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CHAPTER 12.5

Pediatric General Surgery

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Resection of Cystic Hygroma, Branchial Cleft Cyst, Thyroglossal Duct Cyst, or Other Cervical Mass

Surgical Considerations

Description: Common lesions requiring dissection in the neck and floor of the mouth include branchial cleft remnants; thyroglossal duct remnants; vascular malformations (hemangiomas); lymphatic malformations (cystic hygromas); and infected or enlarged lymph nodes refractory to antibiotic therapy.

Surgical approach: Ideally, an acutely inflamed node (*typically Staphylococcus aureus*) usually is incised and drained; a chronically infected node (e.g., cat-scratch disease, atypical TB) or an enlarged node (lymphoma) is excised. Remnants of the first and second (rarely third) branchial clefts are lateral masses found and excised from (respectively), the parotid region anterior to the ear, sometimes extending to the external auditory canal, or the anterior border of the sternocleidomastoid muscle, sometimes extending through the carotid bifurcation to the tonsillar fossa. Thyroglossal duct remnants are midline lesions that involve the central portion of the hyoid bone and may extend up to the base of the tongue. When acutely infected and resistant to a course of antibiotics, they can be drained; when quiescent, thyroglossal duct remnants are excised. Occasionally, it is advantageous for the anesthesiologist to digitally depress the tongue near the foramen cecum to help the surgeon know when the dissection approaches this structure. Vascular and lymphatic malformations may overlap; they tend to be lateral and are sometimes extensive. Significant blood loss may result and resection may involve tedious dissection of neurovascular structures, including the carotid sheath, brachial plexus, sympathetic chain, phrenic nerve, and cranial nerves V, VII, X, XI, and XII.

Transaxillary subcutaneous **endoscopic surgery** allows an alternate approach to resecting these lesions. This approach involves using tiny incisions placed in the ipsilateral axilla through which endoscopic ports are placed and tunneling under the skin to the neck, aided by carbon dioxide insufflation, to resect benign lesions using laparoscopic tools. This is a very new approach and not widely practiced; however, it appears to be safe and effective for a wide variety of lesions, including thyroid and parathyroid lesions. It completely avoids a neck incision, which can be cosmetically unappealing.

Usual preop diagnosis: Cystic hygroma; branchial cleft cyst/fistula; thyroglossal duct cyst; atypical mycobacterial adenitis

Summary of Procedures

	Lateral Lesions (Branchial Cleft Remnant Lymph Node, Vascular + Lymphatic Malformations)	Midline Lesions (Thyroglossal Duct Remnants)
Position	Neck extended, turned to contralateral side	Neck extended
Incision	Oblique	Transverse
Special instrumentation	Facial nerve monitor; nerve stimulator	None
Unique considerations	Nerve testing	None
Antibiotics	Cefazolin 25 mg/kg iv	

Surgical time	1–6 h	1 h
EBL	5–20 mL/kg	< 5 mL/kg
Postop care	PICU; airway monitoring	None
Mortality	< 2%	< 1%
Morbidity	Airway compromise Fluid accumulation Infection	
Pain score	3–4	3–4

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Patient Population Characteristics

Age range	Newborn–school age
Male:Female	1:1
Incidence	Common
Etiology	Developmental anomaly; mycobacteria
Associated conditions	Hygroma-mediastinal airway involvement; branchial cleft

Anesthetic Considerations

Preoperative

These patients generally are otherwise healthy children. Cervical masses, including cystic hygroma (cystic lymphangioma), may cause airway obstruction and difficult intubation.

Respiratory	The size and extent of the cervical mass should be defined carefully in an effort to detect the potential for airway compromise and to avoid soft-tissue trauma during intubation. Inspiratory stridor suggests supraglottic obstruction, while expiratory stridor is associated with subglottic/intrathoracic obstruction. These patients should have had prior CT/MRI imaging, and all records for these studies, including anesthesia records, should be reviewed. **Tests:** CXR ± CT/MRI scans
Cardiovascular	Cervical masses may be adherent to and/or cause compression of the great vessels. **Tests:** CT/MRI scans
Hematologic	T&C for cystic hygroma, or if a cervical mass involves great vessels or extends into the mediastinum. **Tests:** Hct
Laboratory	Other tests as indicated from H&P.
Premedication	If patient > 7–9 mo, and asymptomatic, consider midazolam (0.5–0.75 mg/kg po) 30 min. prior to arrival in OR. Use premedication cautiously in patients with potential airway compromise.

Intraoperative

Anesthetic technique: GETA with pediatric circuit; OR temperature 75–80°; forced air warmer on OR table; use air/O_2 mixture for ventilation; maintain SpO_2 between 92–94% to minimize retinopathy in premature infants at risk.

Standard pediatric induction (see) in patients without airway compromise. IV

Induction	access should be secured before induction when airway compromise is present or suspected. Mask induction with sevoflurane in 100% O_2 As plane of anesthesia deepens, gently assist ventilation. (Keep PIP < 20 cmH$_2$O). Prior to laryngoscopy, consider atropine (0.02 mg/kg, minimum dose 0.1 mg), if < 1 month, to prevent vagal response. If partial airway obstruction exists, maintain spontaneous ventilation and perform laryngoscopy under deep anesthesia (e.g., 3 MAC of volatile agent). FOB should be available. Have full range of ETT sizes available, since airway narrowing may be present. Once airway is secured, proceed with NMB (e.g., rocuronium 0.6 mg/kg iv, or vecuronium 0.1 mg/kg iv), unless monitoring facial nerve function.	
Maintenance	Standard pediatric maintenance (see p. D-2). Surgeon may infiltrate incision with local anesthetic. Limit bupivacaine to 2.5 mg/kg (maximum: 10 mL of 0.25 % bupivacaine).	
Emergence	Reverse neuromuscular blockade with neostigmine (0.07 mg/kg) and glycopyrrolate (0.01 mg/kg). Confirm air leak around ETT and extubate when fully awake.	
Blood and fluid requirements	Minimal blood loss usual IV: 20–22 ga × 1; 2nd iv if great vessel involvement NS/LR @ 3 mL/kg/h	Minimal 3rd-space losses. Each mL blood loss can be replaced with 3 mL NS/LR. When great vessels are involved, place at least one iv in lower extremity. Blood loss can be quite sudden; have blood available in OR.
Monitoring	Standard monitors (see p. D-1) ± Arterial line, 22 ga	An arterial line is used when there is risk of large blood loss or to assist management of ventilation
Positioning	and pad pressure points. eyes.	
Complications	ETT dislodged/loss of airway Laryngospasm Bronchospasm Hemorrhage	ETT must be carefully secured. Liberal use of benzoin. Avoid tension on ETT by circuit hoses. Hold ETT during surgeon's intraoral examination.

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◤ Postoperative

Complications	Subglottic edema Upper-airway obstruction from edema related to tumor resection Recurrent laryngeal nerve injury	Dexamethasone (0.5–1 mg/kg) and nebulized racemic epinephrine (2.25%) with mist O_2
Pain management	Morphine (0.05–0.1 mg/kg q2 h), hydromorphone (0.01 mg/kg– 0.015 mg/kg q 1 h), acetaminophen (10–15 mg/kg po/ pr q 6 h)	
Tests	As indicated.	

Suggested Readings

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2. Gregory GA, ed: *Pediatric Anesthesia,* 4th ed. Churchill Livingstone, New York: 2002, 664–6.

3. Gross, E, Sichel JY: Congenital neck lesions. *Surg Clin North Am* 2006; 86(2):383–92.

Esophagus-Foreign Body Removal and Dilation

◤ Surgical Considerations

Description: Flexible, diagnostic **esophagogastroduodenoscopy—a** common procedure in pediatrics—usually is performed under GA or heavy sedation in an endoscopy suite or special procedure area. **Rigid esophagoscopy** *(Print pagebreak 1255)* usually is performed for therapeutic indications such as removal of a foreign body (FB), dilation of an esophageal stricture, or injection of varices. The procedure is similar for each diagnosis and generally is performed with ET intubation. FB removal is normally a very short procedure, while dilation and variceal injection can be prolonged and may require multiple insertions/removals of the endoscope. Compression of the trachea distal to the ETT by the rigid esophagoscope is a common occurrence. **Radial balloon dilation,** which involves less shear stress than repeatedly passing a bougie catheter, is becoming a popular method of dilation. This is done under endoscopic and fluoroscopic guidance, and is accompanied by a very low rate of complications.

Usual preop diagnosis: Esophageal FB; stricture; esophageal varices

Summary of Procedures

Position	Supine, head to the side for rigid esophagoscopy
Special instrumentation	Rigid esophagoscopes; forceps; dilators
Unique considerations	Esophagoscope may obstruct airway; dilation may perforate esophagus.
Surgical time	5 min–2 h
Closing considerations	Abrupt ending
EBL	< 5 mL/kg
Postop care	Airway support
Mortality	< 5%
Morbidity	Esophageal perforation: 2–5%
Pain score	2–3

Patient Population Characteristics

Age range	Newborn–school age
Male:Female	1:1
Incidence	1/1000
Etiology	Varices – portal HTN; FB – possible stricture
Associated conditions	Esophageal atresia – stricture; portal HTN – varices

Anesthetic Considerations

Preoperative

Esophagoscopy for FB removal is usually performed in healthy infants and toddlers, although it can occur in any age group. All of these patients should be treated with full-stomach precautions (see p. B-4). Esophageal dilation is usually performed in three distinct patient populations: (a) those with prior tracheoesophageal fistula (TEF) repair; (b) those with prior ingestion of a caustic substance; and (c) those with skin and connective tissue diseases (e.g., epidermolysis bullosa [EB]).

Respiratory	Patients with TEF may have residual BPD or chronic lung disease, or subglottic stenosis due to prolonged intubation. Check anesthesia records for ETT size used. Those with prior caustic ingestion may have Hx of pulmonary aspiration, with resultant chemical pneumonitis and/or fibrosis. Patients with EB may have limited mouth opening and require special care regarding placing and securing of ETT. **Tests:** CXR, if clinically indicated.

Cardiovascular	There may be persistent congenital cardiac anomalies in the TEF patient. **Tests:** EKG, ECHO as indicated. Cardiology consultation, as needed.
Laboratory	No routine lab analyses are required if patient has no underlying chronic illnesses.
Premedication	For esophageal dilation, patient preference is extremely important since some patients have undergone this procedure several times. For FB removal, iv access is usually recommended before induction, though a mask induction may be selected by the anesthesiologist as well.

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Intraoperative

Anesthetic technique: GETA, using a pediatric circuit. Room temperature should be maintained at 75–80°F. Forced air warmer may be used.

Induction	If the patient is presenting for dilation alone and has no evidence to suggest reflux or retained food in the esophagus, a standard inhalation or iv induction may be performed. Rapid-sequence induction is usually appropriate for FB removal. Atropine (0.02 mg/kg if < 1 mo, minimum 0.1 mg) may be administered to attenuate bradycardia from intubation. Preoxygenate for 2–3 min. Apply cricoid pressure. Propofol (2–3 mg/kg) or STP (3–5mg/kg), followed by rocuronium (1 mg/kg) or succinylcholine (1–2 mg/kg). Intubate trachea with age-appropriate ETT. If succinylcholine was used, consider additional neuromuscular blockade.	
Maintenance	Maintain anesthesia with volatile agent/N$_2$O/O$_2$ or propofol (100–250 mcg/kg/min) + remifentanil (0.05–0.2 n mcg/kg/min). Supplement inhalation anesthetic with small doses of fentanyl (e.g., 1–2 mcg/kg) or morphine (0.05–0.1 mcg/kg). Maintain neuromuscular blockade or deep plane of anesthesia. Movement must be avoided with rigid esophagoscopy.	
Emergence	Extubate when fully awake. Neostigmine (0.07 mg/kg) and glycopyrrolate (0.01 mg/kg) to reverse neuromuscular blockade. Do not attempt reversal of neuromuscular blockade until first twitch of train-of-four has returned.	
Blood and fluid requirements	IV: 20–22 ga × 1 NS/LR @ 4–6 mL/kg/h	
Monitoring	Standard monitors (see p. D-1)	
Positioning	Peripheral nerve stimulator and pad pressure points. eyes. radial pulse of dependent arm.	Axillary roll as needed; avoid brachial plexus compression.
Complications	Esophageal perforation Aspiration Accidental extubation Stridor 2° subglottic edema	Esophageal perforation, more common with rigid esophagoscopy, may lead to pneumothorax (R > L)

Postoperative

Complications	Residual neuromuscular blockade Pneumothorax, esophageal perforation	
Pain management	Minimal postop pain	If patient reports marked substernal discomfort, suspect esophageal perforation.
Tests	None	

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Suggested Readings

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2. Li, ZS, Sun ZX, Zou DW, et al: Endoscopic management of foreign bodies in the upper-GI tract: experience with 1088 cases in China. *Gastrointest Endosc* 2006; 64(4):485–92.

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Repair of Tracheoesophageal Fistula and Esophageal Atresia

Surgical Considerations

Description:
The majority of infants with tracheoesophageal fistulae (TEF) have an associated esophageal atresia (EA), as shown in Fig. 12.5-1 (Type C). The Dx is made presumptively when a NG tube cannot be advanced past 8–13 cm and gas is present in the stomach. The complications of aspiration (gastric contents come up the fistula into the trachea) and GI distention compromising respiration (from passage of air down the fistula into the intestines) are *(Print pagebreak 1258)* diminished by repair within a few days of birth. Primary repair without gastrostomy is routine. The absence of stomach and bowel gas suggests a pure EA without fistula (Type A). A staged procedure—initial gastrostomy with deferred thoracotomy—may be used in babies < 1 kg, those with pure EA, or with more critical associated anomalies.
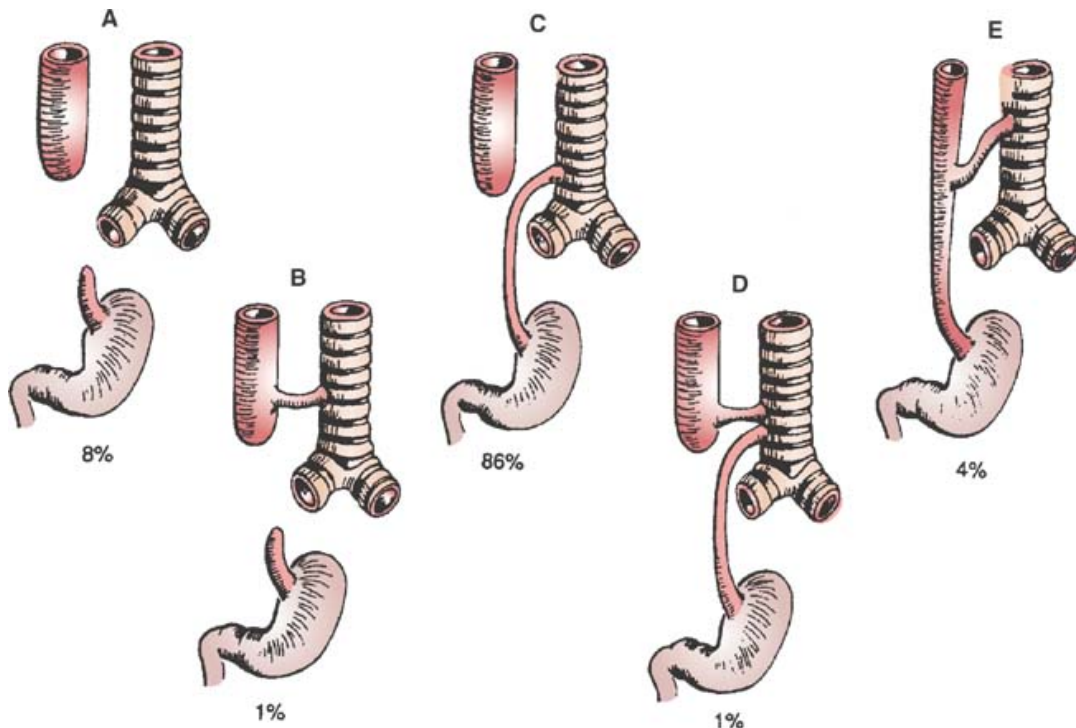

Figure 12.5-1. 1. Types of esophageal atresia: **(A)** pure esophageal atresia; **(B)** proximal fistula; **(C)** esophageal atresia, distal fistula; **(D)** proximal and distal fistula; **(E)** pure tracheoesophageal fistula. (Redrawn from Ravitch MM, et al, eds: *Pediatric Surgery*, Vol 1, 3rd edition. Year Book Medical Publishers, Chicago: 1979.)

Surgical approach: The operation is performed in left-lateral decubitus position through a 4th **interspace right** thoracotomy. Preop EKG is advised to look for cardiac anomalies and confirm a normal left-sided aortic arch. In the case of a right-sided arch

(10%), most surgeons approach the fistula through a **left thoracotomy.** Debate continues as to whether the best approach is retropleural or transpleural. The former is slower, but it may diminish the chances of empyema when the esophageal anastomosis leaks transiently.

Another approach is **thoracoscopy.** There is now extensive experience with this approach, and it is proven to be a safe and effective method of repair in children, even those with complex congenital heart disease. It is performed using three or four trocars in the modified (prone) left-lateral decubitus position, causing the lung to drop forward as 5 mmHg capnothorax is achieved. Dividing the azygous vein is necessary to find the subjacent fistula, branching off the posterior aspect of the trachea (Type C). The right bronchus, aorta, and (rarely) left bronchus may be mistaken for this structure. Division of the fistula may dramatically improve ventilation; until this moment it is sometimes necessary to operate in short 3- to 5-min. bursts, relaxing lung and mediastinal retraction for 1–2 min. when saturations descend to critical levels. Afterwards, the proximal fistula is located (when the anesthesiologist pushes downward on the indwelling [Replogle] tube) and then is dissected upwards into the root of the neck to achieve sufficient length for anastomosis. After the posterior wall of the anastomosis is complete, some surgeons will ask for the NG tube to be replaced by a small (5 or 6 Fr) feeding tube, which is advanced into the stomach, separating the anterior from posterior esophageal wall during closure and permitting enteric feeds during the customary 1 week before an esophagram is performed. This tube must be fixed in place, because it has a tendency to become dislodged. Because neck hyperextension, as would occur during direct laryngoscopy, places significant tension on the anastomosis, post-operative reintubation is to be avoided. When the length of native esophagus is too short, even after lengthening maneuvers, both ends can be tied to the prevertebral fascia or attached to monofilament sutures and brought tangentially out of the back skin (Foker). In the former case, one reoperates months later, after differential growth of the esophagus elongates it relative to the vertebral bodies—or if not, to replace it with stomach or bowel. In the latter case, stretching daily over 1–2 wk may provide sufficient length for secondary anastomosis. A chest tube usually is left in place.

Variant procedures or approaches: Pure EA without fistula (Type A) indicates a long gap—the initial operation is a feeding G-tube along the lesser gastric curve, followed by definitive operation months later or the **Foker procedure.** A pure fistula without EA (Type E) is usually diagnosed later in life and occurs in the neck; it is repaired through a cervical incision.

Usual preop diagnosis: EA; TEF

Summary of Procedures

	Primary Repair	**Gastrostomy**
Position	Lateral	Supine
Incision	Posterolateral thoracotomy (side opposite aortic arch)	LUQ
Special instrumentation	NG tube in upper pouch	G-tube
Unique considerations	Loss of ventilation via fistula; lung compression	May be done under local anesthesia.
Antibiotics	Preop: ampicillin 25 mg/kg iv + gentamicin 2.5 mg/kg iv	
Surgical time	2–4 h	1 h
Closing considerations	Extubation favored	Local anesthetic; wound infiltration
EBL	10 mL/kg	5 mL/kg
Postop care	NICU; humidified mist; avoid CPAP and neck hyperextension	
Mortality	1–20%, depending on associated anomalies	5%
Morbidity	Stricture: 20–40%	–
	Leak: 10–20%	–
	Aspiration	
	Atelectasis	–
	Stridor	–
Pain score	7–8	3–4

Patient Population Characteristics

Age range	Days–weeks
Male:Female	1:1
Incidence	1 in 4,000 births
Etiology	Unknown
Associated conditions	Vertebral, anal, TEF, renal (or radial) anomalies (VATER association); vertebral, anal, cardiac, TEF, renal, limb anomalies (VACTERL association); trisomy 13, 18; hydrocephalus

Anesthetic Considerations

Preoperative

EA and TEF usually are detected in the first day of life, although TEF without atresia may be difficult to diagnose until the patient experiences recurrent pneumonia, cyanosis associated with feeding, or abdominal distention. The fistula is usually at the distal trachea near the carina. Because of the risk of pulmonary aspiration, gastrostomy may be performed within hours of detection. Associated conditions frequently associated with TEF include prematurity (30–40%) and congenital anomalies such as cardiac (20–35%), VATER and VACTERL associations (see above). Routine neonatal preop evaluation includes: serum electrolytes, glucose and hematocrit. Patient should be well-hydrated and should have adequate urine output.

Respiratory	The upper esophageal pouch should be suctioned to minimize aspiration. These patients frequently have respiratory insufficiency 2° prematurity (RDS), or aspiration pneumonitis, and may be intubated and on mechanical ventilation. **Tests:** CXR, ABG
Cardiovascular	Associated cardiac abnormalities include: VSD, PDA, tetralogy of Fallot, ASD, and coarctation of the aorta. At risk for pulmonary HTN with R ← L shunt. **Tests:** EKG, ECHO, catheterization as indicated.
Gastrointestinal	Associated GI anomalies may occur (e.g., imperforate anus, midgut malrotation, duodenal atresia, pyloric stenosis).
Musculoskeletal	Musculoskeletal anomalies are usually of little anesthetic significance, except for possible C-spine involvement.
Hematologic	For the first 2–3 mo of life, the O_2 carrying capacity of blood is increased because of the presence of fetal Hb with its ↓ sensitivity to 2,3-DPG. A shift to the right of the O_2 sat curve results in ↑ O_2–Hb affinity. As a result, tissue oxygenation may be reduced, especially with anemia (Hb < 12 g/dL @ < 2–3 mo). Although TEF repair is not usually associated with significant blood loss, a T&C is indicated. **Tests:** Hct; T&C; others as indicated from H&P.
Laboratory	Serum electrolytes, ABG, blood glucose, to determine metabolic state.
Premedication	Usually none

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Intraoperative

Anesthetic technique: Combined GETA/epidural, using a pediatric circuit. Warm room to 75–80°F and use forced air warmer. If the child is otherwise healthy and extubation is planned within 48 hours, consider placing a caudal or lumbar epidural catheter (see p. D-4) after airway is secured and the child is anesthetized. Patients with large fistulas may need awake gastrostomy or a Fogarty

catheter placed via the gastrostomy, using FOB, to occlude the distal end of the fistula. Alternatively, the Fogarty catheter can be used to occlude the proximal end of the fistula via the trachea.

Induction	Atropine (0.02 mg/kg iv in children < 1 mo, minimum 0.1 mg) is given before induction to ablate vagal response to laryngoscopy. IV induction with care during ventilation to minimize PIP and potential inflation of stomach. Advance ETT to right mainstem and withdraw until bilateral breath sounds are present. Rotate ETT so the bevel faces posteriorly (to prevent intubation of the fistula). Have flexible pediatric bronchoscope available to verify placement of ETT and site of TEF. Keep air leak around ETT to a minimum (leak at 18–35 cm H_2O) to minimize alterations in ventilation 2° changes in chest and pulmonary compliance.	
Maintenance	Avoid high FiO_2 if possible in premature neonates at risk for retinopathy. Use air/O_2 mixture for ventilation to maintain O_2 sat between 95–100%. Use low PIPs to avoid gastric distention by gases passing through fistula. Careful adjustment of ventilation will be necessary during surgical retraction of lung or during insufflation if procedure is done thoracoscopically. Manual ventilation can be helpful in assessing pulmonary compliance. If the patient is not tolerating manipulation by the surgeon, brief breaks may be necessary to restore ventilation and oxygenation. Air/O_2/opioid (e.g., fentanyl 5–10 mcg/kg/h) propofol or low-dose volatile technique is preferred because of better hemodynamic stability. Muscle relaxation (rocuronium 0.6mg/kg iv, vecuronium 0.1 mg/kg) is usually necessary. If epidural is used, GA drug requirements will be reduced. Frequent tracheal suctioning may be needed.	
Emergence	Extubation in OR is preferable, but not always possible. Supplement O_2 as necessary to keep SpO_2 = 95–100% (PaO_2 = 60–80 mmHg). Cardiac or pulmonary complications, or any question regarding adequacy of ventilation mandate continued intubation and ventilation. Reintubation may compromise the new anastomosis.	
Blood and fluid requirements	Blood loss usually minimal IV: 22–24 ga × 2 NS/LR (maintenance) @: 4 mL/kg/h – 0–10 kg 5% albumin	Continue dextrose-containing solution from NICU. Replace 3rd-space losses (6–8 mL/kg/h) with NS/LR. Replace blood loss with 5% albumin mL for mL blood loss; maintain Hct > 35%.
Monitoring	Standard monitors (see p. D-1). Left axillary precordial stethoscope Arterial line (24 ga)	ABG, Hct, and glucose q 60 min
Positioning	and pad pressure points. eyes. Axillary roll Arms should be positioned to be visible and easily available to anesthesiologist.	The patient is turned to the left-lateral decubitus position for a right thoracotomy. Monitor breath sounds in dependent lung. Consider using bronchoscope to recheck tube position. ETT placement may interfere with TEF closure. Migration of ETT above fistula may lead to leak through gastrostomy and difficult ventilating.
Complications	Hypothermia Metabolic acidosis Hypo- or hyperventilation Aspiration Pneumothorax Atelectasis Mucus plug	Typically in ETT or large bronchi

(Print pagebreak 1261)

▼ Postoperative

Complications	Apnea Pneumothorax Hypoventilation Tracheal leak	Maintenance of normothermia lessens incidence of apnea, hypoventilation, and metabolic acidosis. Spontaneous hip flexion is the most reliable

	Inadequate NMB reversal	indication of adequate neuromuscular
	Recurrent laryngeal nerve injury	function.
	Pneumonia	
	Acetaminophen: 10–20 mg/kg pr q 4 h prn	
	Fentanyl 0.5–1.0 mcg/kg iv q 60 min prn	
Pain management	Dilaudid 0.01– 0.015 mg/kg iv	
	Morphine 0.05 mg/kg–0.1 mg/kg iv	
	Epidural analgesia (see E-5)	
Tests	ABG; Hct	

Suggested Readings

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Mediastinal Mass—Biopsy or Resection

Surgical Considerations

Description: Mass lesions in the mediastinum are classified as anterior, middle, and posterior, based on their relationship to the heart, which occupies the middle mediastinum. **Anterior tumors** include lymphomas, thyroid tumors, teratomas, and thymomas. Large lymphomas and, less commonly, teratomas or metastatic germ cell tumors may cause **anterior mediastinal mass syndrome** and/or **SVC compression.** Patients will use accessory muscles, refuse to lie flat, may have a suffused face with venous distention, and are at great risk for distal airway obstruction during induction. As often as possible, operations are performed quickly with the

patient awake and semirecumbent. Steroids are very effective in shrinking lymphomas, causing massive cell death such that tumor histology may demonstrate only necrosis after 36 hours. Preop preparation includes a rigid bronchoscope, plans to advance the ETT into a mainstem bronchus, and consideration of the need to rapidly roll the patient prone. These masses often are approached through a **3rd-rib anterior mediastinotomy (Chamberlain procedure)** or thoracoscopically. For patients with compromised airway, light sedation and core-needle biopsy under image *(Print pagebreak 1262)* guidance (e.g., ultrasound or CT scan) is preferable. **Middle mediastinal tumors** include esophageal duplications, bronchogenic cysts, lymphangiomas and variants, pericardial cysts, and lymph nodes. They are typically approached through a 5th-intercostal space posterolateral thoracotomy or thoracoscopically. **Posterior mediastinal lesions** are usually neurogenic tumors; less commonly, neuroenteric cysts. The former may communicate with the spinal cord through the intervertebral foramina, giving them the appearance of central narrowing ("dumbbell tumor"). They usually arise from the sympathetic ganglia and, when high in the chest, excision may cause Horner's syndrome. They are approached thoracoscopically or via posterolateral thoracotomy.

Surgical approach: The potential for blood loss and airway compromise must always be anticipated when operating on chest lesions adjacent to the great vessels and tracheobronchial tree. When SVC or anterior mediastinal mass syndromes are suspected, they may be confirmed clinically and should be discussed among surgeon, anesthesiologist, and oncologist. **Thoracoscopy** is the gold standard for biopsy. In the absence of an adequate workspace, a mini-thoracotomy may be necessary, but adequate biopsy for diagnostic purposes can typically be achieved with core needle biopsy.
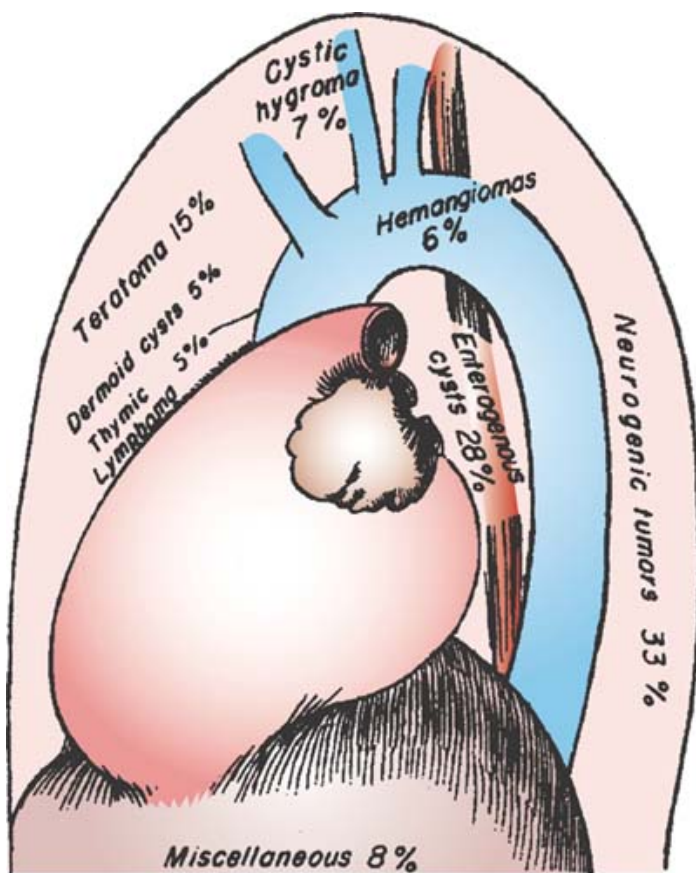

Figure 12.5-2. 2. Distribution of mediastinal cysts and tumor. (Reprinted with permission from Ravitch MM, et al: *Pediatric Surgery*. Year Book Medical Publishers, Chicago: 1986.)

Variant Procedure: In the past, it was a dictum that at least 1 cm^2 of tumor was needed for architecture to diagnose and classify lymphomas. In the age of histochemistry and chromosomal studies, this is less true. Sometimes the Dx can be made on bone marrow aspirate, pleural effusion aspirate, or a Tru-Cut needle biopsy. These alternatives should be considered when large anterior mediastinal masses are encountered.

Usual preop diagnosis: Neuroblastoma; teratoma; duplication cyst of foregut; mediastinal mass (lymphoma)

Summary of Procedures

	Lateral Thoracotomy	Median Sternotomy
Position	Lateral	Supine or semirecumbent
Incision	Posterolateral	Median, parasternal
Special instrumentation	None	Bronchoscope; ± CPB
Unique considerations	Airway or cardiovascular collapse after induction in anterior mediastinal masses	
Antibiotics	Preop: ampicillin 25 mg/kg iv + gentamicin 2.5 mg/kg iv; intraop: cephalosporin irrigation (1 g/500 mL NS)	
Surgical time	2–4 h	1–4 h
Closing considerations	Lung inflation; intercostal block; epidural catheter	
EBL	10–30 mL/kg	10–50 mL/kg
Postop care	Aggressive respiratory therapy; analgesia	
Mortality	< 5%, except symptomatic anterior masses	
Morbidity	Atelectasis/respiratory Cardiovascular collapse with anterior masses	
Pain score	7–8	6–7

(Print pagebreak 1263)

Patient Population Characteristics

Age range	Newborn—teens
Male:Female	1:1
Incidence	1/5000
Etiology	Unknown
Associated conditions	Cervical or axillary cystic hygroma; hemangioma; SVC syndrome

Anesthetic Considerations

Preoperative

The clinical presentation of a mediastinal mass is often nonspecific in an otherwise healthy child. Often, a routine CXR (for some incidental Sx) will show the presence of an anterior mediastinal mass. These patients may suffer acute cardiorespiratory compromise on induction of anesthesia. A careful preop workup is essential to ensure that GA is absolutely necessary before proceeding. This includes a non-diagnostic bone marrow aspirate/biopsy and drainage of pleural fluid, and consideration of peripheral lymph node biopsy.

Respiratory

Respiratory Sx (e.g., dyspnea, cough, stridor, wheezing) are extremely important in guiding additional studies. Note that, when mild airway compromise is present in the awake patient, this can indicate that total obstruction may occur when the patient is anesthetized or after muscle relaxation. The ability to lie supine without respiratory compromise should be determined, but does not guarantee adequate air exchange after receiving sedation or anesthesia. Tracheal and bronchial compression from the tumor may be positional. Preop radiation therapy may ↓ tumor mass and relieve airway obstruction.
Tests: CXR; chest CT/MRI; echocardiogram; supine-sitting

Cardiovascular	flow/volume loops can be useful for evaluating location and extent of airway obstruction in patients who are cooperative > 5 years; Oxygen saturation or ABG is indicated if symptomatic. Sx of a mediastinal mass may include SVC syndrome (e.g., venous engorgement of head and neck, edema of upper body). Other Sx and signs may include syncope and headaches ($\uparrow$ ICP) made worse in the supine position, JVD, papilledema. Cardiac insufficiency may occur due to tumor compression. **NB:** In severely symptomatic patients or large mediastinal masses, consider necessity for cardiopulmonary fem-fem bypass standby. **Tests:** ECHO; EKG if symptomatic
Musculoskeletal	If thymoma present, for Sx of myasthenia gravis. **Tests:** Presence of acetylcholine-receptor antibodies
Laboratory	Electrolytes; CBC; T&C for 2–4 U, depending on body weight and tumor size; other tests as indicated from H&P.
Premedication	If patient > 7–9 mo consider premedication with midazolam (0.5 mg/kg). Use premedication cautiously in patients with large masses, or those that are symptomatic.

(Print pagebreak 1264)

Intraoperative

Anesthetic technique: GETA using pediatric circle. OR temperature 75–80°; forced air warmer.

Induction	An iv is mandatory. Placement of an arterial catheter may be indicated in patients with large masses or in symptomatic patients. If SVC syndrome is present, it is important to have iv access in the lower extremity. Glycopyrrolate (0.01 mg/kg iv) is given to dry secretions and prevent bradycardia 2° deep inhalation induction and laryngoscopy. An awake FOB and intubation in the sitting position may be necessary. Alternatively, a mask induction with sevoflurane/O_2 in the semi-Fowler's (reclining) position may be appropriate. Intubation should be performed with preservation of spontaneous ventilation. Have small styletted ETTs available, in the event of tracheal compression. FOB is useful to confirm ETT placement and to evaluate trachea/bronchi. Use muscle relaxants with caution, because the change from spontaneous to positive pressure ventilation may not be tolerated and may lead to obstruction. **NB:** Surgeon must be present (with rigid bronchoscope immediately available) in the event of acute airway obstruction on induction. If obstruction is unabated, options include median sternotomy and femoral-femoral bypass. **NB:** A simple positional change (e.g., supine to lateral, prone or sitting) may relieve cardiorespiratory collapse.
Maintenance	Spontaneous ventilation/assisted ventilation with volatile agent and 100% O_2 may be appropriate. Supplemental epidural analgesia may be administered if a major resection is planned as opposed to a small incision for biopsy (see). Have surgeon infiltrate wound with bupivacaine 0.25% to reduce volatile anesthetic and opiate requirements.
Emergence	Confirm air leak around ETT (with cuff deflated). Have all emergency airway equipment available and surgeon present. Patient should be fully awake before extubation.
Blood and fluid requirements	Usually minimal blood loss IV: 18–24 ga × 2, depending on age NS/LR @ 10–20 mL/kg iv	If mediastinoscopy is performed, sudden blood loss from torn great vessel may occur. Volume-loading with NS/LR before induction may be appropriate to minimize cardiovascular effects of deep inhalational induction. Esophageal or precordial stethoscope is earliest monitor of airway obstruction. If

Monitoring	Standard monitors (see p. D-1) Arterial line	obstruction worsens acutely, be prepared to change to lateral-decubitus or prone position, which may help alleviate tracheal, bronchial compression and cardiovascular collapse.
Positioning	and pad pressure points. eyes.	
Complications	Cardio/Respiratory failure Loss of airway Hypotension	These cases require great attention to detail. All efforts must be made to maintain spontaneous ventilation. Preparations must be made for resuscitation.

◥Postoperative

Complications	Respiratory failure Pneumothorax	Anesthesiologist must be readily available in the PACU to manage acute airway problems.
Pain management	Ketorolac 0.5 mg/kg(up to 30 mg) iv q 6 h × 24 h Epidural analgesia PCA (see p. E-3–E-4)	Cervical biopsy/mediastinoscopy have minimal postop pain and can be effectively treated with NSAID and local anesthetic infiltration. Use opiates cautiously.
Tests	Hct, ABG, CXR, as clinically indicated.	

(Print pagebreak 1265)

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Neonatal Lung Resection

Surgical Considerations

Description: Neonatal lung resection is performed for a few disorders relatively unique to children, including congenital cystic adenomatoid malformations (CCAM); sequestrations (intralobar 75%, extralobar 25%); congenital lobar overdistention (CLO, formerly called "emphysema"); and congenital pulmonary cysts (Fig. 12.5-3). Many lesions are asymptomatic; they are diagnosed by antenatal ultrasound or later when a CXR is performed for other reasons. CCAMs may compromise respiration and are at low risk for subsequent malignant degeneration. Sequestrations represent little danger, but they are frequently fed by a large artery of near-aortic caliber (often from below the diaphragm) *(Print pagebreak 1266)* with independent venous drainage back into the vena cava, causing significant L → R shunting. CLO resection is performed when the volume of ineffective, dilated lung compresses adjacent functioning lobes, compromising their function. (This condition is worsened by artificial ventilation with high pressure.) The key therapy is surgical—opening the hemithorax enables an oversized lobe to herniate through the incision, decompressing the healthy lung beneath. Most resections are performed on a ventilated lung because it is difficult to selectively intubate small airways.
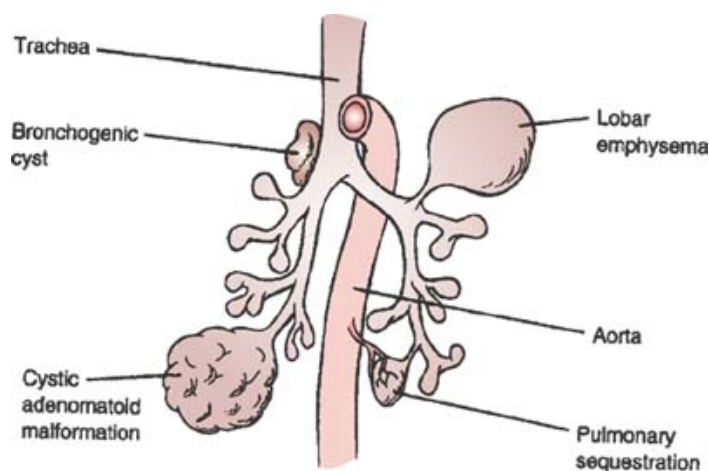

Figure 12.5-3. 3. Classic developmental abnormalities of the tracheobronchial tree. (Reproduced with permission from Oldham KT, Colombani PM, Foglia RP: *Surgery of Infants and Children*. Lippincott-Raven, 1997. After Haller JA Jr, Golladay ES, Pickard LR, et al: Surgical management of lung bud anomalies: lobar emphysema, bronchogenic cyst, cystic adenomatoid malformation, and intralobar pulmonary sequestration. *Ann Thorac Surg* 1979; 28:34.)

Surgical approach: Patients undergoing lateral thoracotomy through the 4th, 5th, or 6th intercostal space benefit from preop placement of an epidural catheter. In some institutions, thoracoscopic resection may be performed. Significant blood loss is possible (infrequent). Often ventilation improves when the aberrant lung segment is removed. A large CCAM, intralobar sequestration, or CLO usually requires formal **lobectomy.** Smaller CCAMs, pulmonary cysts, and extralobar sequestrations are treated with lesser resections. A chest tube usually is left in place at the end of the case.

Variant procedures or approaches: Thoracoscopic lobectomy is increasingly practiced, and at our institution is the preferred method of lung resection. It can be performed safely and effectively, and avoids the morbidity and poor cosmesis of a thoracotomy. Upper-lobe resections can be technically more challenging, but are still possible with thoracoscopy. Insufflation of the hemithorax with 7 Hg carbon dioxide can aid in lung collapse.

Usual preop diagnosis: CCAM; sequestration; CLO; pulmonary cysts; congenital diaphragmatic hernia; pneumothorax

Summary of Procedures

Position	Lateral decubitus
Incision	Lateral thoracotomy
Special instrumentation	Pediatric rib retractor
Unique considerations	Rapid thoracotomy improves ventilation in CLO. Aggressive high-pressure ventilation should be avoided.

Antibiotics	Cefazolin 25 mg/kg
Surgical time	2 h
Closing considerations	Extubation preferable and aided by epidural catheter.
EBL	10 mL/kg
Postop care	NICU
Mortality	< 5%
Morbidity	Bleeding Air leak Atelectasis
Pain score	7–8

Patient Population Characteristics

Age range	Days-weeks
Male:Female	1:1
Incidence	1/5000 live births
Etiology	Bronchopulmonary foregut maldifferentiation
Associated conditions	**Extralobar sequestration:** may occur below the diaphragm. **Sequestrations:** may be associated with high-output heart failure and diaphragmatic hernia. **CCAM:** may cause hydrops fetalis and fetal death. Intermediate forms of sequestration and CCAM exist.

(Print pagebreak 1267)

Anesthetic Considerations

Preoperative

In general, children have significantly decreased respiratory reserve compared with adults because:

1. FRC is closer to RV in children, thereby making airway closure more likely.

2. O_2 consumption is higher (6–8 mL/kg/min vs 3 mL/kg/min).

3. In adults, the decubitus position increases blood flow to the ventilated, dependent lung, while decreasing perfusion to the operated nondependent lung. In children, the nondependent lung may actually receive greater perfusion than the dependent lung, which may be due to a more compliant chest wall in infants and young children.

Premedication	In children > 7–9 mo, consider midazolam 0.5–0.7 mg/kg po or 1–2 mg iv. If airway obstruction or severe pulmonary disease is present, use premedication judiciously.

Intraoperative

Anesthetic technique: Combined epidural/GETA, using a pediatric circle forced-air warmer; OR warmed to 75–80°F; use warming pad on OR table, and warm iv fluids.

Induction	Either inhalation or iv induction may be performed. (For OLV, see below.) The trachea is intubated. An arterial line is indicated for children having a thoracotomy and for VATS in patients with significant lung disease. A CVP is generally not required if iv access is adequate. OLV is used to allow deflation of the operative lung, which is especially useful during

One-lung ventil- ation (OLV) in pediatric patients	VATS. Alternatively, the surgeon may insufflate CO_2 to compress the operative lung. OLV also isolates the lungs to help prevent contamination of the nonoperative lung with blood or purulent fluid from the operative lung. The **three techniques for OLV** in infants and children include: Use of a **single-lumen tube:** a single-lumen tube is advanced into the mainstem bronchus of the nonoperative lung. FOB may be placed through ETT to confirm placement. Disadvantages: may obstruct upper lobe bronchus; cannot suction operative lung; may not have complete collapse of operative lung. Use of a **balloon-tipped catheter or bronchial blocker:** For placing blocker OUTSIDE the ETT: Operative lung intubated with ETT, guide wire passed through ETT, BB advanced over guide wire; second smaller ETT placed in trachea, alongside the BB. BB also can be advanced under direct visualization with FOB guidance via ETT. For placing blocker THROUGH ETT, multiport adapters allow oxygenation while positioning. Disadvantages: requires small ETT, FOB, or fluoroscopy. Use of a **double-lumen tube (DLT):** Can be placed for older children (see table below for approximate sizes). (See Lobectomy, Pneumonectomy, for details.)
Maintenance	Standard maintenance (see p. D-2). Muscle relaxation is appropriate. Inhalation agent or TIVA (see p. B-2) may be used; 100% O_2 or O_2/air mixture; N_2O is avoided. Fentanyl 2–5 mcg/kg or other iv opioid should be given when epidural is not in place.
Emergence	In most cases, the patient can be extubated at the end of surgery. An OG tube should be placed before, and suctioned prior to extubation. Ensure ability to oxygenate and ventilate adequately before extubation.
Blood and fluid requirements	IV: 18–22 ga × 2 NS/LR @ maintenance	Potential for moderate blood loss. Transfuse to maintain Hct > 23. If > 2 mo of age, dextrose-containing solutions are not required.
Monitoring	Standard monitors (see p. D-1). ± Arterial line (22 ga) ± CVP Foley catheter ± TEE	For thoracotomy, ABG, Hct, and glucose should be evaluated as clinically indicated; UO monitored and kept at 1 mL/kg/h. CVP may be useful to evaluate fluid status if large fluid shifts or blood loss is anticipated, or if significant cardiac or respiratory compromise is present.
Positioning	and pad pressure points. eyes.	
Complications	Hypoxia	DDX: Movement of ETT or BB, compromising OLV; bronchospasm; obstruction of ETT by kinking or secretions; pre-existing disease.
	Hypercarbia	Permissible during OLV (40–50 mmHg) to minimize barotrauma.
	↓ BP	Blood loss; hypovolemia; ↓ venous return 2° ↑ intrathoracic pressure

(Print pagebreak 1268)

Table 12. 5-1. Tube Selection for OLV in Children

Age (yr)	ETT (Inner Diameter)	Fogarty Catheter	Arndt Blocker	Univent Tube	DLT (Fr)
0.5–1	3.5–4.0	3	n/a		
1–2	4.0–4.5	4	n/a		
2–4	4.5–5.0	4	5		
4–6	5.0–5.5	5	5		
6–8	5.5–6	6	5	3.5	
8–10	6.0 cuffed	6	5	3.5	26
10–12	6.5 cuffed	6	7	4.5	26–28

12–14	6.5–7.0 cuffed	6	7	4.5	32
14–16	7.0 cuffed	7	7	6.0	35
16–18	7.0–8.0 cuffed	7	7 or 9	7.0	35

▼ Postoperative

Complications	Atelectasis Hypoventilation	Encourage deep breathing, hyperventilation.
	Hypoxia	Supplemental O_2
	Pneumothorax	Check breath sounds, chest wall motion, CXR. May require chest tube.
Pain management	Thoracic epidural	Lumbar (or caudal if < 8 kg and < 1 yr) epidural catheter may be placed and threaded up to thoracic levels.(NB- 1st dilate space with NS prior to threading catheter; ultrasound guidance may also be used to guide placement)
	Ketorolac 0.5 mg/kg iv q 6 h × 48–72 h	max 30mg/dose, if needed to enhance analgesia
Tests	Hct ABG CXR	

(Print pagebreak 1269)

Suggested Readings

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5. Rothenberg SS, Albanese CT: Experience with 144 consecutive pediatric thoracoscopic lobectomies. *J Laparoendosc Adv Surg Tech* A 2007; 17(3):339–41.

Drainage of Empyema

◢ Surgical Considerations

Description: Most empyemas occur in otherwise healthy children when a necrotizing pneumonia causes a parapneumonic effusion that becomes infected. The infected fluid (empyema) has the tendency to become solid over days to weeks. It compresses the diseased lung and responds poorly to antibiotics because it is remote from the circulatory system. Three phases of empyema are recognized, and the key variable determining outcome is fibrin. The early or **exudative phase** occurs when the effusion becomes purulent—liquid pus without fibrin is successfully treated with a chest tube if it is recognized early (uncommon). The second phase, **fibrinopurulent,** occurs over the next days as thick strands of infected fibrin replace exudative fluid. It is the most common phase and is most expeditiously treated by **thoracoscopic ± open empyemectomy.** The last phase, **organized,** occurs when all exudate has been replaced by thick, infected fibrin, compressing the lung and adhering to both visceral and parietal pleura. Fortunately, this stage is rare in children; tedious **thoracoscopic decortication** may be successful, but often **thoracotomy** is required and the procedure is bloody. Some previously common organisms (e.g., *Haemophilius influenzae*) are decreasing with the advent of

pediatric vaccines; *Streptococcus pneumonia, Staphylococcus aureus,* and *Streptococcus pyogenes* remain common pathogens, joined more recently by gram-negative rods. Significant bleeding is not uncommon and bronchopleural fistulae, if not already present, may occur when dead lung adheres to débrided overlying fibrin.

Surgical approach: Ipsilateral long-term venous access (peripherally inserted central or subclavian catheter) is placed before or during surgery. In larger children, a BB may protect the healthy lung from pus, which may extrude from the infected side into the trachea during operation. A **two- or three-port thoracoscopic technique** is most common, aided by hermetic trochars used with 5 mmHg intrathoracic pressure (unless a bronchopleural fistula exists). The first port is placed into a pre-existing chest tube site or the largest known pocket of pus/fibrin observed on preop imaging. Gradually, this space is enlarged until the remaining ports can be inserted under direct vision. As fibrin and pus are removed, trapped lung is liberated and the procedure continues somewhat tediously until the entire lung is free and most fibrin is removed. One or two large-bore chest tubes are placed at the end of the procedure.

Alternate approach is placement of one or more pigtail chest tubes and flushing the chest cavity with a fibrinolytic agent (e.g., tissue plasminogen activator). There is debate whether this approach may result in longer hospital stays, and thoracoscopy remains the gold standard.

Summary of Procedures

	Thoracoscopic	Thoracotomy
Position	Contralateral decubitus	
Incision	Three ports	5th interspace
Special instrumentation	Suction irrigator; chest tube	**Rib retractor; suction; chest tube**
Unique considerations	5 mmHg capnothorax	—
Antibiotics	Cefuroxime (25 mg/kg) and clindamycin (10 mg/kg)	
Surgical time	1.5 h	2 h
Closing considerations	Local anesthetic	± Epidural catheter
EBL	10–20 mL/kg	
Postop care	May be septic for 24 h Extubation ideal	
Mortality	< 5%	< 10% when used for advanced disease
Morbidity	Air leak Bleeding Sepsis Atelectasis Pneumatocele	
Pain Score	3–4	7–8

(Print pagebreak 1270)

Patient Population Characteristics

Age range	1–17 yr
Male: Female	1:1
Incidence	1/150 pneumonias
Etiology	Bacteria infect pleural effusion.
Associated conditions	Chronic granulomatous disease (uncommon)

Anesthetic Considerations

See .

Suggested Readings

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Repair of Pectus Excavatum/Carinatum

◨ Surgical Considerations

Description: Pectus excavatum ("funnel chest") is a sternochondral deformity more common in boys and of greater frequency than pectus carinatum ("pigeon chest"). Both may be associated with scoliosis, spontaneous pneumothorax, and Marfan syndrome—for which children of appropriate body habitus should be screened. It is difficult to confirm significant cardiorespiratory compromise in other than very severe excavatum lesions; *(Print pagebreak 1271)* transient pains are common and psychosocial distress is often the impetus for repair. The timing of repair is variable; some surgeons preferring to operate on younger children (5–6 yr) because of the ease and decreased bleeding, whereas others prefer doing surgery during adolescence to prevent possible recurrence during puberty.
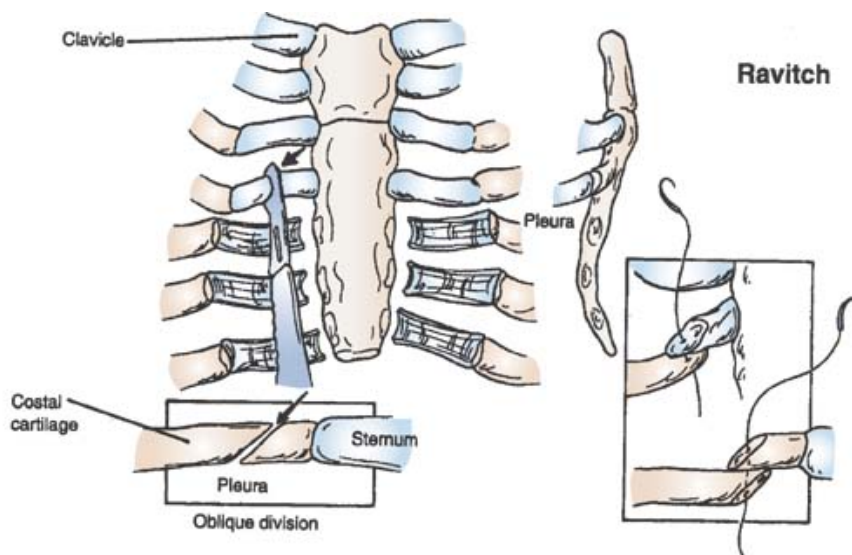

Figure 12.5-4. 4. Ravitch approach: The costal cartilage immediately above the most cephalad abnormal costal cartilage is divided obliquely from medial to lateral, as shown. This is often at the level of the second costal cartilage, at the manubrial-sternal junction. The divided normal costal cartilages are allowed to overlap, the medial portion being anterior and the lateral being posterior. Suture fixation of the transected cartilage provides immobilization, ensuring sternal support at this level (inset). (Reproduced with permission from Oldham KT, Colombani PM, Foglia RP: *Surgery of Infants and Children*. Lippincott-Raven, 1997.)

Surgical approach: The classic **Ravitch** approach involves an omega-shaped chest incision in the supine position. The pectus muscles are detached from the sternum and 3–5 pairs of costochondral cartilages are resected, leaving the perichondrium for subsequent cartilage regeneration (Fig. 12.5-4). A transverse osteotomy of the upper sternum corrects its appearance. In some excavatum patients, a metal bar or "strut" may be placed beneath the sternum but on top of the ribs. If used, the strut is removed 2 yr later in a short operation through a small lateral incision. Hemovac drains are placed beneath the skin to trap bleeding from cut bony surfaces; chest tube(s) are placed if the pleura or pericardium is violated. Significant blood loss from cut surfaces of bones and cartilage occurs in older patients.

A newer approach (**Nuss Procedure**), is now widely practiced. This involves placement of a curvilinear stainless steel bar (pectus bar) via lateral axillary incisions through the ribspace under thoracoscopic guidance beneath the sternum at the point of maximal

sternal depression. The bar travels through both hemithoraces anterior to the heart and lungs; when "flipped" 180° it exerts powerful forces backwards on the ribs and forward on the sternum. Sometimes fixation devices must be added to the ribs to keep the bar from "flipping back" into original position. A chest tube is not always necessary; however, very significant pain results, optimally treated with an epidural catheter. The rapid change of chest-wall shape also has caused thoracic outlet syndrome.

Usual preop diagnosis: Pectus excavatum; carinatum

(Print pagebreak 1272)

Summary of Procedures

	Ravitch	Nuss
Position	Supine	, R side slightly elevated
Incision	Omega, chest	Two right axilla, one left axilla
Special instruments	Periosteal elevators; sternal saw; possible strut	Steel bar; bar bender; stabilizers
Unique considerations	Heart and lungs beneath	Cosmetically superior
Antibiotics	1st generation cephalosporin	
Surgical time	3 h	≥1 h
Closing considerations	Extubate; epidural, if possible	Epidural very important
EBL	10–20 mL/kg	< 5 mL/kg
Postop care	Drains out 1–3 d → home 5 d	→ home 5 d
Mortality	< 2%	
Morbidity	Bleeding Recurrence Pneumothorax Cardiac injury	Bar "flips" Thoracic outlet syndrome
Pain score	5–6	8–9

Patient Population Characteristics

Age range	5 yr–adolescent
Male:Female	5–9:1
Incidence	Uncertain
Etiology	Relationship with reactive airway disease
Associated conditions	Marfan syndrome (5%); mitral valve prolapse (5%)

Anesthetic Considerations

Preoperative

Pectus excavatum (a condition in which there is concave depression of the lower sternum) may be associated with CHD and restrictive lung disease. If the deformity is present without cardiac or pulmonary disease, the patient is asymptomatic and the procedure is cosmetic. Surgery usually occurs between 12–15 yr of age. **Pectus carinatum** (a convex lower sternum) usually is repaired for cosmetic reasons only and usually during the teenage years. Cardiac abnormalities (VSD, PDA, mitral valve anomalies) may be associated with the pectus disorder.

Respiratory

Restrictive lung disease 2° chest-wall deformity may be present. If a longstanding condition, patient may have chronic hypoxemia, with resultant pulmonary HTN and polycythemia. If patient has exercise limitations, there is a need to differentiate between

	cardiac and pulmonary components. **Tests:** CXR: AP, lateral; PFTs; ABG, if symptomatic
Cardiovascular	In both conditions, CHD should be investigated if present. Pulmonary HTN may be 2° pulmonary overcirculation (e.g., VSD), or chronic hypoxemia. **Tests:** ECG; ECHO
Laboratory	Hct; T&C; electrolytes
Premedication	If patient is an asymptomatic child, midazolam (0.75 mg/kg po or 1–2 mg iv).

(Print pagebreak 1273)

◆ Intraoperative

Anesthetic technique: GETA, using a pediatric circle; forced air warmer; maintain OR temperature 75–80°.

Induction	IV or mask induction. With restrictive lung disease, there is ↓ FRC, which will shorten the time to alveolar equilibration for the volatile anesthetics. Hypercarbia will aggravate pulmonary HTN; institute early manual hyperventilation. Tracheal intubation, facilitated by neuromuscular blockade (rocuronium 1 mg/kg, vecuronium 0.1 mg/kg). Use appropriately sized ETT (see p. D-2). With uncuffed ETT, keep air leak to minimum (>20 cmH$_2$O) to avoid alterations in alveolar ventilation with changes in chest and pulmonary compliance.	
Maintenance	Standard maintenance with inhalational anesthetic, TIVA or combination. Insertion of thoracic lumbar epidural catheter will provide for supplemental anesthesia and treatment of postop pain and is highly recommended. Use morphine/hydromorphone-bupivacaine mixture (see p. D-2). If no epidural is placed, bolus with long acting iv opioid (morphine 0.1 mg/kg, hydromorphone 15 mcg/kg) for postoperative pain control.	
Emergence	Plan for extubation in OR. Ensure adequate reversal of neuromuscular blockade with neostigmine (0.07 mg/kg iv) and glycopyrrolate (0.014 mg/kg iv).	
Blood and fluid requirements	Usually minimal blood and 3rd-space losses IV: 18 or 20 ga × 1 NS/LR @ 3–5 kg/h	With chronic hypoxemia or right-side heart disease, maintain Hct > 30. If otherwise healthy, maintain Hct > 22.
Monitoring	Standard monitors (see p. D-1)	Arterial line if pulmonary HTN present.
Positioning	and pad pressure points. eyes.	Elbow padding to avoid ulnar nerve compression. Careful positioning to avoid nerve compression.
Complications	Pneumothorax Atelectasis Subglottic edema	

▼ Postoperative

Complications	Respiratory insufficiency Pneumothorax	2° splinting, preexisting restrictive pulmonary disease, nerve injury related to positioning
Pain management	Epidural (thoracic) or PCA	Standard epidural infusion (see p. E-5). Ketorolac (0.5 mg/kg (p. E-3–E-4) iv q 6 h × 24–72 h), if needed, in addition to the above measures

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Esophageal Replacement, Colon Interposition, Gastric Tube Placement

Surgical Considerations

Description: Esophageal replacement in children usually is performed for caustic stricture or esophageal atresia (EA) refractory to other therapy. Caustic esophageal strictures—usually in toddlers following lye ingestion—are becoming less common; esophageal replacement is indicated after failed attempts at balloon dilation (BD). Patients with EA may have a primary replacement for known long-gap atresia (Type A), or will have a secondary replacement after failed attempts at anastomosis (all types). There is no good long-term esophageal replacement; a segment of colon, stomach, or (rarely) jejunum is the best surrogate.

Surgical approach: Depending on anatomy and surgeon preference, the **distal dissection** occurs in the abdomen and/or chest; the **proximal anastomosis** occurs in the chest or neck. Position changes with redraping may be required, depending on the selection of incisions. The esophageal substitute usually is brought through the bed of the esophagus with small risks to the pulmonary vessels, recurrent laryngeal nerves, and brachiocephalic vein. The **retrosternal approach** may be safer but is less optimal in children because of long-term problems with obstruction and emptying.
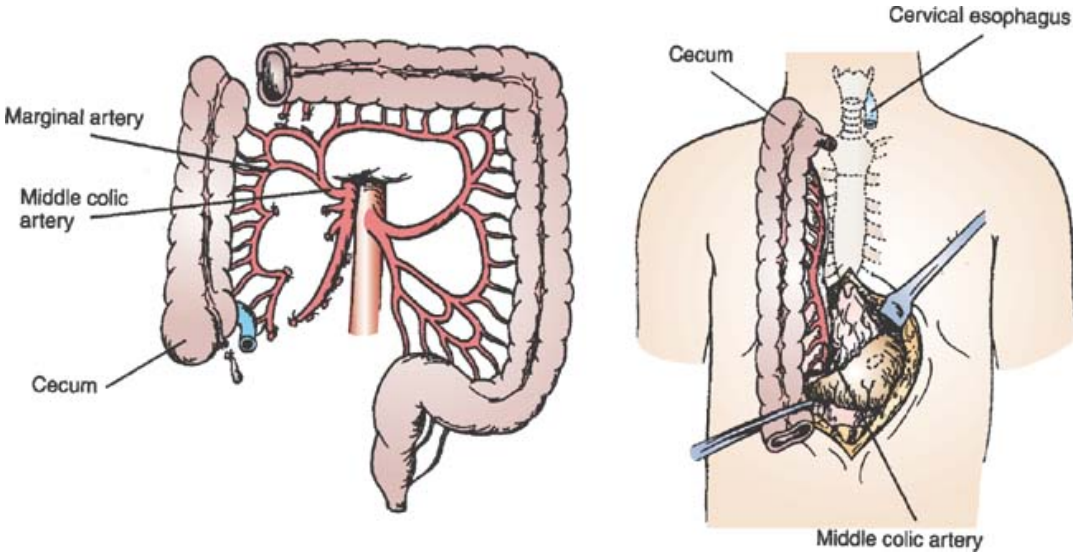
Figure 12.5-5. 5. Esophageal replacement using a right colon interposition in a retrosternal position. (Reproduced with permission from Oldham KT, Colombani PM, Foglia RP: *Surgery of Infants and Children*. Lippincott-Raven, 1997.)

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Variant procedures or approaches: Colon is the most frequent substitute, with the transverse colon attached to either the R colon (isoperistaltic) or L colon (reverse peristaltic) being used. When the stomach is used, it may be pulled up entirely from the abdomen through the chest with **gastroesophageal anastomosis** in the neck **(Orringer)**; alternatively, a **gastric tube** of greater (common) or lesser curve maybe constructed for cervical or thoracic anastomosis. Small bowel is used only when other substitutes are inappropriate—because an additional microvascular anastomosis is needed for graft survival.

Usual preop diagnosis: EA; caustic stricture

Summary of Procedures

Position	Supine, tilted; or supine, ± lateral
Incision	Abdominal and cervical ± thoracotomy
Special instrumentation	Bougie (upper esophagus)
Antibiotics	Preop: ampicillin 25 mg/kg iv + gentamicin 2.5 mg/kg iv
Surgical time	3–5 h (4–6 h with position change)
EBL	20–40 mL/kg
Postop care	PICU
Mortality	< 5%
Morbidity	Respiratory failure
	Anastomotic leak
	Sepsis
	Stricture
Pain score	7–8

Patient Population Characteristics

Age range	1–5 yr
Male:Female	2:1
Incidence	200/yr in the United States
Etiology	Caustic ingestion; EA
Associated conditions	Caustic stricture; imperforate anus; VACTERL association

Anesthetic Considerations

Preoperative

These patients usually are children presenting with a Hx of caustic substance ingestion and subsequent development of esophageal stricture. They frequently have undergone multiple esophageal dilations under GA. Previous anesthesia records should be obtained. Preop, these patients are admitted for bowel prep and, consequently, may be hypovolemic.

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Gastrointestinal	Varying degrees of esophageal reflux may be present. Preop H_2 blocker administration may be appropriate (e.g., ranitidine 1.0 mg/kg iv). If a gastrostomy is present, it should be vented. **Tests:** Electrolytes
Hematologic	Anemia due to poor nutrition **Tests:** CBC; T&C
Laboratory	Other tests as indicated from H&P.
Premedication	IV may already be in place and midazolam (1–2 mg iv) can be administered in holding area. Alternatively, midazolam usually can be given (0.5–0.75 mg/kg po) 30 min. before surgery.

Intraoperative

Anesthetic technique: GETA, using a pediatric circle. Forced-air warmer; heating pad on OR table. Warm room to 75–80°F. An epidural catheter (for intraop and postop pain management) may be placed once child is anesthetized and airway is secured.

Induction	IV induction preferred. If reflux concerns present, preoxygenate for 2–3 min and perform rapid-sequence induction and intubation with cricoid pressure (see p. B-4). Use appropriately sized ETT (see p. D-2). Continue neuromuscular blockade with vecuronium (0.1 mg/kg) or rocuronium (0.6 mg/kg).	
Maintenance	Use air/O_2/isoflurane. Avoid N_2O to minimize increase in size of possible pneumothorax during mediastinal dissection, use appropriate use of NMB with train-of-four monitoring, and dose epidural catheter as needed (see. p. D-3).	
Emergence	Possible extubation in OR vs postop intubation.	
Blood and fluid requirements	Blood loss moderate IV: 22 ga × 2 NS/LR @ –10 mL/kg/h	Replace 3rd-space losses with NS/LR (10 mL/kg/h). Replace blood loss mL for mL with albumin 5%. Transfuse to maintain Hct > 22.
Monitoring	Standard monitors (see p. D-1) CVP: 4 Fr DL or 5Fr TL ± Arterial line (22 ga) Foley catheter	CVP line used for postop TPN (maintain 1 lumen for that purpose). Marked arterial waveform variation with ventilation is a sensitive indicator of hypovolemia. ABG/Hct prn.
Positioning	Shoulder roll and pad pressure points. eyes.	Beware of tracheal extubation with head extension. If necessary, reconfirm ETT position with laryngoscopy.
Complications	Hypoventilation Hypothermia Pneumothorax Dysrhythmias Aspiration	Suprasternal dissection involves traction on trachea and recurrent laryngeal nerve. Mediastinal pull-through may damage great vessels and → pneumothorax, manipulation-induced dysrhythmias, impaired chest-wall compliance.

◤Postoperative

Complications	Subglottic edema Hypoventilation Pneumothorax Recurrent laryngeal nerve injury Mediastinitis	Inadequately treated pain → hypoventilation.
Pain management	Epidural analgesia (see p. E-5). Acetaminophen (10–20 mg/kg pr q 4 h prn) Ketorolac (0.5 mg/kg iv up to 15 mg q 6 h × 24–72 h)	
Tests	CXR Hct	

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Suggested Readings

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Repair of Congenital Diaphragmatic Hernia

◤Surgical Considerations

Description: Congenital diaphragmatic hernia (CDH; Bochdalek Hernia) remains a potentially lethal anomaly due to pulmonary HTN, pulmonary hypoplasia, and associated cardiac dysfunction. In utero Dx allows for delivery at (ideally) or transport to a tertiary center with sophisticated ventilatory support techniques. Early NG tube placement is important to minimize distention of the intrathoracic viscera. Surgery transiently worsens pulmonary HTN and may cause "persistent fetal circulation," in which the fetal circulation reopens to shunt blood around the lungs, causing further hypoxemia, hypercarbia, and acidosis—all stimuli for further pulmonary HTN. Thus, in the sickest newborns, surgery is delayed until after cardiorespiratory stabilization, with an arsenal of supportive measures, including: low-pressure, high-frequency ventilation; passive hypercapnia; oscillating or jet ventilation; NO; and even ECMO, which is becoming less common with the success of the former methods. When ECMO (with anticoagulation) is used, diaphragm repair may be performed: **early during ECMO** (less swelling, more bleeding); **late during ECMO** (more swelling, ability to "come off" if bleeding); or **after ECMO** (less bleeding, less swelling, little recourse if surgery worsens ventilation). (For a description of ECMO, see p. 1503.) When the intestines are reduced from the chest, there is sometimes insufficient room in the abdomen, in which case, an abdominal silo is placed transiently.

Surgical approach: Left-side lesions (Fig. 12.5-6) are 7x more frequent than right; repair is traditionally performed through a subcostal incision, but increasingly a laparoscopic or thoracoscopic approach is being utilized. In children with significant hypercarbia and/or pulmonary hypertension, insufflation with carbon dioxide may not be tolerated, precluding this approach. However infants are surprisingly resilient to intrathoracic insufflation and respiratory acidosis can be effectively managed with hyperventilation.

Small defects cause few ventilation problems and are closed primarily. Larger defects are associated with more challenging ventilation and require prosthetic mesh augmentation, either with synthetic or biologic mesh. Recurrent defects may be approached through the abdomen or chest and sometimes require transfer of muscle flaps (interior oblique). Unless ECMO is used, a chest tube is not necessary.

Variant procedure: In utero therapies for CDH, including tracheal occlusion, have not been shown to improve survival. Although

the defect commonly originates in the posterolateral diaphragm (Bochdalek), less common retrosternal defects (Morgagni) present later in life without the same degree of cardiorespiratory compromise.

Usual preop diagnosis: Diaphragmatic hernia; Bochdalek's hernia (posterolateral diaphragm)

Summary of Procedures

Position	Supine (lateral for thoracic approach)
Incision	Subcostal (posterolateral for thoracic approach)
Special instrumentation	Pre- and postductal arterial monitors
Unique considerations	Reactive pulmonary vasculature
Antibiotics	Preop: ampicillin 25 mg/kg iv + gentamicin 2.5 mg/kg iv
Surgical time	1–2 h
Closing considerations	Assess for changes in ventilation (e.g., PIP, pre- and postductal ABG).
EBL	5–10 mL/kg
Postop care	Paralysis maintained; hyperventilation; fentanyl infusion @ 2–5 mcg/kg/min
Mortality	15–50% without ECMO 25–30% with ECMO
Morbidity	Pulmonary HTN Respiratory failure Sepsis Intestinal obstruction/dysfunction
Pain score	6–7 (7–8 for thoracic approach)

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Patient Population Characteristics

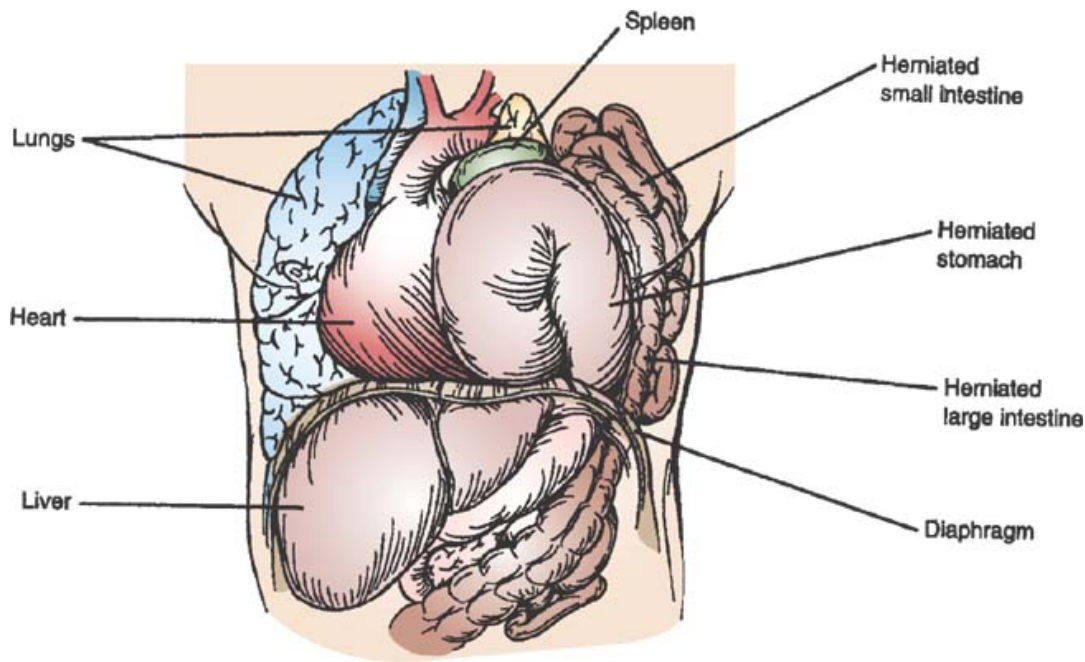|	
Age range	Newborn–wk or mo
Male:Female	1–2:1
Incidence	1 in 4000
Etiology	Unknown
Associated conditions	Malrotation (40–100%); congenital heart disease (23%- VSD, ASD, PDA, TOF); renal anomalies (rare); esophageal atresia (rare); CNS abnormalities (e.g., myelomeningocele, hydrocephalus) (rare)

Figure 12.5-6. 6. Left-sided congenital diaphragmatic hernia demonstrating translocation of the abdominal viscera into the left hemothorax and displacement of the mediastinum to the contralateral side. (Reproduced with permission from Oldham KT, Colombani PM, Foglia RP: *Surgery of Infants and Children.* Lippincott-Raven, Philadelphia: 1997.)

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Anesthetic Considerations

Preoperative

These infants present with varying degrees of respiratory distress. Surgery is performed after the child has been stabilized medically. The majority are already mechanically ventilated, sedated, and paralyzed in the NICU prior to anesthesia consultation. The anesthesiologist needs to be aware of the distinction between early and late diaphragmatic hernias. Late events (occurring near or even after delivery) are associated with mature, well developed lungs and minimal problems with ventilation. These babies often can be extubated in the early postop period, facilitated by epidural analgesia. Some infants may be on ECMO (see).

Respiratory	The lung on affected side is variably hypoplastic and the lung on the contralateral side is compressed and also may be hypoplastic. Pulmonary hypoplasia is most severe in patients with early herniation, and may be minimal in cases of late (even postnatal) herniation. The prognosis is correlated with magnitude of pulmonary hypoplasia and pulmonary muscular abnormalities present on the contralateral side. There is ↓ compliance, → risk for hypoventilation. ↑ PIP →↑ risk for pneumothorax. Persistent pulmonary HTN and progressive hypoxemia may be present. **Tests:** CXR; ABG
Cardiovascular	R → L shunting may occur at level of PDA or preductally (e.g., PFO). The degree of R → L shunting may be dramatically increased by ↑ pulmonary vasoconstriction (2° ↓ PO_2 ↑ PCO_2 ↑ pH, ↑ sympathetic tone) → severe systemic hypoxemia. ↓ CO 2° persistent pulmonary HTN and hypoxemia will lead to metabolic acidosis. **Tests:** CXR; ABG; preoperative echocardiogram needed
Neurological	Myelomeningocele and/or hydrocephalus may be present. Repeated bouts of hypoxemia predispose to intraventricular hemorrhage (IVH) in preterm infant. These areas of hemorrhage have loss of cerebral autoregulation and BP increases are directly transmitted to the microvasculature, with ↑ risk of recurrent

Hematologic	hemorrhage and edema. **Tests:** Head ultrasound Hct should be maintained at 35%. HbF has $\uparrow$ affinity for O_2 and $\downarrow$ sensitivity to 2,3-DPG. This will aggravate cellular hypoxia in the patient with compromised circulatory status. Confirm that vitamin K was administered at birth. **Tests:** CBC; T&C; PT; PTT
Metabolic	Dextrose supplementation needed due to negligible glycogen stores in neonate. In patients with CHF, diuretic administration leads to $\uparrow$ K+ **Tests:** Electrolytes; glucose; BUN; Cr
Gastrointestinal	Constant NG/OG suction. Gastric distention will worsen ventilation.
Laboratory	Other tests as indicated from H&P.
Premedication	None

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Intraoperative

Anesthetic technique: GETA, using a pediatric circle. Forced air warmer. Warm room to 75–80°. Use pressure-limited ventilation (PIP < 30 cmH2O). Continue NO if administered preop. Maintain body temperature as close to 37°C as possible. Warm room to 75–80°F. Consider use of NICU ventilator, particularly if high RR (> 30/min) is required.

Induction	Transported from NICU to OR by anesthesia team. If infant is already intubated, confirm paralysis prior to transport to lessen the risk of patient movement and inadvertent extubation. Transport with full monitoring (ECG, pulse oximetry, arterial pressure tracing). Have airway equipment available (Miller 1 laryngoscope blade, ET 3.0–3.5 with stylets, neonatal mask). Resuscitation drugs (e.g., epinephrine 1 and 10 mcg/mL) should be drawn up. Syringe with NS/LR flush. Prior to any further anesthetic administration, reestablish all monitoring in OR. For nonintubated patients, rapid-sequence induction () is appropriate. Atropine (0.02 mg/kg iv) given prior to induction to counteract bradycardia. If necessary to mask ventilate, avoid high inflation pressures, as this may further dilate the bowel. Place an OG tube prior to induction. Avoid N$_2$O and maintain PIPs as low as possible. For patients with late herniations and healthy lungs, consider caudal epidural catheter advanced to thoracic space instead of iv opioids, and early extubation (OR or NICU); (see). If surgery is performed on ECMO, give high-dose iv opioids (may be given in ECMO circuit) and muscle relaxant.
Maintenance	Opiate-based anesthetic (fentanyl 10–25 mcg/kg iv total), if no epidural in place, with isoflurane supplementation. Ventilate with air/O_2 to maintain O_2 saturation 95–100%, as measured by preductal ABGs/pulse oximetry. Avoid hypoxia, acidosis, hypothermia, which will $\uparrow$ pulmonary vasoconstriction. Keep CO_2 normal or slightly $\uparrow$ (permissive hypercapnia). Continue neuromuscular blockade with pancuronium, rocuronium, or vecuronium. May need to momentarily pause surgery to restore adequate oxygenation and ventilation.
Emergence	Transport back to NICU with full monitoring, airway equipment, and drugs.
Blood and fluid requirements	Blood loss minimal IV: 22–24 ga × 2 NS/LR @ 4 mL/kg/h maintenance These infants are fluid-restricted in NICU. Continue dextrose-containing solution from NICU. If umbilical venous line not present, dopamine may be infused via peripheral iv with dextrose solution serving as the carrier fluid. In emergency, NS/LR, albumin 5%, PRBCs (Hct < 50%) may be given via umbilical artery line.
	Standard monitors (see) Right-side precordial stethoscope Arterial line (umbilical or radial - 24 ga); if Contralateral pneumothorax is detected using a right axillary precordial

Monitoring	possible, right hand (preductal) ± Umbilical vein line Preductal and postductal pulse oximetry	stethoscope. ABG, Hct, glucose q 30–60 min. Changes in pre- and postductal pulse oximetry provide early warning of R→L shunt/pulmonary HTN. (L hand postductal SaO_2 will drop with R→L shunt.
Positioning	and pad pressure points. eyes.	
Complications	Pneumothorax Hypoventilation Hypothermia Metabolic acidosis R → L shunting CHF	With acute deterioration in O_2 sat, pneumothorax on unaffected side is likely. Do not attempt to expand lungs vigorously. Hypoplasia, not atelectasis, is the primary problem. Keep PIP <30 cmH_2O, if possible.

🔻 **Postoperative**

Complications	Same as Intraoperative Complications, above.	Severely affected neonates will usually have been stabilized on high-frequency jet ventilation or ECMO. The goal is to schedule semi-elective surgery when the neonate is medically stable. In case of acute deterioration in the OR, discuss with NICU criteria for initiation of HFJV or ECMO for infants whose oxygenation continues to worsen. High-frequency jet ventilation may be an option prior to ECMO. Post-operatively, these neonates go through a "honeymoon period" of up to 24 h, after which they may develop ↑ pulmonary HTN and deteriorate clinically.
Pain management	Fentanyl (0.5–2.0 mcg/kg/h iv) Epidural analgesia	Tachyphylaxis can develop in 24–48 h.
Tests	CXR ABG Hct Glucose Electrolytes	

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Pyloromyotomy For Pyloric Stenosis

Surgical Considerations

Description: Pyloric stenosis due to idiopathic hypertrophy of the muscular layers of the antrum and pylorus occurs in infants from 1 to 3 months of age, causing projectile vomiting with subsequent dehydration and metabolic alkalosis. Surgical division of the hypertrophied fibers—**pyloromyotomy**—is the treatment of choice. Preop hydration and electrolyte replacement are becoming less frequently needed, as early Dx by ultrasound becomes more common. Aspiration (of food or barium contrast) is avoided by NG suction.

Surgical approach: The operation is performed through either a RUQ, periumbilical, or three laparoscopic incisions. The RUQ incision is now less utilized, while laparoscopic approach in experienced hands can be performed very quickly and effectively. With the open approach, the serosa and hypertrophic muscle of the pylorus are divided with a scalpel handle or Benson spreader. With the laparoscopic approach, a special bladed instrument and blunt retraction are used to perform the myotomy. The anesthesiologist is typically asked to instill 40–60 cc of saline by orogastric tube into the stomach so that leaks can be detected. Careful inspection for a mucosal tear will avoid a *(Print pagebreak 1282)* subsequent leak, the most common serious complication. Mucosal injury is treated by a simple repair or by closing the entire myotomy and creating a new one at an alternate site.
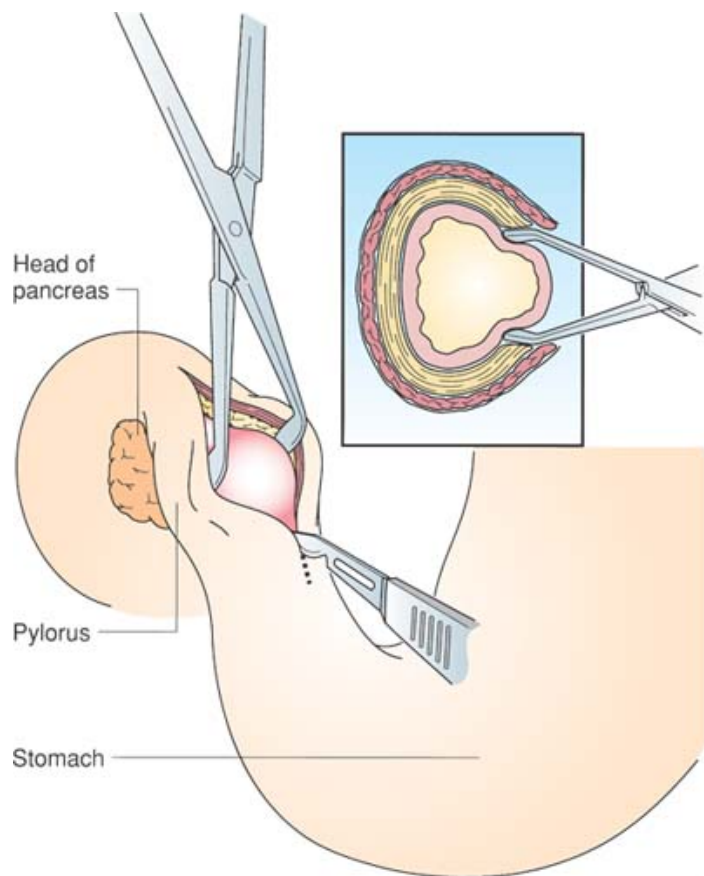
Figure 12.5-7. 7. Ramstedt pyloromyotomy for infantile hypertrophic pyloric stenosis. The cross-sectional view shows herniation of the submucosa into the myotomy site, indicative of an adequate myotomy. (Reproduced with permission from Sato TT, Oldham KT: Pediatric abdomen. In *Surgery: Scientific Principles and Practice,* 3rd edition. Greenfield LJ, Mulholland MW, Oldham KT, et al., eds. Lippincott Williams & Wilkins, Philadelphia: 2001.)

Usual preop diagnosis: Pyloric stenosis; gastroenteritis; GERD

Summary of Procedures

Position	Supine
Incision	Transverse; RUQ; periumbilical, or three laparoscopic ports
Special instrumentation	Benson pyloric spreader; arthrotome (laparoscopy)
Intraop antibiotics	Cefazolin 25 mg/kg iv
Surgical time	0.5–1 h
EBL	< 5 mL/kg
Postop care	Cardiac/apnea monitoring
Mortality	0.3%
Morbidity	Duodenal perforation Incomplete myotomy with recurrent vomiting Dehiscence Hernia
Pain score	4–5

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Patient Population Characteristics

Age range	1–12 wk

Male:Female	4:1
Incidence	3/1000 births
Etiology	Unknown
Associated conditions	Has occurred following repair of other congenital anomalies, such as esophageal atresia, omphalocele.

Anesthetic Considerations

Preoperative

Patients with pyloric stenosis are usually term infants that present in the first month of life with mild-to-moderate dehydration 2° intractable vomiting. While in past these infants usually presented with moderate to severe dehydration, diagnosis by ultrasound has led to earlier intervention, thereby minimizing the degree of electrolyte imbalance. Correction of volume deficit and metabolic abnormalities is the first line of treatment. Surgery should proceed only after patients are medically stabilized, adequate urine output is assured, and metabolic alkalosis is corrected. These procedures are usually done with laparoscopy.

Cardiovascular	Mild-to-moderate dehydration (50–100 mL/kg) is common and this deficit should be replaced with NS over 12 h. **Tests:** Urinary Cl > 20 mEq/L or plasma Cl > 100 mEq/L, when fluid volume restored.
Metabolic	Protracted vomiting → dehydration with hypochloremic hypokalemic metabolic alkalosis. Up to 30% of infants may be hyperkalemic. ↓ K^+ should be treated once alkalemia is resolved and UO is confirmed. **Tests:** ABGs; electrolytes; Ca^+; glucose
Gastrointestinal	Full-stomach precautions (see p. B-4). Prior to induction, it is necessary to pass an OG tube several times to adequately decompress the stomach.
Laboratory	Hct; other tests as indicated from H&P.
Premedication	None

Intraoperative

Anesthetic technique: GETA, using a pediatric circle. Forced-air warmer. Warm OR to 75–80° F. Use air/O_2 mixture to maintain O_2 sat @ 95–100%. Maintain body temperature close to 37°C.

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Induction	An iv catheter should be in place prior to induction for preop fluid management. Decompress stomach with NG or OG tube. Atropine (0.02 mg/kg iv, 0.1 mg minimum) commonly given before stomach decompression. Preoxygenate 2–3 min. Rapid-sequence induction with cricoid pressure should be performed, using propofol (2–3 mg/kg) or STP (4 mg/kg iv) and succinylcholine (1–2 mg/kg iv) or rocuronium (1 mg/kg). Use awake laryngoscopy if difficulty with intubation is anticipated. Intubate trachea with a appropriately sized uncuffed tube, usually 3.5 mm. Air leak should be between 20–30 cm H_2O pressure. If succinylcholine is used, further NMB with rocuronium (0.6 mg/kg) or vecuronium (0.1 mg/kg) will be necessary. If a laparoscopic technique is used, confirm adequate ventilation bilaterally after insufflation of the abdomen.
Maintenance	Volatile agent (isoflurane) and air/O_2 or N_2O/O_2 Avoid opioids to lessen risk of postop apnea due to tendency to hypoventilate due to previous metabolic alkalosis. Maintain muscle relaxation. Surgeon should infiltrate wound site with bupivacaine 0.25% (with epinephrine 1:200,000)—not to exceed 2.5 mg/kg (1 mL/kg), for postop pain relief. Rectal acetaminophen 30 mg/kg can be administered.

Emergence	Reverse NMB with appropriate agent (see p. D-3). Prior to extubation, suction stomach contents via NG/OG tube. Extubate when fully awake.	
Blood and fluid requirements	Minimal blood loss IV: 22 ga × 1 NS/LR @ (maintenance)	Minimal 3rd-space loss
Monitoring	Standard monitors (see p. D-1)	
Positioning	and pad pressure points. eyes.	
Complications	Aspiration	

◣ Postoperative

Complications	Apnea	Pulse oximetry/apnea monitor × 24 h. Differential diagnoses of apnea include hypoglycemia and hypothermia.
	Hypoglycemia (rare)	Rx for hypoglycemia: dextrose 0.5 g/kg iv
Pain management	Acetaminophen (10–15 mg/kg po, 20 mg/kg pr q 6 h prn)	For child with severe dehydration and electrolyte abnormalities, ICU admission may be necessary.
Tests	None routinely indicated.	

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Abdominal Tumor: Resection of Neuroblastoma, Wilms' Tumor, Hepatoblastoma

◤ Surgical Considerations

Description: Pediatric abdominal tumors occur most commonly in children 1–4 yr old, may be massive, and usually arise from the sympathetic chain (including adrenal gland), kidney, or liver. Neuroblastoma and Wilms' tumors are the most common; hepatic tumors (including hemangiomas) are less common but challenging. Because they originate in sympathetic tissue, many neuroblastomas produce catecholamines; however, these rarely have hemodynamic consequences.

Surgical Approach: At first operation, a central line is placed and very large neuroblastomas and hepatoblastomas are biopsied; definitive resection follows neoadjuvant therapy. Small neuroblastomas, small hepatoblastomas, and even large Wilms' tumors (without vascular extension or bilateral involvement) may be excised primarily. The principles of operation for these tumors are similar, beginning with a generous incision (transverse, midline, or thoracoabdominal), depending on tumor location and surgeon preference. The incision may be extended into the chest if control of the suprahepatic vena cava is necessary. Epidural anesthesia is ideal. Mobilization of the tumor from adjacent structures may precede vascular control when the latter is difficult to obtain early, as is often the case. Tumors encasing vessels may be divided to preserve end-organ blood supply. Neuroblastomas tend to invade local structures. Wilms' tumors and hepatoblastomas tend to push aside adjacent structures. Wilms' tumors are bilateral in 10–15% of cases and are prone to vascular extension into the renal vein, IVC, and (rarely) right atrium. Major hepatic resections are sometimes required for hemangiomas that cause CHF or thrombocytopenia (Kasabach-Merritt syndrome).

Laparoscopic assistance is limited generally to biopsy of these lesions for tissue diagnosis. Some hepatoblastomas may be amenable to laparoscopic liver resection. Small, localized neuroblastomas, and posterior mediastinal neural crest lesions are quite amenable to laparoscopic or thoracoscopic resection.

Usual preop diagnosis: Neuroblastoma; Wilms' tumor; hepatoblastoma

Summary of Procedures

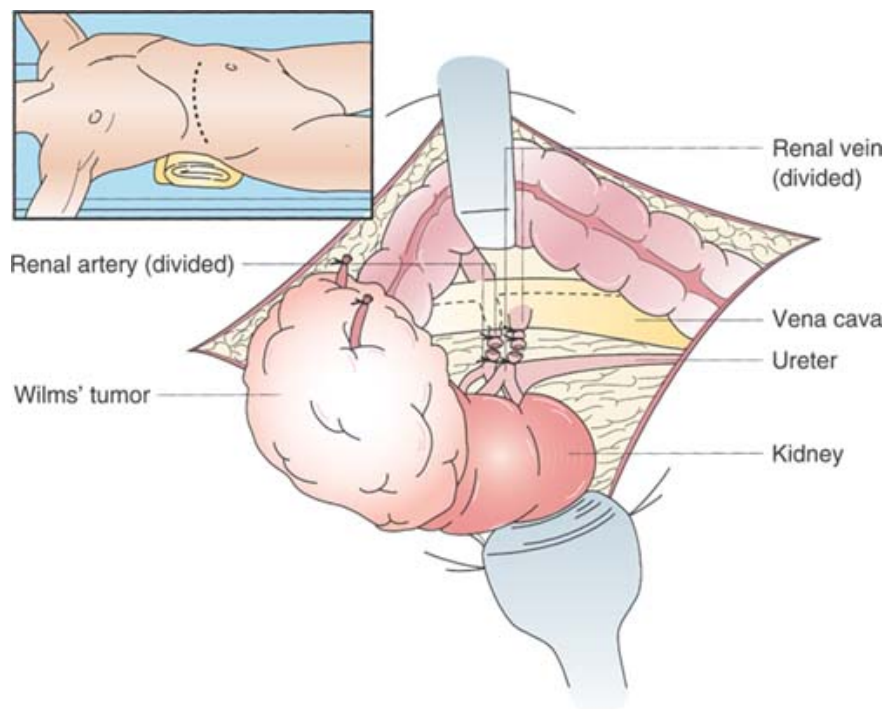|	**Neuroblastoma**	**Wilms' Tumor**	**Hepatic Resections**
Position	Supine, 15° lift		
Incision	Transverse, possible thoracic extension ([Fig. 12.5-8](#))		
Special instrumentation	None	Bypass instruments	CUSA; laser; argon beam coagulator
Unique considerations	Rarely, hormonally active; may wrap blood vessels	Atrial tumor; ivC may be obstructed →↓ ↓ CO.	Possible CHF; Plt trapping
Antibiotics	Cefotaxime 25 mg/kg		
Surgical time	3–6 h		
Closing considerations	None		Hypoglycemia
EBL	20–50 mL/kg		20–100 mL/kg
Postop care	PICU	± PICU	PICU
Mortality	< 5%		
Morbidity	Intestinal obstruction: 10% Postop respiratory atelectasis		¯ Hypoglycemia: 10% Bile leak: 5–10%
Pain score	7–8	7–8	7–8

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Figure 12.5-8. 8. Operative approach to resection of a right renal Wilms' tumor. Insert shows transverse incision. (Reproduced with permission from Laquaglia MP: Childhood tumors. In *Surgery: Scientific Principles and Practice,* 3rd edition. Greenfield LJ, Mulholland MW, Oldham KT, et al, eds. Lippincott Williams & Wilkins, Philadelphia: 2001.)

Patient Population Characteristics

	Neuroblastoma	Wilms' Tumor	Hepatic Resections
Age range	Few months—school age		
Male:Female	1:1		
Incidence	1/10,000	< 1/10,000	
Etiology	Unknown		
Associated conditions	Beckwith-Wiedemann syndrome; aniridia; hemihypertrophy; HTN (rare)	None	

Anesthetic Considerations

Preoperative

Neuroblastoma, Wilms' tumor (nephroblastoma), and hepatoblastoma commonly present as abdominal masses in infants and children < 4 yr old. Abdominal pain, fever, and → BP (2° ↑ catecholamines or renal ischemia) are often associated findings. These patients may have received chemotherapy or XRT preop, and the timing of surgery may be based on multiple factors.

(Print pagebreak 1287)

Respiratory

There may be respiratory compromise (as a result of a large abdominal mass pushing up on the diaphragm), which may worsen in the supine position. Wilms' tumor commonly metastasizes to the lungs.
Tests: CXR, if indicated from H&P.
↑ BP is associated with both Wilms' tumor and neuroblastoma,

Cardiovascular	and volume status should be assessed carefully. Tumor bulk may impede venous return by occluding the IVC. Wilms' tumor may extend through the IVC into the right atrium. These patients may have received chemotherapy, for example adriamycin or doxorubicin, which is associated with cardiac toxicity. (Most commonly at doses > 200 mg/m²). Cardiology consultation may be appropriate. **Tests:** Echocardiogram
Renal	Wilms' tumor may present with hematuria and other GU anomalies such as horseshoe kidney, duplication of urinary tract, aplastic or hypoplastic kidneys. Renal function is usually normal unless both kidneys are affected. **Tests:** BUN; Cr
Endocrine	Neuroblastomas are associated with ↑ catecholamine production. Preop adrenergic blockade (as would be required for a pheochromocytoma) is usually not necessary. **Tests:** Urine VMA and HVA
Gastrointestinal	Persistent, watery diarrhea ($\rightarrow$ hypovolemia, $\downarrow$ K⁺) is associated with neuroblastoma 2° VIP secretion. Intestinal compression from tumor may ↑ risk of gastric aspiration. A surgical bowel prep may cause additional fluid and electrolyte disturbances. **Tests:** Electrolytes
Hematologic	Severe anemia and thrombocytopenia may be present. Blood should be available because of possible massive intraop blood loss. **Tests:** CBC; T&C. availability of parental/directed donor blood, if requested. PT, PTT.
Laboratory	Other tests as indicated from H&P.
Premedication	In patients at risk for gastric aspiration, prophylaxis with ranitidine (0.8 mg/kg iv) should be considered. Patients >12 mo may benefit from midazolam (0.5–0.75 mg/kg po) 30 min. before surgery.

Intraoperative

Anesthetic technique: Combined epidural/GETA, using a pediatric circle; forced air warmer; warm OR to 75°–80F; warm all iv fluids.

Induction	IV catheter insertion before induction may be preferable. An upper extremity or EJ site is preferred due to potential for obstruction of IVC during surgery. A modified rapid-sequence induction is recommended in those patients with a large intraabdominal mass compressing the GI tract. Otherwise, standard pediatric induction (see p. D-1) is appropriate. Children < 6–9 mo may benefit from a preinduction dose of atropine (0.2 mg/kg iv) to ablate vagal response to laryngoscopy.	
Maintenance	Standard maintenance (see p. D-2). Muscle relaxation is appropriate. HTN associated with tumor manipulation can be treated with SNP (0.5–2.0 mcg/kg/min) or esmolol (50–150 mcg/kg/min). Labetalol boluses (0.1 mg/kg iv) may also be used with caution, taking into account potential for blood loss and hypotension.	
Emergence	In most instances, patient can be extubated at the end of surgery. Suction NG tube and confirm air leak around ETT before extubation. If there is no air leak, consider laryngeal edema and need for continued intubation.	
Blood and fluid requirements	Potential for large blood loss/ moderate 3rd-space loss IV: 18–20 ga × 1–2 NS/LR @ maintenance	Tumor resection may be associated with massive blood loss, especially with IVC or renal vein involvement. Avoid placement of iv catheter in lower extremities. 5% albumin may be useful to replace 3rd-space losses (8–10 mL/kg/h). Transfuse to maintain Hct > 23. If > 2 mo of age,

		dextrose-containing solutions are not required.
Monitoring	Standard monitors (see p. D-1) Arterial line: 22 ga CVP line: 4 Fr (subclavian or IJ) confirm position by CXR	ABG, Hct, blood glucose should be measured hourly. CVP measurement may be useful to evaluate fluid status. Monitor UO and keep at 1 mL/kg/h.
Positioning	and pad pressure points. eyes.	
	Hypotension	↓ BP 2° blood loss or IVC obstruction or PE
	HTN	↑ BP 2° tumor or adrenal manipulation
Complications	PE	2° tumor embolization usually from IVC →↓ BP. 45% of patients had hypotension after tumor excision, suggesting that catecholamines are present; Rx may require volume loading/pressor support
	Hypothermia Hypoventilation	Abdominal retractors and packing will interfere with ventilation.

(Print pagebreak 1288)

◤◢ Postoperative

Complications	Atelectasis Hypoventilation	
Pain management	Epidural or iv opiates Ketorolac 0.5 mg/kg iv q 6 × 2 d	See p. E-5 for dosing schedule.
Tests	Hct ABG CXR	

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Laparotomy for Intestinal Perforation, Necrotizing Enterocolitis

Surgical Considerations

Description: Necrotizing enterocolitis (NEC) is an ischemic/inflammatory condition of the entire GI tract, most commonly affecting the terminal ileum, occurring in stressed, premature infants, often after feeding with formula. It may resolve with conservative management (npo, antibiotics, NG suction) or progress to necrosis and perforation, treated by resection and stoma formation or drainage procedure, according to patient weight and surgeon preference. Isolated ileal perforation—occurring without precedent pneumatosis intestinalis—may be a different disease entity; it is sometimes treated by primary repair. Infants with NEC may be septic, thrombocytopenic, and coagulopathic, with organ dysfunction related to prematurity, and have marginal ventilation. Despite expeditious surgery, several blood volumes may be lost and hypothermia may develop. Unstable infants may have surgery performed in the NICU.

Surgical approach: If not already present, central venous access is established at the time of surgery. A transverse laparotomy incision enables inspection of all intestines; dead bowel is resected, a proximal stoma is created in the healthy bowel, and a distal mucous fistula is created to protect potentially viable bowel. Less commonly, a **Hartmann's pouch** is created (distal intestine remains inside without stoma). When proximal bowel is of intermediate viability, a second-look operation is wise.

Variant procedures or approaches: The role of **drainage procedures** is undetermined; some who advocate their use in < 1 kg neonates are less enthusiastic about larger children. The procedure involves placement of a RLQ Penrose drain into the abdominal cavity as a bedside procedure. It is quick, relatively easy, and attended by little bleeding or hypothermia. Between 60–80% of drained children subsequently will require laparotomy.

Usual preop diagnosis: Perforated NEC

Summary of Procedures

	Resection	Drainage
Position	Supine	
Incision	Transverse	RLQ
Special instrumentation	None	Penrose drains
Unique considerations	Temperature support	
Antibiotics	Ampicillin 50 mg/kg + gentamicin 2.5 mg/kg + clindamycin 10 mg/kg iv preop	
Surgical time	1–2.5 h	0.5 h
EBL	10–100 mL/kg	1–2 mL/kg

Postop care	NICU	
Mortality	20–25%	16–20%
Morbidity	Respiratory failure Sepsis Stricture Intracranial hemorrhage	
Pain score	6–7	3–4

(Print pagebreak 1290)

Patient Population Characteristics

Age range	Newborn–weeks
Male:Female	> 1:1
Incidence	5–8% NICU admissions
Etiology	Multifactorial, including intestinal ischemia; bacterial colonization; perinatal stress; immaturity; hypoxia; hyperosmolar feeding; splanchnic ischemia
Associated conditions	Prematurity (80–90%); respiratory distress; PDA

Anesthetic Considerations

Preoperative

Most (80–90%) of these patients are premature infants (< 36 wk gestational age) presenting with sepsis. Respiratory Distress Syndrome (RDS) is often present 2° prematurity of the lungs, and pulmonary insufficiency is likely present. In addition to sepsis, significant 3rd-space losses contribute to hypovolemia and metabolic acidosis. If the patient is extremely unstable, consider surgical intervention at the bedside in the NICU.

Respiratory	Premature infants are at risk for RDS. These infants are usually on mechanical ventilation with ↑ FiO_2 prior to surgery. They also are at ↑ risk for pneumonia, pneumothorax, and pulmonary edema. ventilator settings and recent ABG in preparation for OR mechanical ventilation. **Tests:** CXR; ABG
Cardiovascular	Likely hemodynamic instability 2° to sepsis and/or under-resuscitation. Inotropes. (e.g., dopamine 5–10 mcg/kg/min) may be required to maintain adequate CO. Associated cardiac anomalies (e.g., VSD, PDA) can lead to CHF, further complicating fluid management. Pulmonary overcirculation and intrinsic pulmonary disease contribute to pulmonary HTN. **Tests:** CXR; ABG; ECHO
Neurological	Intraventricular hemorrhage (IVH) may be 2° to prematurity or birth asphyxia. These hemorrhagic regions have impaired autoregulation, and wide variations in BP (20–30 mmHg) can aggravate ischemia/hemorrhage. In addition, these patients may have a seizure disorder. **Tests:** Head ultrasound, if indicated from H&P.
Renal	Presence of PDA and previous Rx with NSAID can lead to impaired renal perfusion and clearance. Aggravating factors are aminoglycoside antibiotics, sepsis, and CHF. **Tests:** BUN; Cr

Metabolic	Metabolic acidosis 2° to sepsis and/or CHF will further worsen myocardial function. Neonate has minimal glycogen stores and impaired ability to mobilize calcium. **Tests:** ABG; Ca†glucose; electrolytes
Hematologic	DIC, and associated thrombocytopenia, anemia may be present. **Tests:** CBC, PT, PTT, fibrinogen, T-antigen; availability of irradiated, washed RBCs and instrumentation (plasma can contain antibody against T-antigen that causes hemolysis).
Laboratory	Others as indicated from H&P
Premedication	None

Intraoperative

Anesthetic technique: GETA, using a pediatric circle. Warm OR to 75°–80°F. Forced-air warmer and warming pad on OR table. Use air/O_2 mixture for ventilation and maintain SpO_2 between 92–94% (PaO_2 < 70 mmHg) to minimize *(Print pagebreak 1291)* risk of retinopathy. Avoid high concentrations of O_2. Consider use of NICU ventilator if patient requires ↑ RR or ↑ PIPs. Epidural catheter insertion is not recommended in the presence of sepsis.

Induction	These patients usually are intubated. If not, intubate with full-stomach precautions (see p. B-4). Suction stomach. Give atropine 0.02 mg/kg iv (0.1 mg minimum dose) before laryngoscopy. Preoxygenate for 1 min. Miller 0/1 blade with O_2 side port, if available. Apply cricoid pressure until airway secured. ETT should have leak at 18–35 cm H_2O pressure.	
Maintenance	Opioid technique (fentanyl 10–30 mcg/kg iv total)—avoid myocardial depression from volatile agents. Avoid N_2O (↑ bowel size). Muscle relaxation required.	
Emergence	Postop ventilation generally required. Transport to NICU with full monitoring (pulse oximetry, ECG, arterial line). Have laryngoscope and appropriately sized mask and ETT available. Extra volume (albumin 5% in 20 mL syringes) may be needed during transport.	
Blood and fluid requirements	Anticipate moderate-to-large blood and fluid losses. IV: 22–24 ga × 2 (or 1 + CVP)	Neonates are usually fluid-restricted in NICU to lessen incidence of PDA. 3rd-space losses are usually significant. Rx: ↑ BP with volume before increasing dopamine. Maintain solution Hct > 35%. Albumin 5% (10 mL/kg iv) boluses as needed. Crystalloid/colloid > 100 mL/kg total not uncommon. Hct, glucose, Ca†† ABG, Plt count, PT/PTT, electrolytes q 30–60 min. I-stat if available.
	Continue dextrose-containing solution from NICU to avoid hypo-glycemia. Warm fluids.	Because of the potentially large blood loss/kg, ensure that blood replacement is available in the room, and that additional factor replacement is available on call.
Monitoring	Standard monitors (see p. D-1) A-line pref. preductal (RUE) ± CVP line 3 Fr	CUP line is not as important as arterial line for intraop care, but may be useful for administering inotropic drugs.
Positioning	eyes pad pressure points	
	Hypothermia Metabolic acidosis Hypovolemia	Aggressive volume replacement and maintaining normothermia will prevent or ameliorate metabolic acidosis. Bicarbonate replacement = base deficit × wt (kg) × 0.3.
	Hyperkalemia 2° blood products(rare)	Minimized by requesting that newest blood available be sent up. If blood is irradiated, it may need to be washed prior to

Complications

	transfusion. (check w/ blood bank for policy).
Pneumothorax	↓ O_2sats, ↓ PIPs. for mucus plugging or mainstem intubation.
Hypocalcemia	Frequent blood sampling is necessary. Rx: $CaCl_2$(10 mg/kg iv) in dilute solution via CUP line or Ca gluconate (30 mg/kg iv) via peripheral line.
Hypoglycemia	Continue 10% dextrose infusion from NICU.

◥ Postoperative

Complications	Hypovolemia due to blood loss, and 3rd-spacing Metabolic acidosis and/or sepsis Pulmonary edema Retinopathy of prematurity (ROP)
Pain management	Morphine (0.05–0.10 mg/kg iv) q 1–2 h prn or via continuous infusion for initial 24–48 h
Tests	CBC Electrolytes, Ca++, Glucose ABG CXR, if central line placed.

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Repair of Biliary Atresia and Choledochal Cysts

Surgical Considerations

Description: "Biliary atresia" is a misnomer, because the pathology seems to be an ascending progressive fibrosis of the biliary tree ultimately manifested by intrahepatic bridging fibrosis and cirrhosis. The obstruction develops postnatally, typically in an otherwise healthy 4- to 6-wk-old girl, though it may be confused with neonatal hepatitis or with the cholestasis seen in sick neonates fed intravenously. Preop studies often are not diagnostic, and there is some time pressure because of dismal surgical outcomes when a definitive operation is performed after 8–10 wk of age. **Todani** classified choledochal cysts into five types. The first type is the most common: a fusiform ballooning of the extrahepatic bile ducts often involving the gallbladder. Cysts are prone to bile stasis, obstruction, and malignant conversion in adulthood. Some are detected when they become symptomatic; an increasing number are detected on antenatal ultrasound.

Surgical approach: Following preop administration of vitamin K, operation for biliary atresia begins through a transverse RUQ incision (or laparoscopically) for liver biopsy and operative cholangiography. Ascent of contrast into the liver and descent into the duodenum excludes biliary atresia and will terminate the operation. Failure to establish patency of the biliary tree is indication to extend the incision to excise the gallbladder and extrahepatic biliary tree. In doing so, the portal vein and hepatic artery are skeletonized up to the base of the liver (called the portal or hepatic "plate.") ([Fig. 12.5-9](#)) This region is excised (attended by some bleeding) in the hope that bile will drain from the liver above into a Roux-en-Y loop of jejunum, which is sewn to the undersurface of the liver (**portoenterostomy** or **Kasai procedure**). There is currently little support for early liver transplantation. **Choledochal cyst resection** involves a smaller incision, possible cholangiogram, and dissection similar to the Kasai procedure, but only to a level above the cyst (frequently, the bifurcation of the hepatic ducts). Liver biopsy is not always required and cirrhosis is uncommon. Bleeding may result when an inflamed cyst is adherent to the portal vein or hepatic artery. The distal end of the cyst *(Print pagebreak 1293)*
is ligated, the body of it excised, and the proximal bile duct (usually the common hepatic duct) sewn to a Roux-en-Y limb of jejunum.
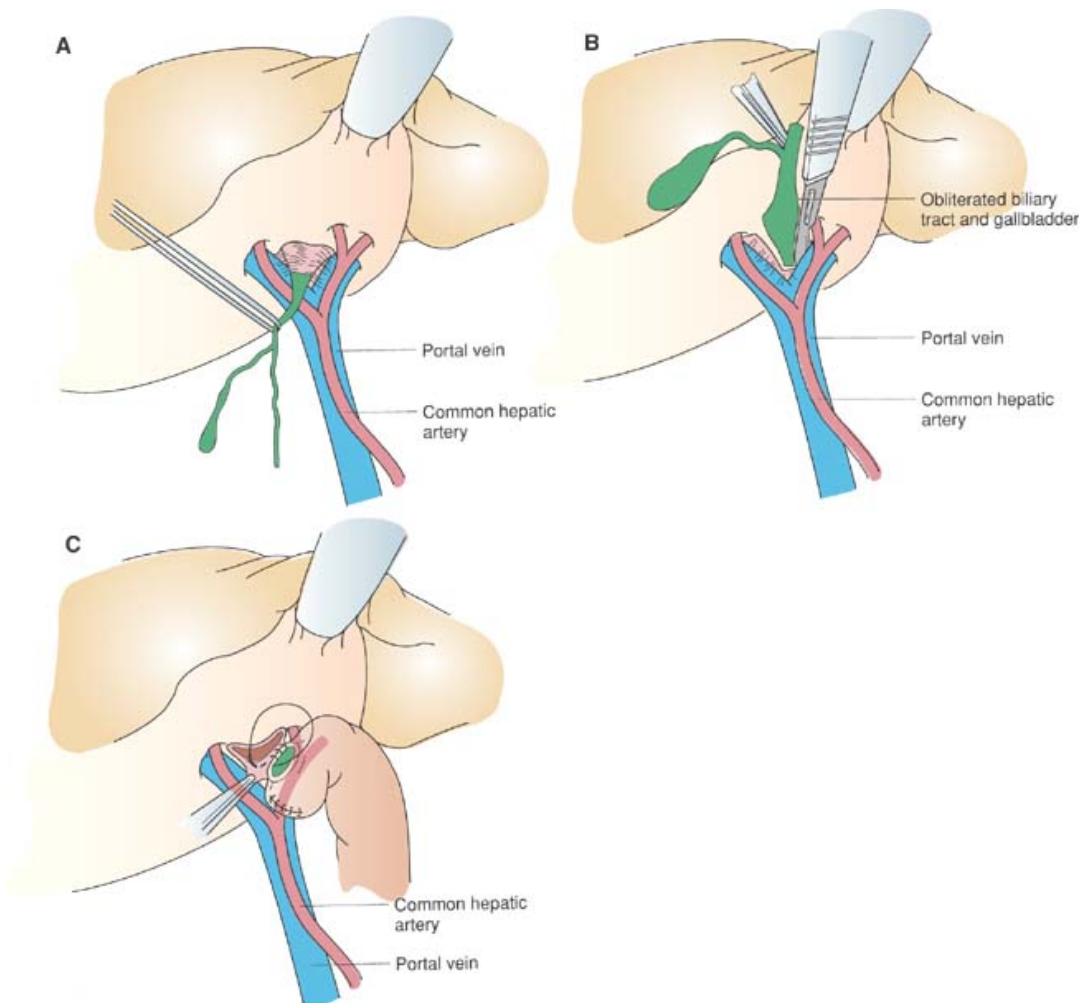

Figure 12.5-9. 9. The essential features of the portoenterostomy for biliary atresia include appropriate mobilization **(A)**

and transection **(B)** of the fibrous biliary tract remnant. **(C)** Creation of a Roux-en-Y jejunal conduit with biliary enteric anastomosis completes the procedure. (Reproduced with permission from Sato TT, Oldham KT: Pediatric abdomen. In *Surgery: Scientific Principles and Practice,* 3rd edition. Greenfield LJ, Mulholland MW, Oldham KT, et al, eds. Lippincott Williams & Wilkins, Philadelphia: 2001.)

Both operations can be performed using laparoscopy, with or without robotic assistance. Dissection is carried out laparoscopically, an Roux limb is created outside the abdomen by bringing the intestine out of an umbilical wound then replacing it back into the belly, and the final reconstruction is performed laparoscopically.

Usual preop diagnosis: Biliary atresia; choledochal cyst; obstructive jaundice

(Print pagebreak 1294)

Summary of Procedures

Position	Supine
Incision	Upper transverse-chevron; right transverse for cholangiogram
Special instrumentation	Cholangiography equipment
Unique considerations	Cholangiogram, if gallbladder patent; ↑ glucose requirement (4–8 mg/kg/min)
Antibiotics	Preop: ampicillin 25 mg/kg iv + gentamicin 2.5 mg/kg iv Intraop: cephalosporin irrigation (1 g/500 mL NS)
Surgical time	4–6 h (1–2 h if cholangiography/biopsy only)
EBL	10–20 mL/kg (5–10 mL/kg for cholangiogram)
Postop care	PICU
Mortality	< 5%
Morbidity	Bile leak: 10–15% Obstruction: 10% Sepsis: 5–10% Respiratory failure: 5%
Pain score	7–8 (4–5 for cholangiogram)

Patient Population Characteristics

Age range	6–12 wk
Male:Female	> 1:1
Incidence	1/15,000 births
Etiology	Viral; autoimmune
Associated conditions	NB: Asplenia syndrome (5–10%); polysplenia (5–10%)

Anesthetic Considerations

Preoperative

Biliary atresia is a postnatal inflammatory disorder of the hepatobiliary tree resulting in fibrosis, cirrhosis, and obstructive jaundice. The Kasai procedure is indicated if the diagnosis of biliary atresia is made in the first 3–4 mo of life. If the Kasai procedure is unsuccessful, the patient may require a liver transplant.

Gastrointestinal	Hepatic function preserved initially (i.e., normal albumin synthesis). Cholestatic jaundice usually present. There may be impaired elimination of drugs, particularly NMBs. Glucose homeostasis is usually normal.

Hematologic	Anemia 2° chronic disease. Impaired vitamin K absorption 2° lack of bile salts. Elevated PT will variably correct with vitamin K administration (phytonadione 1 mg im/iv given during the week before surgery). Have FFP available if PT not corrected after vitamin K. **Tests:** PT; PTT; CBC; T&C
Laboratory	Electrolytes: BUN, Cr, LFTs, albumin, bilirubin, direct and indirect, glucose, others as indicated from H&P. Confirm availability of blood products (PRBCs, FFP).
Premedication	None

(Print pagebreak 1295)

◆ Intraoperative

Anesthetic technique: GETA/epidural, using a pediatric circle. Warm OR to 75°–80°F; use forced-air warmer, warming pad on OR table. (Remember: majority of heat loss is radiant).

Induction	Mask induction is appropriate if no iv in place. NMB (e.g., rocuronium 0.6–1 mg/kg) to facilitate tracheal intubation, using appropriately sized ETT (usually 3.5–4.0 uncuffed ETT) (with leak at 18–35 cmH$_2$O). If coagulation factors are normal, consider epidural or caudal catheter, and advance to thoracic position.	
Maintenance	Isoflurane/air/O$_2$ no N$_2$O, to avoid bowel distention. Continue muscle relaxant to facilitate abdominal closure.	
Emergence	Patient usually extubated in OR and transported to PACU or, in the case of prolonged surgery and/or significant blood loss, to PICU with O$_2$ and monitors in place.	
Blood and fluid requirements	Moderate blood loss IV: 22 ga × 1–2 NS/LR @ 10 mL/kg/h Albumin 5%	Potential for large 3rd-space losses. Plan 10 mL/kg/h of NS/LR for replacement, and be prepared for sudden blood loss. Use albumin 5%, or NS/LR to replace blood loss; transfuse to maintain Hct > 22%. If dextrose infusion required, give 4–6 mg/kg/min.
Monitoring	Standard monitors (see p. D-1) Urinary catheter NG tube Arterial line (22–24 ga) ± CVP line	Hct, blood glucose, ±ABG q 1–2 h and pm. Maintain UO @ 1 mL/kg/h. The presence of ↑↑ BP variations with respiration is a useful indicator of hypovolemia. CVP may be indicated for intravascular volume monitoring.
Positioning	padding – heels, elbows, occiput. eyes.	
Complications	Hypothermia Hypovolemia Hypoventilation Metabolic acidosis	In upper abdominal surgery, the retractors and abdominal packing may limit diaphragmatic excursion, thus requiring higher PIP to adequately ventilate the patient. ETT leak (PIP) > 20 cmH$_2$O to ensure adequate ventilation. ETT position may also change with packing, resulting in R mainstem intubation, requiring repositioning.

▼ Postoperative

Complications	Hypovolemia Transfusion-associated disease Atelectasis	3rd-space losses continue in the immediate postop period. Postop mechanical ventilation with TV 10–

	Cholangitis	12 mL/kg and PEEP 3–5 cmH$_2$O to minimize atelectasis.
Pain management	Fentanyl (1–2 mcg/kg/iv q 1 h pm) MSO$_4$(0.05–0.1 mg/kg iv q 2–4 h prn)	Epidural analgesia if catheter in place (see p. E-5). Bupivicaine dose should be limited to 0.25–0.3 mg/kg 2° decreased hepatic clearance and serum protein binding capacity.
Tests	Hct ABG	

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Repair of Abdominal Wall Defects: Omphalocele/Gastroschisis

Surgical Considerations

Description: Omphalocele is a herniation of bowel and sometimes viscera into an enlarged umbilical cord that may be categorized as small (< 2 cm, sometimes called a 'hernia of the cord'); medium (2–5 cm defect); or giant (≥ 6 cm and containing liver). The larger the defect, the more difficult the repair for lack of skin and muscle; primary repair is virtually never possible for giant defects. Omphaloceles are associated with genetic defects (trisomy 21) and may be part of other syndromes (e.g., OEIS, pentalogy of Cantrell, which includes cardiac defects). The surprisingly tough membrane of the umbilical cord protects the intestines from

exposure to amniotic fluid. **Gastroschisis** is not associated with chromosomal anomalies or syndromes. It involves a 1–2 cm defect to the right of the umbilicus, through which bowel, and sometimes stomach or gonads, extrude and are exposed to the sclerosing effects of amniotic fluid, causing variable degrees of "peel" (bowel-wall thickening).

Surgical approach: Central venous catheter placement precedes or accompanies the initial operation. Enlargement of the defect is sometimes necessary to permit visceral reduction, provided there is sufficient abdominal domain. If not, reduction will cause bowel ischemia and respiratory embarrassment. Some surgeons will use a maximal transduced bladder or stomach pressure (20 mmHg) or maximal PIP (35 mmHg) as an indicator that primary repair is dangerous. In this case, a prosthetic abdominal wall of Silastic is created (or purchased) and applied to the edges of the defect, creating a tubular prominence called a 'silo'. In the NICU the silo is gradually reduced in size over 3–10 d, whereupon the abdomen is closed primarily (Fig. 12.5-10). Small and medium size omphaloceles are treated similarly. Return of intestinal function will take 3–7 d for omphaloceles and 1–4 wk for gastroschisis.

Variant procedures or approaches: Sutureless approaches to both gastroschisis and omphalocoele are emerging, and can be effective means of closing these defects with outstanding cosmetic results. For giant omphalocoele, sclerosing solutions (silver sulfasalazine, tincture of mercurochrome) can be applied to cause epithelialization. Many months later, the resulting unsightly bulge may be excised and closure of the abdominal defect attempted without undue respiratory or bowel compromise. Alternatively compression wraps applied around the abdomen work to reduce bowel content over a period of months. The remaining fascial defect decreases in size until it resembles an umbilical hernia, which may close spontaneously or require later minor surgical closure. With gastroschisis, sutured closure of the fascial defect is unnecessary. In cases where the bowel can be primarily reduced, the remnant umbilical cord is used as a biological dressing over the defect, and a large plastic dressing is applied (e.g., Tegaderm). The defect closes spontaneously over the ensuing weeks, and re-epithelialization occurs, as bowel function returns. For irreducible bowel, a silo is applied and sequential reduction is performed. After the bowel is reduced completely, a plastic dressing with absorbant nonstick gauze is applied and spontaneous closure *(Print pagebreak 1297)* ensues. Cosmetic results are typically superior to suture closure, and there is never a concern for high ventilatory pressures.
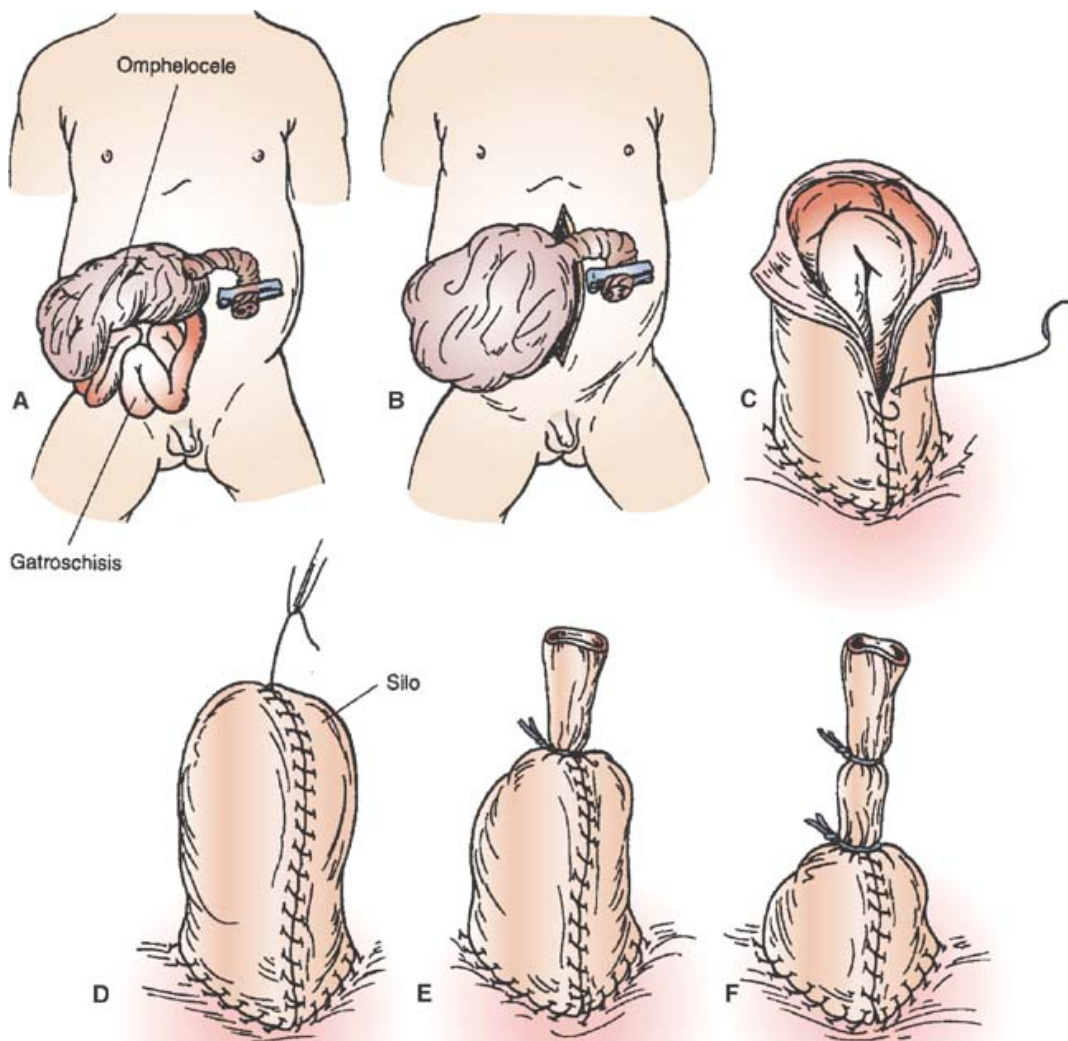
Figure 12.5-10. 10. Management of gastroschisis and omphalocele (both shown together): **(A)** Gastroschisis defect. **(B)** Extension of opening with midline incision (optional). **(C)** Use of silo if primary closure is not possible. **(D)** Finished silo. **(E, F)** Staged ligation of silo with reduction of silo contents into abdominal cavity proper. (Reproduced with permission from Oldham KT, Colombani PM, Foglia RP: *Surgery of Infants and Children.* Lippincott-Raven, Philadelphia: 1997.)

Variant procedures or approaches: Giant omphaloceles are sometimes treated without initial attempts at definitive surgery. Instead, the amniotic membrane retaining the intestinal contents is treated with daily applications of a **sclerosing solution** (silver sulfasalazine, tincture of mercurochrome). This causes the membrane to thicken and eventually epithelialize. Many months later, the resulting unsightly bulge may be excised and closure of the abdominal defect attempted without undue respiratory or bowel compromise.

Usual preop diagnosis: Omphalocele; gastroschisis; pentalogy of Cantrell; exstrophy cloaca

(Print pagebreak 1298)

Summary of Procedures

Position	Supine
Incision	Midline
Special instrumentation	None; for staged repair, reinforced Silastic sheeting or pre-made (Bentec) silo
Antibiotics	Preop: ampicillin 25 mg/kg iv + gentamicin 2.5 mg/kg iv
Surgical time	2 h
Closing considerations	Assess respiratory and cardiovascular function after muscle closure by PIP, ABG, MAP. Impaired ventilation and venous return will result from overaggressive attempts at closure.
EBL	5–10 mL/kg
Postop care	Assisted ventilation; volume support (gastroschisis)
Mortality	Omphalocele: 28% Gastroschisis: 15–23%
Morbidity	Respiratory failure Intestinal ischemia/obstruction Infection
Pain score	5–6 (primary); 4–5 (staged repair)

Patient Population Characteristics

Age range	Newborn
Male:Female	1:1
Incidence	1/3000–1/10,000 live births
Etiology	Unknown
Associated conditions	Gastroschisis: malrotation, intestinal atresia Omphalocele: cardiac, renal anomalies Trisomy 13, 18, 21 Beckwith-Wiedemann syndrome (hypoglycemia, macroglossia) Pentalogy of Cantrell: omphalocele, sternal, diaphragmatic, pericardial, cardiac anomalies Exstrophy cloaca: omphalocele, exstrophy bladder, imperforate anus

Anesthetic Considerations

Preoperative

Newborns with omphalocele/gastroschisis present for urgent surgery. The large exposed surface area of abdominal contents allows substantial evaporative heat and fluid losses. Omphalocele is associated with other congenital anomalies (e.g., VSD, Beckwith-Wiedemann syndrome [infantile gigantism, macroglossia, hypoglycemia]). The majority of these patients should be medically stabilized in the nursery before coming to the OR.

Respiratory	If premature (< 36 wk gestational age), infant is at ↑ risk for RDS and respiratory insufficiency. **Tests:** CXR; ABG
Cardiovascular	With omphalocele, there is a 20% incidence of cardiac anomalies (VSD, PDA). Check for murmur. **Tests:** ECHO for omphalocele, or if murmur is found.
Gastrointestinal	Intestinal atresia may be present. Hypovolemia from evaporative loss and under-resuscitation likely; check for evidence of dehydration, urine output, ABG. Full-stomach precautions (see p. B-4).
Endocrine	Beckwith-Wiedemann associated with hypoglycemia (term infant glucose should be > 36 mg/dL). **Tests:** Glucose; electrolytes
Laboratory	CBC; T&C; PT; PTT; UA; ABG

(Print pagebreak 1299)

Intraoperative

Anesthetic technique: GETA, using a pediatric circle; warm OR to 75°–80°F; forced-air warmer, warming pad on OR table. (Remember majority of heat loss is radiant.)

Induction	Atropine (0.02 mg/kg iv; minimum dose, 0.1 mg) is given before induction in patients < 9 mo to ablate vagal response to laryngoscopy. Pass an OG tube to decompress stomach. Assure adequate intravascular volume status (capillary refill < 2 sec; warm, pink extremities). Preoxygenate with 100% O_2 for 2–3 min. prior to rapid-sequence intubation. Propofol (2–3 mg/kg) or STP (4 mg/kg) and rocuronium (1 mg/kg) or succinylcholine (1–2 mg/kg) iv administered to facilitate tracheal intubation. Use appropriately sized ETT to keep air leak at 18–35 cmH_2O. Lower pressure air leak may make ventilation difficult if primary closure of abdomen is accompanied by significant rise in intraabdominal pressure. For small defects, place an epidural catheter inserted via the caudal or lumbar route after intubation. If positioning for the epidural catheter insertion is difficult, do not proceed; use IV Fentanyl or morphine for pain management. An epidural catheter may be placed at the end of the case for postop analgesia.
Maintenance	Avoid high FiO_2 Use air/O_2 mixture for ventilation to maintain O_2 sat 95–100% and PaO_2 < 100. If no epidural is placed, then use a primarily narcotic-based technique with fentanyl (10–25 mcg/kg iv total), low-dose isoflurane as needed. Note initial PIP prior to abdominal closure. Maintain neuromuscular blockade to facilitate abdominal closure. If an epidural catheter is available, dose with local anesthetic and opiate (see p. D-5) to supplement inhalation iv agent.
Emergence	Remain intubated postop unless defect is very small. Transport to NICU on 100% O_2
Blood and fluid requirements	Marked 3rd-space fluid loss Minimal-moderate blood loss IV: 22–24 ga × 1–2, upper extremities	Continue dextrose-containing solution from NICU. Replace 3rd-space losses (10–15+ mL/kg/h). Replace blood loss with albumin 5% and/or blood mL for mL. Maintain Hct > 30%. Lower extremities usually

	NS/LR @ 4 mL/kg/h	edematous due to abdominal venous and lymphatic compression.
Monitoring	Standard monitors (see p. D-1) Arterial line (24-ga radial)	ABG pre- and postabdominal closure. Hct, glucose, electrolytes q 60 min. CVP; reserve 1 lumen for postop TPN.
	± CVP - 3 Fr if large repair planned	Respiratory variation on arterial waveform is sensitive indicator of hypovolemia.

Positioning	Urinary catheter
	± intragastric catheter
	  and pad pressure points.
	  eyes.
		Arms positioned to have ready access to arterial line.

Complications	Hypothermia Hypovolemia Respiratory insufficiency/hypoventilation Atelectasis Volume overload/pulmonary edema	Some institutions monitor intraabdominal pressure during closure. If intragastric pressure is > 20 mmHg and CVP increases by 4 mmHg with initial primary closure, it should be converted to a staged repair. Raised abdominal pressure will cause an acute restrictive ventilatory defect and promote abdominal visceral ischemia.

(Print pagebreak 1300)

▼ Postoperative

Complications	Respiratory failure Bowel ischemia/necrosis Renal failure Peritonitis	1. Respiratory insufficiency due to raised abdominal pressure; may require release of repair and converting to a staged repair.
	Sepsis/metabolic acidosis Pneumothorax RDS Hypothermia	2. Abdominal 3rd spacing will persist in immediate postop period → ↓ intraabdominal pressure → bowel ischemia + ↓ renal perfusion. Persistent metabolic and/or respiratory acidosis mandates staged repair.
Pain management	Continuous epidural or iv infusion (see p. E-5)	
Tests	ABG Hct Glucose Electrolytes, Ca^{++}	UO maintained at > 0.5 mL/kg/h

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Pull-Through For Hirschsprung's Disease

Surgical Considerations

Description: Congenital aganglionosis, called **Hirschprung's disease** (HD), begins at the dentate line of the anus and extends proximally for a variable distance. It produces functional obstruction because the involved bowel is tonically contracted. The "transition zone" to ganglionic bowel occurs in the distal colon in 80% of cases; in 10%, it occurs in the small bowel. Sx range from mild-to-severe constipation, sometimes complicated by toxic enterocolitis. When severe, it may be life-threatening and mandates a rapid **loop colostomy**. Three classical operations (**Swenson, Soave, Duhamel**) and a newer perineal one-stage pull-through (**POOP**) were developed to remove or bypass the affected bowel (Fig. 12.5-11). Today, classic three-stage operations are being reduced to one or two stages, often assisted by laparoscopy.

Surgical Approach: Initial diagnosis is with contrast enema, followed by a transanal rectal biopsy to demonstrate absence of ganglion cells. Standard surgical approach in a neonatally diagnosed Hirschsprung's disease is now a **one-stage neonatal repair,** using a Soave or Swenson procedure, which avoids a colostomy and may be performed via a *(Print pagebreak 1301) (Print pagebreak 1302)* circumanal incision. Laparoscopy or umbilical incision is used to biopsy the colon to determine the transition zone. Once ganglionated bowel is identified on frozen section, it is pulled down to the anus by the transanal approach.
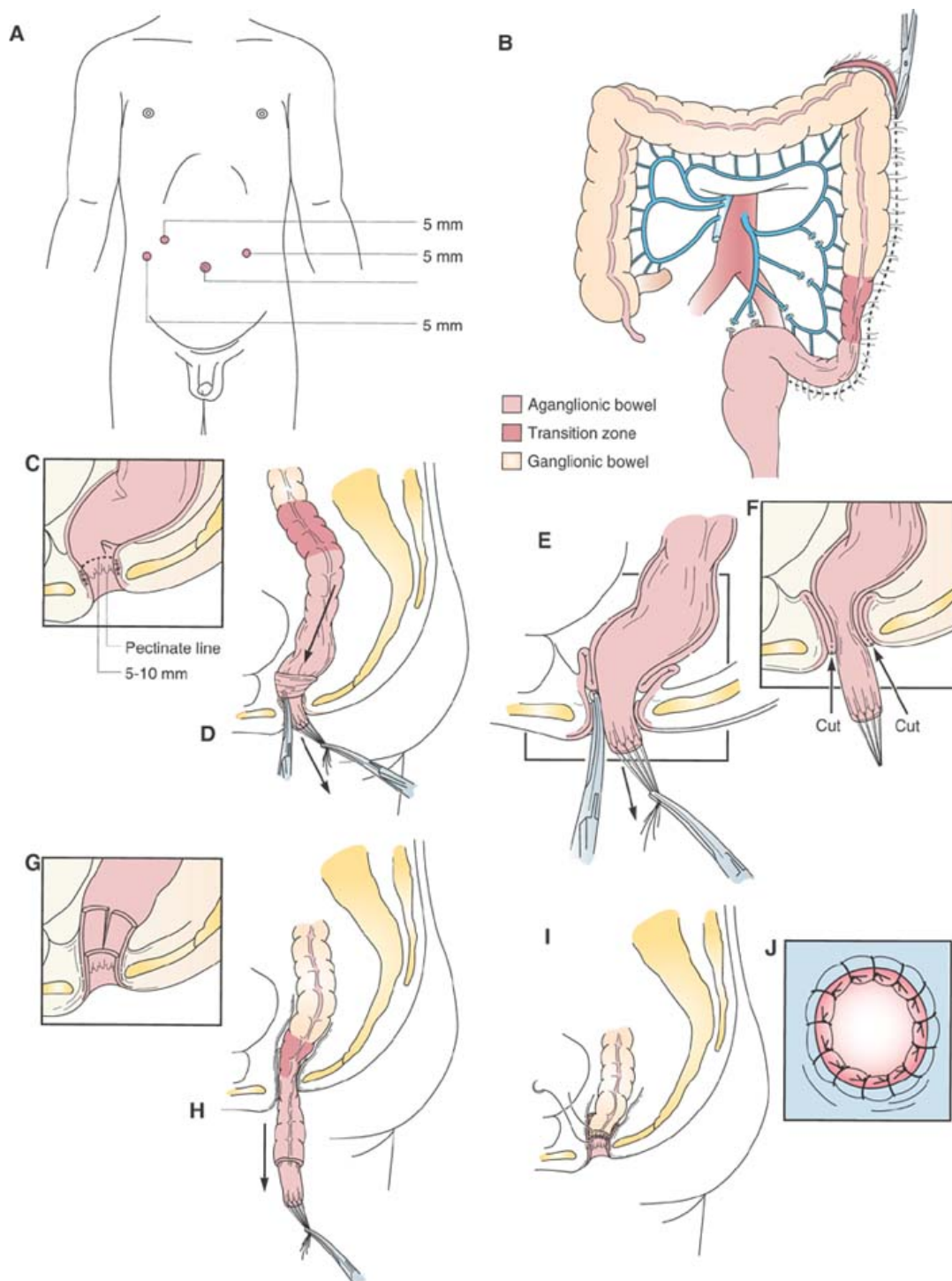
Figure 12.5-11. 11. Laparoscopically assisted pull-through for Hirschsprung's disease. **(A)** Sites for operative trocar placement. **(B)** Division of colon and rectal mesentery with mobilization of proximal colon. **(C)** Circumferential incision in rectal mucosa 5–10 mm cephalad to the pectinate line. **(D)** Mucosal traction sutures to facilitate further dissection from rectal muscular cuff. **(E)** Transanal submucosal dissection is continued cephalad to meet the caudal extent of the transperitoneal rectal dissection. **(F)** Circumferential incisions of rectal muscular cuff. **(G)** Rectal muscular cuff is split posteriorly to accommodate the pull-through segment (segment is not shown here). **(H)** Rectum and sigmoid colon are pulled through the rectal muscular cuff to the anastomotic sites. **(I)** Colon is transected at appropriate site with confirmation of ganglion cells by frozen section. **(J)** Transanal, end-to-end single layer colorectal anastomosis. (Reproduced with permission from Sato TT, Oldham KT: Pediatric abdomen. In *Surgery: Scientific Principles and Practice,* 3rd edition. Greenfield LJ, Mulholland MW, Oldham KT, et al, eds. Lippincott Williams & Wilkins, Philadelphia: 2001.)

A more traditional approach is to biopsy through a LLQ incision initially, bringing out a loop ("leveling") colostomy above the transition zone, identified using frozen sections. Subsequent definitive repair is performed when the child is larger in one stage (or two if a protective proximal stoma needs subsequent closure). Positioning depends on the approach chosen; some surgeons prefer a

lower body antibacterial preparation, others position the child in lithotomy position and prepare the abdomen and perineum. Positioning neonates transversely across an operating table rotated 90° affords good surgical access to the perineum and anesthesia access to the head. Significant bleeding is infrequent; operative time often is determined by the delay for frozen sections, which are challenging for most pediatric pathologists. Where skilled pediatric pathologists are unavailable, some surgeons will perform a RUQ transverse colostomy in the hope that the transition zone is distal to it. This is a significantly faster procedure, followed by permanent sections on which ganglia are more easily identified; it is inadequate in 10–20% of 'long-segment' patients.

Usual preop diagnosis: Hirschsprung's disease; congenital aganglionosis; congenital megacolon

Summary of Procedures

	Preliminary Colostomy	**Pull-through**
Position	Supine	Supine → lithotomy
Incision	LLQ transverse	Low transverse
Special instrumentation	None	Staplers
Unique considerations	Frozen section to confirm ganglion cells	No monitors or iv lower extremity; frozen sections
Antibiotics	Preop: ampicillin 25 mg/kg iv + gentamicin 2.5 mg/kg iv	
Surgical time	1–1.5 h	1–2 h (POOP) 3–4 h (Duhamel, Swenson, Soave)
Closing considerations	None	Reprep/drape
EBL	< 5 mL/kg	5–10 mL/kg
Postop care	Cardiac/apnea monitor	PICU
Mortality	With enterocolitis: 10% Without enterocolitis: 0–2%	< 5%
Morbidity	Prolapse Stricture Hernia	Anastomotic leak: 5% Wound infection: 4% Pelvic abscess: 3%
Pain score	4	6–7

Patient Population Characteristics

Age range	Newborn–18 mo (normally)	1 yr
Male:Female	4:1	
Incidence	1/5000	
Etiology	Unknown	
Associated conditions	Trisomy 21 (5%); GU anomalies (< 5%); neurofibromatoses	

(Print pagebreak 1303)

Anesthetic Considerations

Preoperative

Children with Hirschsprung's disease (congenital aganglionosis) may have had prior colostomies and may present for colorectal reanastomosis. They may be mildly malnourished, but otherwise healthy.

GI — Diarrhea may be present with associated malabsorption state.
Tests: Electrolytes

Laboratory	Hct; T&C
Premedication	For infants > 7–9 mo, consider midazolam 0.5–0.75 mg/kg po administered 30 min. before induction.

◆ Intraoperative

Anesthetic technique: Combined epidural/GETA, using a pediatric circle; warm OR to 75–80°F; forced-air warmer.

Induction	Mask induction is preferable, unless iv is already in place. Keep air leak around ETT to 18–35 cmH$_2$O. For more involved procedure, consider placement of epidural catheter.	
Maintenance	Low-dose volatile agent and air/O$_2$ with muscle relaxation for majority of cases. During last 30 min, N$_2$O can be substituted for air. Epidural anesthesia will provide the majority of analgesia, but not the degree of muscle relaxation that will be necessary. Supplemental muscle relaxants (e.g., pancuronium or vecuronium 0.1 mg/kg), therefore, are required.	
Emergence	The goal is to extubate at end of case. Reverse neuromuscular blockade with neostigmine (0.07 mg/kg iv) and atropine (0.02 mg/kg) or glycopyrrolate (0.01 mg/kg).	
Blood and fluid requirements	Mild blood loss IV: 20–22 ga × 1–2 in upper extremities NS/LR @ maintenance	These cases are usually not associated with large blood losses. Plan 10 mL/kg/h of crystalloid for replacement. Use 5% albumin for rapid volume expansion; transfuse to maintain Hct > 23%. As a result of bowel prep, patient may require 10–20 mL/kg iv of NS/LR to offset volume deficit.
Monitoring	Standard monitors (See p. D-1) Urinary catheter ± Arterial line (22 ga)	ABG, Hct, blood glucose prn. Maintain UO @ 1 mL/kg/h. Arterial line helpful for monitoring BP, lab draws, and presence of respiratory variations as indicator of volume status.
Positioning	padding, particularly over lateral fibular head (common peroneal nerve). eyes.	
Complications	Hypothermia Hypovolemia	Majority of heat loss is radiant (skin), but potential for large volume shifts mandates warming fluids.

◆ Postoperative

Complications	Hypothermia Hypovolemia	
Pain management	Continuous epidural	Bupivacaine +/- hydromorphone, clonidine will provide analgesia for 8–16 h (see p. E-4).
Tests	Hct if sig. blood loss	

(Print pagebreak 1304)

Suggested Readings

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Pull-Through for Imperforate Anus, Cloaca

Surgical Considerations

Description: Imperforate anus anomalies are classified as **high** or **low,** depending on whether the distal rectum ends above or below the levator muscle. Usually the rectum terminates as a "fistula" entering the perineum or pelvic structures anterior to the external anal sphincter. Rarely the rectum ends blindly, often associated with Trisomy 21. If the fistula terminates on the perineum, it is called a "perineal fistula" or "anterior anus." In girls, it often terminates inside the fourchette but outside the hymen, called a "vestibular" fistula. Fistulas to the vagina or uterus are rare; when they occur, they may be in conjunction with urethral anomalies. This combined structure—including rectum, vagina, and urethra—is called a 'cloaca.' In boys, the fistula often ends in the urethra, occasionally the prostate, and rarely the bladder neck.

Surgical approach: At birth, associated conditions (e.g., VACTERL syndrome) are excluded while one waits 24 hours for the appearance of meconium through a sometimes-hard-to-see perineal fistula. The operation is then performed according to the estimated site of the fistula. Low lesions are dilated or repaired; high lesions are treated with a divided RLQ colostomy. Definitive repair of high lesions occurs after months following contrast studies. This operation—called a **perineal sagittal anorectoplasty (PSARP)** or **Pena procedure**—is performed in the prone jackknife position. If the fistula is high, it occasionally will be necessary to turn the patient over for abdominal mobilization of the sigmoid colon.

Laparoscopic approaches are quickly replacing the PSARP, especially for high lesions. High lesions are also amenable to early **laparoscopic mobilization and pull-through.** This can be done with low fistulas as well, but dissection of the common wall between the urethra and fistula must be performed with care.

Usual preop diagnosis: Imperforate anus

Summary of Procedures

	Low Lesions	High Lesions
Position	Supine, lithotomy	Prone, possible turn to spine or lithotomy
Incision	Midline perineal	Midline sacral, transverse abdominal
Special instrumentation	Muscle stimulator	+ Urethral sound; vaginal pack
Unique considerations	None	Pressure points; prone position
Antibiotics	Preop: ampicillin 25 mg/kg iv + gentamicin 2.5 mg/kg iv	
Surgical time	1–1.5 h	3–6 h
EBL	< 5 mL/kg	5–20 mL/kg
Postop care	Apnea monitor if neonate	PICU
Mortality	20%, due to associated anomalies	≥ 40%, due to associated anomalies
Morbidity	Anal stenosis: 5–10% Mucosal prolapse: 5%	Intestinal obstruction: 5–10% Neurogenic bladder: < 5% Urethral stricture: 1–3%
Pain score	3–4	5–6

(Print pagebreak 1305)

Patient Population Characteristics

Age range	Newborn–6 mo	12–18 mo
Male:Female	1.5:1	
Incidence	1/5000	
Etiology	Unknown	
Associated conditions	CHD (common); esophageal atresia (15%); GU anomalies; sacral/spinal cord anomalies; VATER association	

Anesthetic Considerations

Preoperative

Definitive repair is performed via the sacral and/or perineal route at 12 mo. Children with rectal or anal agenesis without fistula will have had colostomies in newborn period. Other anomalies (e.g., VATER association, VSDs, vertebral anomalies, anal agenesis, tracheoesophageal fistula [TEF]), esophageal atresia (EA), and/or renal or radial bone abnormalities may be present.

Respiratory	If VATER association present, cervical spine film and neck ROM. Avoid extreme head flexion. If prior TEF repair, concerns as previously noted in Anesthetic Considerations for Repair of Tracheoesophageal Fistula/Esophageal Atresia, p. 1259. **Tests:** CXR; cervical spine film
Cardiovascular	Patients with VATER association have a 20% incidence of CHD (e.g., VSD). Obtain cardiology consultation prior to surgery. **Tests**: ECHO
Gastrointestinal	Colostomy may be present; thus, anesthesia records may be available for review.
Renal	Renal abnormalities may be present. **Tests:** BUN; Cr; electrolytes
Musculoskeletal	Radial bone deformities may be present. There is no evidence to suggest that VATER patients are at ↑ risk for malignant hyperthermia (MH).
Laboratory	Hct; T&C (parental/directed donor blood availability.)
Premedication	If > 7–9 mo, consider midazolam (0.5–0.75 mg/kg po) 30 min. prior to arrival in OR.

Intraoperative

Anesthetic technique: Combined epidural/GETA, using a pediatric circle or Bain circuit with humidified and warmed gases. Warm OR to 75°–80°F; heating pad on OR table.

(Print pagebreak 1306)

Induction	Awake intubation if airway management problems anticipated; otherwise, standard pediatric induction (see p. D-1). Secure iv access and administer muscle relaxant (e.g., vecuronium or pancuronium [0.1 mg/kg]) to facilitate ET intubation. Maintain air leak at > 15–35 cmH$_2$O. Lumbar epidural catheter inserted after induction.
Maintenance	Volatile agent/air/O$_2$ with epidural analgesia (2 mL 0.25% bupivacaine or Chirocaine @ start, 1 mL/h maintenance), or morphine (0.1 mg/kg iv) or fentanyl (2–5 mcg/kg iv). Maintain neuromuscular blockade as surgically indicated.
Emergence	Usually extubated at end of case. Reverse neuromuscular blockade with neostigmine (0.07 mg/kg iv) and atropine (0.02 mg/kg iv). Ability to flex hips is a sign of adequate

reversal.

Blood and fluid requirements	Moderate blood/3rd-space losses IV: 20–22 ga × 2 NS/LR@ maintenance	Place iv's in upper extremities, since positioning of legs may impede venous flow. Maintain Hct > 22. This age group does not require dextrose infusions. 3rd-space losses 5 mL/kg/h.
Monitoring	Standard monitors (see p. D-1) Urinary catheter ± 24 ga radial arterial line	Maintain UO @ 0.5–1 mL/kg/h. Marked arterial wave-form variation with ventilation is a sensitive indicator of hypovolemia. ABG/Hct/glucose prn.
Positioning	and pad pressure points. eyes.	Patient may be turned during procedure.
Complications	Metabolic acidosis Hypovolemia →↓ BP Hypothermia	Mild metabolic acidosis may occur with significant bleeding, or when 3rd-space losses are replaced with bicarbonate-deficient fluids (NS, albumin 5%, PRBCs).

⚠️**Postoperative**

Complications	Subglottic edema Respiratory depression 2° to opiates	
Pain management	Continuous epidural analgesia. Fentanyl (1–2 mg/kg iv q 1 h prn), Morphine (0.05–0.1 mg/kg iv q 1–4 h) Dilaudid (0.002 mg/kg iv q 1 h)	See p. E-4. Aggressive pain management warranted.
Tests	Hct ABG Electrolytes	

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(Print pagebreak 1307)

Repair of Inguinal & Umbilical Hernias, Hydrocele

Surgical Considerations

Description: Inguinal hernia repair (**herniorrhaphy**) and its variant, **hydrocele repair,** are the most frequently performed operations in pediatric surgery. Most pediatric hernias are indirect; they occur when the processus vaginalis (a small pouch of peritoneum dragged down to the scrotum during gonadal descent) fails to obliterate. Infants, particularly the premature, are more likely than toddlers to develop bilateral and incarcerated hernias. Hydroceles are identical to hernias in origin but have a smaller neck and derive their name because this neck is so small that only intraperitoneal fluid, not bowel, can pass through it. Hydroceles tend to close spontaneously (80%) during the first 2 years of life; those that fail to resolve are repaired at 2 years. Hydroceles are termed 'communicating' when they empty/fill with postural change. Umbilical hernias have a tendency to close over the first 5 years of life (95%), and are repaired when large (> 2 cm) or persistent. Complications of hernia/hydrocele repair include damage to the vas deferens or testicular vessels, metachronous contras-lateral hernias (10%) if just one side is repaired initially, and a very low incidence of infertility when bilateral repairs are undertaken. Bleeding, if any, is minor, recurrence uncommon (≥ 1%) and bowel resection is rarely necessary even when a hernia is incarcerated. Overnight admission for apnea monitoring is suggested in premature children (≥ 48–60 wk corrected age). **Hydrocele repair** complications are similar to those of herniorrhaphy. **Umbilical hernia repairs** have very few complications. Acetaminophen pr at the beginning of the procedure aids postop pain management.

Surgical approach: Inguinal hernias and hydroceles are repaired through a lower-lateral abdominal skin crease incision (more recently, laparoscopically), permitting separation of the sac from spermatic cord structures, followed by high ligation ± distal fenestration (in hydroceles). Umbilical hernia repair is performed through a transverse incision in the infraumbilical skin fold, through which the sac is resected from the undersurface of the skin and healthy fascial edges closed.

Usual preop diagnosis: Inguinal hernia; umbilical hernia; hydrocele

Summary of Procedures

	Inguinal	Umbilical
Position	Supine	
Incision	Inguinal, bilateral	Infraumbilical
Unique considerations	Prematurity	Abdominal compression if hernia large
Antibiotics	None	
Surgical time	40 min	
Closing considerations	Nerve block, caudal	Umbilical block
EBL	5 mL/kg	
Postop care	Apnea monitor; hospitalization for premature infants	None
Mortality	< 1%	
Morbidity	Apnea Recurrence	None
Pain score	3–5	3–5

(Print pagebreak 1308)

Patient Population Characteristics

Age range	Premature–adolescent	> 2 yr
Male:Female	5:1	N/A
Incidence	1–2%	1%
Etiology	Patent processus vaginalis	Persistent umbilical defect
Associated conditions	Gonadal dysgenesis (Rare)	None

Anesthetic Considerations

🔺Preoperative

Hernia repair is most commonly performed in otherwise healthy infants in the first 2 years of life, often on an outpatient basis. It is also performed on premature infants (< 36 wk gestational age at birth) and other neonates requiring intensive care. Premature infants are particularly prone to inguinal hernias. Postop apnea can occur in infants ≥ 50–60 wk postconceptual age, particularly if the infant was premature, has neurologic disease, anemia, or required intensive care in the early neonatal period. Infants ≥ 50 wk post-conception usually require overnight admission Br monitoring (post-op apnea and ↓ HR).

Respiratory	Bronchopulmonary dysplasia (BPD), tracheomalacia, and subglottic stenosis are consequences of prolonged mechanical ventilation and immature lungs at birth. prior NICU Hx. ↓ FRC and ↑ PVR make infants with this disease more susceptible to hypoxia. They may require supplemental nasal O_2 on a chronic basis. **Tests:** CXR
Cardiovascular	Prior PDA ligation is possible. These patients may be on diuretic therapy for intrinsic lung disease (e.g., BPD) with resultant decreased intravascular volume. **Tests:** CXR; electrolytes
Neurological	Premature infants may be prone to seizure disorders. Premature infants have immature respiratory centers and may exhibit paradoxical apneic/bradycardic episodes in response to hypoxemia. **Tests:** Anticonvulsant levels
Hematologic	Anemia is common at 3 mo of age (physiologic nadir) and increases risk of postop apnea.
Tests	Hct; PT; PTT; Plt, as indicated from H&P.
Laboratory	Other tests as indicated from H&P.
Premedication	If appropriate (e.g. infants > 8 mo), midazolam (0.5–0.75 mg/kg po) 30 min. prior to arrival in OR.

🔶Intraoperative

Anesthetic technique: Typically, GETA or LMA (± caudal or ilioinguinal/iliohypogastric block), using a pediatric circle. An alternative in ex-preterm infants at high risk for postop apnea is spinal anesthesia without GA (see p. E-4), though this is practice more rarely. Warm OR to 75°–80° F and use a forced-air warmer

Induction	Mask induction in children with sevoflurane/N_2O/O_2 Secure iv. If appropriate, position child for placement of caudal anesthetic: bupivacaine 0.25% ± epinephrine 1:200,000 @ 1 mL/kg. If child otherwise healthy and >18 mo old, can proceed with LMA; otherwise, tracheal intubation is preferred. If premature, consider atropine. Intubation may be facilitated with rocuronium (1 mg/kg) or vecuronium (0.1 mg/kg).
Maintenance	Standard pediatric inhalational anesthetic (see p. D-2) is appropriate. With caudal anesthetic or nerve block, decrease amount of volatile anesthetic and avoid or reduce opiates. If LMA and spontaneous ventilation is used, deepen anesthetic to 2 MAC of inhalational agents at incision to minimize risk of laryngospasm. Caudal bupivacaine onset time 15 min.
Emergence	Reverse neuromuscular blockade with neostigmine (0.07 mg/kg iv) and atropine (0.02 mg/kg iv). Extubate only when fully awake.
Blood and fluid requirements	Negligible blood loss IV: 22–24 ga × 1 NS/LR @ maintenance	Infants receiving diuretics will require 10–20 mL/kg iv of NS/LR to avoid ↓ BP 2° volatile anesthetics. In children < 1 mo old, use dextrose-containing iv solution (e.g., D10W for maintenance, LR for replacement fluids)

Monitoring	Standard monitors (see p. D-1)	Premature infants may become hypoglycemic. ↓ blood glucose during surgery.
Positioning	and pad pressure points. eyes.	
Complications	Laryngospasm Bronchospasm Local anesthetic toxicity Hypothermia Hypoglycemia	Rx bronchospasm: albuterol inhaler, mist, mask, deepen anesthesia

(Print pagebreak 1309)

▼ Postoperative

Complications	Apnea/bradycardia Subglottic edema	Can ↓ incidence of apnea/bradycardia by administering caffeine (10 mg/kg iv) intraop or in NICU/PACU.
Pain management	Field block Acetaminophen (10–20 mg/kg po q 4–6 h prn)	If no caudal used, a field block (bupivacaine 0.25% 2–3 mL) at end of surgery reduces pain in the immediate postop period. It is usually performed by the surgeon.
Tests/monitoring	Apnea monitor and pulse oximeter for 12–18 h for: all patients < 44 wks, born before 37 wks with current age <52 wks; and premature infants <60 wks	Caffeine is no substitute for monitoring and attentive parents/nurses.

Suggested Readings

1. Beckerman RC, Brouillette RT, Hunt CE, eds: *Respiratory Control Disorders in Infants and Children.* Williams &Wilkins, Baltimore: 1991, 161–77.

2. Cote CJ, Zaslavsky A, Downes JJ, et al: Postoperative apnea in former preterm infants after inguinal herniorrhaphy. A combined analysis. *Anesthesiology* 1995; 82(4):809–22.

3. Hanallah RS, Welborn LG, McGill WA: Postanesthetic apnea in full-term infants. *Anesthesiology* 1994; 81(1):264–5.

4. Rescorla FJ: Hernias and umbilicus. *In Surgery of Infants and Children*
. Oldham KT, Colombani PM, Foglia RP, eds. Lippincott-Raven, Philadelphia: 1997, 1069–82.

5. Stehling L, ed: *Common Problems in Pediatric Anesthesia,* 2nd edition. Mosby-Year Book, St. Louis: 1992, 69–85.

6. Walther-Larsen S, Rasmussen LS: The former preterm infant and risk of post-operative apnoea: recommendations for management. *Acta Anaesthesiol Scand* 2006; 50(7):888–93.

7. Welborn LG, Greenspun JC: Anesthesia and apnea. Perioperative considerations in the former preterm infant. *Pediatr Clin North Am* 1994; 41(1):181–98.

(Print pagebreak 1310)

Surgery for the Undescended Testicle

Surgical Considerations

Description: Also called "cryptorchidism," this occurs when a testicle fails to follow the usual pattern of descent. Testicles begin fetal life just inferior to the kidney and, through differential growth, migrate to the base of the ipsilateral hemiscrotum, attached there by the gubernaculum. Problems occur when testicular descent does not occur, occurs partially, or occurs incorrectly. Testicles that are found in the abdomen, inguinal canal, perineum, thigh, suprapubic fat, or contralateral scrotum may be associated with subsequent problems, including infertility and malignant degeneration. Transposition and fixation of the testicles into their normal location (**orchidopexy**), does not eliminate these problems; rather, it places the testicle in a position where it can be more easily evaluated and may mitigate the progressive infertility thought to occur when testicles remain outside the scrotum. Because testicular descent is a dynamic process, cryptorchidism is not addressed until 18–24 mo of life, because a significant portion of initially cryptorchid testes will descend into the scrotum during this time.

Surgical approach: The operation begins in a similar fashion to a hernia repair, as 95% of cryptorchid testes have an associated hernia sac. One exception is if the testicle is thought to be **intraabdominal.** In this circumstance, many surgeons will begin with a laparoscopic abdominal examination, using the vas deferens and testicular vessels to locate the testis. If it is high in the abdomen, it may be brought immediately to the perineum (difficult if the testicular vessels are short), or a two-step **Fowler-Stevens** approach is undertaken. In this approach, the gubernacular vessels supplying the inferior pole of the testis are encouraged to hypertrophy by division of the spermatic vessels, and the testicle is left in the abdomen near the internal ring. At a second operation   6 months later, the testicle is brought down, much as in the primary operation following hernia repair. This involves creation of a passage down to the base of the ipsilateral hemiscrotum, through which the testicle is advanced as far as the vas deferens permits. The tough outer layer of the testicle—the tunica albuginea—is then attached to the scrotum in a subcutaneous pocket outside the dartos fascia to discourage migration back up to a high location. There is scant blood loss; however, there is a small risk to testicular viability. Small, high, abnormal testes with short vessels and vas associated with poor gubernacular vessels are deemed better removed than left in a high location where malignant degeneration might go undetected. A caudal block may be preferable to injection of local anesthesia at multiple sites.

Usual preop diagnosis: Undescended testicle; cryptorchidism

Summary of Procedures

	Orchidopexy	First of Two-stage Repair
Position	Supine	
Incision	Lower groin crease	Laparoscopic or open
Special instrumentation	–	One to three ports if laparoscopic
Unique considerations	Length of vas and vessels	Length of vas deferens
Antibiotics	None	
Surgical time	1–1.5 h	30 min
EBL	< 5 mL/kg	
Postop care	Home	
Mortality	< 1%	
Morbidity	Bleeding Orchiectomy	
Pain score	4–5	2–3

(Print pagebreak 1311)

Patient Population Characteristics

Age range	18–24 mo
Incidence	1/2000 births
Etiology	Unknown
Associated conditions	Prematurity; gastroschisis; intersex anomaly; Turner's syndrome (potential for airway, cardiac, and renal problems)

Anesthetic Considerations

See [Anesthetic Considerations for Pediatric Urology, Inguinoscrotal Procedures, p. 1339](#).

Suggested Readings

1. Kogan SJ, Gill B: Cryptorchidism and pediatric hydrocele/hernia. In: *Glenn's Urologic Surgery,* 5th edition. Graham SD Jr. Glenn JF, eds. Lippincott Williams & Wilkins, Philadelphia: 1998; 833–42.

2. Rozanski TA, Bloom DA: Male genital tract. In: *Surgery of Infants and Children: Scientific Principles and Practice.* Oldham KT, Colombani PM, Foglia RP, eds. Lippincott-Raven, Philadelphia: 1997, 1550–2.

3. Thorup J, Haugen S, Kollin C, et al: Surgical treatment of undescended testes. *Acta Paediatr* 2007; 96(5):631–7.

Resection of Sacrococcygeal Teratoma

Surgical Considerations

Description: Occasionally during gestation, a group of cells composing all three germ layers segregates and begins autonomous development as a teratoma. When this occurs just anterior to the coccyx, the tumor may remain small and local, or grow up into the abdomen or down into the peritoneum, attaining sizes as large as the child itself. Although a few centers attempt fetal surgery for very large lesions, in most hospitals the child is delivered by the appropriate route (cesarian delivery for large external lesions) and the mass is addressed in the neonatal period or whenever it is diagnosed thereafter. Most (though not all) sacrococcygeal teratomas (SCTs) are initially benign; however, they may soon transform into malignancy beginning at 2 months of age.

Surgical approach: Small teratomas are approached prone from the rectum; larger ones, with high blood flow, may first have an intraabdominal procedure to ligate feeding vessels and mobilize the tumor. Once prone, a V-shaped incision is created down to the posterior aspect of the anteriorly displaced anus. Surgical principles of dissection include avoiding entry into the rectum (a colostomy is rarely necessary); meticulous hemostasis, including ligation of the median sacral artery; and removal of the coccyx, from which the tumor arises and may recur. At the end of the procedure, the levator muscles are brought together and the anus is suspended from the presacral fascia. Bleeding can be massive, and adjacent structures (bowel, bladder, and presacral nerve plexus) are distorted and prone to injury.

Usual preop diagnosis: Sacrococcygeal teratoma.

Differential diagnosis: May appear similar to meningomyelocele.

Summary of Procedures

Position	Prone, sometimes preceded by supine
Incision	Perineal chevron, sometimes preceded by transverse abdominal
Special instrumentation	Hegar dilators
Unique considerations	Intraabdominal blood supply
Antibiotics	Ampicillin 25 mg/kg and gentamicin 2.5 mg/kg
Surgical time	2–5 h
Closing considerations	Extubation depends on duration and blood loss
EBL	20–80 mL/kg
Postop care	NICU, prone
Mortality	Fetal, due to hydrops and high flow state; < 10% neonatal Bleeding

Morbidity	Colostomy Pelvic nerve damage → bowel and bladder dysfunction Recurrence and/or malignant degeneration

(Print pagebreak 1312)

Patient Population Characteristics

Age range	1–2 mo
Male:Female	1:1
Incidence	1/15,000 births
Etiology	Unknown
Associated conditions	Constipation; heart failure; Currarino's triad; malignant degeneration

Anesthetic Considerations

Preoperative

Sacrococcygeal teratoma is a rare tumor of infancy. Sometimes diagnosed prenatally, it also can present as late as 18–24 mo. Patients may present with urinary obstruction by the tumor mass; lower extremity pain, numbness, or weakness; or bowel obstruction.   10% may have a sacral anomaly or myelomeningocele.

Respiratory	There may be respiratory compromise as a result of a large abdominal mass pushing up on the abdominal contents and the diaphragm. **Tests:** CXR, if indicated from H&P.
Cardiovascular	Sacrococcygeal teratoma may be associated with high-output cardiac failure due to AV fistulae within the tumor. Consultation with a cardiologist may be appropriate. **Tests:** ECG; ECHO may be necessary.
Renal	Postrenal obstruction may compromise renal function. **Tests:** BUN; Cr
Gastrointestinal	Intestinal compression by the tumor may cause ↑ risk of gastric aspiration. **Tests:** Electrolytes
Hematologic	This tumor may be associated with coagulopathy. **Tests:** PT; PTT; INR
Laboratory	Other tests as indicated from H&P.
Premedication	In patients at risk for gastric aspiration, prophylaxis with metoclopramide (0.1 mg/kg iv) and ranitidine (0.8 mg/kg iv) should be considered. Patients > 10 mo may benefit from midazolam (0.5–0.75 mg/kg) po 30 min. before surgery. If iv is present, iv midazolam 0.05–0.1 mg/kg may be used (e.g., for 10 kg child, 0.5–1 mg midazolam).

(Print pagebreak 1313)

Intraoperative

Anesthetic technique: GETA, using a pediatric circle; warm OR to 75–80°F; warm all iv fluids. Due to risk of coagulopathy and the possibility of spine malformations, epidural catheter usually is not considered.

Induction	Usually an inhalation induction. If an iv is present, then an iv induction is performed. A modified rapid-sequence induction is recommended in those patients with a large intraabdominal mass compressing the GI tract. Otherwise, standard pediatric induction (see p. D-1) is appropriate. An uncuffed tube normally is used. The appropriate size for the ETT is one that will allow a small leak around the tube when positive pressure is applied (18–35 cmH$_2$O).	
Maintenance	Standard maintenance (see p. D-3). Muscle relaxation is appropriate.	
Emergence	Depending on blood loss and fluid requirements, the patient may need to remain intubated at the end of the procedure. If extubation is elected, suction NG and confirm air leak around ETT before extubation. If there is no air leak, consider laryngeal edema and the need for continued intubation.	
Blood and fluid requirements	Potential for massive blood loss. IV: Two large-bore iv catheters (e.g., 22–18 ga)	Tumor resection may be associated with massive blood loss, due to large pelvic venous bed, AV fistula, coagulopathy. Close monitoring of Hct is necessary, along with correction of acidosis and Ca^{++} replacement.
Monitoring	Standard monitor (see p. D-1) Central line Arterial line (22 ga)	

⚠️**Postoperative**

Complications	Bleeding Coagulopathy Hypoventilation Laryngeal edema	PICU usually required. Maintain normothermia; correct metabolic acidosis. Postop ventilation requirement due to hypoventilation, laryngeal edema.
Pain management	Fentanyl 1 mcg/kg/h iv Morphine 0.1 mg/kg/h	Approximate doses; titration required.
Tests	ABG Hct PT/PTT	

Suggested Readings

1. Cowles RA, Stolar CJ, Kandel JJ, et al: Preoperative angiography with embolization and radiofrequency ablation as novel adjuncts to safe surgical resection of a large, vascular sacrococcygeal teratoma. *Pediatr Surg Int* 2006; 22(6):554–6.

2. Robinson S, Laussen PC, Brown TCK, et al: Anaesthesia for sacrococcygeal teratoma–a case report and a review of 32 cases. *Anaesth Intens Care* 1992; 20:354–86.

3.
Sasaoka N, Kitamura S, Kninouchi K, et al: Perinatal and perianesthetic management of the sacrococcygeal teratoma in a neonate. *Masui* 1998; 47(12):1482–5.

Anesthesia for Minimally Invasive Surgery in Pediatric Patients

Gregory B. Hammer

In recent years there has been a significant increase in the practice of minimally invasive surgery in pediatric patients. Specific considerations for these surgeries (as in adult patients) include the effects of pneumoperitoneum *(Print pagebreak 1314)* on respiratory and cardiac function. ↑ abdominal pressure →↓ diaphragmatic excursion, ↑ atelectasis, and V/Q mismatch. ↑ CO$_2$ levels can be difficult to control with mechanical ventilation; thus, manual ventilation may be necessary. There is risk of pneumothorax and pneumomediastinum. Use of Trendelenburg position further decreases FRC and lung compliance, and increases the work of

breathing. Cephalad movement of the carina may cause endobronchial intubation. Venous return may be impaired, causing ↓ CO. These effects are most pronounced in children < 6 months old. These children also may be at risk for reversal of L → R shunts through a patent foramen ovale (PFO) or ductus arteriosus.

Minimally invasive procedures that are frequently performed in pediatrics include: appendectomy, pyloric stenosis, hernia repair, Nissen fundoplication, cholecystectomy, splenectomy, laparoscopically assisted bowel resection, thoracoscopy (VATS), and congenital diaphragmatic hernia repair. The general principles for anesthesia for minimally invasive surgery in pediatric patients are as follows:

Preoperative

1. Be vigilant about respiratory and cardiac function. Note baseline lung function (SaO_2, CXR, ABG);   for any cardiac defects (e.g., L → R shunt, ↓ CO).

2.   PT/PTT if epidural is considered (usually not placed for laparoscopy or thoracoscopy, but it should be considered at the end of the procedure if the decision is made to do open surgery).

3. Blood should be available for major cases including VATS for empeyema. Although there usually is little blood loss with minimally invasive surgery, the potential for large-vessel disruption exists.

Premedication	In patients at risk for aspiration, prophylaxis with ranitidine (0.8 mg/kg iv) should be considered. Patients > 7–9 mo may benefit from midazolam (0.5–0.75 mg/kg po) 30 min before surgery.

Intraoperative

Anesthetic technique: GETA, using a pediatric circle; forced-air warmer; warm OR to 70–75°F; warm iv fluids.

Induction	Inhalation induction using sevoflurane, N_2O, followed by iv placement. If patient is at risk for aspiration, rapid-sequence induction is appropriate. For ET intubation in children < 6–8 yr of age, an uncuffed tube is preferred, with the goal being to attain a seal allowing for a leak of 18–35 cmH$_2$O. A cuffed tube (usually a half size smaller than the appropriate uncuffed tube) also may be used for children > 2 yr old. If OLV is required, see [Anesthetic Considerations for Pediatric Thoracic Surgery p. 1267](#), for placement. Note distance of end of ETT from carina. As abdominal girth is increased during CO_2 insufflation, it is common for the tube to advance to an endobronchial position.
Maintenance	Standard maintenance (see [p. D-3](#)). Muscle relaxation is appropriate. An OG tube is placed to empty the stomach of any residual premedication and excess air introduced during PPV. Continued communication between anesthesiologist and surgeon is essential. Pay attention to changes in positioning (e.g., Trendelenburg), intraabdominal pressure (n1= 15 cmH$_2$O), airway pressures, BP.
Emergence	In most cases, the patient can be extubated at the end of surgery.
Blood and fluid requirements	IV: 22–20 ga catheter × 1 Maintenance fluids	Potential for 3rd-space and blood loss, especially with VATS surgery for empyema.
Monitoring	Standard monitors (see [p. D-1](#)) ± Arterial line Urinary catheter	Consider arterial line if patient has significant cardiac or respiratory compromise.
Positioning	and pad pressure points. eyes.	
Complications	↑ CO_2 (40–50 mmHg) (common) ↑ PIP (common) Endobronchial intubation (common) Difficult ventilating (common)	2° Trendelenburg position, ↑ abdominal girth. In thoracoscopy, if SLV is used, may need to raise lung and ventilate transiently.

Hypovolemia		$\rightarrow \downarrow$ CO. Rx: crystalloid or albumin 10–20 mL/kg.
Pneumothorax		
Pneumomediastinum (rare)		
Inadvertent cannulation of vessel (rare)		CO_2 embolus (rare)

(Print pagebreak 1315)

Postoperative

Complications	Respiratory function impairment Bleeding Residual subcutaneous CO_2 Pneumothorax	Respiratory function may still be significantly impaired in the postop period and should be monitored closely.
Pain management	Ketorolac 0.5 mg/kg iv q 6 h MSO_4 0.05–0.1 mg/kg	If significant intraoperative bleeding, avoid ketorolac for 24 h post-op

Suggested Readings

1. Bissonnette B, Dalens BJ: *Pediatric Anesthesia.* McGraw-Hill, New York: 2002.

2. Cote CJ, Todres ID, Ryan JF, et al: *A Practice of Anesthesia for Infants and Children.* WB Saunders, New York: 2001.

3. Gregory GA: *Pediatric Anesthesia,* 4th edition. Churchill Livingstone, New York: 2002.

4. Pennant JH: Anesthesia for laparoscopy in the pediatric patient. *Anesth Clin North Am* 2001; 19(1):69–88.

5. Wedgewood J, Doyle E: Anesthesia and laparoscopic surgery in children. *Pediatric Anesthesia*. 2001; 11:391–9.

Ex Utero Intrapartum Treatment (Exit) Procedure

Surgical Considerations

Description: The EXIT (Ex Utero Intrapartum Treatment) strategy was developed as a means of establishing an airway after iatrogenic occlusion of the fetal trachea to promote lung growth for fetuses with severe congenital diaphragmatic hernia (CDH). The EXIT strategy can be viewed as a "half" delivery in which a **hysterotomy** is performed, only the head and shoulders are "delivered", and uterine relaxation is maintained by high concentrations of an inhalational anesthetic and intravenous tocolytics, ensuring the maintenance of uteroplacental blood flow and gas exchange. Using this strategy, operations as long as 3 hours on uteroplacental "bypass" have been performed without significant maternal bleeding and uterine contraction. It provides time to perform procedures such as direct laryngoscopy, bronchoscopy, tracheotomy, arterial and venous access, administration of surfactant, resection of neck or lung masses, and cannulation for ECMO (extracorporeal membrane oxygenation) support, thereby converting a potential emergent crisis into a controlled situation.

Surgical Technique: A successful EXIT procedure is a carefully orchestrated event in which all members of the OR team have specific roles and responsibilities. The scrubbed personnel consist of two pediatric/fetal surgeons, a maternal-fetal medicine specialist/obstetrician, a pediatric anesthesiologist, a neonatologist, and a nurse. Unlike the EXIT procedure, a conventional Cesarean delivery makes no attempt to prevent bleeding from the hysterotomy since hemostasis is achieved by return of uterine tone following the relatively rapid delivery of the fetus. Because of the significant hemorrhage from a conventional hysterotomy, the EXIT procedure is carried out using a **hemostatic *(Print pagebreak 1316)* uterine stapling device** (US Surgical CS 57, US Surgical/Tyco, Norwalk, CT). First, a low transverse skin crease incision is used. The decision to use a Mallard versus Pfannenstiel fascial incision is determined by uterine size (e.g. presence/absence polyhydramnios) and placental position. If the operation is performed in the late 3rd trimester and the placenta is posterior or fundic, the lower uterine segment can be opened and the uterus left in situ. An anterior or previa placenta often necessitates moving the uterus out of the abdomen/pelvis. The hysterotomy in this situation is not in the lower uterine segment. Intraop ultrasonography is critical to map placental position. If polyhydramnios is

present, amnioreduction is performed to avoid underestimation of the proximity of the placental edge to the hysterotomy. Two applications of the uterine stapler are usually necessary for an adequate opening. Bleeding often occurs where the staple lines fail to intersect and is easily controlled with suture ligation. Only the necessary fetal parts are delivered in order to maintain uterine volume and avoid vigorous contractions and placental separation. A **sterile pulse oximeter** is attached to the palm of the fetal hand. It is covered with foil and Tegaderm tape to prevent aberrant readings due to the operating room lights. The long oximeter cord is passed across the field to the anesthesiologist. The fetal eyes are covered with a warm wet laparotomy pad. The fetus is continuously bathed in warm saline. Care is taken not to manipulate or unnecessarily expose the umbilical cord in order to avoid spasm of the vessels. Sterile instruments that need to be available include a laryngoscope with at least two different sized blades and extra bulbs (batteries are not sterilized and are inserted separately), two sizes of a rigid bronchoscope, a light cord, various endotracheal (some with surfactant adapters) and tracheostomy tubes, endotracheal tube stylettes, a hand bag device with a manometer and sterile tubing that is passed off the field to an oxygen source, a sterile neonatal stethoscope, and a sterile syringe filled with surfactant (if necessary). IV access is obtained if possible. Alternatively, a mixture of fentanyl, and a NMB agent such as pancuronium can be administered im (deltoid) to the fetus immediately after the hysterotomy. After the airway is obtained and secured, the umbilical cord is clamped and divided and the child taken to the resuscitation table by the neonatologist. The placenta is delivered and the uterus closed in the standard fashion. Oxytocin is administered immediately prior to clamping the umbilical cord to enhance uterine tone.

Indications: Clinical situations in which the fetal airway or cardiovascular well-being is significantly threatened by conventional Cesarean or vaginal delivery are candidates for the EXIT strategy. Some examples are:

- Intrinsic laryngotracheal anomalies resulting in congenital high airway obstruction syndrome (CHAOS): laryngeal web/atresia/cyst/stenosis, tracheal stenosis/atresia

- Extrinsic airway compression: cervical teratoma/lymphangioma (may or may not result in CHAOS)

- Epignathus

- Severe hydrops from a cystic adenomatoid malformation of the lung after 32 weeks gestation

- EXIT to ECMO for severe CDH with congenital heart disease

- Delivery of thoracoomphalopagus twins

- Delivery of twins discordant for a potentially obstructing neck lesion

Summary of Procedures

Position	L uterine displacement
Incision	Low transverse
Special Instructions	Fetal monitoring
Unique Considerations	Need to maintain uterine relaxation
Child	Fetal hypoxia, bradycardia
Antibiotics	Cefazolin 1 gm iv
Surgical Time	2 h
Closing Considerations	Extubation
Post-operative care	Variable–moderate
Mortality	Rare
Morbidity	Risk of hemorrhage

(Print pagebreak 1317)

Sterile Equipment (on surgical field)

ETT	2.5, 3.0, 3.5 uncuffed, and available stylets
Laryngoscopes and blades	Miller 0,1 Wis-Hipple 1,1.5
LMA	1, 1.5

Suction catheters	6 Fr, 8 Fr
Other	Mask, capnograph tubing, oral airways, umbilical tape, steri strips, stethoscope

Non-sterile equipment Readily Available

Fiberoptic bronchoscope	appropriate for neonatal airway
Ambu-bag	
Additional oxygen source	

Maternal Risks and Outcomes: The most serious and immediate maternal risk during the EXIT procedure is **intraop hemorrhage**. This may result from **uterine atony**, and can be minimized by decreasing the concentration of the inhalational anesthetic and administering oxytocin before umbilical cord ligation. This, in combination with the hemostatic uterine stapling device, has kept the average maternal blood loss well within the accepted range for traditional Cesarean delivery. In addition, **placental injury** may occur during hysterotomy, resulting in hemorrhage. This has occurred in the setting of polyhydramnios, in which the edge of the placenta was compressed, obscuring it from view by the ultrasonographer. It is advisable to perform intraop amnioreduction in cases with severe polyhydramnios with a potentially nearby placenta before performing an EXIT procedure to allow better placental visualization. In one study, the short-term maternal outcomes after 34 EXIT procedures were compared to those from 52 non-laboring patients who underwent non-emergent primary cesarean delivery of singleton fetuses. The rates of chorioamnionitis and endometritis, and the postop hematocrit and hospital stays were similar between groups. The incidence of **wound infection** was increased in those undergoing EXIT procedure (15%) compared to controls (2%).

Lower uterine segment transverse hysterotomy is preferred for the EXIT procedure as it allows the possibility of future vaginal delivery. However, a low anterior placenta or an extremely large neck mass may make this incision impossible. In such cases, a classical hysterotomy is necessary which would preclude future vaginal deliveries because of the risk of uterine rupture during labor. Thus, all pregnant women should be counseled that Cesarean delivery may be required for all future pregnancies and that there is an increased risk of abnormal placentation with subsequent pregnancies.

Anesthesia Considerations

The features which distinguish the EXIT procedure from a conventional Cesarean delivery are, in large part, due to the anesthetic management. Of paramount importance is the uterine relaxation achieved with an inhalational agent, most commonly isoflurane. Isoflurane has been administered in concentrations up to 2.5% to completely anesthetize the fetus in order to allow fetal laryngoscopy, bronchoscopy, tracheostomy or tumor resection. Preservation of uteroplacental gas exchange with high concentrations of maternal isoflurane is well tolerated by the fetus for EXIT procedures lasting up to 180 min. Careful attention to the maintenance of maternal systemic blood pressure, often with the use of phenylephrine and ephedrine, is essential in order to safely use the high concentration of isoflurane required for uterine relaxation. Intraop fluid administration is kept to an absolute minimum 2° the postop predisposition to maternal pulmonary edema while on tocolytic agents. Occasionally, additional uterine relaxation is required, even when the end-tidal isoflurane concentration is ≥ 2.5%. This suggests that extensive manipulation of the uterus, (e.g., forward displacement of the uterus to perform a posterior hysterotomy because of an anterior placenta), may stimulate the uterus to contract, even if high concentrations of isoflurane are used. For this situation, the intraop use of nitroglycerine provides excellent temporary uterine relaxation and is well-tolerated. Pulmonary edema does not occur as a result of intraop intermittent dosing of nitroglycerine when it is used as an adjunct for uterine relaxation.

(Print pagebreak 1318)

Preoperative

Conduct a rigorous preop evaluation of the mother, including CV history; evaluate all fetal anomalies in question. The most common indication for an EXIT procedure is the presence of a prenatally diagnosed neck mass which is anticipated to result in severe airway obstruction following birth; severe micrognathia, mandibular hypoplasia may also require this approach.

Full Stomach Precautions	Pretreatment with Bicitra 30 mL po, ranitidine 50 mg iv
Positioning	Left uterine displacement

Intraoperative

Anesthetic technique: GETA, rapid-sequence induction. Primary goal is to maintain complete uterine relaxation, to support materal-fetal gas exchange, and assure fetal oxygenation. Uterine blood flow is not auto-regulated, but directly related to MAP.

Maintain blood pressure with phenylephrine as necessary. Maintain fluid resuscitation to moderate due to propensity of pulmonary edema while on tocolytic agents. High concentration of isoflurane or sevoflurane to maintain uterine relaxation. Nitroglycerin can also be used to facilitate relaxation. Intrauterine infusion with normal saline may be necessary to preserve uterine volume and prevent separation of placenta.

Induction	Rapid sequence induction, with propofol, or STP, and succinylcholine. (see)	
Maintenance	Volatile agent at high concentration to maintain uterine relaxation	
Special considerations	Coordination necessary between maternal anesthesia team, surgical team and pediatric anesthesia regarding cord clamping and delivery. Cord is clamped, volatile agent immediately discontinued, N$_2$O continued, fentanyl and midazolam given; oxytocin bolus and continuous infusion of oxytocin titrated to uterine response. Once hemostasis is achieved, and uterine tone is restored, anesthetic agents are restarted.	
Care of fetus/neonate	Infant: delivery of fetal head and upper extremity. Commence fetal monitoring with fetal scalp electrode, O$_2$sat monitoring (normal SaO$_2$- 65–75%). If possible, place iv catheter. Alternatively, additional anesthetic can be administered IM via deltoid muscle (fentanyl 2–3 mcg/kg, pancuronium 0.1 mg/kg.). After the airway is secured, the cord is clamped and delivery completed. Once airway secure, O$_2$sat should increase to >90%. If unable to secure, consider surgical intervention. Secure ETT with umbilical tape, steri-strips. Secure iv access if not obtained previously. Hemodynamic management may include resuscitation with iv fluids, transfusion. Transfer to NICU unless further immediate surgical intervention needed.	
Emergence	Usually extubated	
Blood and fluid requirements	Moderate blood loss IV: 16–18 ga × 1–2	Blood products available in room due to potential for hemorrhage; Cautious crystalloid administration due to potential for pulmonary edema related to the use of tocolytics.
Monitoring	Standard monitors A-line	CVP to guide fluid resuscitation
Positioning	L-uterine displacement	
Complications	Maternal hemorrhage Uterine atony	

(Print pagebreak 1319)

Postoperative

Complications (maternal)	Hemorrhage	H/H regularly (e.g., 30 min. for the 1st h); transfuse as necessary
	Pulmonary edema	2° overly aggressive resuscitation, prolonged use of NTG
Complications (neonate)	Hypovolemia Respiratory compromise	2° fetal hemorrhage via umbilical cord 2° aspiration, over-resuscitation-ventilatory support as necessary
Tests	CXR to verify ETT position	
Pain Management	Maternal Neonate	Patient-controlled analgesia Fentanyl 1–2 mcg/kg iv q 1° prn; MSO$_4$(0.05–0.1 mg/kg iv q 2–4°)

Suggested Readings

1. Bouchard S, Johnson MP, Flake AW, et al: The EXIT procedure: experience and outcome in 31 cases. *J Pediatric Surgery* 2002; 37(3):418–26.

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3. Hedrick HL: Ex utero intrapartum therapy. *Semin Pediatr Surg* 2003; 12:190–5.

4. Hirose S, Sydorak RM, Tsao K, et al: Spectrum of intrapartum management strategies for giant fetal cervical teratoma. *J Pediatr Surg* 2003; 38:446–50.

5. Mychalishka GB, Bealor JF, Graf JL, et al: Operating on placental support: the ex utero intrapartum treatment (EXIT) procedure. *J Pediatr Surg* 1997; 32:227–30.

6. Myers LB: *Anesthesia for Ex Utero Intrapartum Treatment (EXIT Procedure)*. BC Decker Inc, Hamilton: 2005.

7. Noah MM, Norton ME, Sandberg P, et al: Short-term maternal outcomes that are associated with the EXIT procedure, as compared with cesarean delivery. *Am J Obstet Gynecol* 2002; 186:773–3.

8. Otteson TD, Jackam DJ, Mandell DL: The ex utero intrapartum treatment (EXIT) procedure. *Arch Otolaryng. Head and Neck Surg* 2006; 132:686–9.