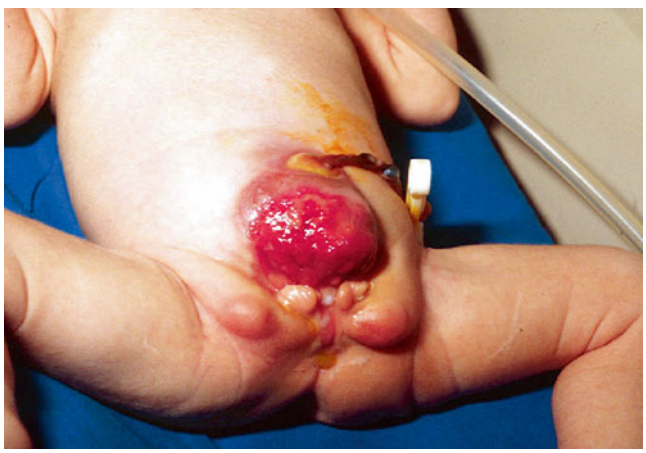

**Fig. 10.16** Bladder exstrophy. This congenital defect in the anterior abdominal wall reveals the bladder wall, malformed genitalia, and widened pelvis with an absent symphysis pubis (Courtesy of Dr. RJ. Banchs, Children's Hospital, University of Illinois. Chicago, Ill)

### Management

After delivery, care should be taken to avoid damage to the bladder plate. Moist nonadherent dressings should be applied prior to transfer of the child to the specialist center, and the umbilicus tied rather than clamped. In cloacal exstrophy, exomphalos is managed using the techniques described above.

### Surgical Considerations in Bladder Exstrophy

The long-term aims of surgery are the reconstruction of the bladder for social urinary continence, treatment of vesicoureteric reflux, reconstruction of the genitalia to allow for cosmetic appearance, sexual and urinary function, and, in the case of cloacal exstrophy, reconstruction to obtain fecal continence. As a result of the wide diastasis of the pubic bones, pelvic osteotomies are often required in order to close the pelvic brim anteriorly and reduce the risk of wound dehiscence and bladder prolapse.

Surgery may be performed in staged procedures: the bladder is closed early in the neonatal period with or without pelvic osteotomies, depending on surgical preference; the genitalia is repaired at 3–6 months of age, in some centers with a radical bladder neck reconstruction at this stage (Kelly procedure) and a secondary hypospadias procedure at 3 years; and finally, bladder augmentation and ureteric reimplantation are performed if required in later childhood. If the bladder closure and osteotomies are performed in a single procedure, a multidisciplinary approach involving anesthesia, urology, and orthopedics is the prescription for success. In this case, the anticipated duration of surgery will be quite prolonged (see below). A single stage procedure of bladder closure, bladder neck reconstruction, and epispadias repair in the neonatal period has been described (Mitchell procedure), although concerns that urethral blood flow may be compromised with this technique must be considered [215]. The complication rate after single stage repair is reportedly similar to those after a staged repair, although soft tissue defects may be more common in the former [216].

### Anesthetic Considerations

Neonates with bladder exstrophy are usually born at term without other associated anomalies. Surgery for primary bladder closure is ideally performed in the first few days of life, while the pelvic bones remain malleable. Blood loss is significant if pelvic osteotomies are performed, and a blood transfusion is often required. A plaster cast or external fixator may be applied at the end of surgery for support. Although systolic blood pressure remains a reliable metric for detecting hypovolemia in neonates, central venous access may be useful adjunct measure to monitor fluid status during this surgery as urine output is not easily quantified. Intravenous access should be placed in the upper extremities (or neck) to retain access to the lines and to ensure that all fluids remain in the circulation. With the prolonged duration

of surgery and the need to monitor blood pressure, to perform laboratory tests (hemoglobin, electrolyte, and glucose concentrations), and to respond to sudden blood loss, arterial access should be considered. Surgery may be prolonged (4–6 h or greater). A combination of general anesthesia and epidural anesthesia allows many neonates to be extubated at the end of surgery. Some units advocate the use of tunneled epidural catheters to facilitate immobilization and reduce wound complications [217].

## Posterior Urethral Valves

Posterior urethral valves (PUV) are the most common cause of lower urinary obstruction in males, occurring more commonly in non-Caucasians at a rate of 1:5,000 live births. Other less common causes of lower urinary obstruction include prune-belly syndrome and urethral stenosis or atresia. PUV is usually an isolated finding that causes severe obstructive uropathy, with 20–60 % of these neonates developing chronic kidney disease in childhood and 11–51 % progressing to end-stage renal failure in their lifetime [218]. Severe obstruction and oligohydramnios during lung development (16–24 weeks gestation) may cause pulmonary hypoplasia leading to substantial fetal and perinatal mortality (33–75 %) [219].

### Diagnosis

PUV are frequently identified from the appearance of bilateral hydronephrosis during routine antenatal ultrasound (accounting for 10 % of cases of antenatal hydronephrosis), although many do not present until later in childhood, with urinary tract infection, failure to thrive, or continence. Late diagnosis is associated with less severe renal impairment and better long-term prognosis. At birth, renal ultrasound demonstrates a thick-walled bladder and hydronephrosis and provides an assessment of the degree of renal cortical damage. The urethral valves can be demonstrated in a voiding cystourethrogram or directly at cystoscopy.

### Management

Definitive treatment for PUV in neonates is relief of the obstruction by catheterization and antibiotic prophylaxis, with cystoscopy and transurethral ablation. The results of antenatal treatment with vesicoamniotic shunt have been disappointing to date. Long-term follow-up is required, with active management of bladder dysfunction and reflux.

### Anesthetic Considerations

Cystoscopy and resection of PUV during the neonatal period is a minor procedure that requires a brief general anesthetic. Nonetheless, most prefer to secure the airway in these neonates with a tracheal tube (rather than a supraglottic device) because the neonate may be positioned either cross-table or at the end of the operating room table and the duration of surgery is somewhat unpredictable, dependent on the extent of the pathology. Significant comorbidities such as pulmonary hypoplasia and renal dysfunction must be considered when planning the anesthetic prescription. Antibiotic prophylaxis is essential. A single-shot caudal epidural block can provide excellent perioperative analgesia depending on the extent of the surgery.

## Sacrococcygeal Teratoma

Sacrococcygeal teratoma occurs in 1–2:40,000 live births, representing 35–60 % of all teratomas [220]. Females are more commonly affected than males by a 3–4:1 margin (Fig. 10.17). These tumors arise from an embryonic cell line in the pelvis that contains cells in different proportions from the ectoderm, mesoderm, and endoderm [221]. Structurally, sacrococcygeal teratomas are classified as cystic, solid, or a combination of the two. Cystic teratomas comprise 15 % of all sacrococcygeal teratomas, have more differentiated cells, and are usually benign. The majority of sacrococcygeal teratomas are solid or mixed (Fig. 10.18). The more solid the composition of the teratoma, the more likely it is to be malignant.

Perinatal mortality in neonates, whose tumors are diagnosed antenatally, is 25–37 %. Mortality is more likely in fetuses with rapidly growing vascular teratomas that act physiologically as arteriovenous malformations. These malformations lead to hydrops, polyhydramnios, high-output cardiac failure, preterm birth, and death. Two variables suggest a greater risk for a poor prognosis: the ratio of the tumor

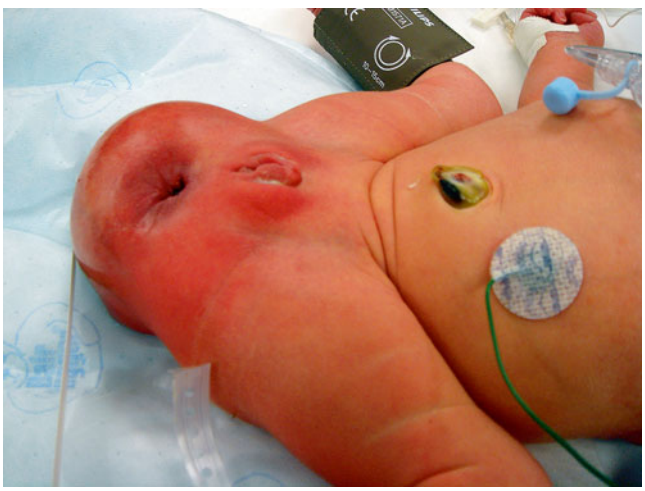

**Fig. 10.17** Sacrococcygeal teratoma. This tumor was located on the outside of the sacrum, completely external to the pelvis. Consistent with the greater incidence of sacrococcygeal teratomas in females, this neonate was a female (Courtesy of Dr. W. Pegoli, Division of Pediatric Surgery, Strong Hospital, University of Rochester, Rochester, NY)

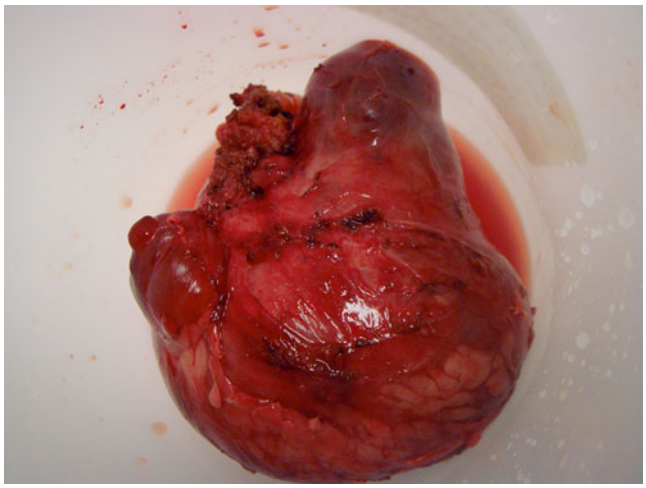

**Fig. 10.18** Excised sacrococcygeal teratoma. The tumor appears to be multiloculated, but mostly solid in this case

volume to the fetal weight >0.11 determined before 32 weeks gestation and tumor morphology <60 % cystic [222].

At delivery, 90 % of sacrococcygeal teratomas are benign; the minority is malignant. However, the malignancy rate increases dramatically from 10 % at birth to 75 % by 1 year of age and 100 % by 5 years of age if the tumor is not resected. Hence, early detection and antenatal intervention or surgical excision of the tumor at birth is crucial to achieve long-term survival.

The Currarino triad, which is comprised of a presacral tumor, anorectal malformation, and sacral anomaly, follows an autosomal dominant familial inheritance pattern from a genetic defect on chromosome 7. Urogenital anomalies have been identified in females with sacrococcygeal teratomas and should be suspected in any female with voiding difficulties [223].

## Diagnosis

Sacrococcygeal teratomas are often detected antenatally using ultrasound. Differential diagnoses include meningocele, lymphangioma, lipoma, or taillike remnant. At delivery, 85–95 % of these teratomas are external midline sacral masses. The skin covering the mass is usually normal, although hemangiomas, ulcers, and evidence of necrosis may be present [220]. Investigations should be performed preoperatively to define the borders of the mass within the pelvis. In older children, the tumor may be entirely intrapelvic, without external evidence of the tumor. The Altman classification of sacrococcygeal tumors is based on postnatal assessment of the external and internal elements of the teratomas (Table 10.7) [224].

**Table 10.7** The Altman classification of sacrococcygeal tumors [224]

| |
|---|
| Type 1—tumor is predominantly external with minimal presacral component |
| Type II—tumor presents externally, but with substantial intrapelvic extension |
| Type III—tumor is present externally, but the bulk of the tumor is intrapelvic with extension into the abdomen |
| Type IV—presacral tumor with no external component |

## Management

Complications associated with sacrococcygeal tumors relate to its vascularity, size, and position. In utero, the fetus should be monitored for the development of hydrops and placentomegaly. These occur in rapidly growing vascular teratomas that cause a vascular steal syndrome, which in turn may precipitate high-output cardiac failure necessitating an urgent in utero intervention to prevent premature delivery and/or death. These interventions may include amnioreduction, cyst aspiration, radiofrequency ablation, shunts, and surgical debulking [225, 226]. Outcomes after in utero interventions are similar to those who did not undergo interventions, despite the worsened features present in the intervention group, with a mortality between 25 and 45 % [226, 227]. Cesarean section is indicated for large tumors, that is, for those larger than the neonate's biparietal diameter [220]. Vaginal deliveries are best avoided in neonates with large tumors as the latter may rupture causing the neonate to rapidly exsanguinate. Rectal examination should be performed with great care to avoid rupturing the tumor. Imaging techniques including abdominal X-ray, echocardiogram, ultrasound, and/or MRI will help to define the anatomy, location, and vascularity of the tumor. Tumor markers should be monitored (alpha-fetoprotein and beta HCG): alpha-fetoprotein increases in the presence of a malignancy. These should be followed postoperatively to detect a malignant recurrence.

## Outcomes

If the sacrococcygeal teratoma is identified as an incidental finding during the antenatal period, the expected survival rate is 90 %. Mortality approaches 60 % in complicated pregnancies, and 100 % in the presence of hydrops or placentomegaly, which reflects high-output heart failure due to shunting through the vascular teratoma.

The prognosis in terms of malignancy depends on the tumor type, stage, location (Altman classification), and completeness of excision, in addition to the child's age at the time of the operation. If the initial resection is performed after the neonatal period, the risk of a recurrence increases substantially, especially if the serum alpha-fetoprotein concentration is increased. Up to 7 % of tumors recur, mostly within the first 3 years. These tumors recur locally, although metastases are possible. The long-term prognosis in these children, including those with a malignant sacrococcygeal teratoma, exceeds 80 % due to platinum-based multimodal chemotherapy [220].

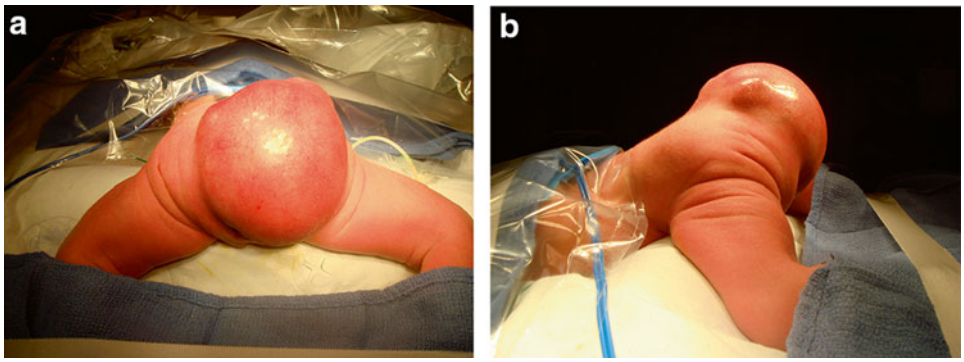


**Fig. 10.19** Sacrococcygeal teratoma. (**a**) Caudal view. (**b**) Lateral view. The neonate was anesthetized, the tracheal intubated, and the neonate positioned prone for surgery. Note the large size of the tumor relative to the neonate (Courtesy of Dr. W. Pegoli, Division of Pediatric Surgery, Strong Hospital, University of Rochester, Rochester, NY)

Functional results are usually very good, although 17 % of patients develop a neuropathic bladder and 6 % develop complete fecal incontinence. This is possibly a tumor effect rather than surgical morbidity [225].

### Surgical Considerations

Once the airway is secured, monitoring and vascular access (including arterial access) are established, and the bladder is catheterized, the neonate is turned prone (Fig. 10.19a, b). The coccyx should be removed with the tumor for a complete excision of the tumor. If the tumor has a small intrapelvic component, it should be resectable in this position. An abdominal approach may be indicated for larger intrapelvic tumors or in cases where early vascular control is required.

### Anesthetic Considerations

Excision of sacrococcygeal teratoma is a high-risk procedure, with significant perioperative morbidity and mortality. In some cases, it may be prudent to have two experienced anesthesiologists to provide anesthesia for these cases as sacrococcygeal teratomas have been known to hemorrhage suddenly and massively. The perioperative risks relate primarily to a major hemorrhage from the highly vascular tumor, in the context of a neonate who may be premature and have pulmonary hypertension, renal and hepatic impairment, and a coagulopathy associated with high-output cardiac failure. Access to the neonate may be compromised if surgery is performed in the prone position. It is essential to make preparations for major blood loss with crossmatched fresh blood and blood products. Intraoperative cardiac arrest has been reported from hyperkalemia and hypocalcemia associated with a rapid, massive transfusion, especially when transfused rapidly through a central venous catheter, and hyperkalemia has been associated with surgical manipulation of a necrotic tumor [228]. Blood should be transfused slowly, preferably through peripheral IV access (not through a central line), especially if the blood is old.

At the conclusion of surgery, the neonate should be transferred to the intensive care unit in the prone position. The bladder catheter remains in situ for 24 h. The serum concentration of alpha-fetoprotein should be monitored on a regular basis to assess the risk of a malignant recurrence.

## Biliary Atresia

Biliary atresia (BA) is the progressive obliteration and sclerosis of the extra- and intrahepatic bile ducts leading to liver fibrosis, cirrhosis, and death if untreated, occurring in 1:10,000–15,000 live births. Its etiology is unknown. It is associated with other anomalies in 15–20 % of cases. Biliary atresia splenic malformation syndrome (BASM) occurs in 10 % of cases, with polysplenia or asplenia, cardiac abnormalities, situs inversus, malrotation, preduodenal portal vein, and absent vena cava [229].

### Classification

BA is classified according to the level of obstruction of the extrahepatic bile ducts (Table 10.8). Type III is further subdivided according to the pattern of obstruction of the common bile duct (CBD) and distal ducts. The most common type of BA is type IIIb.

### Diagnosis

The key feature of BA is prolonged jaundice (conjugated hyperbilirubinemia) beyond the first 2 weeks of life with signs of biliary obstruction (pale stools and dark urine), in an otherwise healthy term neonate [229]. Infants who present later may show signs of failure to thrive due to fat malabsorption, with coagulopathy due to failure to absorb vitamin K, hepatosplenomegaly, and ascites [230]. The initial meconium is usually colored, as the obstructive jaundice develops postnatally. Diagnosis of BA is usually made by liver biopsy, or occasionally laparoscopic cholangiogram with direct

**Table 10.8** Classification of biliary atresia

| |
|---|
| Type I—obstruction at common bile duct (5 % of cases) |
| Type II—obstruction at the common hepatic duct (2 % of cases) |
| Type III—obstruction the porta hepatis (>90 % of cases) |
| Subtype a. Patent CBD, atrophic gall bladder |
| Subtype b. Fibrous CBD, atrophic gall bladder |
| Subtype c. Absent common hepatic duct, mucocele of gall bladder |
| Subtype d. Miscellaneous |

puncture of the gall bladder, or radioisotope scan to detect bile acid in the intestine (hepatobiliary iminodiacetic acid (HIDA) scan) [229].

The differential diagnosis of BA includes choledocal cyst, inspissated bile syndrome, and other infective/metabolic causes of neonatal hepatitis, which should be excluded with a TORCH screen, metabolic screen, and ultrasound. Choledocal cyst is a cystic disorder of unknown etiology affecting the pancreatobiliary system. Children may present with jaundice and an abdominal mass at any age from birth to adulthood. Without treatment, this disorder may progress to cholangitis or cirrhosis. The anesthetic considerations are similar to BA, although underlying hepatic function is usually normal, apart from obstructive jaundice.

### Management

Once the diagnosis has been made, any coagulopathy should be corrected and surgery planned. Being a rare condition, best outcomes are usually obtained when these neonates are referred to a specialist center. In the UK, children with BA should be referred to one of three national specialist centers. Long-term prognosis is linked to the timing of operative correction of bile flow, so ideally, surgery should be performed as soon as possible, usually at age 1–2 months. Jaundice usually clears early in 50–60 % of patients. These children have a good 5-year prognosis, although liver transplantation may be required for those with persistent jaundice or clinically significant portal hypertension. Long-term survival is expected in 90 % of cases, although neonates may have significant long-term morbidity that is related to hepatic cirrhosis or the effects of immunosuppression after liver transplantation.

### Surgical Approach

The initial surgery consists of an open Kasai procedure. Laparoscopic techniques do not appear to offer advantages such as fewer adhesions, over the open approach [231–235]. The Kasai procedure involves resection of the extrahepatic biliary tree including the portal plate and the fashioning of a Roux-en-Y jejunal anastomosis at this level to restore bile flow to the intestinal tract. If the diagnosis is not clear before the laparotomy, then an intraoperative cholangiogram can be performed before dissection [229]. Factors that predict success after a Kasai procedure include a preoperative direct bilirubin <2, absence of liver fibrosis, and limited episodes of cholangitis [230].

### Anesthetic Considerations [230]

Coagulopathy should be corrected preoperatively using vitamin K. Platelets and fresh frozen plasma may occasionally be required as well. Oral neomycin and clear fluids should be given for 24 h preoperatively. Broad-spectrum prophylactic antibiotics are essential before skin incision and for 5 days postoperatively to prevent cholangitis (e.g., gentamicin and cefoxitin). Isotonic maintenance fluids containing dextrose are required to avoid intraoperative hypoglycemia, e.g., 1–5 % dextrose in lactated Ringer's solution or 5 % dextrose in PlasmaLyte. Transfusion is usual, although excessive blood loss is uncommon. Hepatorenal syndrome has not been reported in this age group. Ascites is uncommon, but if it develops, losses should be replaced with 5 % albumin. Active warming and invasive access are required as surgery usually takes 2–4 h. An opioid-based/muscle relaxant technique is ideal, avoiding nitrous oxide to prevent bowel distension. The surgeon may kink the inferior vena cava during mobilization of the liver resulting in unexpected hypotension, which may require the immediate infusion of additional intravenous fluids to restore circulatory homeostasis. At the end of surgery, the tracheas of most neonates can be extubated. These neonates are best managed in a high-dependency unit with morphine analgesia [236].

## Necrotizing Enterocolitis

Necrotizing enterocolitis (NEC) is the most common surgical neonatal emergency affecting up to 0.5 % of all live births and 10 % of low birth weight (<1,500 g) live births [237]. Advances in neonatal care have improved survival rates for premature and low birth weight infants, as well as those affected by this disease.

### Pathogenesis

The etiology of NEC remains unclear although risk factors include prematurity, early formula feeding, cardiac disease, low birth weight, transfusion in the preceding 48 h (transfusion-associated NEC), and sepsis [238, 239]. Breast milk appears to be protective, likely due to transferred immunoglobulins. Multiple gut factors predispose to the development of NEC in preterm neonates including dysmotility, abnormal microbiota, reduced mucin barrier, increased gut permeability, decreased immunoglobulins and gut immunity, increased risk of ischemia, and slow gastric emptying [240, 241]. This in turn may facilitate bacterial translocation across the bowel wall triggering an inflammatory cascade that results in ischemic damage to the bowel. The pathological organisms are often

**Table 10.9** Bell classification for diagnosing NEC [242]

| |
|---|
| Stage IA—suspected disease: temperature instability, increased aspirates, mild distension; radiology normal or dilated loops |
| Stage IB—as above, with bright red blood per rectum |
| Stage IIA—proven NEC, mildly ill: as above with absent bowel sounds, ± abdominal tenderness; radiology shows intestinal dilatation, ileus, pneumatosis intestinalis. |
| Stage IIB—proven NEC, moderately ill: mild metabolic acidosis, mild thrombocytopenia, absent bowel sounds, abdominal tenderness +/− redness of abdominal wall or abdominal mass; radiology shows portal vein gas +/− ascites |
| Stage IIIA—advanced NEC, severely ill: as above with hypotension, bradycardia, metabolic acidosis, disseminated intravascular coagulation, neutropenia, generalized peritonitis, tenderness and distension; radiology as above with definite ascites |
| Stage IIIB—advanced NEC, severely ill with perforation: as above with pneumoperitoneum on abdominal X-ray |

endogenous bowel flora suggesting an imbalance in the defensive mechanisms rather than a specific virulent organism, although clusters of cases have been known to occur.

## Diagnosis

NEC is primarily a clinical diagnosis [237]. It is classified according to the criteria described by Bell (Table 10.9) [242].

Early signs include feeding intolerance, bilious vomiting or increased nasogastric aspirates, abdominal distension with or without tenderness, hemodynamic instability, and blood per rectum (Fig. 10.20). Thrombocytopenia, coagulation abnormalities, and increased inflammatory markers such as C-reactive protein are common. Radiological investigations are often helpful in confirming the presence of NEC. Pathognomonic findings of NEC on abdominal X-ray include distended loops of bowel, pneumatosis intestinalis, and portal venous gas with or without free perforation (Fig. 10.21). The value of ultrasound and other imaging modalities as diagnostic or prognostic tests has yet to be established. Recent laboratory investigations have identified several biomarkers that herald the onset of NEC/sepsis [243, 244]. Such insights may provide the basis for future studies to identify biomarkers that will identify a neonate's risk of developing NEC.

## Outcomes

Despite early and aggressive therapy and support, the mortality from NEC remains substantial, in our local series ranging from 30 to 90 % with pan-intestinal disease [245]. In a large prospective study, perioperative mortality was 30 % for all neonates with NEC, compared with 6 % in those managed medically [245, 246]. The mortality rate in neonates who were treated with primary peritoneal drainage alone was 50 %. Significant morbidity occurs in up to 25 % of operative neonates, including stricture formation and failure to thrive, and in those who require extensive resection, short bowel syndrome, and long-term requirement for parenteral nutrition with associated risk of liver disease and sepsis [247]. Neonates with NEC may also experience worse neurological outcomes, particularly those with advanced disease that require surgical intervention [248].

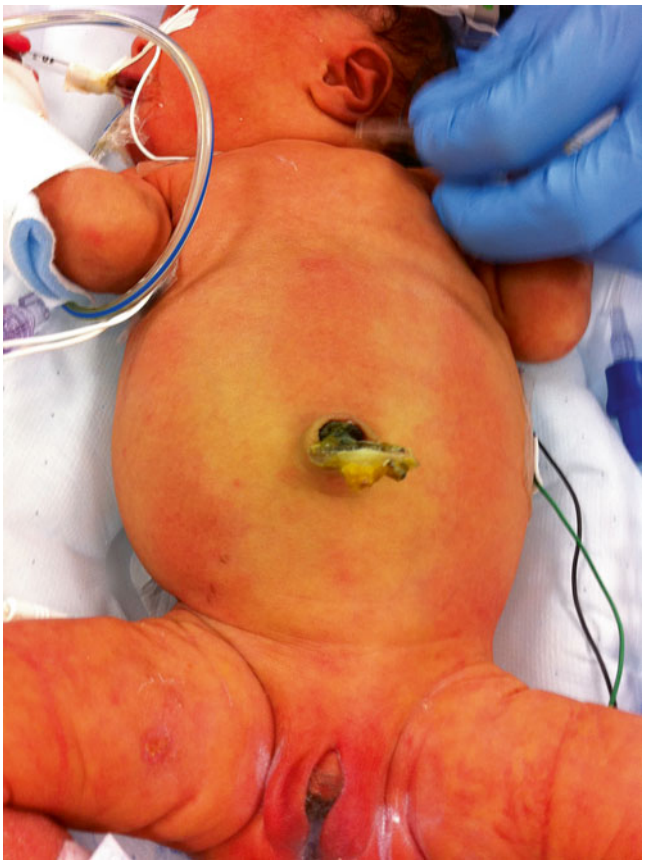

**Fig. 10.20** NEC in a preterm neonate. This neonate developed NEC and a distended abdomen. Note the "rectus muscle-sparing" lines separated from the erythema of the anterior abdominal wall (Courtesy of Dr. YH Lee, Division of Pediatric Surgery, Strong Hospital, University of Rochester, Rochester, NY)

## Management

The primary approach to NEC is to adopt strategies that prevent the disorder. Such strategies include standardized enteral feeding, exclusive use of human breast milk and milk-based fortifiers, minimal antibiotic exposure, minimal gastric acid blockade therapy, and the use of high-quality probiotics, if the preceding measures fail [240, 249, 250].

Definitive studies for managing NEC once it has occurred are lacking, and treatment has been determined by expert consensus and the neonate's clinical condition [251]. The

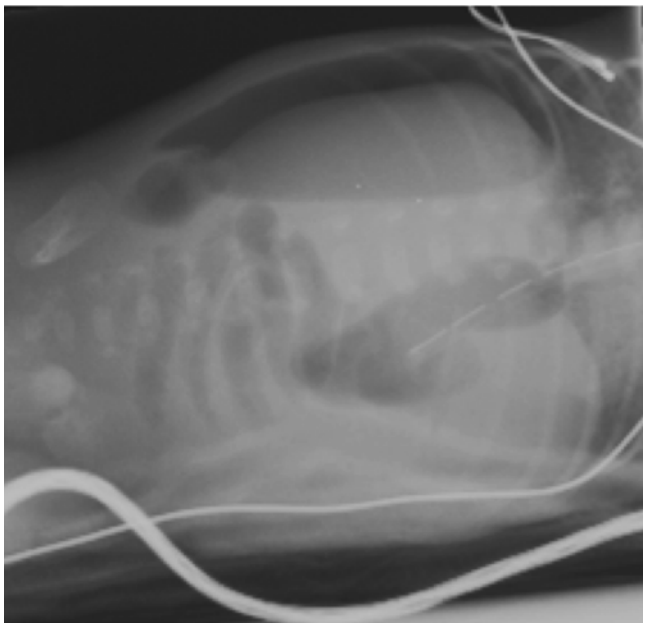

**Fig. 10.21** Lateral radiograph of a neonate with NEC. The neonate was positioned in the left lateral decubitus position with a multi-orifice gastric tube in the stomach. Free air is evident against the right (*upper*) lateral abdominal wall, outlining the liver and falciform ligament (Courtesy of Dr. YH Lee, Division of Pediatric Surgery, Strong Hospital, University of Rochester, Rochester, NY)

first-line treatment is medical, targeting sepsis and preventing further intestinal damage. The neonate is kept nil by mouth for 7–10 days, with a nasogastric tube in situ to decompress the stomach, intravenous broad-spectrum antibiotics, and appropriate cardiorespiratory and hematological support. Nutritional challenges can be addressed using total parenteral nutrition (TPN).

It is important to appreciate a little known risk of red cell hemolysis when considering to transfuse with fresh frozen plasma or blood products with plasma [252]. The T antigen, also known as the Thomsen-Friedenreich (or T) cryptantigen, is a naturally occurring but concealed red cell antigen (cryptantigen) that becomes activated when bacteria (e.g., streptococcus, pneumococcus, and Clostridium perfringens) carrying neuraminidase activate the T antigen. Transfusion of plasma that contains immunoglobulin M anti-T antigen binds this activated T antigen causing polyagglutination and red cell hemolysis. Activated T antigen is present in approximately 11–27 % of neonates with NEC, with a greater frequency in more severe NEC (category III NEC 30 % vs. II 4 %) [253, 254]. The magnitude of the risk of T antigen in neonates with NEC is unclear, although many clinicians avoid transfusing plasma-rich blood products to these neonates and many blood banks screen plasma for antibodies to T antigen and release only plasma with low or no titers of T antigen to neonates with NEC. Nonetheless, any child with NEC who develops hemolysis after a transfusion should be investigated to identify the cause, not overlooking the possibility that activated T antigen is the putative agent [7].

Surgical intervention is required in 10–20 % of neonates with NEC, increasing to 50 % in very low birth weight neonates. The indications for surgery include serial examinations that indicate worsening physiological parameters or failure of medical treatment. The precise indications for surgery remain controversial; ideally, surgery is indicated for the presence of gangrenous bowel, before it has perforated [237]. However, there are no reliable metrics to define such a clinical scenario. Absolute indications for surgery include evidence of perforation, clinical deterioration despite maximal medical therapy, an abdominal mass with persistent obstruction or sepsis, and the presence of an intestinal stricture. Relative indications include abdominal tenderness, distension or discoloration where the clinical diagnosis may be in doubt, the finding of portal venous gas on plain abdominal X-ray, a fixed intestinal loop, and thrombocytopenia.

## Surgical Approach

The surgical objectives are to control sepsis, to excise necrotic bowel, and to preserve intestinal length [237, 247]. A laparotomy remains the mainstay approach for most neonates with NEC. In the very low birth weight group (<1,000 g) with evidence of perforation, peritoneal drainage has been proposed as either an interim or definitive alternative to laparotomy, although a recent systematic review suggested that this approach is associated with increased morbidity [255]. Surgical options at laparotomy include resection with enterostomy, resection with primary anastomosis, a proximal diverting jejunostomy for extensive disease, and "clip and drop" or the watch and wait with possible "second look" laparotomy [237, 247]. The extent of the disease, the stability of the neonate, and the surgeons' experience/preference will determine which of these options are undertaken. For a stable neonate with focal or multifocal disease, a resection with anastomosis is appropriate. For an unstable neonate in whom the viability of the distal bowel is uncertain, a stoma may be fashioned. In the presence of pan-intestinal disease (>75 % of the small and large bowel involved), either a proximal diverting jejunostomy or the "clip and drop" approach requiring a repeat laparotomy in the next few days is performed. NEC is responsible for one-third of the cases of surgical short bowel syndrome in NICU. Although mortality has been substantial in these neonates, a multifaceted approach to resting and preserving bowel function, nutrition, infectious prophylaxis, and surgical consultation dramatically improved survival [204]. A general guide for the ability of the gut to support enteral feeds long term is the presence of 30 cm of bowel with the ileocecal valve or 50 cm without [237]. In extreme cases where the entire intestine is necrotic, withdrawal of care may be an important consideration.

The neonatal liver is fragile and often enlarged in these infants. Aggressive perioperative resuscitation can result in hepatic engorgement and may result in capsular rupture and life-threatening hemorrhage. Surgical handling can also have similar catastrophic consequences. The laparotomy incision may be performed more caudally or obliquely especially in extremely low birth weight infants, to lie below the liver edge. Strict avoidance of liver instrumentation can help decrease the risk of hemorrhage.

Laparoscopy may be used as a diagnostic tool in NEC if the neonate is stable, if there are signs of obstruction, and if the diagnosis is uncertain. Some have attempted gasless laparoscopic surgery to diagnose and manage NEC in neonates with limited success [256].

### Anesthetic Considerations

Laparotomy for NEC in a premature neonate <1,000 g provides a significant challenge for the anesthesiologist. The potential for rapid blood loss in a neonate with cardiorespiratory instability, DIC, and sepsis requires meticulous preparation. In the operating theater, anesthesia may be induced using an opioid such as fentanyl in incremental IV doses of 5–10 mcg/kg up to 25–50 mcg/kg and/or ketamine 2–4 mg/kg and rocuronium [10, 257]. The clearance of fentanyl decreases with decreasing gestational age in neonates with normal intra-abdominal pressure [258]. Inhalational anesthetics are infrequently used in neonates with NEC. Balanced salt solution (10–20 ml/kg) should be administered before induction of anesthesia to prevent hypotension as anesthesia is induced. More recently, remifentanil has been investigated in preterm neonates [259, 260]. The duration of action of remifentanil in premature neonates between 24 and 41 weeks gestation and full-term neonates is similar, 5–10 min. This has been attributed to the similar activity of nonspecific tissues esterases throughout gestation [261]. Animal evidence also suggests that remifentanil may effectively attenuate ischemic-reperfusion injury in the intestines [262]. If true in humans, remifentanil may provide a salutary effect in neonates with potentially ischemic bowel. Before anesthesia is discontinued, a longer-acting opioid should be administered to provide postoperative analgesia.

Surgery may be performed in the operating room or in the NICU (see Anesthesia Outside the OR, Chap. 12). Indications for surgery in the NICU include minor procedures (insertion of a peritoneal drain); a very small, unstable neonate; and ventilation with HFOV. For anesthesia in the NICU, a TIVA technique is required. In such cases, incremental doses of IV fentanyl (10–20 mcg/kg) or a remifentanil infusion, together with ketamine and rocuronium, should provide hemodynamic stability and adequate surgical conditions. The extent of the procedure depends on the hemodynamic stability of the neonate, and close cooperation between surgeon, neonatologist/intensivist, and anesthesiologist is required at all times.

Inotropic support (dopamine, dobutamine, epinephrine, or norepinephrine) is often required, in neonates with NEC. In order to accurately monitor the responses to this support, arterial pressure monitoring is highly recommended. The inotropic support should be tailored to the neonate's requirements and titrated to the desired end point [263]. In addition, venous access large enough to rapidly deliver blood products should be secured. 5 % albumin, blood, platelets, and clotting factors may be required before or during surgery. Warmed IV fluid boluses of 10–20 ml/kg should be given depending on the clinical condition of the child and measured losses, guided by the results of arterial blood gas estimation. Since these neonates are often of very low birth weight, their albumin levels are low. Balanced salt solutions may be used to replace small fluid shifts but are best limited in volume administered to preclude exacerbating preexisting hypoalbuminemia and dilutional coagulopathy. If large volumes of fluid are required (up to 50 ml/kg), it is prudent to switch from balanced salt solutions to albumin and blood products early to maintain the hematological and coagulation profile. At the same time, care must be taken to avoid over transfusing the child, as this could open a ductus arteriosus or risk catastrophic bleeding from a distended liver. The neonate may remain critically ill after surgery requiring full intensive care support. Mild controlled hypothermia may be a therapeutic option in neonates with multiple organ dysfunction [264].

## References

1. Morray JP, Geiduschek JM, Ramamoorthy C, et al. Anesthesia-related cardiac arrest in children: initial findings of the Pediatric Perioperative Cardiac Arrest (POCA) Registry. Anesthesiology. 2000;93:6–14.
2. Flick RP, Sprung J, Harrison TE, et al. Perioperative cardiac arrests in children between 1988 and 2005 at a tertiary referral center: a study of 92,881 patients. Anesthesiology. 2007;106:226–37.
3. Van der Griend BJ, Lister NA, McKenzie IM, et al. Postoperative mortality in children after 101,885 at a tertiary hospital. Anesth Analg. 2011;112:1440–7.
4. Thomas J. Reducing the risk in neonatal anesthesia. Pediatr Anesth. 2014;24:106–13.
5. Arnold PD. Coagulation and the surgical neonate. Pediatr Anesth. 2013;24:89–97.
6. Kenton AB, Hegemier S, Smith EO, et al. Platelet transfusions in infants with necrotizing enterocolitis do not lower mortality but may increase morbidity. J Perinatol. 2005;25:173–7.
7. Gibsen BE, British Committee for Standards in Haematology, et al. Transfusion guidelines for neonates and older children. Br J Haematol. 2004;124:433–53.
8. Sloan S. Neonatal transfusions. Pediatr Anesth. 2011;21:25–30.
9. Haynes AB, Weiser TG, Berry WR, et al. A surgical safety checklist to reduce morbidity and mortality in a global population. N Engl J Med. 2009;372:491–9.

10. Robinson S, Gregory GA. Fentanyl-air-oxygen anesthesia for ligation of patent ductus arteriosus in preterm infants. Anesth Analg. 1981;60:331–4.
11. Lonnquist PA. Major abdominal surgery of the neonate: anaesthetic considerations. Best Pract Res Clin Anaesthesiol. 2004; 18:321–42.
12. de Graaff JC, Bijker JB, Kappen TH, et al. Incidence of intraoperative hypoxemia in children in relation to age. Anesth Analg. 2013;117:169–75.
13. Weiss M, Gerber AC. Rapid sequence induction in children—it's not a matter of time! Paediatr Anaesth. 2008;18:97–9.
14. Eich C, Timmermann A, Russo SG, et al. A controlled rapid-sequence induction technique for infants may reduce unsafe actions and stress. Acta Anaesthesiol Scand. 2009;53:1167–72.
15. Lerman J. On cricoid pressure: "May the force be with you". Anesth Analg. 2009;109:1363–6.
16. Walker RWM, Ravi R, Haylett K. Effect of cricoid force on airway caliber in children: a bronchoscopic assessment. Br J Anaesth. 2010;104:71–4.
17. Oh J, Lim T, Chee Y, et al. Videographic analysis of glottic view with increasing cricoid pressure force. Ann Emerg Med. 2013; 61:407–13.
18. Hillier SC, Scamberger MS. Transcutaneous and end-tidal carbon dioxide analysis: complimentary monitoring strategies. J Intensive Care Med. 2005;20:307–9.
19. Trevisanuto D, Giuliotto S, Cavallin F, et al. End-tidal carbon dioxide monitoring in very low birth weight infants: correlation and agreement with arterial carbon dioxide. Pediatr Pulmonol. 2012;47:367–72.
20. Tingay DG, Mun KS, Perkins EJ. End tidal carbon dioxide is as reliable as transcutaneous monitoring in ventilated postsurgical neonates. Arch Dis Child Fetal Neonatal Ed. 2013;98:F161–4.
21. Singh BS, Gilbert U, Singh S, et al. Sidestream microstream end tidal carbon dioxide measurements and blood gas correlations in neonatal intensive care unit. Pediatr Pulmonol. 2013;48:250–6.
22. Freer Y, Lyon A. Temperature monitoring and control in the newborn baby. Paediatr Child Health. 2011;22:127–30.
23. Witt L, Dennhardt N, Eich C, et al. Prevention of intraoperative hypothermia in neonates and infants: results of a prospective multicenter observational study with a new forced-air warming system with increased warm air flow. Pediatr Anesth. 2013;23:469–74.
24. Murat I, Humblot A, Girault L, Piana F. Neonatal fluid management. Best Pract Res Clin Anaesthesiol. 2010;24:365–74.
25. O'Brien F, Walker IA. Fluid homeostasis in the neonate. Pediatr Anesth. 2014;24:49–59.
26. Apfelbaum JL, Caplan RA, Connis RT, et al. Practice guidelines for preoperative fasting and the use of pharmacologic agents to reduce the risk of aspiration: application to healthy patients undergoing elective procedures. Anesthesiology. 2011;114:495–511.
27. Sumpelmann R, Kretz F-J, Luntzer R, et al. Hydroxyethyl starch 130/0.42/6:1 for perioperative volume replacement in 1130 children: results of an European prospective multicenter observational postauthorization safety study (PASS). Paediatr Anaesth. 2012;22:371–8.
28. Hall NJ, Stanton MP, Kitteringham LJ, et al. Scope and feasibility of operating on the neonatal intensive care unit: 310 cases in 10 years. Pediatr Surg Int. 2012;28:1001–5.
29. Davidson AJ. Neurotoxicity and the need for anesthesia in the newborn. Does the Emperor have no clothes? Anesthesiol. 2012;116:507–9.
30. Hall NJ, Pacilli M, Eaton S, et al. Recovery after open versus laparoscopic pyloromyotomy for pyloric stenosis: a double blind multicentre randomised controlled trial. Lancet. 2009;373:390–8.
31. Sinha CK, Paramalingam S, Patel S, et al. Feasibility of complex minimally invasive surgery in neonates. Pediatr Surg Int. 2009;25:217–21.
32. Carrington EV, Hall NJ, Pacilli M, et al. Cost-effectiveness of laparoscopic versus open pyloromyotomy. J Surg Res. 2012; 179:315–20.
33. Dingemann J, Ure BM. Systematic review of level 1 evidence for laparoscopic pediatric surgery: do our procedures comply with the requirements of evidence-based medicine?? Eur J Pediatr Surg. 2013;23:474–9.
34. Rothenberg SS. Thoracoscopic repair of esophageal atresia and tracheo-esophageal fistula in neonates: evolution of a technique. J Laparoendosc Adv Surg Tech A. 2012;22:195–9.
35. Holcomb GW, Rothenberg SS, Klaas MA. Thoracoscopic repair of esophageal atresia and tracheoesophageal fistula. A multi institutional analysis. Ann Surg. 2005;242:422–30.
36. Chan IH, Lau CT, Chung PH, et al. Laparoscopic inguinal hernia repair in premature neonates: is it safe? Pediatr Surg Int. 2013;29:327–30.
37. Olsen M, Avery N, Khurana S, et al. Pneumoperitoneum for neonatal laparoscopy: how safe is it? Pediatr Anesth. 2013;23: 457–9.
38. Nasr A, Bass J. Thoracoscopic vs open resection of congenital lung lesions: a meta-analysis. J Pediatr Surg. 2012;47:857–61.
39. Lerman J, Kondo Y, Suzuki Y, et al. Chapter 27: General abdominal and urologic surgery. In: Coté CJ, Lerman J, Anderson B, editors. A practice of anesthesia for infants and children. Philadelphia, PA: Elsevier; 2012.
40. Groenewald CB, Latham GJ. An unexpected cause of cardiac arrest during laparoscopy in an infant with supravalvar aortic stenosis. Pediatr Anesth. 2013;23:91–3.
41. Gillory LA, Megison ML, Harmon CM, et al. Laparoscopic surgery in children with congenital heart disease. J Pediatr Surg. 2012;47:1084–8.
42. Slater B, Rangel S, Ramamoorthy C, et al. Outcomes after laparoscopic surgery in neonates with hypoplastic heart left heart syndrome. J Pediatr Surg. 2007;42:1118–21.
43. Pacilli M, Pierro A, Kinglsey C, et al. Absorption of carbon dioxide during laparoscopy in children measured using a novel mass spectrometric technique. Br J Anaesth. 2006;97:215–9.
44. Bliss D, Matar M, Krishnaswami S. Should intraoperative hypercapnea or hypercarbia raise concern in neonates undergoing thoracoscopic repair of diaphragmatic hernia of Bochdalek? J Laparoendosc Adv Surg Tech A. 2009;19:s55–8.
45. Bishay M, Giacomello L, Retrosi G, et al. Decreased cerebral oxygen saturation during thoracoscopic repair of congenital diaphragmatic hernia and esophageal atresia in infants. J Pediatr Surg. 2001;46:47–51.
46. McHoney M, Corizia L, Eaton S, et al. Carbon dioxide elimination during laparoscopy in children is age dependent. J Pediatr Surg. 2003;38:105–10.
47. Parelkar SV, Oak SN, Bachani MK, et al. Minimal access surgery in newborns and small infants; five years experience. J Minim Access Surg. 2013;9:19–24.
48. Kalfa N, Allal H, Raux O, et al. Tolerance of laparoscopy and thoracoscopy in neonates. Pediatrics. 2005;116:e785–91.
49. Ure BM, Suempelmann R, Metzelder M, et al. Physiological responses to endoscopic surgery in children. Semin Pediatr Surg. 2007;16:217–23.
50. Li LW, Zhang W, Ai YQ, et al. Influence of laparoscopic carbon dioxide pneumoperitoneum on neonate circulation and respiration. J Int Med Res. 2013;41:889–94.
51. McHoney M, Mackinlay G, Munro F, et al. Effect of patient weight and anesthetic technique on CO2 excretion during thoracoscopy in children assessed by end-tidal CO2. J Laparoendosc Adv Surg Tech A. 2008;18:147–51.
52. Kalfa N, Alla H, Raux O, et al. Multicentric assessment of the safety of neonatal videosurgery. Surg Endosc. 2007;21:303–8.
53. Kuebler JF, Ure BM. Minimally invasive surgery in the neonate. Semin Fetal Neonatal Med. 2011;16:151–6.

54. Tobias JD. Anesthesia for neonatal thoracic surgery. Best Pract Res Clin Anaesthesiol. 2004;18:303–20.
55. Hammer GB. Chapter 13: Anesthesia for thoracic surgery. In: Coté CJ, Lerman J, Anderson B, editors. A practice of anesthesia for infants and children. Philadelphia, PA: Elsevier; 2012.
56. Choudhry DK. Single-lung ventilation in pediatric anesthesia. Anesthesiol Clin North America. 2005;23:693–708.
57. Langston C. New concepts in the pathology of congenital lung malformations. Semin Pediatr Surg. 2003;12:17–37.
58. Guidry C, McGahren ED. Pediatric Chest 1. Developmental and physiologic conditions for the surgeon. Surg Clin N Am. 2012;92:615–43.
59. Adzick NS, Flake AW, Crombleholme TM. Management of congenital lung lesions. Semin Pediatr Surg. 2003;12:10–6.
60. Raychaudhuri P, Pasupati A, James A, et al. Prospective study of antenatally diagnosed congenital cystic adenomatoid malformations. Pediatr Surg Int. 2011;27:1159–64.
61. Kotecha S, Barbato A, Bush A, et al. Antenatal and postnatal management of congenital cystic adenomatoid malformation. Paediatr Respir Rev. 2012;13:162–70.
62. Yong PJ, Von Dadelszen P, Carpara D, et al. Prediction of pediatric outcome after prenatal diagnosis and expectant antenatal management of congenital cystic adenomatoid malformation. Fetal Diagn Ther. 2012;31:94–102.
63. Davenport M, Eber E. Long term respiratory outcomes of congenital thoracic malformation. Semin Fetal Neonatal Med. 2012;17:99–104.
64. Stocker JT, Madewell JE, Drake RM. Congenital cystic adenomatoid malformation of the lung. Classification and morphologic spectrum. Hum Pathol. 1977;8:155–71.
65. Stocker JT. Congenital pulmonary airway malformation-a new name for and an expanded classification of congenital cystic adenomatoid malformation of the lung. Histopathology. 2002;41 Suppl 2:424–58.
66. Fitzgerald DA. Congenital cyst adenomatoid malformations: resect some and observe all? Pediatr Respir Rev. 2007;8:67–76.
67. Khosa JK, Leong SL, Borzi PA. Congenital cystic adenomatoid malformation of the lung: indications and timing of surgery. Pediatr Surg Int. 2004;20:505–8.
68. Davenport M, Cacciaguerra S, Patel S, et al. Current outcome of antenatally diagnosed cystic lung disease. J Pediatr Surg. 2004;39:549–56.
69. Waszak P, Claris O, Lapillonne A, et al. Cystic adenomatoid malformation of the lung: neonatal management of 21 cases. Pediatr Surg Int. 1999;15:326–31.
70. Azizkhan RG, Crombleholme TM. Congenital cystic lung disease: contemporary antenatal and postnatal management. Pediatr Surg Int. 2008;24:643–57.
71. Colon N, Schlegel C, Pietsch J, et al. Congenital lung anomalies: can we postpone resection? J Pediatr Surg. 2012;47:87–92.
72. Peters RT, Burge DM, Marven SS. Congenital lung malformations: an ongoing controversy. Ann R Coll Surg Engl. 2013;95:144–7.
73. Delacourt C, Hadchouel A, Dunlop NK. Shall all congenital cystic lung malformations be removed? The case in favour. Paediatr Respir Rev. 2013;14:169–70.
74. Kotecha S. Should asymptomatic congenital cystic adenomatous malformations be removed? The case against. Paediatr Respir Rev. 2013;14:171–2.
75. Guruswamy V, Roberts S, Arnold P, et al. Anaesthetic management of a neonate with congenital cyst adenoid malformation. Br J Anaesth. 2005;95:240–2.
76. Nishimoto C, Inomata S, Kihara S, et al. Anesthetic management of four pediatric patients with CCAM for pulmonary lobectomy. Masui. 2002;51:162–5.
77. Baud D, Windrim R, Kachura JR, et al. Minimally invasive fetal therapy for hydropic lung masses: three different approaches and review of the literature. Ultrasound Obstet Gynecol. 2013;42:440–8.
78. Krivchenya DU, Rudenko EO, Dubrovin AG. Congenital emphysema in children: segmental lung resection as an alternative to lobectomy. J Pediatr Surg. 2013;48:309–14.
79. Iodice F, Harban F, Walker I. Anesthetic management of a patient with bilateral congenital lobar emphysema. Pediatr Anesth. 2008;18:340–1.
80. Arora MK, Karamchandani K, Bakhta P, et al. Combination of inhalational, intravenous, and local anesthesia for intubation in neonates with congenital lobar emphysema. Pediatr Anesth. 2006;16:997–1003.
81. Goyal A, Jones MO, Couriel JM, et al. Oesophageal atresia and tracheo-oesophageal fistula. Arch Dis Child Fetal Neonatal Ed. 2006;91:F381–4.
82. Knottenberlt G, Skinner A, Seefelder C. Tracheo-oesophageal fistula (TOF) and oesophageal atresia (OA). Best Pract Res Clin Anaesthesiol. 2010;24:387–401.
83. Spitz L. Oesophageal atresia. Orphanet J Rare Dis. 2007;2:24.
84. Jacobs IJ, Que J. Genetic and cellular mechanisms of the formation of esophageal atresia and tracheoesophageal fistula. Dis Esophagus. 2013;26:356–8.
85. Holzki J. Bronchoscopic findings and treatment in congenital tracheo-oesophageal fistula. Pediatr Anesth. 1992;2:297–303.
86. Passi Y, Sampathi V, Pierre J, et al. Esophageal atresia with double tracheoesophageal fistula. Anesthesiology. 2013;118:1207.
87. Diaz LK, Akpek EA, Radhika D, et al. Tracheoesophageal fistula and associated congenital heart disease: implications for anesthetic management and survival. Pediatr Anesth. 2005;15:862–9.
88. Stringer MD, McKenna K, Goldstein RB, et al. Prenatal diagnosis of esophageal atresia. J Pediatr Surg. 1995;30:1258–63.
89. Okamoto T, Takamizawa S, Hiroshi A. Esophageal atresia: prognostic classification revisited. Surgery. 2009;145:675–81.
90. La Placa S, Giuffre M, Gangemi A, et al. Esophageal atresia in newborns: a wide spectrum from the isolated forms to a full VACTERL phenotype? Ital J Pediatr. 2013;39:45.
91. Babu R, Pierro A, Spitz L, et al. The management of oesophageal atresia in neonates with right-sided aortic arch. J Pediatr Surg. 2000;35:56–8.
92. Solomon BD. VACTERL/VATER Association. Orphanet J Rare Dis. 2011;6:56.
93. Solomon BD, Baker LA, Bear KA, et al. An approach to the identification of anomalies and etiologies in neonates with identified or suspected VACTERL (vertebral Defects, anal atresia, tracheoesophageal fistula with esophageal atresia, cardiac anomalies, renal anomalies, and limb anomalies) Association. J Pediatr. 2014;164:451–7.e1.
94. De Jong EM, Felix JF, Deurloo JA, et al. Non-VACTERL-type anomalies are frequent in patients with esophageal atresia/tracheoesophageal fistula and full or partial VACTERL association. Birth Defects Res A Clin Mol Teratol. 2008;82:92–7.
95. Lopez PJ, Keys C, Pierro A, et al. Oesophageal atresia: improved outcome in high-risk groups? J Pediatr Surg. 2006;41:331–4.
96. Alabbad SI, Shaw K, Puligandla PS, et al. The pitfalls of endotracheal intubation beyond the fistula in babies with type C esophageal atresia. Semin Pediatr Surg. 2009;18:116–8.
97. Ni Y, Yao Y, Liang P. Simple strategy of anesthesia for the neonate with tracheoesophageal fistula: a case report. Int J Clin Exp Med. 2014;7(1):327–8.
98. Deanovic D, Gerber A, Dodge-Khatatami A, et al. Tracheoscopy assisted repair of tracheo-esophageal fistula (TARTEF): a 10-year experience. Pediatr Anesth. 2007;17:557–62.

99. Huang J, Tao J, Chen K, et al. Thoracoscopic repair of oesophageal atresia: experience of 33 patients from two tertiary referral centres. J Pediatr Surg. 2012;47:2224–7.
100. Rothenberg SS. Thoracoscopic repair of esophageal atresia and tracheoesophageal fistula in neonates, first decade's experience. Dis Esophagus. 2013;26:359–64.
101. Bishay M, Giacomello L, Retrosi G, et al. Hypercapnia and acidosis during open and thoracoscopic repair of congenital diaphragmatic hernia and esophageal atresia: results of a pilot randomized controlled trial. Ann Surg. 2013;258:895–900.
102. McKinnon G. Esophageal atresia surgery in the 21st century. Semin Pediatr Surg. 2009;18:20–2.
103. Delacourt C, Hadchouel A, Toelen J, et al. Long term respiratory outcomes of congenital diaphragmatic hernia, esophageal atresia, and cardiovascular anomalies. Semin Fetal Neonatal med. 2012;17:105–11.
104. Kovesi T. Long-term respiratory complications of congenital esophageal atresia with or without tracheoesophageal fistula: an update. Dis Esophagus. 2013;26:413–6.
105. Caplan A. Psychological impact of esophageal atresia: review of the research and clinical evidence. Dis Esophagus. 2013;26:392–400.
106. Andropoulos DB, Rowe RW, Betts JM. Anaesthetic and surgical airway management during tracheo-oesophageal fistula repair. Pediatr Anesth. 1998;8:313–9.
107. Knottenbelt G, Costi D, Stephens P, et al. An audit of anesthetic management and complications of tracheo-esophageal fistula and esophageal atresia repair. Pediatr Anesth. 2012;22:268–74.
108. Krosnar S, Baxter A. Thoracoscopic repair of esophageal atresia with tracheoesophageal fistula: anesthetic and intensive care management of a series of eight neonates. Pediatr Anesth. 2005;15:541–6.
109. Broemling N, Campbell F. Anaesthetic management of congenital tracheoesophageal fistula. Pediatr Anesth. 2011;21:1092–9.
110. Haroon J, Chamberlain RS. An evidence-based review of the current treatment of congenital diaphragmatic hernia. Clin Pediagtr (Phila). 2013;52:115–24.
111. Tovar JA. Congenital diaphragmatic hernia. Orphanet J Rare Dis. 2012;7:1.
112. Bosenberg A, Brown RA. Management of congenital diaphragmatic hernia. Curr Opin Anaesthesiol. 2008;21:323–31.
113. Seydel B, Detry O. Morgagni's hernia. NEJM. 2010;362:e61.
114. Samangaya RA, Choudhri S, Murphy F, et al. Outcomes of congenital diaphragmatic hernia: a 12-year experience. Prenat Diagn. 2012;32:523–9.
115. Veenma DCM, de Klein A, Tibboel D. Developmental and genetic aspects of congenital diaphragmatic hernia. Pediatr Pulmonol. 2012;47:534–5.
116. Garne E, Haeusler M, Barisic I, et al. Congenital diaphragmatic hernia: evaluation of prenatal diagnosis in 20 European regions. Ultrasound Obstet Gynecol. 2002;19:329–33.
117. The Congenital Diaphragmatic Hernia Study Group. Defect size determines survival in infants with congenital diaphragmatic hernia. Pediatrics. 2007;120:e651–7.
118. Hedrick HL, Danzer E, Merchant A. Liver position and lung-to-head ratio for prediction of extracorporeal membrane oxygenation and survival in isolated left congenital diaphragmatic hernia. Am J Obstet Gynecol. 2007;197:422.e1–4.
119. Suda K, Bigras JL, Bohn D, et al. Echocardiographic predictors of outcome in newborns with congenital diaphragmatic hernia. Pediatrics. 2000;105:1106.
120. Garriboli M, Duess JW, Ruttenstock E, et al. Trends in the treatment and outcome of congenital diaphragmatic hernia over the last decade. Pediatr Surg Int. 2012;28:1177–81.
121. Chiu PPL, Ijsselstijn H. Morbidity and long term follow-up in CDH patients. Eur J Pediatr Surg. 2012;22:384–92.
122. Congenital Diaphragmatic Hernia Study Group, Morini F, Valfre L, Capolupo I, et al. Congenital diaphragmatic hernia: defect size correlates with developmental defect. J Pediatr Surg. 2013;48:1177–82.
123. Takahashi S, Sago H, Kanamori Y, et al. Prognostic factors of congenital diaphragmatic hernia accompanied by cardiovascular malformation. Pediatr Int. 2013;55:492–7.
124. Lally KP, Lasky RE, Lally PA, et al. Standardized reporting for congenital diaphragmatic hernia—an international consensus. J Pediatr Surg. 2013;48:2408–15.
125. Harrison MR, Sydorak RM, Farrell JA, et al. Fetoscopic temporary tracheal occlusion for congenital diaphragmatic hernia: prelude to a randomized, controlled trial. J Pediatr Surg. 2003;38:1012–20.
126. Jani JC, Nicolaides KH, Gratacos E, et al. Severe diaphragmatic hernia treated with endoscopic tracheal occlusion. Ultrasound Obstet Gynecol. 2009;34:304–10.
127. Speggiorin S, Fierens A, McHugh K, et al. Bronchomegaly as a complication of fetal endoscopic tracheal occlusion. A caution and a possible solution. J Pediatr Surg. 2011;46:e1–3.
128. Ruano R, Yoshisaki CT, Da Silva MM, et al. A randomized controlled trial of fetal endoscopic tracheal occlusion versus postnatal management of severe isolated congenital diaphragmatic hernia. Ultrasound Obstet Gynecol. 2012;39:20–7.
129. Boloker J, Bateman DA, Wung JT, et al. Congenital diaphragmatic hernia in 120 infants treated consecutively with permissive hypercapnea/spontaneous respiration/elective repair. J Pediatr Surg. 2002;37:357–66.
130. Logan JW, Rice HE, Goldberg RN, Cotten CM. Congenital diaphragmatic hernia: a systematic review and summary of best-evidence practice strategies. J Perinatol. 2007;27:535–49.
131. Van den Hout L, Tinbboel D, Vifhuize S, et al. The VICI trial: high frequency oscillation versus conventional mechanical ventilation in newborns with congenital diaphragmatic hernia: an international multicentre randomized controlled trial. BMC Pediatr. 2011;11:98.
132. Bialkowski A, Moenkemeyer F, Patel N. Intravenous sildenafil in the management of pulmonary hypertension associated with congenital diaphragmatic hernia. Eur J Pediatr Surg. 2013 Oct 25. [Epub ahead of print].
133. Vijfhuize S, Schaible T, Kraemer U, et al. Management of pulmonary hypertension in neonates with congenital diaphragmatic hernia. Eur J Pediatr Surg. 2012;22:374–83.
134. Beres AL, Puligandla PS, Brindle ME, et al. Stability prior to surgery in congenital diaphragmatic hernia: is it necessary? J Pediatr Surg. 2013;48:919–23.
135. Morini F, Bagolan P. Surgical techniques in diaphragmatic hernia. Eur J Pediatr Surg. 2012;22:355–63.
136. Congenital diaphragmatic hernia group. Minimally invasive repair of congenital diaphragmatic hernia. J Pediatr Surg. 2011;46:11158–64.
137. Ellinas H, Seefelder C. Congenital thoracoscopic repair in neonates: is thoracoscopy feasible? Pediatr Anesth. 2010;20:967–8.
138. Peevy KJ, Speed FA, Hoff CJ. Epidemiology of inguinal hernia in preterm neonates. Pediatrics. 1986;77:246–7.
139. Choi W, Hall NJ, Garriboldi M, et al. Outcomes following laparoscopic inguinal hernia repair in infants compared with older children. Pediatr Surg Int. 2012;28:1165–9. doi:10.1007/s00383-012-3188-1.
140. Pennant JH. Anesthesia for laparoscopy in the pediatric patient. Anesthesiol Clin North America. 2001;19:69–88.
141. Lee SL, Gleason JM, Sydorak RM. A critical review of premature infants with inguinal hernias: optimal timing of repair, incarceration risk, and postoperative apnea. J Pediatr Surg. 2011;46:217–20.
142. Cote CJ, Zaslavsky A, Downes JJ, et al. Postoperative apnea in former preterm infants after inguinal herniorrhaphy. A combined analysis. Anesthesiology. 1995;82:809–22.

143. Lacrosse D, Pirotte T, Veyckmans F. Caudal block and light sevoflurane mask anesthesia in high-risk infants: an audit of 98 cases. Ann Fr Anesth Reanim. 2012;31:29–33.
144. Walther-Larsen S, Rasmussen LS. The former preterm infant and risk of postoperative apnoea: recommendations for management. Acta Anaesthesiol Scand. 2006;50:888–93.
145. Sale SM, Read JA, Stoddart PA, Wolf AR. Prospective comparison of sevoflurane and desflurane in formerly premature infants undergoing inguinal herniotomy. Br J Anaesth. 2006;96:774–8.
146. Craven PD, Badwani N, Henderson-Smart D-J, O'Brien M. Regional (spinal, epidural, caudal) versus general anesthesia in preterm infants undergoing inguinal herniorrhaphy in early infancy (review). Cochrane Database Syst Rev. 2003;3, CD003669.
147. Welborn LG, Hannallah RS, Fink R, et al. High-dose caffeine suppresses postoperative apnea in former preterm infants. Anesthesiology. 1989;71:347–9.
148. Davidson A, McCann ME, Morton N, et al. Protocol 09PRT/9078: a multi-site randomised controlled trial to compare regional and general anaesthesia for effects on neurodevelopmental outcome and apnoea in infants: the GAS study (ACTRN12606000441516, NCT00756600). The Lancet protocol reviews. http://www.thelancet.com/protocol-reviews/09PRT9078. Accessed 6 Dec 2012.
149. Modarressi T. The question of an infectious etiology or contribution to the pathogenesis of infantile hypertrophic pyloric stenosis. J Pediatr Gastroenterol Nutr. 2014;58:546–8. doi:10.1097/MPG.
150. Georgoula C, Gardiner M. Pyloric stenosis a 100 years after Ramstedt. Arch Dis Child. 2012;97:741–5.
151. McAteer JP, Ledbetter DJ, Goldin AB. Role of bottle feeding in the etiology of hypertrophic pyloric stenosis. JAMA Pediatr. 2013;167:1143–9.
152. Krogh C, Biggar RJ, Fischer TK, et al. Bottle-feeding and the risk of pyloric stenosis. Pediatrics. 2012;130:e943–9.
153. Aspelind G, Langer JC. Current management of hypertrophic pyloric stenosis. Semin Pediatr Surg. 2007;16:27–33.
154. Glatstein M, Carbell G, Boddu SK, et al. The changing clinical presentation of hypertrophic pyloric stenosis: the experience of a large tertiary care pediatric hospital. Clin Pediatr. 2011;50:192–5.
155. Taylor ND, Cass DT, Holland AJ. Infantile hypertrophic pyloric stenosis: has anything changed? J Paediatr Child Health. 2013;49:33–7.
156. Tutay GJ, Capraro G, SPirko B, et al. Electrolyte profile of pediatric patients with hypertrophic pyloric stenosis. Pediatr Emerg Care. 2013;29:465–8.
157. Iqbal CW, Rivard DC, Mortellaro VE, et al. Evaluation of ultrasonographic parameters in the diagnosis of pyloric stenosis relative to patient age and size. J Pediatr Surg. 2012;47:1542–7.
158. Oomen MWN, Hoekstra LT, Bakx R, et al. Open versus laparoscopic pyloromyotomy for hypertrophic pyloric stenosis: a systematic review and meta-analysis focusing on major complications. Surg Endosc. 2012;26:2104–10.
159. Turial S, Enders J, Schier F. Microlaparoscopic pyloromyotomy in children: initial experiences with a new technique. Surg Endosc. 2011;25:266–70.
160. Bissonnette B, Sullivan PJ. Pyloric stenosis. Can J Anaesth. 1991;38:668–76.
161. Stoddart PA, Brennan L, Hatch D-J, Bingham R. Postal survey of paediatric practice and training among consultant anaesthetists in the UK. Br J Anaesth. 1994;73:559–63.
162. Black SJ, Carson EM, Doughty A. How much and where: assessment of knowledge level of the application of cricoid pressure. J Emerg Nurs. 2012;38:370–4.
163. Landsman I. Cricoid pressure: indications and complications. Paediatr Anaesth. 2004;14:43–7.
164. Rapp HJ, Altenmueller CA, Waschke C. Neuromuscular recovery following rocuronium bromide single dose in infants. Pediatr Anesth. 2004;14:329–35.
165. Driessen JJ, Robertson EN, Booij LHDJ. Acceleromyography in neonates and small infants: baseline calibration and recovery of the responses after neuromuscular blockade with rocuronium. Eur J Anaesthesiol. 2005;22:11–5.
166. Hassid S, Nicaise C, Michel F, et al. Randomized controlled trial of sevoflurane for intubation in neonates. Pediatr Anesth. 2007;17:1053–8.
167. Davis PJ, Galinkin J, McGowan FX, et al. A randomized multicenter study of remifentanil compared with halothane in neonates and infants undergoing pyloromyotomy. 1. Emergence and recovery profiles. Anesth Analg. 2011;93:1380–6.
168. Breschan C, Jost R, Stettner H, et al. Ultrasound-guided rectus sheath block for pyloromyotomy in infants: a retrospective analysis of a case series. Pediatr Anesth. 2013;23:1199–204.
169. Willschke H, Machata AM, Rebhandl W, et al. Management of hypertrophic pylorus stenosis with ultrasound guided single shot epidural anaesthesia—a retrospective analysis of 20 cases. Paediatr Anaesth. 2011;21:110–5.
170. Ghazal E, Amin A, Wu A, et al. Impact of rocuronium vs succinylcholine neuromuscular blocking drug choice for laparoscopic pyloromyotomy: is there a difference in tine to transport to recovery? Pediatr Anesth. 2013;23:316–21.
171. Taylor RH, Lerman J. Minimum alveolar concentration of desflurane and hemodynamic responses in neonates, infants, and children. Anesthesiology. 1991;75:975–9.
172. Lerman J. Surgical and patient factors involved in postoperative nausea and vomiting. Br J Anaesth. 1992;69 Suppl 1:24S–32.
173. Hajivassiliou CA. Intestinal obstruction in neonatal/pediatric surgery. Semin Pediatr Surg. 2003;12:241–53.
174. Best KE, Tennant PW, Addor MC, et al. Epidemiology of small intestinal atresia in Europe: a register-based study. Arch Dis Child Fetal Neonatal Ed. 2012;97:F353–8.
175. Grosfeld JL, Ballantine TVN, Shoemaker R. Operative management of intestinal atresia and stenosis based on pathologic findings. J Pediatr Surg. 1979;14:368–75.
176. Vecchia LKD, Grosfeld JL, West KW, et al. Intestinal atresia and stenosis. A 25-year experience with 277 cases. Arch Surg. 1998;133:490–7.
177. Carlyle BE, Borowitz DS, Glick PL. A review of pathophysiology and management of fetuses and neonates with meconium ileus for the pediatric surgeon. J Pediatr Surg. 2012;47:772–81.
178. Kumar N, Curry I. Bile-stained vomiting in the infant: green is not good! Arch Dis Child Educ Pract Ed. 2008;93:84–6.
179. Hagendoorn J, Viera-Travassos D, van der Zee D. Laparoscopic treatment of intestinal malrotation in neonates and infants: retrospective study. Surg Endosc. 2001;25:217–20.
180. Hsiao M, Langer JC. Surgery for suspected rotation abnormality: selection of open vs laparoscopic surgery using a rational approach. J Pediatr Surg. 2012;47:904–10.
181. Kiely EM, Pierro A, Pierce C, Cross K, De Coppi P. Clot dissolution: a novel treatment of midgut volvulus. Pediatrics. 2012;129:e1601–4.
182. Kenny S, Tam PKH, Garcia-Barcelo M. Hirschsprung's disease. Semin Pediatr Surg. 2010;19:194–200.
183. Saeed A, Barreto L, Neogii SG, et al. Identification of novel genes in Hirschsprung disease pathway using whole genome expression study. J Pediatr Surg. 2012;47:303–7.
184. Georgeson KE, Cohen RD, Hebra A, et al. Primary laparoscopic-assisted endorectal pull-through for Hirschsprung's disease. A new gold standard. Ann Surg. 1999;229:678–83.
185. Nah SA, De Coppi P, Kiely EM, et al. Duhamel pull-through for Hirschsprung's disease: a comparison of open and laparoscopic techniques. J Pediatr Surg. 2012;47:308–12.
186. Holscheneider A, Hutson J, Pena A. Preliminary report on the international conference for the development of standards for the treatment of anorectal malformations. J Pediatr Surg. 2005;40:1521–6.

187. Levitt MA, Pena A. Anorectal malformations. Orphanet J Rare Dis. 2007;2:33.
188. Rintala RJ. Congenital anorectal malformations: anything new? J Pediatr Gastroenterol Nutr. 2009;48:s79–82.
189. Berde CB. Convulsion associated with pediatric regional anesthesia. Anesth Analg. 1992;75:164–6.
190. Kart T, Christrup LL, Rasmussen M. Recommended use of morphine in neonates, infants and children based on a literature review: Part 1-Pharmacokinetcs. Pediatr Anaesth. 1997;7:5–11.
191. Hall RW, Kronsberg SS, Barton BA, et al. Morphine, hypotension, and adverse outcomes among preterm neonates: who's to blame? Secondary results from the NEOPAIN trial. Pediatrics. 2005;115:1351–9.
192. Anand KJS, Anderson BJ, Holford NHG, et al. Morphine pharmacokinetics and pharmacodynamics in preterm and term neonates: secondary results from the NEOPAIN trial. Br J Anaesth. 2008;101:680–9.
193. Mastrolacovo P. Risk factors for gastroschisis. BMJ. 2008; 336:1386–7.
194. Gill SK, Broussard C, Devine O, et al. Association between maternal age and birth defects of unknown etiology—United States 1997-2007. Birth Defect Res A Clin Mol Teratol. 2012;94: 1010–18.
195. Kirby RS, Marshall J, Tanner JP, et al. Prevalence and correlates of gastroschisis in 15 states, 1995-2005. Obstet Gynecol. 2013; 122:275–81.
196. Kim K, Wang Y, Kirby RS, et al. Prevalence and trends of selected congenital malformations in New York state, 1983 to 2007. Birth Defects Res A Clin Mol Teratol. 2013;97:619–27.
197. Ghionzoli M, James CP, David AL, et al. Gastroschisis with intestinal atresia—predictive value of antenatal diagnosis and outcome of postnatal treatment. J Pediatr Surg. 2012;47:322–8.
198. Horton AL, Powell MS, Wolfe HM. Intrauterine growth patterns in fetal gastroschisis. Am J Perinatol. 2010;27:211–7.
199. Nasr A, Langer JC. Canadian paediatric surgery network. J Pediatr Surg. 2012;47:2022–5.
200. Grant NH, Dorling J, Thornton JG. Elective preterm birth for fetal gastroschisis. Cochrane Database Syst Rev. 2013 (6): CD009394.pub2.
201. Nasr A, Wayne C, Bass J, et al. Effect of delivery approach on outcomes in fetuses with gastroschisis. J Pediatr Surg. 2013; 48:2251–5.
202. Ledbetter DJ. Congenital abdominal wall defects and reconstruction in pediatric surgery: gastroschisis and omphalocele. Surg Clin N Am. 2012;92:713–27.
203. Aljahdali A, Mohajerani N, Skarsgard ED, et al. Effect of timing of enteral feeding on outcome in gastroschisis. J Pediatr Surg. 2013;48:971–6.
204. Amin SC, Pappas C, Iyengar H, et al. Short bowel syndrome in the NICU. Clin Perinatol. 2013;40:53–68.
205. Choi WW, McBride CA, Bourle C, et al. Long-term review of sutureless ward reduction in neonates with gastroschisis in the neonatal unit. J Pediatr Surg. 2012;47:1516–20.
206. Pastor AC, Phillips JD, Fenton SJ, et al. Routine use of a SILASTIC spring-loaded silo for infants with gastroschisis: a multicenter randomized controlled trial. J Pediatr Surg. 2008;43: 1807–12.
207. Mayhew JF, Mychaskiew G. Gastroschisis. Pediatr Anesth. 2009;19:54.
208. Lobo JD, Kim AC, Davis RP, et al. NO free ride? The hidden costs of delayed operative management using a spring-loaded silo for gastroschisis. J Pediatr Surg. 2010;45:1426–32.
209. Raghavan M, Montgomerie J. Anesthetic management of gastroschisis—a review of our practice over the past 5 years. Pediatr Anesth. 2008;18:1055–9.
210. Vegunta RK, Wallace LJ, Leonardi MR, et al. Perinatal management of gastroschisis: analysis of a newly established clinical pathway. J Pediatr Surg. 2005;40:528–34.
211. Yaster M, Schere TL, Stone MM, et al. Prediction of successful primary closure of congenital abdominal wall defects using intraoperative measurements. J Pediatr Surg. 1989;24:1217–20.
212. Puffinbarger NK, Taylor DV, Tuggle DW, et al. End-tidal carbon dioxide for monitoring primary closure of gastroschisis. J Pediatr Surg. 1996;31:280–2.
213. Mortellaro VE, St Peter SD, Fike FB, Islam S. Review of the evidence on the closure of abdominal wall defects. Pediatr Surg Int. 2011;27:391–7.
214. Siffel C, et al. Bladder exstrophy: an epidemiologic study from the International Clearinghouse for Birth Defects Surveillance and Research, and an overview of the literature. Am J Med Genet C Semin Med Genet. 2011;157C(4):321–32.
215. Purves T. Modern approaches in primary exstrophy closure. Semin Pediatr Surg. 2011;20:79–84.
216. Gearhart JP, Baird AD. The failed complete repair of bladder exstrophy: insights and outcomes. J Urol. 2005;174:1669–73.
217. Kost-Byerly S, Jackson EV, Yaster M, et al. Perioperative anesthetic and analgesic management of newborn bladder exstrophy repair. J Pediatr Urol. 2008;4:280–5.
218. Ansari MS, Gulia A, Srivastava A, Kapoor R. Risk factors for progression to end-stage renal disease in children with posterior urethral valves. J Pediatr Urol. 2010;6:261–4.
219. Morris RK, Kilby MD. Long-term renal and neurodevelopmental outcome in infants with LUTO, with and without fetal intervention. Early Hum Dev. 2011;87:607–10.
220. Davenport KP, Blanco FC, Sandler AD. Pediatric malignancies: neuroblastoma, Wilm's tumor, hepatoblastoma, rhabdomyosarcoma, and sacrococcygeal teratoma. Surg Clin N Am. 2012;92:745–67.
221. Winderl LM, Silverman RK. Prenatal identification of a completely cystic internal sacrococcygeal teratoma (Type IV). Ultrasound Obstet Gynecol. 1997;9:425–8.
222. Shue E, Bolouri M, Jelin EB, et al. Tumor metrics and morphology predict poor prognosis in prenatally diagnosed sacrococcygeal teratoma: a 25-year experience at a single institution. J Pediatr Surg. 2013;48:12225–31.
223. Shalaby MS, O'Toole S, Driver C, et al. Urogenital anomalies in girls with sacrococcygeal teratoma: a commonly missed association. J Pediatr Surg. 2012;47:371–4.
224. Altman RP, Randolph JG, Lilly JR. Sacrococcygeal teratoma: American Academy of Pediatrics Surgical Section Survey 1973. J Pediatr Surg. 1974;9:389–98.
225. Ledrick H, Flake AW, Crombleholme TM, et al. Sacrococcygeal teratoma: prenatal assessment, fetal intervention, and outcome. J Pediatr Surg. 2004;39:430–8.
226. Lee MY, Won HS, Hyun MK, et al. Perinatal outcome of sacrococcygeal teratoma. Prenat Diagn. 2011;31:1217–21.
227. Van Mieghem T, Al-Ibrahim A, Deprest J, et al. Minimally invasive therapy for fetal sacrococcygeal teratomas: case series and systematic review of the literature. Ultrasound Obstet Gynecol. 2014;43:611–9. doi:10.1002/uog.13315.
228. Kim J-W, Gwak M, Park J-Y, et al. Cardiac arrest during excision of a huge sacrococcygeal teratoma. A report of two cases. Korean J Anesthesiol. 2012;63:80–4.
229. Davenport M. Biliary atresia: clinical aspects. Semin Pediatr Surg. 2012;21:175–84.
230. Jacob R. Anesthesia for biliary atresia and hepatectomy in paediatrics. Indian J Anesthesial. 2012;56:479–84.
231. Chan KW, Lee KH, Tsui SY, et al. Laparoscopic versus open Kasai portoenterostomy in infant with biliary atresia: a retrospective review on the 5-year native liver survival. Pediatr Surg Int. 2012;28:1109–13.

232. Yamataka A, Lane GJ, Cazares J. Laparoscopic surgery for biliary atresia and choledochal cyst. Semin Pediatr Surg. 2012;21:201–10.
233. Diao M, Li L, Cheng W. Initial experience of single-incision laparoscopic hepaticojejunostomy using conventional instruments for correctable biliary atresia. J Laparoendosc Adv Surg Tech A. 2012;22:615–20.
234. Oetzmann von Sochaczewski C, Petersen C, Ure BM, et al. Laparoscopic versus conventional Kasai portoenterostomy does not facilitate subsequent liver transplantation in infants with biliary atresia. J Laparoendosc Adv Surg Tech A. 2012;22:408–11.
235. Wong KK, Chung PH, Chan KL, et al. Should open Kasai portoenterostomy be performed for biliary atresia in the era of laparoscopy? Pediatr Surg Int. 2008;24:931–3.
236. Green DW, Howard ER, Davenport M. Anaesthesia, perioperative management and outcome of correction of extrahepatic biliary atresia in the infant: a review of 50 cases in the King's College Hospital series. Pediatr Anaesth. 2000;10:581–9.
237. Kastenberg Z, Sylvester KG. The surgical management of necrotizing enterocolitis. Clin Perinatol. 2013;40:135–48.
238. Gordon PV, Swanson JR. Necrotizing enterocolitis is one disease with many origins and potential means of prevention. Pathophysiology. 2014;21:13–9. doi:10.1016/j.pathophys.2013.11.015.
239. Wan-Huen P, Bateman D, Shapiro DM, Parravicini E. Packed red blood cell transfusion is an independent risk factor for necrotizing independent risk factor for necrotizing enterocolitis in premature infants. J Perinatol. 2013;33:786–90.
240. Kim JH. Necrotizing enterocolitis: the road to zero. Semin Fetal Neonatal Med. 2014;19:39–44.
241. Stewart CJ, Marrs ECL, Nelson A, et al. Development of the preterm gut microbiome in twins at risk of necrotizing enterocolitis and sepsis. PLoS One. 2013;8(8):e73465.
242. Lee JS, Polin R. Treatment and prevention of necrotizing enterocolitis. Semin Neonatol. 2003;8:449–59.
243. Ng PC, Chan KYY, Poon TCW. Biomarkers for prediction and diagnosis of necrotizing enterocolitis. Clin Perinatol. 2013;40:149–59.
244. Ng PC. Biomarkers of necrotising enterocolitis. Semin Fetal Neonatal Med. 2014;19:33–8.
245. Thyoka M, de Coppi P, Eaton S, et al. Advanced necrotizing enterocolitis Part 1: mortality. Eur J Pediatr Surg. 2012;22:8–12.
246. Hull MA, Fisher JG, Gutierrez IM, et al. Mortality and management of surgical necrotizing enterocolitis in very low birth weight neonates: a prospective cohort study. J Am Coll Surg. 2014;218:1148–55.
247. Pierro A. The surgical management of necrotizing enterocolitis. Early Hum Dev. 2005;81:79–85.
248. Rees C, Pierro A, Eaton S. Neurodevelopmental outcomes of neonates with medically and surgically treated necrotizing enterocolitis. Arch Dis Child Fet Neonatal Ed. 2007;92:F193–8.
249. Huda S, Chaudhery S, Ibrahim H, et al. Neonatal necrotizing enterocolitis: clinical challenges, pathophysiology and management. Pathophysiology. 2014;21:3–12.
250. Patel RM, Denning PW. Therapeutic use of prebiotics, probiotics, and postbiotics to prevent necrotizing enterocolitis. Clin Perinatol. 2013;40:11–25.
251. Downward CD, Renaud E, St Peter SD, et al. Treatment of necrotizing enterocolitis: an American Pediatric Surgical Association Outcomes and Clinical Trials Committee systematic review. J Pediatr Surg. 2012;47:2111–22.
252. Wong MP, Droubatchevskaia N, Chipperfield KM, et al. Guidelines for frozen plasma transfusion. B C Med J. 2007;49:311–9.
253. Osborn DA, Lui K, Pussell P, et al. T and Tk antigen activation in necrotizing enterocolitis: manifestations, severity of illness, and effectiveness of testing. Arch Dis Child Fetal Neonatal Ed. 1999;80:F192–7.
254. Hall N, Ong EGP, Ade-Ajayi N, et al. T cryptantigen activation is associated with advanced necrotizing enterocolitis. J Pediatr Surg. 2002;37:791–3.
255. Rao SC, Basani L, Simmer K, et al. Peritoneal drainage versus laparotomy as initial surgical treatment for perforated necrotizing enterocolitis or spontaneous intestinal perforation in preterm low birth weight infants. Cochrane Database Syst Rev. 2011: CD006182.
256. Leva E, Di Cesare A, Canazza L, et al. The role of laparoscopy in newborns affected by NEC. J Laparoendosc Adv Surg Tech A. 2010;20:187–9.
257. Pani N, Panda CK. Anaesthetic consideration for neonatal surgical emergencies. Indian J Anaesth. 2012;56:463–9.
258. Saarenmaa E, Neuvonen PJ, Fellman V. Gestational age and birth weight effects on plasma clearance of fentanyl in newborn infants. J Pediatr. 2000;136:767–70.
259. Sammartino M, Garra R, Sbaraglia F, et al. Experience of remifentanil in extremely low-birth-weight babies undergoing laparotomy. Pediatr Neonatol. 2011;52:176–9.
260. Penido MG, Garra R, Sammartino M, et al. Remifentanil in neonatal intensive care and anaesthetic practice. Acta Paediatr. 2010;99:1454–63.
261. Welzing L, Evenfeld S, Dlugay V, et al. Remifentanil degradation in umbilical cord blood of preterm infants. Anesthesiology. 2011;114:570–7.
262. Cho SS, Rudloff I, Berger PJ, et al. Remifentanil ameliorates intestinal ischemia-reperfusion injury. BMC Gastroenterol. 2013;13:69.
263. Cox DJ, Groves AM. Inotropes in preterm infants—evidence for and against. Acta Paediatr. 2012;101 Suppl 464:17–23.
264. Hall NJ, Eaton S, Peters MJ, et al. Mild controlled hypothermia in preterm neonates with advanced necrotizing enterocolitis. Pediatrics. 2010;125:e300–8.
265. Dalla Vechia LK, Grosfield JL, West KW, et al. Intestinal atresia: a 25 year experience with 277 cases. Arch Surg. 1998;133:490–7.