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Anesthesia for Thoracic Surgery in Children

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Introduction

This review will focus on the intraoperative anesthetic care of infants and children undergoing non-cardiac thoracic surgery. A brief review of “surgical” disorders afflicting infants and children will be followed by their anesthetic management.

Surgical Lesions of the Chest

Neonates and Infants

A variety of congenital intrathoracic lesions for which surgery is required may present in the newborn period or within the first year of life. These include lesions of the intrathoracic airways, lung parenchyma, and diaphragm.

Pulmonary sequestrations result from disordered embryogenesis producing a nonfunctional mass of lung tissue supplied by anomalous systemic arteries. Intralobar sequestrations are usually isolated anomalies, and may not present until late in childhood or adulthood. Extralobar sequestrations are commonly associated with other congenital anomalies, including bronchial agenesis, duplication of the colon, vertebral anomalies, and diaphragmatic defects. Presenting signs, which occur during the neonatal period up to 2 years of age, include cough, pneumonia, and failure to thrive. Diagnostic studies include CT scans of the chest and abdomen and arteriography. Surgical resection is performed following diagnosis.

Lung hypoplasia may be caused by a variety of intrauterine problems, including compromised intrathoracic space (congenital diaphragmatic hernia, tumor, pleural effusion), oligohydramnios (fetal renal failure with oliguria), and absent or poor fetal breathing movements (Werdnig-Hoffman disease, congenital myotonic dystrophy, anencephaly, agenesis of phrenic nerves). The “scimitar syndrome” presents with hypoplasia of the right lung with dextrocardia and other cardiac deformities. Unilateral lung hypoplasia may be associated with recurrent pneumonia and/or hypoxemia due to ventilation/perfusion (V/Q) mismatching, and may therefore require surgical resection.

Pulmonary arteriovenous (A-V) fistulas occur most commonly along with widespread vascular abnormalities, such as in patients with Osler-Weber-Rendu syndrome (hereditary hemorrhagic telangiectasis). These lesions may present during infancy or in older children with hypoxemia, due to right-to-left shunting of blood, or with congestive heart failure. Acquired A-V fistulas may develop in children with elevated pulmonary artery pressure (e.g., pulmonary hypoplasia, mitral stenosis, cystic fibrosis) or following chest trauma. Many of these fistula can be completely or partially coil-occluded in the catheterization laboratory. Persistent lesions may require surgical resection.

Congenital cystic lesions in the thorax may be classified into three categories. Bronchogenic cysts and dermoid cysts usually do not communicate with the airways and often present later in childhood. Surgical excision is indicated for symptomatic lesions. Cystic adenomatoid malformations (CAM) include structures similar to bronchioles but which lack associated alveoli, bronchial glands, and cartilage. They may become overdistended due to air trapping, leading to respiratory distress in the first few days of life. When they are multiple and air-filled, CAM may resemble congenital diaphragmatic hernia (CDH) radiographically. Treatment is surgical resection of the affected lobe. As with CDH, prognosis depends on the amount of remaining functional lung tissue, which may be diminished due to compression in utero.

Congenital lobar emphysema often presents with respiratory distress shortly after birth. This lesion may be caused by “ball-valve” bronchial obstruction in utero, causing progressive distal overdistension with fetal lung fluid. The resultant emphysematous lobe may compress lung bilaterally, resulting in a variable degree of hypoplasia. Congenital cardiac deformities are present in about 15% of patients. Radiographic signs of hyperinflation and atelectasis may be

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misinterpreted as atelectasis. Positive pressure ventilation may exacerbate lung hyperinflation. Surgical resection is usually performed when the PaO₂ is less than 50 mmHg despite supplemental oxygen administration.

Congenital diaphragmatic hernia is a life-threatening condition occurring in approximately 1 in 2,000 live births. Failure of a portion of the fetal diaphragm to develop allows abdominal contents to enter the chest, interfering with normal lung growth. In 70-80% of CDH, a portion of the left posterior diaphragm fails to close, forming a triangular defect known as the foramen of Bochdalek. Failure of the central and lateral portions of the diaphragm to fuse, on the other hand, results in a retrosternal defect in the foramen of Morgagni. This usually presents with signs of bowel obstruction rather than respiratory distress. Hernias of the foramen of Bochdalek occurring early in fetal life usually cause respiratory failure immediately after birth due to pulmonary hypoplasia. Distension of the gut postnatally (eg, due to bag-and-mask ventilation) exacerbates the ventilatory compromise by further compressing the lungs. The diagnosis is often made prenatally, and fetal surgical repair has been described. Neonates present with tachypnea, scaphoid abdomen, and absent breath sounds over the affected side. Chest radiography (CXR) shows bowel in the left hemithorax with deviation of the heart and mediastinum to the right and compression of the right lung. Right-sided hernias occur late and present with milder signs. In the presence of significant respiratory distress, bag-and-mask ventilation should be avoided and immediate tracheal intubation should be performed. Infants should be ventilated with small tidal volumes and low inflating pressures in order to avoid pneumothorax on the contralateral (right) side. In cases of severe lung hypoplasia and pulmonary hypertension (PaO₂ < 50 mmHg with FiO₂ 1.0), extracorporeal membrane oxygenation (ECMO) may be initiated early in order to avoid progressive lung injury. A particularly poor prognosis is predicted if associated cardiac deformities, a-AdO₂ > 500 mmHg, or severe hypercarbia despite mechanical ventilation are present. Surgical correction via a subcostal incision with ipsilateral chest tube placement may be performed during ECMO.

Tracheoesophageal fistula (TEF) with or without esophageal atresia occurs in approximately 1 in 4,000 live births. In 80-85% of infants, this lesion includes TEF with a distal esophageal pouch and tracheal fistulous connection. Afflicted neonates present with pooled oral secretions and may develop progressive gastric distension and tracheal aspiration of acidic gastric contents. A common association is the VACTERL complex, consisting of vertebral, anorectal, cardiac, tracheoesophageal, renal, and/or limb defects. Esophageal atresia is confirmed when orogastric tube is passed through the mouth and cannot be advanced more than about 7 cm. The tube should be secured and placed on suction, after which a chest radiograph is diagnostic. Occasionally, emergency gastrostomy is performed due to massive gastric distension. Mask ventilation and tracheal intubation are avoided if possible as they may exacerbate gastric distension and respiratory compromise. Evaluation should be performed to diagnose associated anomalies, particularly cardiac defects. Esophageal atresia without connection to the trachea and "H type" TEF occur much less commonly.

Patent ductus arteriosus (PDA) and coarctation of the thoracic aorta (COTA) are relatively common lesions with a wide range of presentations. PDA occurs in about 1 in 2,500 live births and accounts for approximately 10% of congenital heart defects. 40% of premature infants weighing less than 1,000 gm and 20% of those under 1,750 gm have a PDA. The PDA in these infants is typically quite large and commonly results in congestive heart failure due to left-to-right shunting of blood, with pulmonary edema and decreased systemic perfusion. Small PDAs may close spontaneously or in response to administration of indomethacin. Alternatively, small lesions may present with a heart murmur in asymptomatic children. COTA is a localized narrowing of the aorta occurring close to the insertion of the ductus arteriosus into the aorta. COTA occurs in 1 in 1,200 live births. COTA may present in the newborn as a critical aortic obstruction in which a PDA supplies most of the perfusion to the lower body. These patients are frequently critically ill, with a metabolic acidosis and cyanosis of the lower body. Prostaglandin E1 is infused to maintain ductal patency until surgical correction is performed. COTA more typically presents later in childhood with arterial hypertension in the arms and low blood pressure in the lower extremities, with poor or

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absent femoral pulses. Turner's syndrome and bicuspid aortic valves may be associated with COTA.

Childhood

Many of the lesions described above may not be diagnosed until childhood. These include pulmonary sequestration, A-V fistulas, cystic lesions, lobar emphysema, PDA, and COTA. Other disorders for which thoracic surgery is performed in children, either for definitive treatment or diagnostic purposes, include neoplasms, infectious diseases, and musculoskeletal deformities.

Tumors of the lung, mediastinum, and pleura may be primary or metastatic. Primary tumors of the chest are uncommon in children. Perhaps the most common are lymphoblastic lymphoma, a form of non-Hodgkin's lymphoma, and Hodgkin's disease. These neoplasms may present as an anterior mediastinal (thymic) mass with pleural effusion, dyspnea, pain, and/or superior vena cava syndrome (swelling of the upper arms, face, and neck). Neuroblastoma, the most common extracranial solid tumor of childhood, may arise in the thoracic sympathetic chain. Signs and symptoms include Horner's syndrome (lesions of the cervical and upper thoracic sympathetic chain), spinal cord compression, bone pain (skeletal metastasis), or, rarely, with hypertension, tachycardia, and flushing due to catecholamine secretion. Ganglioneuroblastomas and ganglioneuromas are variants of neuroblastoma which are also derived from neural crest cells and are histologically benign. Osteogenic sarcoma (osteosarcoma) and Ewing's sarcoma arise in bone but commonly metastasize to the lung. Other tumors of childhood, including rhabdomyosarcoma and germ cell tumors, may also metastasize to the lung.

Empyema is a complication of bacterial pneumonia most commonly caused by *S. aureus* and *S. pneumoniae*. *H. influenzae* type b is less common owing to the use of the HIB vaccine in young children. Empyema is diagnosed by CXR and is associated with prolonged fever and leukocytosis. Despite therapy with antibiotics and chest tube drainage, with or without urokinase instillation, surgical treatment is often necessary. Rarely, lung abscesses which persist despite antibiotics and percutaneous drainage may also require surgical treatment. Surgical lung biopsy may be performed for diagnostic purposes in cases of interstitial lung disease (ILD), which may be infectious (*pneumocystis*, respiratory syncytial virus, cytomegalovirus) or non-infectious (eg, nonspecific or allergic).

Pectus excavatum results from excessive growth of the costochondral cartilages, with resultant inward depression of the sternum. It may be associated with Marfan's syndrome or lung disease, the latter due to large negative intrathoracic pressure during inspiration. Children with severe deformities may have circulatory impairment due to distortion of the heart and great vessels, or respiratory compromise due to lung compression. Surgical repair is deferred, if possible, until adolescence. Scoliosis is a curvature of the spine measuring 10° or more in the frontal plane. This disorder may present as infantile (< 3 y.o.), juvenile (3-10 y.o.), or adolescent (>10 y.o.) forms. Scoliosis may be associated with congenital malformations of the vertebra, neuromuscular disease (eg, muscular dystrophy), neoplastic diseases (eg, neurofibromatosis), or may be idiopathic. Surgical correction is delayed until the teenage years unless the deformity is severe, and consists of posterior spinal fusion with instrumentation with or without anterior (thoracic) spinal fusion.

Ventilation/Perfusion During Thoracic Surgery

Ventilation is normally distributed preferentially to dependent regions of the lung, so that there is a gradient of increasing ventilation from the most non-dependent to the most dependent lung segments. Because of gravitational effects, perfusion normally follows a similar distribution, with increased blood flow to dependent lung segments. Therefore, ventilation and perfusion are normally well matched. During thoracic surgery, several factors act to increase V/Q mismatch. General anesthesia, neuromuscular blockade, and mechanical ventilation cause a decrease in

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functional residual capacity of both lungs. Compression of the dependent lung in the lateral decubitus position may cause atelectasis. Surgical retraction and/or single lung ventilation result in collapse of the operative lung. Hypoxic pulmonary vasoconstriction (HPV), which acts to divert blood flow away from underventilated lung, thereby minimizing V/Q mismatch, is diminished by inhalational anesthetic agents and other vasodilating drugs. These factors apply to infants, children, and adults. The overall effect of the lateral decubitus position on V/Q mismatch, however, is different in infants compared with older children and adults.

In adults with unilateral lung disease, oxygenation is optimal when the patient is placed in the lateral decubitus position with the healthy lung dependent ("down") and the diseased lung non-dependent ("up"). Presumably, this is related to an increase in blood flow to the dependent, healthy lung and a decrease in blood flow to the non-dependent, diseased lung due to the hydrostatic pressure (or gravitational) gradient between the two lungs. This phenomenon favors the adult patient undergoing thoracic surgery in the lateral decubitus position.

In infants with asymmetric lung disease, however, oxygenation is improved with the healthy lung "up". Several factors account for this discrepancy between adults and infants. Infants have a soft, easily compressible rib cage that cannot fully support the underlying lung. Therefore, functional residual capacity is closer to residual volume, making airway closure likely to occur in the dependent lung even during tidal breathing. When the adult is placed in the lateral decubitus position, the dependent diaphragm has a mechanical advantage, since it is "loaded" by the abdominal hydrostatic pressure gradient. This pressure gradient is reduced in infants, thereby reducing the functional advantage of the dependent diaphragm. Finally, the infant's small size results in a reduced hydrostatic pressure gradient between the non-dependent and dependent lungs. Consequently, the favorable increase in perfusion to the dependent, ventilated lung is reduced in infants. For these reasons, infants are at an increased risk of significant oxygen desaturation during surgery in the lateral decubitus position.

Indications and Techniques for Single Lung Ventilation (SLV) in Infants and Children

Prior to the 1990s, nearly all thoracic surgery in children was performed by thoracotomy. In the majority of cases, anesthesiologists ventilated both lungs with a conventional tracheal tube and the surgeons retracted the operative lung in order to gain exposure to the surgical field. During the past decade, the use of video-assisted thoracoscopic surgery (VATS) has dramatically increased in both adults and children. Recent advances in surgical technique as well as technology, including high resolution microchip cameras and smaller endoscopic instruments, have facilitated the application of VATS in smaller patients. VATS is being used extensively for pleural debridement in patients with empyema, lung biopsy and wedge resections for ILD, mediastinal masses, and metastatic lesions. More extensive pulmonary resections, including segmentectomy and lobectomy, have been performed for lung abscess, bullous disease, sequestrations, lobar emphysema, CAM, and neoplasms. In addition, closure of PDA, repair of hiatal hernias, and anterior spinal fusion have been reported. Although VATS can be performed while both lungs are being ventilated, using CO₂ insufflation and placement of a retractor to displace lung tissue in the operative field, single lung ventilation (SLV) is extremely desirable during VATS. There are several different techniques that can be used for SLV in children.

Single-Lumen Endotracheal Tube (ETT)

The simplest means of providing SLV is to intentionally intubate the ipsilateral mainstem bronchus with a conventional single lumen endotracheal tube (ETT). When the left bronchus is to be intubated, the bevel of the ETT should be rotated 180° and the head turned to the right. The ETT is advanced into the bronchus until breath sounds on the operative side disappear. A fiberoptic bronchoscope (FOB) may be passed through or alongside the ETT to confirm or guide placement.

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When a cuffed ETT is used, the distance from the tip of the tube to the distal cuff must be shorter than the length of the bronchus so that the cuff is not entirely in the bronchus.

This technique is simple and requires no special equipment other than a FOB. This may be the preferred technique of SLV in emergency situations such as airway hemorrhage or contralateral tension pneumothorax.

Problems include failure to provide an adequate seal of the bronchus, especially if a smaller, uncuffed ETT is used. This may prevent the operative lung from collapsing or fail to protect the healthy, ventilated lung from contamination by purulent material from the contralateral lung. One is unable to suction the operative lung using this technique. Hypoxemia may occur due to obstruction of the upper lobe bronchus, especially when the short right mainstem bronchus is intubated.

Variations of this technique have been described, including intubation of both bronchi independently with small ETTs. One mainstem bronchus is initially intubated with an ETT, after which another ETT is advanced over a FOB into the opposite bronchus.

Balloon tipped bronchial blockers

Recently, the use of an end-hole, balloon wedge catheter (Arrow International Corp., Redding, PA) as a bronchial blocker has been described. The bronchus on the operative side is initially intubated with an ETT. A guidewire is then advanced into that bronchus through the ETT. The ETT is removed and the blocker is advanced over the guidewire into the bronchus. An ETT is then reinserted into the trachea alongside the blocker catheter. Alternatively, a Fogarty embolectomy catheter may be placed with or without bronchoscopic guidance. A FOB may be used to confirm position of the blocker. With an inflated blocker balloon the airway is completely sealed, providing more predictable lung collapse and better operating conditions than with an uncuffed ETT in the bronchus.

A potential problem with this technique is dislodgement of the blocker balloon into the trachea. The inflated balloon will then block ventilation to both lungs and/or prevent collapse of the operative lung. The balloons of most catheters currently used for bronchial blockade have low volume, high pressure properties and overdistension can damage or even rupture the airway. A recent study, however, reported that bronchial blocker cuffs produced lower "cuff-to-tracheal" pressures than double lumen tubes. When closed tip bronchial blockers are used, the operative lung cannot be suctioned and continuous positive airway pressure (CPAP) cannot be provided to the operated lung if needed.

Recently, a novel method of insertion of a Fogarty catheter as a bronchial blocker was described by Takahashi, and is illustrated in Figure 1.

The Univent Tube

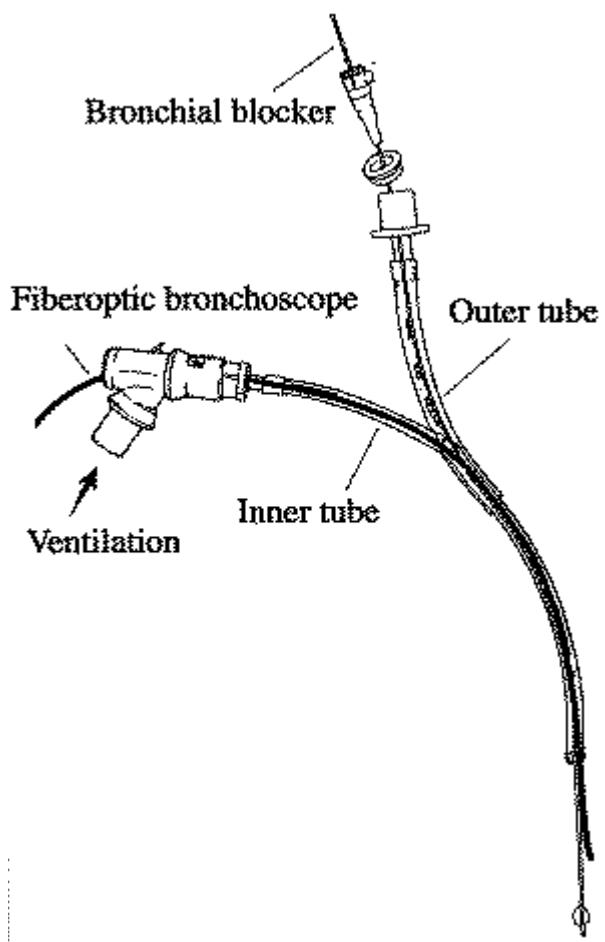
The Univent tube (Fuji Systems Corporation, Tokyo, Japan) is a conventional ETT with a second lumen containing a small tube that can be advanced into a bronchus. A balloon located at the distal end of this small tube, when inflated, serves as a blocker. Univent tubes require FOB for successful placement. Pediatric size Univent tubes are now available in sizes as small as a 3.5 and 4.5 mm internal diameter (ID).

Because the blocker tube is firmly attached to the main ETT, displacement of the Univent blocker balloon is less likely than when other blocker techniques are used. The blocker tube has a small lumen which allows egress of gas and can be used to insufflate oxygen or suction the operative lung.

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Figure 1. (From Takahashi) Technique for a home made pediatric bronchial blocker.

The desired endotracheal tube is cut with a fenestration at approximately the point at which it will be taped at the lips (e.g. 3x the I.D. in cm), and is inserted through another fenestration in a larger tube through which it will fit snugly with lubrication (e.g. a 6.0mm ETT for a 4.0mm ETT). The Fogarty catheter is inserted through the lumen of the larger outer tube, through the fenestration in the inner tracheal tube, from where it may be advanced into a bronchus. The position of the blocker may be confirmed with fiberoptic bronchoscopy through the lumen of the tracheal tube, as illustrated.



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A disadvantage of the Univent tube is the large amount of cross sectional area occupied by the blocker channel, especially in the smaller size tubes. Smaller Univent tubes have a disproportionately high resistance to gas flow. The Univent tube's blocker balloon has low volume, high pressure characteristics so mucosal injury can occur during normal inflation.

Double-Lumen Tubes (DLTs)

All DLTs are essentially two tubes of unequal length molded together. The shorter tube ends in the trachea and the longer tube in the bronchus. DLTs for older children and adults have cuffs located on the tracheal and bronchial lumens. The tracheal cuff, when inflated, allows positive pressure ventilation. The inflated bronchial cuff allows ventilation to be diverted to either or both lungs, and protects each lung from contamination from the contralateral side.

Conventional plastic DLTs, once only available in adult sizes (35, 37, 39, and 41 Fr), are now available in smaller sizes. The smallest cuffed DLT is a 26 Fr (Rusch, Duluth, GA) which may be used in children as young as 8 years old. DLTs are also available in sizes 28 and 32 Fr (Mallinckrodt Medical, Inc., St. Louis, MO) and are suitable for children 10 years of age and older.

In children the DLT is inserted using the same technique as in adults. The tip of the tube is inserted just past the vocal cords and the stylet is withdrawn. The tube is rotated through 90 degrees to the appropriate side and then advanced into the bronchus. In the adult population the depth of insertion is directly related to the height of the patient. No equivalent measurements are yet available in children. If FOB is to be used to confirm tube placement, a bronchoscope with a small diameter and sufficient length must be available.

A DLT offers the advantage of ease of insertion, ability to suction and oxygenate the operative lung with CPAP, and the ability to visualize the operative lung. Left tubes are preferred to right DLTs because of the shorter length of the right main bronchus. Right DLTs are more difficult to accurately position because of the greater risk of right upper lobe obstruction.

DLTs are relatively safe and easy to use. There are very few reports of airway damage from DLTs in adults, and none in children. Their cuffs have high volume, low pressure cuffs should not damage the airway if they are not overinflated with air or distended with nitrous oxide while in place.

Use of these techniques for providing SLV in infants and children is summarized in Table 1.

Table 1. Tube selection for single lung ventilation in children.

AGE (yrs)	ETT (ID)*	BB** (Fr)	Univent®***	DLT (Fr) #
0.5-1	3.5-4.0	5		
1-2	4.0-4.5	5		
2-4	4.5-5.0	5		
4-6	5.0-5.5	5		
6-8	5.5-6	6	3.5	
8-10	6.0 cuffed	6	3.5	26
10-12	6.5 cuffed	6	4.5	26-28
12-14	6.5-7.0 cuffed	6	4.5	32
14-16	7.0 cuffed	7	6.0	35

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AGE (yrs)	ETT (ID)*	BB** (Fr)	Univent®***	DLT (Fr)†
16-18	7.0-8.0 cuffed	7	7.0	35

* Sheridan® Tracheal Tubes, Kendall Healthcare, Mansfield, MA.

** Arrow International Corp., Redding, PA.

*** Fuji Systems Corporation, Tokyo, Japan.

26 Fr - Rusch, Duluth, GA; 28-35 Fr - Mallinckrodt Medical, Inc., St. Louis, MO.

ID = internal diameter, Fr = French size, DLT = double-lumen tube.

Monitoring and Anesthetic Techniques

A thorough preoperative evaluation is essential in caring for pediatric patients scheduled for thoracic surgery. As discussed above, imaging and laboratory studies will have been performed preoperatively according to the lesion involved. Guidelines for fasting, choice of premedication, and preparation of the OR are invoked as for other infants and children scheduled for major surgery. Following induction of anesthesia, arterial catheterization should be performed for most patients undergoing thoracotomies as well as those with severe lung disease having VATS. This facilitates close monitoring of arterial blood pressure during manipulation of the lungs and mediastinum as well as arterial blood gas tensions during SLV. For thoracoscopic procedures of relatively short duration in patients without severe lung disease, insertion of an arterial catheter is not mandatory. Placement of a central venous catheter is not generally indicated if peripheral intravenous access is adequate for projected fluid and blood administration.

Inhalational anesthetic agents are commonly administered in 100% O₂. Isoflurane may be preferred due to its lesser effect on HPV compared with other inhalational agents, although this has not been studied in children. Nitrous oxide is avoided. Isoflurane is commonly supplemented with intravenous opioids in order to limit its concentration and impairment of HPV. Alternatively, total intravenous anesthesia may be used with a variety of agents. The combination of regional anesthesia with general anesthesia is particularly desirable for thoracotomies, but may also be beneficial for VATS, especially when chest tube drainage is used following surgery. A variety of regional anesthetic techniques have been described, including intercostal blocks, intrapleural infusions, spinal anesthesia, and epidural anesthesia. Of these, epidural anesthesia best facilitates excellent intraoperative anesthesia and postoperative analgesia.

In order to attenuate the stress response associated with thoracic surgery, minimize the inhaled anesthetic concentration, and provide optimal postoperative analgesia, a combination of epidural opioids and local anesthetic agents should be used. Although local anesthetic agents may spread to thoracic dermatomes when administered via the caudal epidural space, potentially toxic doses of local anesthetics may be required to achieve thoracic analgesia. Thoracic epidural blockade may be achieved with greater safety and efficacy by placing the epidural catheter tip in proximity to the spinal segment associated with surgical incision. Segmental anesthesia may then be achieved with lower doses of local anesthetic than those needed when the catheter tip is distant from the surgical site. In infants, a catheter can reliably be advanced from the caudal to the thoracic epidural space. For example, with the infant in the lateral decubitus position, a 20-gauge epidural catheter may be inserted via an epidural needle or an 18-gauge intravenous catheter placed through the sacrococcygeal membrane, and then advanced 16-18 cm to the mid-thoracic epidural space. Minor resistance to passage of the catheter may be overcome by simple flexion or extension of the spine. If continued resistance is encountered, no attempt should be made to advance the catheter further, as the catheter may become coiled within or exit the epidural space. In older children, a thoracic epidural catheter may be inserted directly between T6 and T8 to provide intraoperative anesthesia and postoperative analgesia. In our practice, an initial dose of hydromorphone 7-8µg/kg and 0.25% bupivacaine 0.5 ml/kg is administered. Subsequent doses of 0.25% bupivacaine 0.3 ml/kg are administered intraoperatively at approximately 90 minute intervals. No intravenous opioids are given during surgery. Postoperatively, a continuous infusion of 0.10% bupivacaine and hydromorphone 3 µg/ml is administered at a rate of 0.3 ml/kg/hr. An advantage of epidural catheter

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compared with “single shot” techniques that adjustments can be made in dosing postoperatively according to the patient’s level of comfort. For example, a “bolus” of epidural anesthetic agents may be given and the infusion rate increased if the patient is experiencing pain. Alternatively, the infusion may be decreased if the patient becomes somnolent. Our dosing regimen for thoracic epidural anesthesia and analgesia is summarized in Table 2.

Table 2. Dosing regimens for epidural anesthesia.

<i>Intraoperative Dose</i>	<i>Postoperative Infusion</i>
<i>Bupiv. 0.25% (ml/kg)HM (µg/kg)</i>	<i>(ml/kg/hr)</i>
0.5 initially, then 0.3 q 90 min.	Bupiv 0.1%+HM 3µg/ml @ 0.3
7-8	

Bupiv. = bupivacaine; HM = hydromorphone

Side Effects of Neuraxial Opioids

Side effects related to neuraxial opioids include nausea and vomiting (N/V), pruritus, somnolence, respiratory depression, and urinary retention. Nausea and vomiting as well as pruritus appear to be relatively uncommon in infants and are primarily seen in children over the age of 3 years. These side effects are more common with morphine compared with hydromorphone and fentanyl. Treatment includes metoclopramide 0.1-0.2 mg/kg IV and ondansetron 0.1-0.2 mg/kg IV Q6 hrs. Pruritus may be treated with diphenhydramine 0.5-1.0 mg/kg IV Q6hrs or nalbuphine 0.1 mg/kg IV Q6hrs. Both of these therapies are also efficacious in the treatment of N/V. Due to greater rostral spread, respiratory depression is more common when morphine is used compared with hydromorphone. Respiratory depression with oxygen desaturation should be treated with 100% O₂ and, if necessary, repeated doses of naloxone 0.5-1.0 µg/kg IV administered incrementally. Persistent N/V, pruritus, and respiratory depression can be treated with a continuous infusion of naloxone 1-5 µg/kg/hr IV. Urinary retention is seen most commonly during the initial 24 hours of therapy, during which time patients may benefit from having a urinary catheter in place.

Conclusion

Perioperative care of infants and children undergoing thoracic surgery presents a great challenge to the anesthesiologist. To meet this challenge, the practitioner benefits from a review of congenital and acquired “surgical” diseases of the chest in this age group. Equally important are an understanding of the physiology of lung ventilation and perfusion during surgery, monitoring requirements, appropriate anesthetic techniques, and methods of providing single lung ventilation safely and effectively. Skill in performing regional anesthetic techniques in infants and children, including thoracic epidural anesthesia and postoperative analgesia, are also important in managing pediatric patients undergoing thoracic surgery.

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