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EDUCATIONAL REVIEW

WILEY Pediatric Anesthesia

Anesthesia of thoracic surgery in children

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Summary
Providing anesthesia in children with thoracic disease is a challenging task. The effects of the underlying disease, the surgical interventions, and preexisting condition of the patient need to be considered when planning perioperative care. The perioperative care for children undergoing thoracic surgery requires specific techniques adapted to the pediatric physiology and anatomy. This review is focused on anesthetic strategies for thoracic surgery with an emphasis on perioperative analgesia including neuraxial techniques.

KEYWORDS
airway, child, device, regional, respiration, technique

1 | INTRODUCTION

Performing anesthesia in pediatric thoracic surgery may be a challenge. Varying stages of the pediatric development require a thorough understanding of the different physiologic states and the anesthetic management for interventions of lung, airway, or other thoracic organs between neck and abdomen, which compromise the cardiorespiratory system. Surgical correction of congenital defects is performed in the neonatal period if symptomatic or secondary, if complications occur. Neoplastic or other acquired lesions manifest at any stage of life. Infectious disease as empyema is a common cause necessitating thoracic surgery in preschool children. Correction of chest deformities is mainly performed in adolescents (Table 1). With the implementation and advances of the video-assisted thoracoscopic surgery, surgical procedures will be performed with increasing frequency in children. Factors to be considered when planning and providing anesthesia for thoracic surgery include type and site of lesion, surgical approach, and comorbidities. Specific aspects of the unique pediatric physiology and anatomy influence anesthetic management. Adult principles cannot be routinely applied.

This review delineates the anesthetic management of pediatric patients presenting for thoracic surgery. Cardiac surgery is beyond the scope of this review. Airway and respiratory physiology, perioperative analgesia focused on regional anesthesia and management of specific surgical procedures are to be reviewed (see also the Audio file S1).

2 | PEDIATRIC AIRWAY AND RESPIRATORY PHYSIOLOGY

Specific considerations of the upper airway anatomy influencing general airway management have been discussed previously.[1] Higher airway resistance and airflow limitations exacerbated by airway manipulation or soiling, a tendency toward lung collapse based on anatomy, physiology, and physics of the pediatric lung in combination with proportionally higher oxygen consumption render young children prone to respiratory complications. In the lateral decubitus position, the highly compliant rib cage is unable to avoid compression of the dependent lung from external padding and positioning in addition to compression by mediastinal and abdominal contents. This results in a lower functional residual capacity close to or below residual volume, making airway closure likely to occur in the dependent lung especially in young infants and newborn. Adverse effects become more obvious after the nondependent lung with its better ventilation/perfusion match is collapsed.[2] In proportion to the body size, the lower hydrostatic gradient cannot ameliorate the ventilation/perfusion-mismatch as in older children and adults. These problems are aggravated in premature infants or in patients with preexisting disseminated lung disease.[2,3]

As a conclusion, tendency toward shunt and hypoxemia is more pronounced when one-lung ventilation is performed in the dependent lung in very young patients contrary to older children and

TABLE 1 Thoracic disease in children necessitating surgical intervention

Etiology	Examples
Congenital	Congenital diaphragmatic hernia
	Tracheo-esophageal fistula
	Esophageal atresia
	Congenital lobar emphysema
	Congenital cystic adenomatoid malformation
	Pulmonary sequestrations
Neoplastic	Lymphoma (lymphoblastic lymphoma, Hodgkin lymphoma)
	Teratoma
	Neuroblastoma
	Thymoma
Infectious	Empyema thoracis
	Consolidated pneumonia/abscess
Acquired	Thoracic trauma
	Inhaled foreign body
	Tracheal stenosis
Chest deformities	Pectus excavatum/carinatum

adults.[4,5] The lateral decubitus position would favor the good lung in the nondependent position.

3 | AIRWAY MANAGEMENT FOR ONE-LUNG VENTILATION

Thoracic surgical access can be achieved by thoracotomy or video-assisted thoracoscopy. Establishing one-lung ventilation is desirable to minimize mechanical lung injury by retractors or surgical instruments, to optimize visualization and to protect against soiling or air leakage. General principles of lung isolation apply for both adult and pediatric patients. A detailed review of one-lung management in children has been published recently.[6] The small size of the pediatric airway is the main factor guiding airway management. Therefore, the use of rather bulky devices for one-lung ventilation (Table 2), as double-lumen tubes (DLT) or the Univent® tube, is restricted to older children (Figure 1). Bronchial blockers or endobronchial intubation with a standard endotracheal tube can be applied in nearly every age group. To avoid malpositioning, fiber-optic bronchoscopic guidance and control of correct positioning is recommended for every technique, as the margin of error correlates to the child`s size. The need for airway manipulations as suctioning or applying continuous positive airway pressure mandates the use of a bronchial blocker with an integrated lumen or a double-lumen tube, as they provide selective access to both lungs.

TABLE 2 Age adapted selection of airway management for one-lung ventilation

Age (years)	ETT (mm inner diameter)	DLT (French)	Bronchial blocker (French)/(position)	Flex. bronchoscope (mm outer diameter)
Newborn	3-3.5	-	3/extraluminal	1.8
<1	3.5-4	-	5/extraluminal	1.8
1-2	4-4.5	-	5/extraluminal	1.8
2-4	4.5-5	-	5/extraluminal	1.8
4-6	5-5.5	-	5/intraluminal	1.8
6-8	5.5-6.5	26	5/intraluminal	1.8
8-10	6.5	26-28	5/intraluminal	2.8
10-12	6.5-7	28-32	7/intraluminal	2.8
12-14	7	32-35	7/intraluminal	2.8

4 | RELEVANCE OF PERIOPERATIVE REGIONAL ANALGESIA

Thoracic epidural anesthesia contributes to reduced perioperative morbidity especially in adults with limited pulmonary function by reducing respiratory and cardiac complications and the incidence of acute and chronic pain.[7,8] Increasing evidence supports the implementation of optimized analgesic regimens including regional analgesia into the perioperative management as the effects of perioperative pain and associated deleterious sequelae became evident also in children.[9,10] Regional anesthesia has been shown to reduce pain scores, the incidence of nausea and vomiting, pulmonary complications, and markers of endocrine stress response.[10] In younger children with immature neuronal structures, adequate regional anesthesia can avoid exposure to potential neurotoxic anesthetics and reduce hypersensitivity resulting from inadequate analgesia.[11] Regional anesthesia includes intercostal blockade, paravertebral, and epidural anesthesia (Table 3). In patients undergoing surgery for chest deformities, epidural and paravertebral analgesia reduce pain levels and length of hospital stays after pectus excavatum or funnel chest repair. Within recent years, there is growing evidence for the feasibility and beneficial effects of epidural and paravertebral analgesia even in very young pediatric patients undergoing thoracotomy and thoracoscopy.[12] Though neuraxial techniques improve effective analgesia, the impact on morbidity and mortality, as shown for adults, is less conclusive in pediatric patients, possibly explained by a more preserved lung function, the higher primary failure rate, the small numbers of well controlled studies and the limited size and heterogeneous character of the existing studies.

5 | PRACTICAL ASPECTS OF NEURAXIAL TECHNIQUES

In young children, epidural and paravertebral analgesia is inserted after induction of general anesthesia in contrast to the practice in cooperative adolescents and adults.[13] Among anesthetists, there is much hesitance to perform neuraxial anesthesia in a sedated patient. Nevertheless, there is evidence that thoracic epidural analgesia in pediatrics is equally safe when inserted under general anesthesia.[14] Ultrasonography is used increasingly to facilitate epidural and

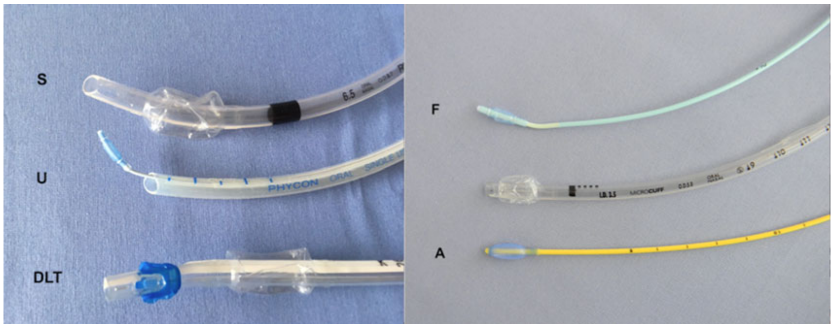

FIGURE 1 Airway management: Univent®-tube (*U*) (3.5 mm ID) and 26 French DLT (*DLT*) in relation to a standard ETT (*S*) (6.5 mm ID). 5 French Fuji® (*F*) and Arndt® (*A*)-bronchial blockers next to a 3.5 mm ID ETT

TABLE 3 Recommendations for regional anesthesia in thoracic surgery

Type	Needle/catheter (Gauge)	Drug	Initial bolus	Continuous application
Epidural	<30 kg: 20/25; 19/23 >30 kg: 18/21	ropivacaine 0.2% + sufentanil 0.5 μg/mL	<3 month 0.2 mg/kg >3 month: 0.3 mL/kg	<3 month: 0.1-0.2 mL/kg/h >3 month: 0.1-0.2 mL/kg/h
Paravertebral	<30 kg: 19/23 >30 kg: 18/21	ropivacaine 0.2%	Total 0.5 mL/kg (3 separate sites)	0.2 mL/kg/h
Intercostal	22	ropivacaine 0.5% + epinephrine 5 μg/mL	Total 0.5 mL/kg (6 segments)	(single shot)

paravertebral anesthesia. Significant differences regarding the pediatric neuraxial anatomy exist, that is, a very short skin-epidural distance, a narrow epidural space and a softer ligamentum flavum, which increase the technical challenge and result in a small margin of safety.[15] Advancing the catheter via the caudal or lumbar route was thought to avoid direct trauma at the thoracic level in children under the age of 1 year. An increased incidence of infection and malposition and a higher traumatizing effect caused by this method has been discussed. Catheter-related complications seem to be higher than in adults, especially in neonates and small infants, though the overall rate of severe damage seems to be reasonably low confirming feasibility and safety. Thoracic paravertebral analgesia seems to be associated with a safer profile compared to thoracic epidural analgesia based on the distance between the paravertebral space and the spinal cord. Within recent years, ultrasound guidance results in increased efficacy in placement. Single shot and continuous paravertebral analgesia are common.[12] In general, neuraxial anesthesia may provide a safe, effective, and improved analgesia compared to systemic opioid analgesia. The choice of technique depends on the type of surgery, patient factors, and the experience of the anesthesiologist. The existence of sporadic reports on spinal damage, the higher technical challenge, and less pronounced effects of neuraxial anesthesia on pediatric outcome require a thorough assessment of the individual risk and benefit in every single case. Alternative techniques and the use of ultrasound guidance should be considered to increase patient safety.

6 | PHARMACOLOGY OF NEURAXIAL DRUGS IN CHILDREN

Pharmacodynamics and -kinetics of local anesthetics differ in very young pediatric patients compared to adults resulting in an increased risk of accumulation and toxicity.[16] Though the larger volume of distribution limits peak plasma levels after a single dose, the risk of accumulation is increased after continuous application.[16] Immature organ function and metabolism need to be considered in infants younger than 3 months. The blood-brain barrier is more permeable. Ropivacaine seems to be relatively safe even in young children less than 3 months of age and can be considered the local anesthetic of choice with a maximal dose of 0.2 mg/kg/h for continuous application[16] (Table 3). Accumulation of ropivacaine 0.2% seems to be minimal for children >3 months even when continuously administered. Levobupivacaine is associated with less toxicity than the R-isomer. The epidural application of opioids results in improved analgesia also in children (Table 3). Epidural sufentanil offers favorable pharmacokinetic and -dynamic properties. For paravertebral analgesia, doses are often higher compared to epidural analgesia. As an alternative, the administration of intrathecal morphine provides potent analgesia for 12-24 hours.[12]

7 | SPECIFIC LESIONS AND PROCEDURES

7.1 | Surgical approach: video-assisted thoracic surgery (VATS) versus thoracotomy

Thoracoscopic procedures are associated with reduced musculoskeletal trauma, less pain resulting in enhanced recovery and optimized magnified visualization.[17] Novel surgical instruments facilitate VATS in small and newborn children. VATS is possible even in the repair of esophageal atresia with tracheal fistula or a congenital diaphragmatic hernia, reserving thoracotomy for complicated and extensive disease not accessible by VATS. Establishing one-lung ventilation is desirable for both approaches. During thoracotomy, retraction of the inflated lung can improve visualization in emergency or lack of lung separation, whereas this is usually impossible in thoracoscopic procedures without CO_2-insufflation. CO_2-insufflation into the hemithorax is used to improve visualization, either as single means or in combination with specific lung isolation. Low gas flow and an insufflation pressure between 4-6 mbar seem to be sufficient.[17] Care must be taken to avoid or limit side effects as hypothermia, hypercarbia, and excessive increases of the intrathoracic pressure lead to cardiopulmonary compromise. Regional anesthesia (ie, thoracic epidural or paravertebral anesthesia, intercostal blockade) provide effective perioperative analgesia, depending on the extent of the surgical intervention.

8 | EMPYEMA

Pneumonia in children may be complicated in 5-10% by parapneumonic empyema with an even increasing incidence.[18] Pulmonary gas exchange in terms of an accompanying pneumonia may be insufficient, especially during one-lung ventilation. Lack of clinical improvement after antibiotic therapy and chest drainage should prompt a surgical consultation. There is an emerging role for primary thoracoscopy in empyema. Thoracotomy is reserved for special cases in persistent sepsis or complicated empyema.[19] Lung isolation is mandatory as soiling of the less affected side could lead to respiratory impairment after positioning or surgical manipulation. Primary bronchoscopy with a supraglottic airway device before surgery can be considered in the presence of massive secretions potentially complicating one-lung ventilation. Any change in position can dislodge secretions and result in respiratory deterioration. Adequate venous access for goal-directed fluid and hemodynamic management is mandatory to restore perfusion as indicated by hemodynamic or biochemical parameters, capillary refill, or urine output.[20] Dependent on the comorbidity, the extent of the operation and the presence of acute septicemia, regional anesthesia or further monitoring should be established as indicated. For surgical interventions of limited extent, intercostal blockade may induce effective analgesia. Thoracic epidural anesthesia has been shown to be safe and improves analgesia in children undergoing thoracotomy and decortication. As the parietal pleura is the anterior border of the paravertebral space, complete decortication and the risk of infection are contraindications for thoracic paravertebral analgesia. Postoperative admission to a high dependency unit is necessary to provide respiratory care.

9 | TRACHEO-ESOPHAGEAL FISTULA (TEF)

TEF is found in 1 of 3.000 neonates. Fifty percent of the children are born with other abnormalities (ie, VACTERL), mainly cardiac (~50%). Problems may arise from concomitant cardiac disease, prematurity including low birth weight (especially <2 kg) and respiratory insufficiency, all of which often need preoperative optimization. Airway management is influenced by the size and site of the fistula, serving as a conduit between stomach and airways. For many years, the standard textbook approach has been to avoid mask ventilation and aim for early intubation with preserved spontaneous ventilation minimizing air leakage and gastric distention until identification and subsequent closure of the fistula. Management has changed over the years. In patients with small fistulae without respiratory compromise, controlled ventilation seems to be relatively safe. Risk factors include large, pericarinal fistulae and presence of respiratory distress.[21] In children undergoing thoracotomy and presenting with respiratory distress, spontaneous ventilation is not always sufficient. Endotracheal intubation distal to the fistula should be performed if possible. Lung separation with a balloon tipped catheter may be a strategy to avoid gastric insufflation.

Intraoperative problems are endotracheal tube dislocation caused by surgical manipulation or positioning with resulting gastric distention and severe respiratory complications. The availability of a flexible bronchoscope is mandatory to correct potential life threatening dislocation of the endotracheal tube or respective airway device. Transcutaneous CO_2-monitoring is helpful. If performing thoracoscopic repair, lung collapse can be hastened by CO_2-insufflation. One-lung ventilation may result in increased pulmonary vascular resistance, so patients with cardiac disease and intracardiac shunts can be compromised.[21] CO_2-absorption, hypothermia, and acidosis can aggravate this. In addition to standard monitoring, invasive arterial and central venous access should be sought for patients with cardiorespiratory impairment. Epidural, paravertebral, and caudal anesthesia have been proven beneficial. Postoperative intensive care is necessary for all patients. The need for ventilation is determined by the extent of the operation and possible complications, adequate pain management, and the presence of cardiac or pulmonary comorbidity.[21]

10 | CONGENITAL DIAPHRAGMATIC HERNIA (CDH)

Abdominal viscera herniating through a diaphragmatic defect into the hemithorax with subsequent lung hypoplasia are hallmarks of this lesion. Pulmonary hypertension, persistent patent ductus arteriosus, or foramen ovale may result. Associated congenital lesions include cardiac, central nervous, and gastrointestinal disorders. The size of the hernia, respiratory compromise, and the presence of cardiovascular disease determine morbidity and mortality.[22] As problems arise directly after birth, delivery and primary care should be planned in a tertiary hospital.

Therapeutic aims are the pre- and perioperative stabilization with a focus on avoiding aggressive ventilation. Most neonates with CDH require mechanical ventilation, including high frequency oscillatory ventilation or even extracorporeal circulation support in severe cases. Lung compression by gastric contents may be aggravated by vigorous attempts of mask ventilation, gastric distention further compressing lung parenchyma. Reduced alveolar surface, atelectasis and shunting, pulmonary hypertension, and a persistent right to left shunt promote hypoxemia. Early endotracheal intubation is indicated and a nasogastric tube should be inserted. Aggressive ventilation causing baro- and volutrauma further damage the lung resulting in long-term damage. Protective ventilation includes limited peak pressures and permissive hypercapnia. High frequency oscillatory ventilation is frequently used in compromised patients, extracorporeal membrane oxygenation can be considered in refractory cases. Pulmonary hypertension is targeted by correction of hypoxemia and acidosis. Pharmacologic therapy includes inhaled nitric oxide, phosphodiesterase inhibitors, prostaglandins and –cyclins.[22] A right (preductal) arterial cannula is inserted. Pre- and postductal oxygen saturations are monitored indicating changes in right to left shunt. Vasoactive therapy is often required. Surgical therapy includes repositioning of the displaced viscera and closure of the diaphragmatic defect by the abdominal approach. VATS or thoracotomy approach is used less often, so lung isolation is usually not required to facilitate surgical exposure. Aggressive ventilation resulting in RDS and pneumothorax should be avoided in the perioperative period. Abdominal closure can result in hemodynamic and respiratory complications. Postoperative intensive care including ventilation is necessary, as respiratory impairment often persists owing to lung hypoplasia. Survival is influenced by concomitant defects, the presence of organ failure, and degree of recovery. Prenatal, intrauterine interventions are increasingly used with different therapeutic approaches.

11 | CONCLUSION

Thoracic anesthesia in children may be a challenging task. In order to establish a safe and adequate perioperative management, the anesthesiologist needs to incorporate the patient's age and preoperative condition, the pathophysiology of the underlying disease and implications of the planned intervention. A detailed concept for every patient should be tailored including airway management for OLV and perioperative analgesia as well as the perioperative disposition. Simply transferring adult management principles is often not feasible. A clear understanding of the interdependent pathologies and developing changes enables the clinician to deal with possible complications. Further clinical studies will be needed to determine the impact of protective ventilation and the benefit of neuraxial anesthesia in children.

CONFLICT OF INTEREST

The authors report no conflict of interest.

REFLECTIVE QUESTIONS

After reading this article, the reader should be able to answer the following questions.

What are the main differences between adult and pediatric patients presenting for thoracic surgery influencing the anesthetic management?

Explain the perioperative problems encountered in children presenting with empyema?

Which regional anesthetic techniques can be performed to provide adequate pain relief for thoracotomies and thoracoscopic surgery?

Discuss the technical options and pharmacologic aspects of neuraxial anesthesia in especially young children presenting for thoracic surgery.

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SUPPORTING INFORMATION

Additional Supporting Information may be found online in the supporting information tab for this article.

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