Pediatric thoracic anesthesia

Brenda Golianu[a] and Gregory B. Hammer[b]

Purpose of review

Surgical interventions, including video-assisted thoracoscopic surgeries, are increasingly being performed in the neonatal and pediatric populations. Thoracic anesthesia in infants and children poses special challenges for the anesthesiologist. These include assessment of the patient's clinical condition, obtaining and maintaining single lung ventilation, and maintaining adequate ventilation and oxygenation while the surgery is in progress.

Recent findings

This review will outline the anesthetic management of infants and children undergoing thoracic surgery, including preoperative assessment, and anesthetic induction and maintenance. The physiology and methods of single lung ventilation will be reviewed, including the use of bronchial blockers, Univent tubes and double-lumen tubes. Special considerations for video-assisted thoracoscopic surgery, pectus repair and mediastinal masses will be discussed.

Summary

These techniques will provide the anesthesiologist with a number of strategies for assessing the pediatric thoracic patient and for managing pediatric single lung ventilation.

Keywords

anesthesia for video-assisted thoracoscopic surgery, bronchial blockers in children, pediatric anesthesia, pediatric thoracic anesthesia, pediatric thoracic surgery, single lung ventilation in children

Curr Opin Anaesthesiol 18:5–11. © 2005 Lippincott Williams & Wilkins.

[a]Assistant Professor of Anesthesia and [b]Professor of Anesthesia and Pediatrics, Stanford University School of Medicine, Stanford, California, USA

Correspondence to Brenda Golianu MD, Assistant Professor of Anesthesia, Stanford University, 300 Pasteur Drive, Stanford, CA 94305, USA
Tel: +1 650 723 5728; fax: +1 650 725 8544; e-mail: bgolianu@stanford.edu

Current Opinion in Anaesthesiology 2005, 18:5–11

Abbreviations

DLT	double lumen tube
ETT	endotracheal tube
SLV	single lung ventilation
V/Q	ventilation/perfusion

0952-7907

Introduction

Thoracic anesthesia in infants and children poses special challenges for the anesthesiologist. Children may suffer from a wide variety of conditions, and may present with different degrees of pulmonary compromise which may not be evident from a cursory examination. A thorough understanding of pediatric physiology as well as of the principles of pediatric anesthesia and thoracic anesthesia is important in order to care for these children safely. This review outlines anesthetic assessment and methods of achieving single lung ventilation (SLV) in children, and describes special circumstances, including anesthesia for video-assisted thoracoscopic surgery, pectus repair and mediastinal masses.

Preoperative assessment

A thorough preoperative evaluation, including appropriate imaging and laboratory studies according to the lesion involved, is essential in caring for the pediatric patient scheduled for thoracic surgery. Special attention must be paid to the clinical status of the child, and any underlying acute or chronic conditions that may impact the perioperative course. The history in older children focuses on complaints of dyspnea, cyanosis, wheezing, coughing, and weight loss. Infants often show less specific signs, such as poor feeding, irritability, or change in sleep habits. If the child has had previous surgery, the perioperative course should be examined. Because children tolerate the loss of large amounts of usable lung tissue without obvious distress, the appearance of dyspnea or diminished exercise tolerance is an ominous sign. The chest is inspected for asymmetric expansion and use of accessory muscles and then is auscultated for wheezes, rales, rhonchi, and absent breath sounds in both the supine and sitting positions. Measurement of oxygen saturation by pulse oximetry and evaluation of venous HCO_3, elevated in children with chronic CO_2 retention, generally supplant the need for arterial blood gas analysis. While pulmonary function testing may be useful in infants and children for monitoring progress of their underlying pulmonary process [1], it is not routinely used for perioperative assessment. In a recent study in patients undergoing spinal fusion [2], there was no correlation between deterioration of preoperative pulmonary function and the risk of postoperative pulmonary complications.

Preparation for surgery starts with a discussion of the proposed anesthetic with the parents and, if appropriate, the child. The anesthetic plan, including monitors,

possible complications, and potential for postoperative ventilation, is discussed. Guidelines for fasting, choice of premedication, and preparation of the operating room are used as for other infants and children scheduled for major surgery. In addition to routine monitors, including capnography, transcutaneous CO_2 monitoring may provide a useful approximation of arterial CO_2 tension [3•].

Following induction of anesthesia, placement of an intravenous catheter, and tracheal intubation, arterial catheterization should be performed for most patients undergoing thoracotomy as well as those with severe lung disease having thoracoscopic surgery. This facilitates 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, arterial cannulation is usually not required. Arterial cannulation for pressure and arterial blood samples is useful and is needed if extensive blood loss or resection of lung tissue is expected or if the child is already critically ill. Percutaneous arterial cannulas (24-gauge in neonates, 22-gauge in children up to 8–10 years of age, and 20-gauge in pre-adolescents and older) are usually used. Central venous monitoring is used less commonly but can be helpful for guiding extensive intravenous fluid therapy. Urinary drainage may be useful for particularly lengthy operations. Although blood loss is generally minimal in thoracic procedures, the possibility of blood loss due to manipulation of inflamed tissues, as in the case of empyema, or possible injury to the great vessels exists, and may necessitate blood transfusion.

The choice of anesthetic agents depends on both the patient's status and the surgical lesion. Nitrous oxide can accumulate in cysts with air–fluid levels and should be avoided in such cases or in patients requiring a high fraction of inspired oxygen (FiO_2). Inhalation agents are especially useful in patients with bronchospasm but may precipitate hypotension in patients with poor cardiac function. Muscle relaxants are routinely used along with controlled ventilation employing humidified gases. Intermittent manual ventilation may provide useful information to the anesthesiologist about changes in chest compliance or airway resistance.

Inhalation anesthetic agents are commonly administered in 100% O_2 during maintenance of anesthesia. Isoflurane may be preferred due to less attenuation of hypoxic pulmonary vasoconstriction (HPV) compared with other inhalational agents, although this has not been studied in children. Use of intravenous opioids may facilitate a decrease in the concentration of inhalational anesthetics used, and therefore limit impairment of hypoxic pulmonary vasoconstriction. Alternatively, total intravenous anesthesia may be used with a variety of agents. There is some evidence that propofol does not inhibit hypoxic pulmonary vasoconstriction [4]. Thoracic epidural anesthesia preserves this condition [5], and the combination of general anesthesia with regional anesthesia and postoperative analgesia is particularly desirable for thoracotomy. Combined regional and general anesthesia may also be beneficial for thoracoscopic procedures, especially when thoracostomy tube drainage, a source of significant postoperative pain, is used following surgery. A variety of regional anesthetic techniques have been described for intraoperative anesthesia and postoperative analgesia, including intercostal and paravertebral blocks, intrapleural infusions, and epidural anesthesia. Pain management is further covered in a separate review in this issue [6].

Physiology of single lung ventilation in children

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 ventilation/perfusion (V/Q) mismatch. Compression of the dependent lung in the lateral decubitus position may cause atelectasis. Surgical retraction and/or SLV result in collapse of the operative lung. Hypoxic pulmonary vasoconstriction acts to divert blood flow away from underventilated lung regions, thereby minimizing V/Q mismatch, and may be diminished by inhalational anesthetic agents and other vasodilating drugs. The overall effect of the lateral decubitus position on V/Q mismatch, however, is different in infants compared to 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'). 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 (i.e. gravitational) gradient between the two lungs. This phenomenon promotes V/Q matching in the adult patient undergoing thoracic surgery in the lateral decubitus position.

In infants with unilateral 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. The infant's small size also 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.

Finally, the infant's increased oxygen requirement, coupled with a small functional residual capacity, predisposes to hypoxemia. Infants normally consume 6–8 ml of O_2/kg/min compared with a normal O_2 consumption in adults of 2–3 ml/kg/min. For these reasons, infants are at an increased risk of significant oxygen desaturation during surgery in the lateral decubitus position [7•].

Selective endobronchial intubation

The simplest means of providing SLV is to intentionally intubate the ipsilateral mainstem bronchus with a conventional single lumen endotracheal tube (ETT) [8]. When the left bronchus is to be intubated, the bevel of the ETT is rotated 180° and the head turned to the right [9]. The tube is advanced into the bronchus until breath sounds on the operative side disappear. A fiberoptic bronchoscope may be passed through or alongside the tube to confirm or guide placement. 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 [10].

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

Problems with using a single lumen ETT for SLV include failure to provide an adequate seal of the intended bronchus, especially if a smaller, uncuffed ETT is used. This may prevent the operated lung from adequately collapsing or fail to protect the healthy, ventilated lung from contamination by purulent material from the contralateral lung. One is unable to suction the operated 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 [11–14]. One mainstem bronchus is initially intubated with an ETT, after which another ETT is advanced over a fiberoptic bronchoscope into the opposite bronchus.

Balloon-tipped bronchial blockers

The use of an end-hole, balloon wedge catheter as a bronchial blocker has been described [15]. The bronchus on the operative side is initially intubated with an ETT. A guidewire is then advanced into that bronchus through the ETT. The tube is removed and the blocker is advanced over the guidewire into the bronchus. A second ETT is then reinserted into the trachea alongside the blocker catheter. The catheter balloon is positioned in the proximal mainstem bronchus under fiberoptic visual guidance. Alternatively, a Fogarty embolectomy catheter (Edwards Lifesciences, Irvine, CA, USA) may be placed with or without fiberoptic bronchoscope guidance [16–18]. With an inflated blocker balloon the airway is completely sealed, providing more predictable lung collapse and better operating conditions than with an ETT in the bronchus [19].

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 operated 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 [20]. A recent study, however, reported that bronchial blocker cuffs produced lower 'cuff to tracheal' pressures than double lumen tubes [21]. When closed tip bronchial blockers are used, the operated lung cannot be suctioned and continuous positive airway pressure cannot be provided to the operated lung if needed.

Adaptors have been used that facilitate ventilation during placement of a bronchial blocker through an indwelling endotracheal tube [22,23]. The risk of hypoxemia during blocker placement is diminished, and repositioning of the blocker may be performed with fiberoptic guidance during surgery. The increasing use of the Cook 5 French (Fr) pediatric bronchial blocker (Cook Critical Care, Bloomington, IN, USA) shows promising results for children aged 2–16 years [24].

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 [25–27]. A balloon located at the distal end of this small tube serves as a blocker. Univent tubes require fiberoptic bronchoscope for successful placement. Univent tubes are now available in sizes as small as 3.5-mm and 4.5-mm internal diameter for use in children over 6 years of age [28]. 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 operated lung.

A disadvantage of the Univent tube is the large amount of cross-sectional area occupied by the blocker channel, especially in the smaller sized tubes [29] which have a disproportionately high resistance to gas flow [30]. The Univent tube's blocker balloon has low-volume, high-pressure characteristics so mucosal injury can occur during normal inflation [31,32].

Double lumen tubes

All double lumen tubes (DLTs) are essentially two tubes of unequal length molded together. The shorter tube ends in the trachea and the longer tube in the bronchus. This tube is not available in the USA. 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.

Marraro [33] described a bilumen tube for infants which consists of two separate uncuffed tracheal tubes of different length attached longitudinally. 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, USA) 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, USA) and are suitable for children 10 years of age and older.

In children the DLT is inserted using the same technique as in adults [34]. The tip of the tube is inserted just past the vocal cords and the stylet is withdrawn. The tube is rotated through 90° 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 [36]. No equivalent measurements are yet available in children. If fiberoptic bronchoscopy is to be used to confirm tube placement, a bronchoscope with a small diameter and sufficient length must be available [35].

A DLT offers the advantage of ease of insertion, ability to suction and oxygenate the operative lung with continuous positive airway pressure, 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 [37]. Right DLTs are more difficult to position accurately because of the greater risk of right upper lobe obstruction. DLTs are safe and easy to use; there are very few reports of airway damage from these tubes in adults, and none in children. Their 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.

Table 1. Tube selection for single lung ventilation in children

Age (years)	ETT (ID)	BB (Fr)	Univent (ID)	DLT (Fr)
0.5–1	3.5–4.0	2–3		
1–2	4.0–4.5	3		
2–4	4.5–5.0	5		
4–6	5.0–5.5	5		
6–8	5.5–6	5	3.5	
8–10	6.0 cuffed	5	3.5	26
10–12	6.5 cuffed	5	4.5	26–28
12–14	6.5–7.0 cuffed	7	4.5	32
14–16	7.0 cuffed	7	6.0	35
16–18	8.0–8.5 cuffed	7–9	7.0	35

ETT, endotracheal tube; ID, internal diameter in mm; BB, balloon-tipped bronchial blocker; Fr, French; DLT, double lumen tube.

Guidelines for selecting appropriate tubes (or catheters) for SLV in children are shown in Table 1. There is significant variability in overall size and airway dimensions in children, particularly in teenagers. The recommendation shown is based on average values for airway dimensions. Larger DLTs may be safely used in large teenagers.

Postoperative care

Tracheal extubation at the completion of surgery is often possible after simple subsegmental resection or lobectomy. However, the patient's underlying cardiopulmonary reserve, the course of the surgery, and the expected postoperative course may preclude extubation. Although postoperative pain can cause significant splinting, intercostal or epidural blocks, coupled with judicious parenteral narcotics, can minimize the discomfort (see Pain management review in this issue [6]). Whether in the operating room or in the intensive care area, before extubation the patient must be awake, breathing well, able to cough and maintain an airway, and able to maintain acceptable oxygenation with no more than 40% inspired oxygen. A chest radiograph should be obtained as soon as possible after surgery to detect any significant pneumothorax or atelectasis. Atelectasis is common and usually responds to humidity, encouragement to cough, and, if necessary, endotracheal suction.

The expected postoperative course depends on both the surgical procedure and the underlying diseases. After simple lobectomy, most children develop normally and have normal exercise tolerance [38].

Video-assisted thoracoscopic procedures

During the past decade, the use of video-assisted thoracoscopic surgery has dramatically increased in

children [39••]. Advantages of thoracoscopy include smaller chest incisions, reduced postoperative pain, and more rapid postoperative recovery compared with thoracotomy. Thoracoscopic surgery is being used extensively for pleural debridement in patients with empyema [40], lung biopsy, hiatal hernia repair, spinal fusion, patent ductus arteriosus repair [41], and sometimes for metastatic lesions or mediastinal masses [42]. Thoracoscopy can be performed while both lungs are being ventilated; however, SLV is usually preferable to improve visualization of thoracic contents and reduce the chance of lung injury being caused by the use of retractors. Anesthetic management for this procedure begins with a thorough understanding of the underlying pathology, severity of pulmonary disease, ability to tolerate lateral decubitus position and positive pressure ventilation. Nitrous oxide should not be used. An arterial line is usually not necessary but may help to monitor the hemodynamic responses to positive pressure. Care must be taken to monitor blood and fluid therapy as hypovolemia may exacerbate these responses. $EtCO_2$ monitoring can be unreliable, and transcutaneous CO_2 or arterial blood gas monitoring may be helpful. If the patient is tolerating the procedure poorly, as may happen with very small infants, intermittent reinsuflation of the lungs, positive end expiratory pressure to the dependent lung or continuous positive airway pressure to the operative lung, while decreasing visualization, may allow the surgery to be continued.

Pectus repairs

Children with pectus excavatum (funnel chest) or the less common pectus carinatum (pigeon breast) deformity often appear asymptomatic, but may have cardiac or pulmonary compromise related to the structural abnormality. Patients with pectus excavatum may present with reduced forced vital capacity and total lung volume. The heart may be displaced to the left and compressed, leading to arrhythmias, right axis deviation on electrocardiogram, and a functional murmur, most noticeable in the standing position or during exercise, which may indicate the need for an echocardiogram to evaluate function. The echocardiogram may show reduced stroke volume. There is also an increased incidence of mitral valve prolapse in patients with pectus deformities.

Operative management involves a premedication, inhalation or i.v. induction and endotracheal intubation. SLV is usually not necessary. An additional i.v. is placed in case of bleeding, while an arterial catheter is usually not necessary. Ventilation is with 8–10 cc/kg tidal volume, subacute bacterial endocarditis prophylaxis is given if warranted, and a thoracic epidural is placed for postoperative pain control. If a minimally invasive technique is used for the pectus repair, intravenous patient-controlled analgesia along with a non-steroidal agent such as ketorolac is generally sufficient.

Anesthesia for the patient with a mediastinal mass

Anesthetic management of children with mediastinal diseases demands careful preoperative evaluation and planning [43]. Anesthetic induction alone can lead to severe airway obstruction, hemodynamic compromise and death [44]. History and physical examination should focus not only on signs such as cyanosis and stridor but also on maneuvers or circumstances that change the signs. The practitioner should determine whether sleep, excitement, position, movement of the head and neck, or coughing changes the degree of obstruction. Although chest radiographs, tomograms, and barium studies provide some information, computed tomography (CT) scans are best at delineating airway or cardiovascular obstruction. CT scans have the added advantage of demonstrating extension of infection or tumor into structures such as the pericardium. Signs of lower airway disease can be caused by mediastinal tumors.

Compression of the lower airways and lung tissue can be responsible for wheezing, atelectasis, obstructive emphysema, and recurrent pneumonias. This is important because wheezing caused by compression of lower airways and lung tissue usually does not respond to bronchodilators, nor will atelectasis caused by compression respond to chest physical therapy. In older, more cooperative children, maximal inspiratory and expiratory flow volume loops obtained with the patient upright and supine can quantitate the functional degree of impairment and help distinguish fixed from variable obstructions. Cardiovascular involvement may be related to direct compression of the heart or of the great vessels. Echocardiography or CT scanning can delineate impingement. The important determination is assessment of functional impairment. If the child has arrhythmias, pulsus paradoxus, hypotension, or superior vena caval syndrome, the risk of general anesthesia increases dramatically.

Induction of anesthesia may remove compensatory efforts by the patient. The child's position, pattern of ventilation, or sympathetic tone while awake may have been responsible for barely maintaining adequate cardiopulmonary function. In these situations the anesthesiologist and surgeon must determine alternative approaches to the lesion. If the child has a better airway, easier ventilation, or less hypotension in one position, efforts are made to maintain this position. Biopsy of accessible lesions under local anesthesia should be considered if there is significant cardiopulmonary compromise. In extreme cases, radiation or corticosteroid therapy may shrink the tumor mass quickly, allowing a biopsy to be done later with less risk to the patient.

If general anesthesia is employed, the surgeon should be present at induction and prepared for interventions such

as passage of a rigid bronchoscope or immediate release of a pneumomediastinum by subxiphoid thoracotomy. Of utmost importance is that patients, family, pediatrician, and surgeon all understand the risk of cardiovascular and respiratory compromise that exists when performing tissue biopsies under general anesthesia. Mask induction with a volatile agent and 100% oxygen is preferred to intravenous induction if there is concern about airway obstruction. Thus, some of the negative intrathoracic pressure of spontaneous ventilation and any positive effect this has on maintenance of airway patency are preserved. Airway obstruction may significantly worsen with positive pressure ventilation.

Major complications include airway obstruction, perforation of the airway, and massive blood loss. There continue to be sporadic reports of death during induction and maintenance of anesthesia in children with mediastinal masses, usually related to airway or hemodynamic compromise related to the mass effect. From a review of the 44 pediatric patients with mediastinal masses, Ferrari and Bedford [45] noted that significant anesthesia-related problems occurred in the patients who were symptomatic before surgery. They noted that general anesthesia could be administered with the following caveats: spontaneous ventilation must be maintained, induction of anesthesia should be in the sitting position, intravenous access should be in the lower extremity, and a rigid bronchoscope and experienced bronchoscopist must be available. The anesthesiologist not only must be prepared for each complication but must also notify the surgeon immediately if there is loss of airway, difficulty in ventilation, or sudden hypotension.

Conclusion

Thoracic anesthesia in infants and children poses special challenges for the anesthesiologist. These include careful preoperative preparation, obtaining SLV in a small airway, and maintaining a delicate balance of ventilation and hemodynamics while allowing the surgeon access to a very limited intrathoracic cavity. Ensuring adequate monitoring, intravenous access, arterial cannulation and blood replacement, and constant communication with the surgeon about developing situations are essential to success.

References and recommended reading

Papers of particular interest, published within the annual period of review, have been highlighted as:

- • of special interest
- •• of outstanding interest

1 Stocks J. Infant respiratory function testing: is it worth all the effort? Paediatr Anaesth 2004; 13:537–540.

2 Yuan N, Skaggs DL, Davidson WSL, *et al.* Preoperative polysomnograms and infant pulmonary function tests do not predict prolonged post-operative mechanical ventilation in children following scoliosis repair. Pediatr Pulmonol 2004; 38:256–260.

3 • Tobias JD. Noninvasive carbon dioxide monitoring during one-lung ventilation: end-tidal versus transcutaneous techniques. J Cardiothorac Vasc Anesth 2003; 17:306–308.
This study describes the relationship between end-tidal and transcutaneous methods of measuring PC02.

4 Van Keer L, Van Aken H, Vandermeersch E, *et al.* Propofol does not inhibit hypoxic pulmonary vasoconstriction in humans. J Clin Anesth 1989; 1:284–288.

5 Ishibe Y, Shiokawa Y, Umeda T, *et al.* The effect of thoracic epidural anesthesia on hypoxic pulmonary vasoconstriction in dogs: an analysis of the pressure-flow volume curve. Anesth Analg 1996; 82:1049–1055.

6 Golianu B, Hammer GB. Pain management for pediatric thoracic surgery. Curr Opin Anesthesiol 2005; 18:12–20.

7 • Shaffer TH, Wolfson MR, Panitch HB. Airway structure, function and development in health and disease. Paediatr Anaesth 2004; 14:3–14.
This is an excellent review of pediatric pulmonary physiology.

8 Rowe R, Andropoulos D, Heard M, *et al.* Anesthetic management of pediatric patients undergoing thoracoscopy. J Cardiothorac Vasc Anesth 1994; 8:563.

9 Kubota H, Kubota Y, Toshiro T, *et al.* Selective blind endobronchial intubation in children and adults. Anesthesiology 1987; 67:587–589.

10 Lammers CR, Hammer GB, Brodsky JB, Cannon WB. Failure to isolate the lungs with an endotracheal tube positioned in the bronchus. Anesth Analg 1997; 85:944.

11 Cullum AR, English CW, Branthwaite MA. Endobronchial intubation in infancy. Anaesthesia 1973; 28:66–70.

12 McLellan I. Endobronchial intubation in children. Anaesthesia 1974; 29:757–758.

13 Yeh TF, Pildes RS, Salem MR. Treatment of persistent tension pneumothorax in a neonate by selective bronchial intubation. Anesthesiology 1978; 49:37–38.

14 Watson CB, Bowe EA, Burk W. One-lung anesthesia for pediatric thoracic surgery: a new use for the fiberoptic bronchoscope. Anesthesiology 1982; 56:314–315.

15 Hammer GB, Manos SJ, Smith BM, *et al.* Single lung ventilation in pediatric patients. Anesthesiology 1996; 84:1503–1506.

16 Ginsberg RJ. New technique for one-lung anesthesia using a bronchial blocker. J Thorac Cardiovasc Surg 1981; 82:542–546.

17 Lin YC, Hackel A. Paediatric selective bronchial blocker. Paediatr Anaesth 1994; 4:391–392.

18 Turner MWH, Buchanon CCR, Brown SW. Paediatric one lung ventilation in the prone position. Paediatr Anaesth 1997; 7:427–429.

19 Mohan VK, Darlong VM, Kashyap L, *et al.* Fiberoptic-guided Fogarty catheter placement using the same diaphragm of an adapter within the single-lumen tube in children. Anesth Analg 2002; 95:1241–1242.

20 Borchardt RA, LaQuaglia MP, McDowall. Wilson RS. Bronchial injury during lung isolation in a pediatric patient. Anesth Analg 1998; 87:324–325.

21 Guyton DC, Besselievre TR, Devidas M, *et al.* A comparison of two different bronchial cuff designs and four different bronchial cuff inflation methods. J Cardiothorac Vasc Anesth 1997; 11:599–603.

22 Takahashi M, Horinouchi T, Kato M, *et al.* Double-access-port endotracheal tube for selective lung ventilation in pediatric patients. Anesthesiology 2000; 93:308–309.

23 Arndt GA, De Lessio ST, Kranner PW, *et al.* One-lung ventilation when intubation is difficult – presentation of a new endobronchial blocker. Acta Anaesthesiol Scand 1999; 43:356–358.

24 Wald SH, Mahajan A, Kaplan MB, Atkinson JB. Experience with the Arndt paediatric bronchial blocker. *Br J Anaesth* [online serial] 2004; Oct 14.

25 Kamaya H, Krishna PR. New endotracheal tube (Univent tube) for selective blockade of one lung. Anesthesiology 1985; 63:342–343.

26 Karwande SV. A new tube for single lung ventilation. Chest 1987; 92:761–763.

27 Gayes JM. Pro: one-lung ventilation is best accomplished with the Univent endotracheal tube. J Cardiothorac Vasc Anesth 1993; 7:103–105.

28 Hammer GB, Brodsky JB, Redpath J, Cannon WB. The Univent tube for single lung ventilation in children. Paediatr Anaesth 1998; 8:55–57.

29 Frolich MA, Janelle GM. Postoperative atelectasis after one-lung ventilation with the Univent tube in a child. J Clin Anesth 2003; 15:159–163.

30 Slinger PD, Lesiuk L. Flow resistances of disposable double-lumen, single-lumen, and Univent tubes. J Cardiothorac Vasc Anesth 1998; 12:142–144.

31 Kelley JG, Gaba DM, Brodsky JB. Bronchial cuff pressures of two tubes used in thoracic surgery. J Cardiothorac Vasc Anesth 1992; 6:190–194.

32 Benumof JL, Gaughan SD, Ozaki GT. The relationship among bronchial blocker cuff inflation volume, proximal airway pressure, and seal of the bronchial blocker cuff. J Cardiothorac Vasc Anesth 1992; 6:404–408.

33 Marraro G. Selective bronchial intubation in paediatrics: the Marraro paediatric bilumen tube. Paediatr Anaesth 1994; 4:255–258.

34 Brodsky JB, Mark JBD. A simple technique for accurate placement of double-lumen endobronchial tubes. Anesth Rev 1983; 10:26–30.

35 Slinger PD. Fiberoptic bronchoscopic positioning of double-lumen tubes. J Cardiothorac Anesth 1989; 3:486–496.

36 Brodsky JB, Macario A, Mark JBD. Tracheal diameter predicts double-lumen tube size: a method for selecting left double-lumen tubes. Anesth Analg 1996; 82:861–864.

37 Benumof JL, Partridge BL, Salvatierra C, Keating J. Margin of safety in positioning modern double-lumen endotracheal tubes. Anesthesiology 1987; 67:729–738.

38 Shaffer TH, Wolfson MR, Panitch HB. Airway structure, function and development in health and disease. Paediatr Anaesth 2004; 14:3–14.

39 Tobias JD. Anaesthesia for neonatal thoracic surgery. Best Pract Res Clin •• Anaesthesiol 2004; 18:303–320.
An outstanding review of neonatal anesthesia for thoracic procedures.

40 Cohen G, Hjortdal V, Ricci M, *et al.* Primary thoracoscopic treatment of empyema in children. J Thorac Cardiovasc Surg 2003; 125:79–83.

41 Nezafati MG, Nahmoodi E, Hashemian SH, Hamedanchi A. Video-assisted thoracoscopic surgical (VATS) closure of Patent Ductus Arteriosus: report of three-hundred cases. Heart Surg Forum 2002; 5:57–59.

42 Hammer GB. Single-lung ventilation in infants and children. Paediatr Anaesth 2004; 14:98–102.

43 Hammer GB. Anaesthetic management for the child with a mediastinal mass. Paediatr Anaesth 2004; 14:95–97.

44 Narang S, Harte BH, Body SC. Anesthesia for patients with a mediastinal mass. Anesth Clin North Am 2001; 19:559–577.

45 Ferrari LR, Bedford RF. General anesthesia prior to treatment of anterior mediastinal masses in pediatric cancer patients. Anesthesiology 1990; 72:991.