Chapter

30 Anaesthesia for Thoracic Surgery in Children*

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Introduction

Anaesthesia for thoracic surgery in children poses different problems from those encountered in adult practice. It is a low-volume specialty largely confined to specialist paediatric hospitals. Anaesthesia may be required for a heterogeneous range of conditions, will frequently be of an urgent or emergency nature and can very often be challenging. This chapter will cover the management of congenital and acquired lung abnormalities, intrathoracic masses, intrapleural collections and pectus surgery. Patient positioning, surgical retraction of the lung and underlying disease processes all contribute to the demands placed on the paediatric thoracic anaesthetist. Thoracotomy for cardiac surgery (e.g. coarctation repair) is covered in Chapter 31 and thoracotomy for oesophageal anomalies is covered in Chapter 18.

Congenital Abnormalities of the Lung

Congenital Lobar Emphysema (CLE)

This condition is due to bronchial cartilaginous dysplasia that generates a ball-valve effect resulting in pathological emphysematous accumulation of air within the affected lobe. It is associated with poor deflation of that lobe. Usually a single lobe is affected, most commonly the left upper. There is a spectrum of disease which usually presents in the neonatal period. Presentation may be that of a coincidental X-ray finding; alternatively, a neonate may present in extremis, with hypoxia, hypercapnia and mediastinal shift caused by hyperinflated lung tissue (Figure 30.1). When a child presents acutely, urgent lobectomy is indicated.

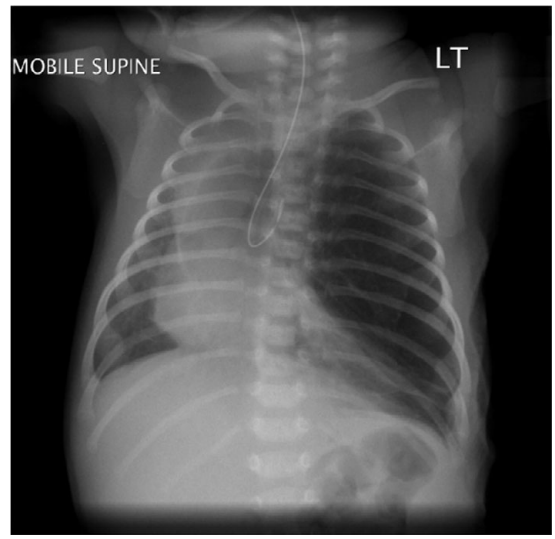

Figure 30.1 Chest X-ray showing congenital lobar emphysema.

Congenital Cystic Abnormalities of the Lung

There are three main types of congenital cystic abnormalities.

- Congenital cystic adenomatous malformation
- Pulmonary sequestration
- Bronchogenic cysts

In common with congenital lobar emphysema, there is a spectrum of disease. Symptoms can be caused by mass effect or by secondary infection.

Congenital Cystic Adenomatous Malformation (CCAM)

CCAM results from localised arrest of maturation of fetal lung. A disorganised mass of air and/or blood-filled cysts is present which does not usually communicate with normal lung (Figure 30.2). An antenatal diagnosis is often made, but the

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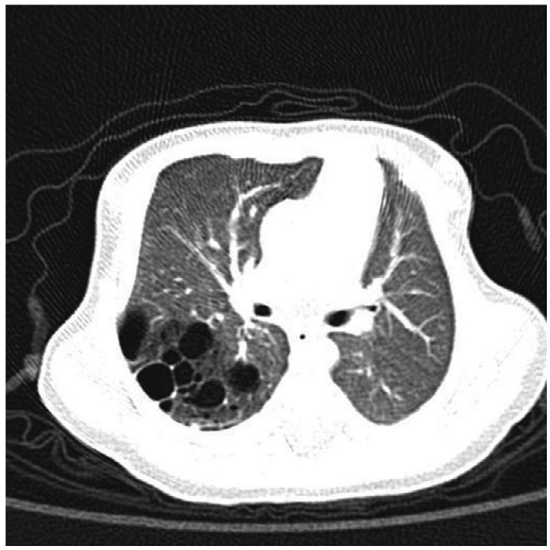

Figure 30.2 CT scan showing congenital cystic adenomatous malformations in the lung.

immediate course of action depends on the clinical condition of the child once born. Resection of the abnormal mass may be required urgently to relieve compression, although this is not usually as marked as with congenital lobar emphysema. The affected area may be removed electively later in childhood to prevent infection and to remove the abnormal tissue, which has potential to undergo malignant change.

Pulmonary Sequestration

This is a separate bronchopulmonary mass or cyst which is disconnected from the bronchial tree and has a separate blood supply arising from the aorta. It forms when a supernumerary lung bud arises from the primitive foregut. Other congenital abnormalities are present in 65% of cases. Appropriate preoperative investigation (e.g. contrast CT scan) is required to identify the blood supply.

Bronchogenic Cysts

These are solitary, unilocular and often mucus filled. They are often an incidental radiographic finding but may become infected.

Acquired Pathology

Thoracic Tumours in Children

Primary lung malignancies are rare in children. Extensive intrathoracic tumours such as neuroblastoma may require de-bulking or resection through a thoracotomy. Such tumours are not usually intrapulmonary. Thoracotomy may be required for metastatectomy.

Anterior Mediastinal Mass

Anterior mediastinal masses are a common presenting feature of haematological malignancy, such as lymphoma, or occasionally primary malignancy. Histological diagnosis of a mediastinal mass is essential to direct therapy. Mediastinal masses can compress the trachea, bronchi or great vessels. Respiratory symptoms are frequently the presenting feature and may be rapidly progressive. Occasionally a child with a mediastinal mass presents in extremis with airway obstruction. Stridor, respiratory difficulty at rest or orthopnea are particularly concerning signs. CT scan images obtained preoperatively are particularly helpful to identify compression of major structures. Preoperative steroids may relieve symptoms to some extent in haematological malignancy but may make the mass shrink quickly and provoke tumour lysis syndrome.

Although most children requiring anaesthesia for biopsy of a mediastinal mass tolerate the procedure without major incident, catastrophic airway and cardiovascular compromise can occur. Alterations in chest wall muscle tone, for example following administration of neuromuscular blocking drugs, or minor postural changes can provoke total airway obstruction or occlude venous return. Such complications must be anticipated following induction of anaesthesia. Splinting the obstruction with a rigid bronchoscope and/or turning the patient prone may rescue the situation. If this does not relieve the obstruction, the only solution may be the emergency provision of cardiopulmonary bypass. For this reason, surgery for mediastinal masses should be performed by paediatric cardiac surgeons in a cardiac surgical unit.

Pleural Collections

Pleural drainage became incorporated into surgical practice in 1917 to treat empyema associated with the influenza pandemic. Pleural drainage removes air, blood or other fluid from the pleural space, allowing lung re-expansion and eliminating mediastinal shift. Negative intrapleural pressure during spontaneous respiration cannot be

achieved if gas or fluid intervenes between the two pleural layers.

Empyema

Empyema is a complication of bacterial pneumonia (usually pneumococcal) in approximately 5–10% of children. It results in inflammatory debris forming a thick, inelastic covering of the lung, restricting expansion, often accompanied by a purulent pleural effusion. Areas of lung may be necrotic, with the potential for the development of a bronchopleural fistula.

Children with this condition are frequently systemically unwell with fever and bacteraemia and may have been ill for several days or weeks before presenting for surgery. Some children will be septicaemic and haemodynamically compromised; fluid resuscitation may be necessary. Blood should be cross-matched; many of these children have become anaemic during the illness, and blood loss from the inflamed lung surface is occasionally significant. Severely ill children may require a period of optimisation in intensive care before proceeding to surgery and may require postoperative ventilation. Oxygenation is often marginal at presentation and may be compromised further during one-lung ventilation (OLV). Most previously well children improve markedly after decortication.

Video-assisted thoracoscopic surgery (VATS) and decortication is the surgical treatment of choice to break down the fibrin strands and evacuate the pus. In patients with marked pleural thickening and encasement of the lung, thoracotomy and open decortication may be required. The thick inflammatory debris encapsulating the lung is excised, allowing the lung to re-expand, and any necrotic tissue is removed.

Lung Abscess

This may be associated with primary bacterial infection but may also be precipitated by foreign body inhalation. It may require lung resection. Destruction of lung tissue and erosion into a bronchus with bronchopleural fistula formation may have occurred. Although OLV may not assist with the surgical field, its use may prevent soiling of the non-operative lung and may be necessary at intubation in the presence of a bronchopleural fistula.

Bronchiectasis

Chronic infection damages the muscular and elastic components of affected bronchi. It is a feature of cystic fibrosis. In children, it is often associated with underlying immune compromise or immune suppression and is a common long-term complication of children receiving organ transplantation in early life. Surgical resection of localised disease is indicated to prevent infection of normal lung tissue. Provision of OLV is indicated during resection to prevent soiling and infection of the healthy lung.

Chest Wall Deformity

Pectus excavatum is more common than pectus carinatum. Unless extremely severe, the indication for correction is cosmetic, and children undergoing this surgery should be old enough to understand and to consent to surgery themselves. The Ravitch procedure involves a major incision across the chest, detachment of costal cartilages from the sternum and surgical re-modelling of the sternum. This has been replaced by the minimally invasive Nuss procedure. A curved steel bar is inserted under endoscopic guidance under the sternum and then rotated 180° to raise the sternum. Safe insertion of the Nuss bar requires thoracoscopy with CO_2 insufflation to create space anterior to the mediastinum for its insertion. Whichever procedure is used, the major issue is the control of postoperative pain. Strategies include thoracic epidural analgesia, paravertebral block (either via single-shot or catheter infusion) and patient-controlled analgesia (e.g. with morphine and ketamine). Each approach has a distinct risk-benefit profile.

Anaesthesia for Thoracic Surgery: Specific Considerations

The importance of preoperative assessment and continuing communication with the surgical and operating theatre staff cannot be overstated, and use of the WHO Safe Surgery Guidelines to ensure the correct side is operated on is mandatory. If lung isolation is planned, topical local anaesthetic to the larynx and trachea can be used, as repeated manipulation may be required to position the tracheal tube correctly. Nitrous oxide is contraindicated in thoracic anaesthesia as it may diffuse into and expand any gas-filled cavity.

Vascular Access

Thoracic surgery may involve the mobilisation of large blood vessels, or operating on inflamed, friable tissue. Intra-operative bleeding can be brisk during tumour surgery, and significant plasma losses from either raw tissue surfaces or consequent to lymphatic disruption can occur during the postoperative period. Adequate venous access is essential for fluid replacement, and cross-matched blood should be available. Central venous pressure monitoring can be misleading in the lateral decubitus position, but central venous cannulation is indicated if haemodynamic instability is anticipated or if there is inadequate peripheral venous access. Invasive arterial pressure monitoring is helpful because of the potential for intraoperative haemodynamic instability and for blood gas analysis.

Hypoxic Pulmonary Vasoconstriction (HPV)

HPV is the mechanism by which the body limits blood flow through unventilated or hypoxic areas of lung. If HPV is inhibited, then the flow of deoxygenated blood increases through non-ventilated areas of lung. Much has been written about the inhibitory effects of inhalational anaesthetic agents on HPV, but in practice it is not a problem unless high concentrations of inspired agent are used.

Lateral Decubitus Position

Most thoracic procedures require the patient to be in the lateral decubitus position, operative side uppermost. Increased ventilation/perfusion (V/Q) mismatch may result in hypoxaemia as:

- Surgical retraction of the upper (operative) lung or OLV causes collapse of the operative lung.
- The dependent lung may be compressed by the mediastinum and abdominal organs.
- HPV may be impaired by inhalational anaesthetic agents.

The effect of the lateral decubitus position on V/Q mismatch may be more marked in infants than older children. In older children with unilateral lung disease, oxygenation is usually better when the patient is in the lateral decubitus position with the healthy lung 'down'. The hydrostatic pressure difference between upper and lower lungs diverts blood flow away from the upper lung to the healthy lower lung. This pressure gradient is less in infants, making this phenomenon less important. Also, infants have a compliant thoracic wall, which supports the lower lung less effectively; during tidal ventilation, airway closure is more likely to occur because functional residual capacity (FRC) approaches closing volume. Consequently, in infants with unilateral lung disease, oxygenation is improved with the healthy lung 'up', although this is clearly not practical during surgery.

The effect on oxygenation is noticeable during surgery in the lateral decubitus position in infants and young children. A predictable sequence of events occurs:

- FRC increases when moved from supine to the lateral position.
- On opening the pleural space, FRC decreases to 25% below baseline, falling further to 50% of baseline during lung retraction (if OLV is not used).
- FRC then returns to the baseline on completion of surgery.

Oxygenation follows a similar sequence, and provided it is within defined boundaries, modest hypoxaemia is acceptable, and surgery can usually proceed.

Lung Retraction

Surgical access to the operative lung can be facilitated by ventilating only the dependent lung, allowing the operative lung to collapse. In adults and older children, OLV is achieved relatively easily. In smaller children, this is more challenging, so the surgeon often needs to retract the operative lung for adequate exposure. This necessitates effective dialogue between surgeon and anaesthetist, particularly as there may also be some mediastinal distortion. When lung is retracted, there is decreased lung compliance. This may be accompanied by hypoxaemia; typically, the SpO^2 will decrease to 85–90%. If there is no further perturbation in the surgical field, SpO^2 will gradually increase as hypoxic pulmonary vasoconstriction lessens the volume of blood passing through the collapsed lung. Lung retraction should be gentle, to avoid both lung contusion and mediastinal compression, which occludes venous return to the heart, which in turn causes haemodynamic compromise. Positive end expiratory pressure

(PEEP) should be used during a thoracotomy. This maintains lung volume in the 'down' lung, both aiding oxygenation and supporting the mediastinum (which then maintains its position in the chest cavity).

Bronchoscopy

The anaesthetist undertaking paediatric thoracic work should be able to use a flexible bronchoscope to assist with accurate tracheal tube (TT) or bronchus blocker placement, as well as to allow tracheobronchial toilet. Competence in fibreoptic bronchoscopy is also useful in evaluating extrinsic airway compression, subglottic stenosis and tracheomalacia, although these and other laryngotracheal investigations are more commonly undertaken by ENT surgeons.

The smallest flexible fibreoptic bronchoscope with a suction channel has a diameter of 2.8 mm; without a suction channel, it is 2.2 mm. There are two important considerations when choosing the correct-sized bronchoscope: whether it can fit smoothly into the TT, and whether you are able to ventilate around it (Figure 30.3). There are useful formulae to help with this:

- For the bronchoscope to fit smoothly down the TT, the outer diameter of the bronchoscope (ODB) needs to be <90% of the internal diameter (ID) of the TT: ODB/IDTT <0.9.
- For there to be sufficient space around the bronchoscope to allow for some ventilation to occur, it needs to take up <50% of the ID of the TT: ODB/IDTT <0.7.

For example, although a 2.8 mm scope will fit down a 3.5 TT (ODB/IDTT = 2.8/3.5 = 0.8), the ratio is greater than 0.7, so it will not be possible to ventilate whilst the bronchoscope is in place. It is important to note that although some ventilation will occur during bronchoscopy, patients who are critically unwell can decompensate rapidly due to the increase in airway resistance and reduction in ventilation.

Techniques for rigid bronchoscopy in adults cannot simply be transposed to small children. A jet ventilation technique may cause barotrauma in children with normal lungs and cannot be recommended for paediatric practice. When lungs are poorly compliant or there is airway obstruction, air is poorly entrained. In children, ventilation through a rigid bronchoscope is performed by attaching a Mapleson F breathing system to the side arm of a Storz bronchoscope, occluding the main channel by a diaphragm, a window or the operator's thumb. If there is airway obstruction, for example caused by an impacted foreign body, air trapping in the lungs can be problematic; expiration must be unimpeded and of adequate duration. A rigid telescope inserted through a small bronchoscope also causes expiratory embarrassment. A 1.9 mm telescope inside a 3.0 mm internal diameter bronchoscope or a 2.8 mm telescope in a 3.5 mm bronchoscope are the smallest acceptable combinations.

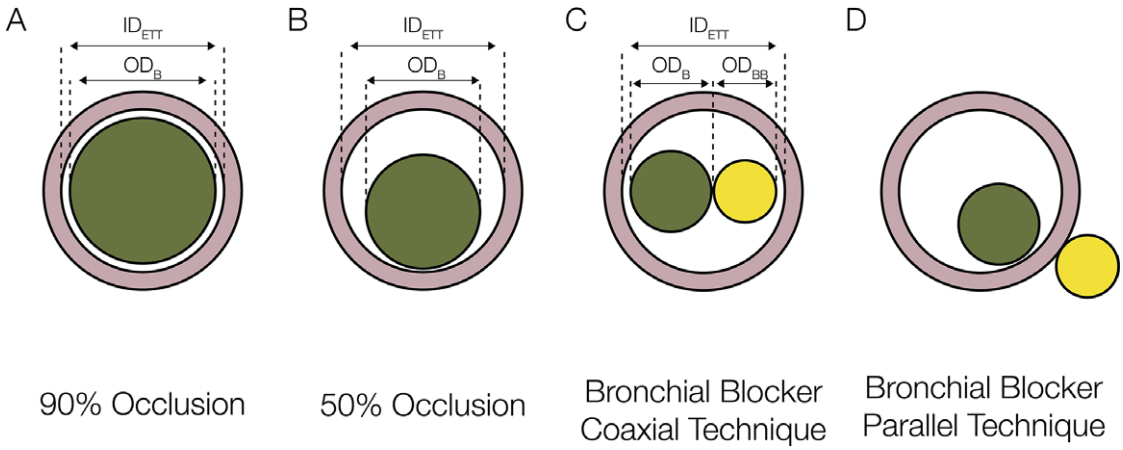

Figure 30.3 (A) Bronchoscope able to fit into ETT, but no ventilation, $OD_B/ID_{TT} < 0.9$. (B) Allowing for some ventilation, $OD_B/ID_{TT} < 0.7$. (C) Coaxial technique, bronchoscope and bronchial blocker able to fit, $(OD_B + OD_{BB})/ID_{TT} < 0.9$. (D) Parallel technique with bronchial blocker placed outside of the ETT.
Notes: Green circle = bronchoscope; yellow circle = bronchial blocker; pink circle = ETT).

Maintenance of anaesthesia during rigid bronchoscopy can be with inhalational or intravenous agents, the latter having the advantages of reduced pollution with anaesthetic gases and a lower carbon footprint.

One-Lung Ventilation

Lung isolation is standard practice in adult thoracic surgery. The non-operative lung alone is ventilated, allowing the operative lung to deflate. This improves surgical access whilst reducing operating times and lung trauma caused by surgical retraction. Contamination of the non-operative lung and trachea by blood or pus draining from the operative lung may be minimised. In adults, OLV is readily achieved using a double-lumen tube; one lumen lies in a mainstem bronchus, the other in the trachea and the inflatable cuff around the bronchial lumen allowing lung isolation. Double-lumen tubes are not available in small sizes, so OLV in children requires alternative strategies (Figure 30.4). The smaller the child, the harder it is to achieve this, so greater justification for its use is required. Strategies for OLV in children include use of:

- An endobronchially placed single lumen tracheal tube
- Bronchial blockers
- A Univent tube
- A conventional double-lumen tube

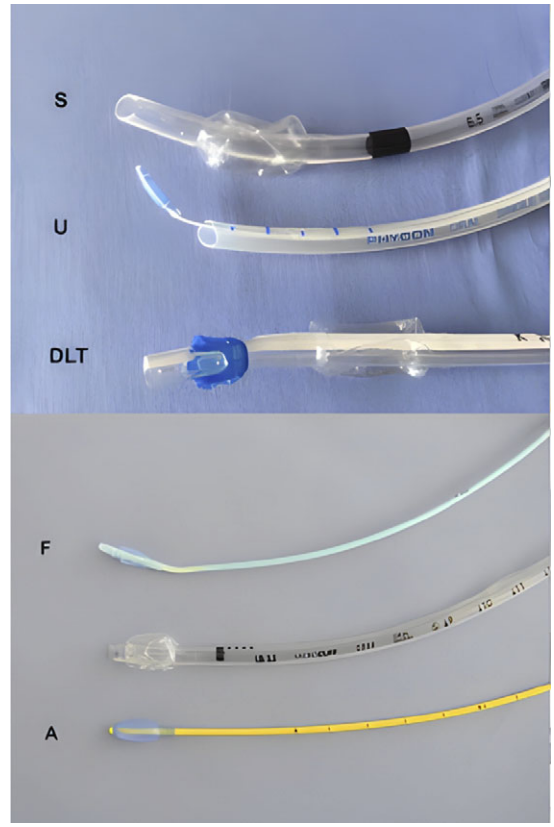

Figure 30.4 Airway management: Univent-tube (U) (3.5 mm ID) and 26 French DLT (DLT) in relation to a standard ETT (S) (6.5 mm ID). Five French Fuji (F) and Arndt (A)-bronchial blockers next to a 3.5 mm ID ETT.
Source: Semmelmann A, Kaltofen H, Loop T. Anesthesia of thoracic surgery in children. *Paediatric Anaesthesia* 2018 April; 28(4):326–31. Reproduced with permission of Wiley.

Single-Lumen Tube

This is the simplest method in a small child and can usually be achieved in babies from around 3 kg upwards, although the smaller the patient, the more difficulty is encountered. The mainstem bronchus on the non-operative side is intubated with a conventional tube that is 0.5 mm diameter smaller than normal. Placement of a TT into the right main bronchus is easier than the left due to the shallower right bronchial angle. A blind approach for left main bronchus intubation involves rotating the TT through 180° after traversing the glottis, raising the child's right shoulder and turning their head to the right. The tube is then advanced until breath sounds are no longer audible on the right. If a tube is advanced without these manoeuvres, it will usually enter the right main bronchus.

Tube placement assisted by a fibreoptic bronchoscope is the preferred method. The bronchoscope is loaded with the TT, placed into the desired bronchus and, once in position, the tube is advanced off the bronchoscope. In small babies, this is not simple; the bronchoscope is easily dislodged as the tube is advanced. If right bronchial intubation cannot be achieved easily, and a fibreoptic bronchoscope is not available to guide placement, a mirror image technique of that used for left-sided intubation may help.

Tolerances in small children for correct tube position are as little as 2–3 mm, and positioning the tube to ensure that the upper lobe remains ventilated can be awkward. The upper lobe bronchus on either side may originate very close to the carina, and its orifice may be occluded by the tube tip or cuff. Failure to ventilate the upper lobe is suggested by persistently low oxygen saturation

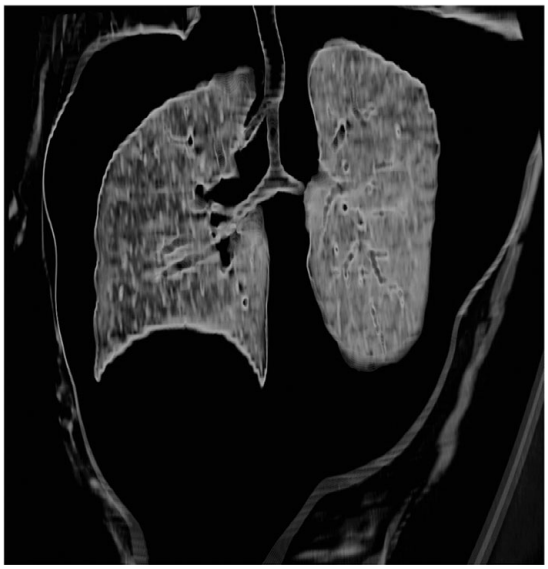

Figure 30.5 Scan showing aberrant tracheal bronchus.

and is confirmed by failure to hear breath sounds at the lung apex. This is a particular problem on the right side because of the shorter distance between the carina and the origin of the upper-lobe bronchus or when a cuffed tube is used. Difficulty may also occur when selectively intubating the right main bronchus, as the upper lobe bronchus can arise at the carina or directly from the trachea (Figure 30.5). The right upper lobe bronchus arises from the trachea in pigs, and so-called 'pig bronchus' is a normal variant in up to 2% of humans.

Chest auscultation to check tube position is important after positioning for surgery is completed. Moving a child, especially a small infant, frequently disrupts what seemed to be perfect one-lung ventilation due to the tube moving very slightly. Loss of satisfactory OLV can also be due to failure to create an adequate seal in the bronchus with an uncuffed tube, leading to inadequate collapse of the operative lung. An alternative technique is to intubate the trachea with a cuffed tube, position the patient on the operating table and then use the bronchoscope to selectively intubate the appropriate bronchus. However, cuffed tubes are more prone to occluding the upper lobe bronchus and also may slip out of the bronchus. It is very important not to overinflate the cuff once placed in the bronchus, causing inadvertent damage. A disadvantage of selective bronchial intubation with a single lumen is the inability to deliver continuous positive airway pressure (CPAP) or suction down the operative lung.

Balloon-Tipped Bronchial Blockers

Bronchial blockers can be used from the age of approximately 6 months to 8 years. They feature a balloon at their distal tip, which is passed under bronchoscopic guidance into the bronchus of the operative lung. It is then inflated under direct observation to ensure that an appropriate position and seal has been achieved, using the lowest balloon volume. The bronchial blocker is passed within (coaxial) or alongside (parallel to) a single-lumen TT. For the parallel technique, the bronchial blocker is first passed into the glottis followed by the TT.

Several balloon-tipped catheters have been described including vascular balloon catheters used off license. These include:

- Arndt blockers
- Uniblocker (Fuji systems)
- Vascular balloon catheters
  - Fogarty arterial embolectomy catheters
  - Miller atrioseptostomy catheters

Arndt Blockers

Arndt bronchial blockers are the smallest commercially available devices and have the advantage of a nylon looped wire that slides over the bronchoscope to aid positioning (Figure 30.6). Once this wire is removed, it cannot be replaced (which may make repositioning more difficult). The Arndt catheter has a central lumen, allowing for CPAP and suctioning of the operative lung. The smallest Arndt catheter is 5 Fr, which has an outer diameter of 1.7 mm; for the bronchial blocker and bronchoscope to fit down the TT coaxially, the smallest TT for a 5 Fr Arndt catheter and a 2.2 bronchoscope would be a 4.5 mm, suitable for a two-year-old child:

$$(OD_{BB} + OD_B)/ID_{TT} = (2.2 + 1.7)/4.5 = 0.86$$

A parallel insertion technique (alongside the TT) enables the use of bronchial blockers in smaller children. This technique can be used from the age of six months, with a 5 Fr Arndt catheter and a 3.5 microcuff TT.

Uniblocker (Fuji Systems)

The Fuji Uniblocker is a stiff, polyurethane covered catheter with an angled tip. It is available

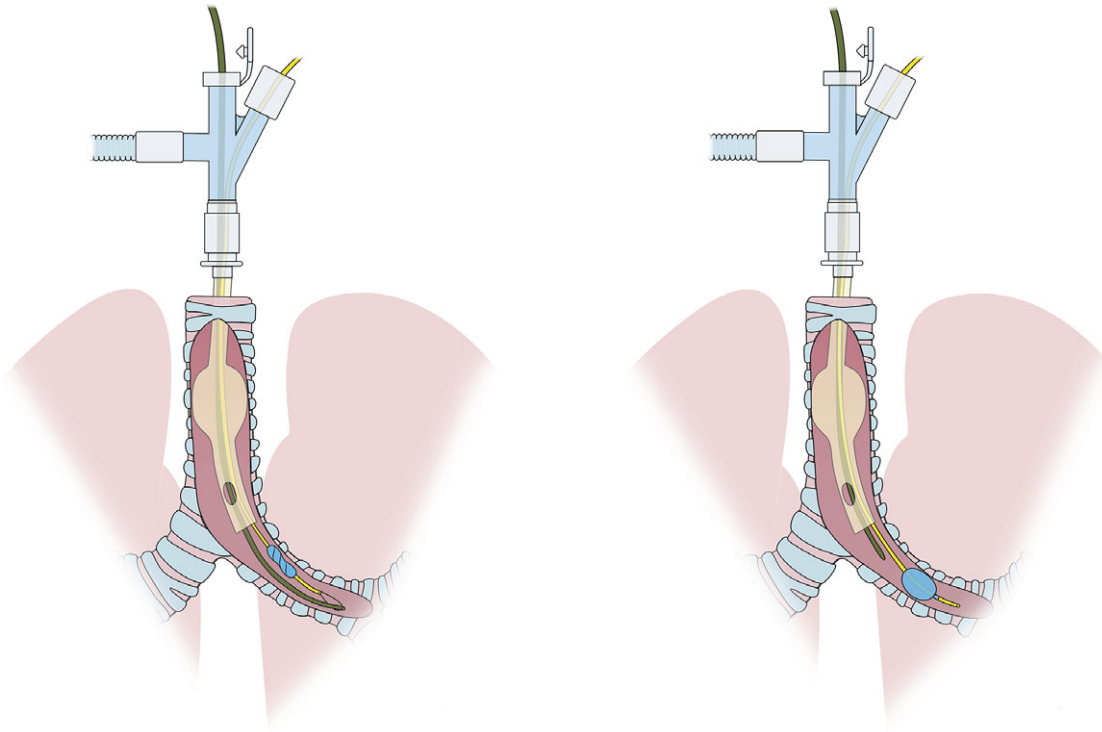

Figure 30.6 Schematic diagram of coaxial Arndt bronchial blocker placement with multi-port airway adapter. The removable distal wire loop aids placement using a flexible bronchoscope passed down an ETT.

in 5 Fr, which can be used in children up to the age of about eight years. Unlike the Arndt blocker, it does not have a central channel for suctioning or CPAP delivery.

Vascular Balloons

Although not designed as bronchial blockers, vascular balloon-tipped catheters have been used successfully for one-lung ventilation in paediatric patients. A commonly used catheter is the Fogarty arterial embolectomy catheter, in sizes 2 Fr to 5 Fr. All except the 2 Fr and 3 Fr catheters have a guidewire enabling the tip to be guided endobronchially. An alternative vascular balloon-tipped catheter is the 5 Fr Miller atrioseptostomy catheter, which has a pre-formed angled tip, aiding placement. Neither the Miller or Fogarty catheters have a central port for suction or CPAP.

Bronchial blockers designed for airway use (Arndt and Uniblocker) have high-volume, low-pressure balloons, thus minimising mucosal trauma, and should be used in preference to vascular balloon catheters which have high-pressure balloons. All balloons should be inflated under direct observation to minimise the volume used to produce an adequate bronchial seal.

The parallel technique may be easier when using a stiffer bronchial blocker with an angled tip, such as the Univent tube or vascular balloon catheters.

Univent Tube

The Univent tube from Fuji Systems Corporation in Tokyo is a conventional tracheal tube with a second lumen dedicated to a bronchial blocker. As the second lumen is an integral part of the tube, displacement of the blocker is unlikely unless the tube itself is dislodged. If double-lung ventilation is required, the bronchial blocker can easily be withdrawn into its lumen. The second lumen reduces the cross-sectional area of the ventilating lumen, thus restricting the size of the bronchoscope that can be used to position the bronchial blocker. For paediatric use, the Univent tube is available in 3.5 and 4.5 mm ID. However, the Univent tube is bulky; the outer diameter of a 3.5 mm ID Univent tube has an external diameter similar to a 5.5–6.0 mm ID uncuffed tube. It is

therefore only suitable for use from the age of about six years.

Double-Lumen Tubes (DLT)

These entail two cuffed tubes of unequal length moulded together; the shorter tube sits in the trachea and the longer in the bronchus. Inflating the bronchial cuff allows diversion of ventilation to either lung, according to whether the bronchial or tracheal lumen is ventilated. The cuff protects each lung from contamination by infected debris or blood from the contralateral side. Insertion is performed via direct laryngoscopy; the DLT is advanced through the larynx, then rotated through 90° to the appropriate side, and the bronchial component is advanced into the corresponding bronchus. Use of a fibreoptic bronchoscope is very helpful in achieving successful placement. A DLT allows suction and the application of CPAP, thus improving oxygenation, to the operative side. Although bulky and rigid, there are few reports of airway trauma associated with their use.

DLTs are available in left- or right-sided tubes, although left-sided tubes are more frequently used to minimise occlusion of the right upper lobe bronchus. DLTs are of limited use in children, as the smallest available size is 26 Fr, which can be used from about the age of eight years. A helpful guide to size the correct DLT is:

$$\text{Size} = (\text{Age} \times 1.5) + 14.$$

Once the patients are fully grown, the correct-sized DLT is based on gender and height (Figure 30.7). Females who are <1.6 m require a 35 Fr DLT, whereas females >1.6 m are more suited to 37 Fr. In males who are <1.7 m, 39 Fr is usually appropriate, whilst males >1.7 m need a 41 Fr DLT.

Indications for OLV

Single-lung ventilation is difficult to achieve in children and so should be justified in its use.

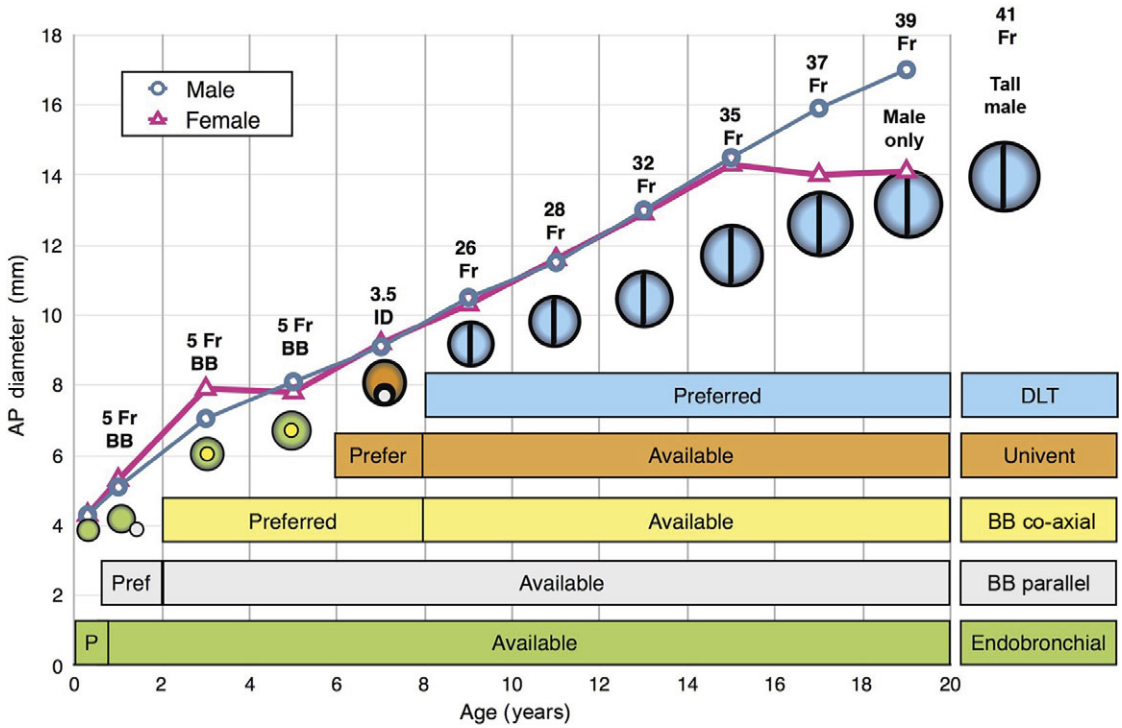

Figure 30.7 Anteroposterior trachea diameter versus age for male and female paediatric patients. Trachea diameters are from cadaveric and radiologic studies. Male and female airway sizes are similar until 15 years of age, when the female trachea stops growing, but the male trachea continues to grow. Superimposed is the preferred airway device for lung isolation for a given age, placed on the graph at the given diameter of the device. Note that in order to use an airway device for a certain age, the diameter of that device must be smaller than the trachea AP diameter at that age. DLT = double-lumen tracheal tube; Univent = Fuji Univent tracheal tube; BB coaxial = bronchial blocker coaxial technique; BB parallel = bronchial blocker parallel technique; Endobronchial = endobrochial intubation with selective laser trabeculoplasty (SLT).
Source: Letal M, Theam M. Paediatric lung isolation. *BJA Education* 2017 February; 17(2):57–62. Reproduced with permission of Elsevier.

- Strong indication for OLV:
  - Major gas trapping in one lung or pleural space, such as bronchopleural fistula and congenital lobar emphysema
  - Lobectomy for bronchiectasis or similar need to prevent airway soiling by blood or infective material
  - Minimally invasive thoracic surgery
- Moderate indication for OLV:
  - Lobectomy or pneumonectomy for cystic malformations or tumour
  - Anterior spinal surgery
  - Oesophageal or aortic surgery
- Contraindication to OLV:
  - Unacceptable hypoxia after institution of OLV
  - Technical inability to isolate one lung safely

Video-Assisted Thoracoscopic Surgery

As in other surgical specialties, minimally invasive thoracic surgery has gained increasing acceptance. Advantages including reduced pain and faster recovery. Surgical instrument development has enabled VATS even in neonates. Satisfactory surgical exposure requires distancing of the lung from the chest wall; carbon dioxide insufflation into the hemithorax can be used to achieve this, either alone or in combination with OLV. Care by the operator is required to avoid creating excessive intrapleural pressure and compromising venous return; insufflation pressure should be kept between 4 and 6 mbar.

Ventilation Strategies

Thoracotomy generally precludes spontaneous ventilation, as there is an inability to generate negative intrapleural pressure, and mediastinal shift prevents lung expansion. Occasionally, spontaneous ventilation is preferred until lung isolation is achieved to prevent a tension pneumothorax, or to prevent gas trapping. In practice, this is rarely immediately problematic or life-threatening, and muscle relaxation and positive pressure ventilation are usually safe.

In severe congenital lobar emphysema, novel ventilatory modes may be needed to allow some exhalation. Trial and error may identify the best means of ventilating the child until the chest wall has been opened; in some instances, spontaneous ventilation may be maintained. To allow for adequate oxygenation in neonates with severe disease, extreme hypercapnia may need to be tolerated until the chest wall is opened, using a technique with a very slow respiratory rate and no PEEP. Haemodynamic compromise caused by mediastinal shift resolves instantly; the pleural space is opened and the hyperinflated lobe delivered through the chest wall. OLV may be impossible to achieve safely in cases presenting acutely because of hypoxia and distorted tracheobronchial anatomy. In asymptomatic cases, OLV prevents or, at worst, reduces gas trapping in the emphysematous lobe caused by the instigation of positive pressure ventilation.

During surgery, ventilation is tailored to the individual patient and may require unusual settings. Modified ventilatory strategies to optimise exhalation may be required. The whole surgical team should be aware of the need for either urgent pleural drainage or thoracotomy. A modern ventilator offering spirometry is useful; manual ventilation may be necessary in small infants. Permissive hypercapnia may be prudent. A sudden change in compliance may reflect either surgical manipulation or tube displacement, and dialogue between surgeon and anaesthetist is essential. End-tidal capnography may underestimate $PaCO_2$, particularly if OLV is used.

Pleural Drainsrains

There are three important components to a pleural drain:

- A tube. This should be large enough. Small drains are adequate for gas, but larger drains may be required for fluid, blood or pus.
- A one-way valve is required (usually an underwater seal). This allows expulsion of air during spontaneous expiration or positive pressure inspiration and prevents re-entry of air through the drain during spontaneous inspiration.
- A collecting chamber. This may be single, or the unit may have several drains in series to prevent increased resistance to drainage as fluid levels increase.

Suction applied to the collecting chamber increases the pressure gradient between pleural space and collecting chamber. Bilateral pleural drains should not be connected to the same suction source lest differential resistance to drainage results in mediastinal shift. Pleural drains should

not be clamped or inadvertently occluded, especially in patients receiving positive pressure ventilation – failure to drain pleural air can quickly cause a tension pneumothorax. A drain connected to a suction unit with the suction turned off has the same effect as clamping the drain. Stopping suction on a pleural drain requires disconnection from the suction unit.

Regional Anaesthesia

Epidural analgesia has traditionally been seen as the gold standard for thoracic surgery due to its role in attenuating the stress response and providing optimal postoperative analgesia. Other regional techniques are increasingly being used (e.g. paravertebral, erector spinae plane blocks) that have fewer limitations and improved safety profiles. Neuraxial block performed under US guidance is becoming more common in children and may improve safe insertion of epidurals. Multiple epidural techniques are used.

Epidural

Thoracic epidural can be provided either by a catheter inserted at the level of the operation, or, in smaller children, it may be threaded up the epidural space after caudal insertion. The aim is for the catheter tip to lie in close proximity to the spinal segment of the corresponding surgical incision, thus using lower infusion rates of local anaesthetic than a more distant catheter. Epidural analgesia requires careful postoperative supervision.

Paravertebral Block

Paravertebral blocks (PVBs) are well established in adult thoracic surgery as they provide good intra- and postoperative analgesia and have been shown to be a safe and effective method of pain relief in children. PVBs are performed under ultrasound guidance, unilaterally or bilaterally, using either single-shot or a continuous infusion catheter technique. PVBs cover up to four dermatomal levels, so multilevel injections may be required, particularly to cover for chest drain insertion. For a thoracotomy, needle insertion should be at the level of T6. Under US guidance, the caudad and cephalad spread can be accessed by scanning in a paramedian longitudinal plane. A dose of 0.5 ml kg^{-1} for children usually covers four dermatomes, with an infusion rate of 0.2 ml $kg^{-1}h^{-1}$.

A catheter may be inserted into the paravertebral space for continuous postoperative analgesia, which has been shown to be an effective and safe method of post-thoracotomy pain relief. The catheter can be inserted under either US guidance or by the surgeon under direct vision. Unlike the epidural space, there are no opiate receptors in the paravertebral space, so additives to the local anaesthetic can be used, such as clonidine.

Erector Spinae Plane Block

Erector spinae plane block (ESPB) is a fascial plane block, where local anesthetic is placed between the erector spinae muscle and transverse process. Although relatively recently described, it has been shown to be safe, effective and easy to perform, with potentially fewer complications of neuraxial injury and pneumothorax than epidural and paravertebral blocks. ESPBs have a larger dermatomal spread than PVBs, with a dose of 0.1ml kg^{-1} required per dermatome. The local anaesthetic spreads anteriorly to the dorsal and ventral rami and may reach the epidural space. Analgesia has been shown to last up to 12 hours, and this can be extended by the placement of an erector spinae catheter.

A further advantage of ESPBs is the possibility of performing the block in anticoagulated patients, as any haematoma formed will be superficial and compressible.

Serratus Anterior Plane Block

Although serratus anterior plane block (SAPB) provides safe and effective analgesia after thoracic surgery, there is increasing evidence that ESPB provides superior analgesia and longer duration of action.

Intercostal Nerve Blocks

Intercostal nerve blocks may provide satisfactory intraoperative analgesia, but their use is limited due to a brief analgesic effect. They are easy to perform, with or without ultrasound or under direct vision at the time of surgery.

Postoperative Management and Analgesia

Children undergoing intrathoracic surgery require admission to a high-dependency unit postoperatively, and adequate provision must be made for

pain management, chest physiotherapy and non-invasive CPAP. Full ventilatory support is sometimes necessary, and paediatric intensive care facilities must be available.

Thoracic surgery is extremely painful, so effective pain management is an essential part of the perioperative pathway of these children. Insufficient analgesia prevents coughing, deep breathing and mobilisation, increasing the risk of respiratory complications.

Post-thoracotomy pain is multi-factorial, with nociceptive and neuropathic pain arising from both somatic and visceral afferents. Successful postoperative pain management strategies must therefore be multimodal. Intra- and postoperative analgesia for thoracotomy requires a combination of regional anaesthetic technique with systemic analgesia, both opioid and non-steroidal. The choice of technique is influenced by the age of the child, the underlying pathological process and the preference and experience of the anaesthetist.

Systemic Analgesia

Opioid infusion, preferably with patient-controlled or nurse-controlled boluses, is essential for the first 48 hours after thoracotomy. This is required in addition to any single-shot regional techniques, due to a mean duration of thoracic blocks of 10–12 hours. Both regular paracetamol and NSAIDs should also be prescribed as their effect is additive. Good analgesia allows early mobilisation and helps to prevent problems with sputum retention.

NMDA-receptor antagonists, such as ketamine and magnesium sulphate, can be used intraoperatively to reduce postoperative opioid consumption. Dexamethasone, 0.15 mg kg^{-1}, should also be administered for both its antiemetic and analgesic enhancing properties.

Key Points

- Surgical access to the operative lung can be facilitated by ventilating only the dependent lung, allowing the operative lung to collapse. In small children, this is hard to achieve, as double-lumen tubes are only available for children over the age of 8–10 years.
- Anaesthetising a child with an anterior mediastinal mass can precipitate total airway collapse. It may be necessary to insert a rigid bronchoscope to maintain an airway.
- In the infant with congenital lobar emphysema, positive pressure ventilation can lead to acute hyperinflation of the affected lobe with severe respiratory and haemodynamic compromise. It may be necessary to try various ventilatory strategies to identify the best means of ventilating the child until the chest wall has been opened.
- Thoracic surgery can be very painful. Regional and local analgesia should be employed wherever possible, supplemented by patient- or nurse-controlled morphine infusion and regular paracetamol and NSAIDs.

Further Reading

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