Chapter 11: ANESTHESIA FOR THORACIC SURGERY

J. Grant McFadyen, MBChB, FRCA, Stefan Burdac, MD, Michael Richards, MBBS, FRCA, Lynn D. Martin, MD, MBA

Introduction

Many infants require thoracic surgery to correct congenital anomalies. Older children require surgery to remove tumors and pulmonary abnormalities. This chapter provides information on the lesions for which surgery is required and on the anesthesia care required. It also provides information on pneumothorax and its treatment. The information contained in this chapter will help the anesthetist meet the challenge of delivering safe care for the baby or child undergoing thoracic surgery.

Thoracic Surgery for Neonates and Infants

Some neonates and infants require thoracic surgery to treat congenital lesions, such as diaphragmatic hernia, trachea-esophageal fistula, and several congenital abnormalities of the lung. The following section discusses these lesions and provides information concerning the anesthesia care required.

Congenital Diaphragmatic Hernia (CDH)

The diaphragm forms at about 10 weeks of gestation. If its formation is incomplete, the baby is born with a congenital diaphragmatic hernia. The hole in the incompletely developed diaphragm allows organs that normally reside in the abdomen to enter the thoracic cavity in utero and produce bilateral lung hypoplasia, pulmonary hypertension, and abnormal pulmonary vascular reactivity. Other congenital anomalies may also be present. The herniated abdominal contents, which may include the stomach, colon, kidney, and liver, often interfere with lung development. (Figure 11-1)
Figure 11-1: Diaphragmatic Hernia in a Neonate.

This radiograph shows a large amount of bowel and probably part of the liver in the left chest of this neonate who had a CDH. His heart is displaced into the right chest. Note: no visible bowel is seen in the abdomen. Courtesy of Han Minh Lee, MD

The severity of the defect in lung development and subsequent lung hypoplasia are related to the age at which the abdominal organs enter the chest and on the amount of tissue herniated. The earlier the organs enter the chest and the more abdominal contents herniated, the worse the lung hypoplasia. Once they enter the chest, the abdominal organs compress the lung on the affected side and cause it to stop growing. As a result it is very hypoplastic. The abdominal contents also displace the mediastinum to the other side of the chest, which compresses that lung and causes that lung to also be somewhat hypoplastic. As a result these infants are frequently born with about two-thirds of a functioning right lung as their only means of oxygenation and CO₂ removal. The abdominal mass not only hinders normal lung development, but it also reduces the total cross-sectional area of the pulmonary vascular bed and alters its reactivity, which frequently results in pulmonary hypertension. These abnormalities of the pulmonary circulation prevent the natural transition from intrauterine to extra-uterine circulation. Due to elevated right-sided intravascular pressures, venous blood is shunted right-to-left across the foramen ovale (PFO) and ductus arteriosus (PDA), causing severe hypoxemia. Neonates with a CDH usually exhibit signs and symptoms of respiratory distress and hypoxemia immediately after birth. The classic triad of CDH is cyanosis, shortness of breath, and apparent dextrocardia. The dextrocardia is apparent (and not actual) because the herniated abdominal

2 This chapter is a modification of a chapter in Gregory GA, Andropoulos DB. Gregory’s Pediatric Anesthesia., Wiley-Blackwell, Oxford UK, 2012
contents push the heart and mediastinum to the opposite side of the chest. When the bowel is removed from the chest, the heart returns to its normal position in the chest. Physical examination shows a scaphoid abdomen (a baby’s abdomen normally protrudes), a bulging chest, decreased breath sounds on the affected side, distant or displaced heart sounds, and occasionally the presence of bowel sounds in the chest that contains the herniated bowel. A chest radiograph, if available, shows a bowel gas pattern in the chest, poor aeration of the affected chest, and shift of the mediastinum to the contralateral side (Figure 11-1). In the past, CDH was considered a neonatal surgical emergency. This is seldom the case today. Because many patients with CDH have severe hypoxemia, in the past these neonates were hyperventilated with 100% oxygen in the hope that the alkalosis and the high oxygen concentrations in the lung would produce pulmonary vasodilation and improve oxygenation. However, the mechanical ventilation required to produce respiratory alkalosis and the increased inspired oxygen required damaged the only functioning lung. The initial management of patients with CDH is now to delay surgical intervention until the acidosis and hypoxemia are corrected. Medical management focuses on stabilizing the cardiorespiratory system and improving pulmonary circulation by improving oxygenation, correcting metabolic acidosis, and reducing right-to-left shunting of blood. However, cardiorespiratory stabilization should not come at the expense of further damage to the lung (volutrauma or barotrauma) from overly aggressive ventilatory strategies.

It is best to avoid attempting to ventilate the lungs with a bag-and-mask before intubating the trachea at birth because doing so may fill the bowel and stomach with gas, which will further decrease lung compliance and increase the risk of volutrauma and barotrauma in the only functioning lung. Early tracheal intubation and decompression of the stomach via an oral gastric tube are important initial steps to prevent/treat distention of the bowel and stomach. Echocardiography, if available, can help document associated cardiac anomalies, pulmonary hypertension, pulmonary blood flow, right-to-left shunting of venous blood, and right heart dysfunction.

The anesthetist’s goals during anesthesia are to provide sufficient analgesia and an adequate depth of anesthesia with drugs that have minimal effects on pulmonary vascular resistance and myocardial function. The ventilatory goals during surgery are the same as those before surgery, optimizing acid–base status and oxygenation, decreasing right-to-left shunting of blood, and avoiding changes in the pulmonary circulation by minimizing barotrauma or volutrauma. It is usually best to avoid making large changes in the mechanical ventilation established by the neonatologists preoperatively unless it is absolutely necessary to do so. They have spent a considerable amount of time finding the best ventilation pattern and inspired oxygen concentration for the patient. Making unnecessary changes in ventilation can be disastrous for the patient. If there is rapid deterioration in the patient’s cardiorespiratory status during surgery, it should be suspected that he/she is having a pulmonary hypertensive crisis or a pneumothorax. A pulmonary hypertensive crisis can sometimes be treated acutely with hyperventilation, but
hyperventilation should only be used for this purpose when absolutely necessary. Meticulous attention should be paid to the newborn’s temperature, as hypothermia may further increase pulmonary vascular resistance and decrease pulmonary blood flow. Nitrous oxide is usually avoided in these patients because they require higher inspired oxygen concentrations (FiO₂) than can be achieved during nitrous oxide administration. Furthermore, the nitrous oxide may diffuse into the herniated abdominal contents and worsen lung compression. If the neonate is hemodynamically stable and an anesthesia machine is available, low-concentrations of inhaled anesthetic may be administered. However, it is often better to use a high-dose narcotic technique (e.g., Fentanyl 100-200mcg/kg titrated to effect) with a muscle relaxant, because this combination of drugs usually causes less hemodynamic instability by reducing/preventing the release of catecholamine. Catecholamines raise pulmonary vascular resistance and initiate a pulmonary hypertensive crisis. If the patient is given high doses of narcotics and is paralyzed with muscle relaxants, he/she will certainly require postoperative mechanical ventilation and intensive care. Adequate postoperative pain relief is important because untreated pain also worsens hypoxemia and carbon dioxide retention by limiting movement of the chest and diaphragm.

Tracheoesophageal Fistula and Esophageal Atresia

Patients with a Tracheoesophageal Fistula (TEF) and Esophageal Atresia have an interruption of the esophagus and usually have an abnormal connection between the trachea and a portion of the esophagus. Other congenital anomalies may also be present. For instance, approximately 25% of them have congenital heart disease. Many have the VATER association, which includes V, vertebral defects; A, anal defects; T, tracheoesophageal fistula; E, esophageal atresia; and R, radial or renal anomalies or the VACTERL association, which includes C, cardiac, and L, limb anomalies in addition to those in the VATER association. The most common type of TEF (about 90%) is type C, where a fistula exists between the trachea and the lower esophageal segment (Figure 11-2). The upper esophageal segment ends in a blind pouch in the mediastinum. The opening between the trachea and the esophagus is usually posterior and is just above the bifurcation of the trachea. This connection may allow gastric fluid to enter the lung and cause aspiration pneumonia.
Figure 11-2: Tracheoesophageal Fistulae

This figure shows the different types of T-E fistulas. It also gives the incidence of each type of fistula in general and at the University of Minnesota. Type C is the most common form. [http://www1.umn.edu/eatef/whatis.html](http://www1.umn.edu/eatef/whatis.html)

TEF should be suspected if there is maternal polyhydramnios (too much fluid in the amniotic sac) or a TEF is seen on prenatal ultrasound. Polyhydramnios occurs because the esophageal obstruction prevents the baby from swallowing amniotic fluid and the fluid normally produced by the lungs each day. Newborn infants with TEF have excessive salivation, drooling, cyanotic spells, and coughing and choking following feeding because fluid or milk enters the lungs through the fistula. Esophageal atresia can usually be confirmed in the delivery room because it is impossible to pass a suction catheter from the oropharynx into the stomach. If a plain radiograph of the chest and abdomen is available, the stomach is often distended with air that entered the stomach via the TEF. The lungs should be protected from aspiration of fluid or gastric contents through the fistula by avoiding feedings, positioning the infant upright to prevent reflux of gastric contents through the fistula into the lungs, and by intermittently or continuously suctioning secretions from the upper esophageal pouch. Other anomalies should be sought preoperatively, particularly cardiac anomalies. Complete repair of a TEF is often accomplished in one-stage; the fistula is ligated and the proximal and distal ends of the esophagus are then connected. However, the fistula ligation and esophageal repair should only be done at the same time if the bowel anastomosis can be accomplished without causing excessive tension on the suture line. If this happens, the suture line may break down. If the infant has other significant anomalies or if her/his ventilation is impaired by gastric distention due to air entering through the fistula, a gastrostomy is performed under local anesthesia to decompress the stomach and minimize aspiration of gastric contents. When this is done, definitive repair if the TEF is usually performed 24-to-72 hours later. The surgical approach for repair of a TEF is a right thoracotomy, unless the aortic arch is known to be right-sided.
Chapter 11: ANESTHESIA FOR THORACIC SURGERY

The major anesthesia consideration during TEF repair is maintaining adequate ventilation of the lungs without forcing gas through the fistula into the stomach and bowel. This must be avoided. Spontaneous breathing of inhaled anesthetics for the induction of anesthesia allows reduces the risk of gastric distention and worsening hypoxemia and acidosis. The tracheal tube is placed following direct laryngoscopy. Correct placement of the tube is confirmed by auscultating both lung fields and by listening over the stomach. If breath sounds are loud over the stomach (there should always be some breath sounds heard there) the tube is proximal to the TEF and should be advanced slowly until the breath sounds over the stomach diminish or disappear. One way to place the tracheal tube in the correct position is to insert it into the trachea with the long part of the tube’s bevel posterior. The tracheal tube is advanced into the right main-stem bronchus while someone listens with a stethoscope over the stomach. The tube is then slowly withdrawn until loud breath sounds are heard over the stomach. Then the tube is advanced into the trachea until the breath sounds over the stomach decrease or disappear, and the breath sounds of both lungs are heard equally. These patients should be allowed to breath spontaneously if possible, but the patient’s cardiorespiratory status may require muscle relaxants and gentle positive pressure ventilation to assure adequate oxygenation and removal of carbon dioxide. It is important to assure that the fistula is still occluded by the TT after the patient is turned on her/his side for surgery. This is done by listening for breath sounds over the down lung and by hearing poor or no breath sounds over the stomach. Attaching a stethoscope to the chest wall over the down lung allows the anesthetist to detect changes in ventilation during surgery. If a gastrostomy was placed preoperatively to decompress the stomach, correct positioning of the TT can be confirmed by submerging the end of the gastrostomy tube 1-2cm into a container of water and looking for gas bubbles during ventilation. If bubbles are seen, the tip of the TT is proximal to the fistula. If no gas bubbles are observed, the TT is distal to the fistula. The gastrostomy tube can also be connected to a capnograph, if available. If the endotracheal tube is proximal to the fistula, there will be CO2 in the gas aspirated from the gastrostomy; if the tip of the tracheal tube is distal to the fistula, no CO2 is observed. Collapse and retraction of the lung during the thoracotomy will impair ventilation. Blood clots and/or secretions in the airway may occlude the tracheal tube, which will necessitate frequent suctioning of the tube during surgery. An arterial catheter, if available, should be inserted in newborns whose cardiorespiratory status is unstable and in those with associated anomalies, especially cardiac anomalies. After the fistula is ligated, an air leak will develop, potentially impairing ventilation; the air leak lasts until the esophageal anastomosis is completed. During surgery a catheter is usually passed into the blind upper pouch to identify the upper esophagus. Under direct vision the surgeon advances it into the distal esophagus during surgery and performs the esophageal anastomosis around this catheter. When the anastomosis is complete, the catheter is withdrawn until its tip is just above the suture line; the distance from the tip of the catheter to the lips is determined and a mark is made on the catheter; catheters longer than this should not be used to suction the esophagus postoperatively, otherwise the catheter may disrupt the suture line. If the distal portion of the esophagus is absent or too short
to be anastomosed to the proximal segment, the fistula is ligated, and the upper segment of the esophagus is sometimes externalized via an esophagostomy to drain saliva. The two segments of esophagus can be bridged with an interposed bowel segment or tube graft at about one year of age. The decision to extubate the trachea at the end of surgery requires a discussion between the surgeon and the anesthetist. They must balance the child’s cardiorespiratory status, healing of the esophageal anastomosis, and the availability and need for postoperative mechanical ventilation and intensive care (ICU). Traditionally, the trachea was extubated when the patient had awakened from anesthesia, but this was found to be associated with an increased risk of intraventricular hemorrhage (IVH). Tracheomalacia could sometimes occur at the fistula site and cause the trachea to collapse during inspiration. If this occurs it may be necessary to leave a tracheal tube in place and ventilate the child’s lungs after surgery.

**Congenital Cystic Lung Disease**

Congenital cystic lung disease occurs in 1/10,000-1/25,000 live births and may be categorized as congenital lobar emphysema (CLE), bronchopulmonary sequestrations (BPS), congenital cystic adenomatous malformations (CCAM), and bronchogenic cysts (BC). Small lesions may be asymptomatic, but larger lesions may cause respiratory distress in the newborn. Initially asymptomatic lesions may become infected or cause a pneumothorax; a malignant tumor may develop later in life. Serial imaging has revealed, however, that many large lesions may actually decrease in size with time. While there is consensus that all symptomatic lesions should be resected, there is some debate whether asymptomatic lesions should be observed rather than resected. If asymptomatic CCAMs are followed conservatively, only 10% of them will require surgery later. It is therefore still recommended that a CCAM, intralobar BPS, or BC is resected between 3-6 months of age. Extralobar BPS can remain asymptomatic for life but can also be associated with problems. A period of observation has been advocated. Asymptomatic CLE may resolve spontaneously and should be observed.

When anesthetizing neonates with these congenital lung lesions, it is important to determine if the patient will tolerate positive pressure ventilation (PPV). PPV in lesions that have a bronchial connection to abnormal lung parenchyma can result in over-distension of the abnormal lobe and compression of normal lung tissue through a ball-valve effect. This can lead to compromised ventilation, mediastinal shift, compression of the great vessels, and decreased cardiac output. When there is doubt whether a bronchus connects to the thoracic lesion, spontaneous ventilation is indicated during induction and maintenance of anesthesia. Generally, CCAM and CLE have a bronchial connection. (Table 11-1)
Table 11-1: Whether a Bronchus Connects to the Lesion and Whether Positive Pressure Ventilation Can Be Done.

<table>
<thead>
<tr>
<th>Lesion</th>
<th>Connects with Bronchus</th>
<th>Positive Pressure Ventilation OK?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cystic Adenomatoid Malformation</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Congenital Lobar Emphysema</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Bronchopulmonary Sequestration</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Bronchogenic Cyst</td>
<td>No</td>
<td>Yes</td>
</tr>
</tbody>
</table>

This table lists common thoracic lesions and whether they are connected to a bronchus. If they are connected, it is possible to overdistend the affected lesion with positive pressure ventilation and cause further respiratory distress.

If OLV is used PPV and neuromuscular blockade can be safely used once the affected lung is isolated. For postoperative analgesia, intravenous opioids or, preferably, a thoracic epidural can be placed at the desired dermatome level. A catheter can also be threaded to the desired position from the caudal canal (See Chapter 21). Recently more congenital lung lesions have been resected using video assisted thoracic surgery (VATS). While this technique is challenging in infants and results in significantly longer operative time, it is safe and may reduce hospital stay.

**Congenital Lobar Emphysema (CLE)**

CLE is an abnormally emphysematous pulmonary lobe that communicates with the bronchial tree (Figure 11-3). It is most common in the left upper lobe, followed by the right middle lobe and the left lower lobe. It often enlarges before 28 weeks gestation because fetal lung fluid becomes trapped within the lesion, similar to postnatal air trapping. Between this time and birth, the lesion may regress and result in a normal looking lung at birth.
Figure 11-3: Congenital Lobar Emphysema

This radiograph and CT scan show CLE taking up most of the left lung.

Even though usually asymptomatic, it is important that patients with CLE are carefully evaluated at birth, since they are at risk for trapping air in the emphysematous lobe. Overinflation of the lung lesion may ultimately lead to “tension emphysema” and compression of the contralateral lung. At this stage it can be confused with a tension pneumothorax, and a chest tube may be inappropriately placed, leading to further respiratory distress. Large lesions may decrease cardiac output and eventually cause cardiac collapse. These patients need emergent thoracotomy and rapid lobe exteriorization.
The primary anesthetic concern for patients with CLE is avoiding overdistension of the affected lung tissue. PPV can cause rapid expansion of the lesion through a ball-valve effect, so an effort should be made to allow the patient to breath spontaneously. If PPV is necessary, low inflating pressures should be used. OLV is typically necessary for isolation of the affected area, and once initiated it is safe to switch to PPV. Nitrous oxide should be avoided throughout the case. At the end of the procedure one should return to two-lung ventilation to check for air leaks at the resection site. The trachea should be extubated early or, if the patient is to remain intubated, he/she should be allowed to breathe spontaneously to avoid reduce the risk of an air leak occurring.

**Bronchopulmonary Sequestration (BPS)**

A BPS is a portion of nonfunctioning lung tissue without a bronchial connection. It typically has an anomalous blood supply. BPS is usually found in the lower lung lobes, with the majority of these lesions found intralobar (inside lobe pleura); the remainder of them is extralobar (with their own pleura). BPS can be confused with CCAM and some lesions are considered ‘hybrid’, having features of both BPS and CCAM.

BPS is often diagnosed in utero. At birth it is usually asymptomatic and presents later in life as pneumonia resistant to antibiotic therapy. Sometimes when a BPS is large, it can compress the lungs and cause respiratory distress. If it has a large blood supply, it can also lead to high output heart failure. There are few unique anesthesia concerns. OLV is helpful for surgical resection. Because there is no connection between a bronchopulmonary sequestration and the bronchial tree, it is safe to use positive pressure ventilation throughout anesthesia and surgery.

**Congenital Cystic Adenomatous Malformation (CCAM)**

A CCAM is a discrete intrapulmonary mass that may be either solid or cystic, and is typically characterized by increased adenomatous respiratory bronchioles. Cysts can be of various sizes, from 1mm to over 10cm and can be diagnosed by computerized tomography (CT). Figure 11-4. Although the lesion is nonfunctional, it communicates with the normal tracheobronchical tree and this can lead to air trapping during positive pressure ventilation. CCAMs are usually found only in one lobe but occur in all lobes with equal frequency. When the lesion does involve more than one lobe, a pneumonectomy may be required. Associated anomalies are uncommon. Most CCAMs are asymptomatic and are resected electively in the neonatal period. While there is a communication between the lesion and the tracheobronchical tree, CCAMs are usually solid or have small cysts, which causes them to act more like a solid lesion. It is safe to use positive pressure ventilation in these patients. Most lesions can be resected without lung isolation, but if necessary, OLV can be accomplished by intubating a mainstem bronchus.
Figure 11-4: Congenital Cystic Adenomatous Malformation

Radiograph and CT scan of a CCAM. Notice that the lesion occupies a significant portion of the right lower lung.

Bronchogenic Cysts (BCs)

BCs are the result of abnormal budding or branching of the tracheobronchial tree. They are usually mediastinal, solitary, unilocular cysts filled with air, fluid, or mucous. They do not communicate with the bronchopulmonary tree and therefore, like bronchopulmonary sequestrations, pose few additional anesthetic concerns. Positive pressure ventilation can be used.
Mediastinal Tumors

The mediastinum is divided into anterior, middle, and posterior segments. Anterior mediastinal masses are usually neoplasms of the lung, mediastinum, or pleura, including lymphomas, lymphangiomas, teratomas, thymomas, and thymic cysts that usually occur after 4-5 years of age. Middle mediastinal masses are usually bronchogenic cysts, granulomas, and lymphomas and may or may not cause significant respiratory symptoms, depending on whether or not they compress the trachea, bronchi, and blood vessels. Posterior mediastinal masses are usually enteric cysts or tumors of neuroendocrine origin and less frequently cause respiratory complications. Signs and symptoms from mediastinal masses are related to compression of the airway, great vessels, and heart. These symptoms include dyspnea, orthopnea, chest pain, cough, wheezing, stridor, and swelling of the upper arms, face, and neck (superior vena cava syndrome). Orthopnea and superior vena cava syndrome are the symptoms associated with the highest risk of perioperative complications. The patient’s history and physical examination should focus not only on signs and symptoms of airway, great vessel, and heart compression, but also on changes in the patient’s symptoms when he/she changes body position and activity. Do the symptoms worsen or get better when the patient sits or lies in one position or another or exercises? A chest radiograph may show a widened mediastinum; a CT scan may demonstrate the mass size and the presence and degree of airway or great vessel compression (See Figure 11-5).
Figure 11-5: Anterior Mediastinal Mass.

Radiograph showing a widened mediastinum that is caused by the tumor.

CT scan showing an anterior mediastinal mass compressing the trachea and great vessels.
Establishing the correct diagnosis of the tumor type requires a tissue biopsy, and many oncologists require this before beginning chemotherapy, radiation therapy, or surgical intervention. The anesthetist should determine if the procedure is diagnostic or therapeutic because diagnostic tissue biopsies can often be obtained from a peripheral lymph node (if there is one) or from bone biopsy and can be obtained under local anesthesia or minimal sedation, making general anesthesia unnecessary. Ketamine is often used when obtaining these biopsies because it allows spontaneous ventilation and provides hemodynamic stability. Elective surgical procedures that require general anesthesia should be delayed until chemotherapy and/or radiation therapy have reduced the mass size. Therapeutic procedures, on the other hand, frequently necessitate using general anesthesia. Induction of anesthesia can be associated with immediate and severe airway obstruction and circulatory collapse. It is important to remember that airway obstruction and circulatory collapse can occur even in children with anterior mediastinal masses who have no preoperative respiratory or cardiovascular compromise. During the induction of anesthesia and during surgery, the child should be placed in the position that maximizes ventilation, minimizes airway obstruction, and reduces both hypotension and hypoxemia. Induction of anesthesia with inhalation drugs and spontaneous ventilation is common because it maintains normal transpulmonary pressure gradients and gas flow through the conducting airways. Continuous positive airway pressure (CPAP) is often applied to stent open the airways and prevent atelectasis from occurring. Tracheal intubation should be performed while the patient is deeply anesthetized and spontaneously breathing. Positive pressure ventilation is avoided whenever possible. Muscle relaxants are seldom used in these children because these drugs decrease chest wall tone and this increases the risk of airway compression. If obstruction occurs or worsens with the induction of anesthesia, changing the child’s position to the lateral, recumbent, or prone position or intubating the trachea and advancing the TT past the obstruction may alleviate airway obstruction and make ventilation possible. This usually does not alleviate obstruction of the great vessels.

**Practical Considerations for Anesthesia for Thoracic Surgery**

**The Lateral Decubitus Position**

In the lateral decubitus position, ventilation is preferentially distributed to the dependent (down) lung of awake, spontaneously breathing older patients. The distribution of perfusion follows a similar pattern, with more blood flow occurring in the down lung. Thus, ventilation and perfusion are well matched. In infants, however, ventilation is preferentially distributed to the non-dependent (up) lung. Because the hydrostatic pressure gradient between the up lung and the down lung of infants is small, the difference in blood flow between the two lungs is small. Ventilation and perfusion are, therefore, not as well matched in infants as in older patients.
Several factors in the lateral decubitus position significantly affect ventilation/perfusion (V/Q) matching during thoracic surgery. General anesthesia, neuromuscular blockade, and mechanical ventilation decrease the functional residual capacity (FRC) of both the up and down lungs. The down lung becomes atelectatic because the weight of the mediastinum and abdominal contents compress it. Surgical retraction collapses the operative up lung. Finally, hypoxic pulmonary vasoconstriction (HPV) is inhibited by inhaled anesthetics and by vasodilating agents. In non-anesthetized patients, HPV improves V/Q matching by diverting blood away from poorly ventilated areas. The effects on HPV are similar in patients of all ages.

When adult, spontaneously breathing patients with unilateral lung disease are placed in the lateral decubitus position, they oxygenate better when their healthy lung is down and their diseased lung is up. This occurs in part because blood flow to the up, poorly ventilated, diseased lung is decreased, improving V/Q matching. Infants with unilateral lung disease, however, oxygenate better when the healthy lung is up. Since infants have a soft, easily compressible rib cage that will not support the down lung, the down lung collapses and the FRC is closer to the residual volume. This makes airway closure more likely in the down, compressed lung, even during normal tidal volume breathing. In the lateral decubitus position, infants also have less cephalic displacement of the down hemidiaphragm by their abdominal contents. Therefore the contraction force in the down hemidiaphragm is less than that of the up hemidiaphragm, limiting the ventilation efficiency of the down lung. Ventilation is distributed preferentially to an infant’s up lung. The hydrostatic pressure gradient between the up and down lungs is smaller, so the preferential distribution of perfusion to the down lung is less than that of adults.

**One-Lung Ventilation**

**Indications for One-Lung Ventilation (OLV) Include:**

1. Controlling the distribution of ventilation,

2. Avoiding spillage of infected material or contamination of the other lung, and

3. Providing a quiet operative field for the surgeons.

Many techniques are available to provide OLV in children. The surgeon may retract the operative lung mechanically, pack it with sponges, or insufflate CO₂ when the procedure is performed thoracoscopically. All of these maneuvers collapse the lung. Advancing a standard endotracheal tube (TT) into the non-operative bronchus is the simplest way to achieve OLV. When passed blindly the TT usually enters the right main-stem bronchus but can be selectively advanced into the left main stem bronchus by rotating the child’s head to the right and then rotating the TT so the beveled portion of the tube faces right while the TT is advanced. This places the long, pointed portion of the bevel to the left. With selective endobronchial intubation, it is possible to quickly change from OLV to two-lung ventilation, since the TT can easily be pulled back into the trachea.
Using a standard TT may not be ideal, however. If a small, uncuffed TT is used, it may be difficult to completely seal the operative main-stem bronchus. With the tube in the opposite main-stem bronchus, the lung on which surgery is being performed cannot be suctioned, and hypoxemia may occur if the upper lobe bronchus becomes obstructed, particularly on the right.

**Devices Used to Permit OLV:**

*Bronchial blockers* have a small balloon on the end of a catheter that is inflated in the main-stem bronchus of the lung undergoing surgery. The other lung is then ventilated during surgery via a standard TT. In infants and children less than six years of age, *embolectomy catheters* are often used as bronchial blockers. The catheter can be inserted through or alongside a TT and advanced into the bronchus. The balloon is then inflated and the other lung is ventilated via the TT. Embolectomy catheters have a central stylet that can be bent to the left or right to guide placement of the catheter into the appropriate main stem bronchus. If the embolectomy catheter is accidently dislodged into the trachea during surgery, ventilation may be completely blocked. If this occurs, the balloon should be immediately deflated and both lungs ventilated.

The *Arndt Endobronchial* blocker is a bronchial blocker with an inflatable cuff and a central lumen through which a wire with a loop on its end is passed. The bronchial blocker is passed through a special adapter at the proximal (anesthesia circuit) end of the TT. The adapter contains: (1) a connection for the TT, (2) a standard anesthesia 15mm circuit adaptor, (3) a port that can be tightened around the bronchial blocker to prevent it from moving, and (4) a port for a flexible bronchoscope. (Figure 11-6).

![Figure 11-6: Arndt Endobronchial Blocker](image)

*Diagram of Arndt endobronchial blocker (Cook®) and its special airway adapter. Its use requires a flexible bronchoscope.*

The flexible bronchoscope and the blocker are passed under direct vision through the TT into the
operative main stem bronchus. The bronchoscope is then withdrawn into the trachea and the balloon inflated, again under direct visualization. Next, the guide wire is removed from the central channel. Once the wire has been removed, it cannot be replaced. The smallest endobronchial blocker available is 5-French, and the smallest TT that can be used with a 5 French blocker is one with a 5.0mm internal diameter.

**Figure 11-7: Devices That Can Be Used to Allow One Lung Ventilation**

![Devices That Can Be Used to Allow One Lung Ventilation](image)

*Tubes used for one lung ventilation: From left to right: 1) Embolectomy catheter; 2) Standard 3.5mm TT; 3) Arndt endobronchial blocker; 4) Standard 5mm TT; 5) Univent tube; 6) Double-lumen tube - left; 7) Double-lumen tube – right.*

The *Univent tube* is a single-lumen standard TT with a moveable bronchial blocker in the sidewall (**Figure 11-7**). The bronchial blocker contains a low-pressure-high-volume cuff and a central canal that can be used to suction the isolated lung if necessary. Univent tubes are inserted like standard TTs. The bronchial blocker is then advanced into the operative main stem bronchus. The cuff of the bronchial blocker portion of the tube is inflated to isolate the operative lung. The bronchial blocker can be deflated and withdrawn into the main channel of the tube at the end of the procedure to convert from OLV to two-lung ventilation. The smallest Univent tube available has a 3.5mm internal diameter and an external diameter of 8mm, making it comparable to a 6.0mm internal diameter uncuffed standard TT, far too large for small children but useful for someone who is 10 years of age or older.
Double-lumen tubes (DLTs) are the gold standard for OLV in adults because they allow rapid achievement of OLV, facilitate suctioning of both lungs, allow switching from OLV to two-lung ventilation easily and allow the application of CPAP and the administration of oxygen to the operative lung if necessary for treatment of hypoxemia. However, the smallest DLT available is a 26 French, which is appropriate for children 8-10 years of age. If a child needs postoperative mechanical ventilation, the DLT must be replaced with a standard TT. A Univent tube, on the other hand, can be left in place with the blocker withdrawn into the main channel of the tube.

OLV should be initiated as soon as possible after the bronchial blocker is in place so there will be sufficient time for the blocked lung to deflate and become atelectatic. Peak airway pressures should initially be confirmed with two-lung ventilation and then reconfirmed with OLV to be sure that excessive airway pressures are not being applied to the ventilated lung. Blocking ventilation to one lung allows the residual oxygen in that lung to be absorbed from unventilated alveoli and cause absorption atelectasis. This is made easier by administering 100 percent oxygen for at least five minutes before initiating OLV. Mismatching of ventilation/perfusion occurs if portions of the unventilated lung continue to be perfused. Fortunately, surgical manipulation, an open hemithorax, and hypoxic pulmonary vasoconstriction reduce blood flow to the unventilated lung and decrease this V/Q mismatch. The ventilation strategy chosen for one-lung ventilation should focus on preventing acute lung injury (ALI). Recommendations for protective lung ventilation include tidal volumes of 6ml/kg, limiting plateau airway pressure to <20cmH₂O, and using 5-10cmH₂O of positive end-expiratory pressure (PEEP). The FiO₂ should be high enough to maintain the oxygen saturation (SpO₂) above 94%. Several techniques can be used to relieve hypoxemia should it occur during OLV. CPAP 10cmH₂O can be applied to the non-dependent (up) operative lung. One hundred percent oxygen is insufflated to achieve the desired CPAP level. This usually does not cause sufficient lung inflation to interfere with surgical conditions. The position of the lung isolation device should be reconfirmed by auscultation or by flexible bronchoscopy, if available. If persistent hypoxemia occurs, OLV should be converted to two-lung ventilation. Once the hypoxemia is relieved, OLV can again be re-initiated.

Pneumonectomy

Children with congenital abnormalities, neoplasms, trauma, or infection often require pneumonectomy or partial pneumonectomy. To decide if a patient will tolerate removing all or part of a lung, a good history and physical examination is very important. The history should focus on how well the patient tolerates walking, moving, and other exercise and whether he/she has evidence of hypoxemia while exercising or especially when at rest. The physical examination should look for signs of airway obstruction, such as wheezing, stridor, or cyanosis. The anesthetist should also look for evidence of a tracheal shift from its normal midline position, asymmetric chest movement, abnormal auscultatory findings, and signs of respiratory distress as evidence of airway obstruction. Children frequently tolerate loss of large amount of lung without symptoms.
However, if the patient develops significant respiratory symptoms after a pneumonectomy, it is an ominous sign. Infants with insufficient functioning lung mass to meet their needs often have nonspecific symptoms, such as poor feeding, irritability, choking, or changes in sleep habits. Insertion of an arterial cannula, if possible, should be done to monitor arterial blood gas and arterial blood pressure during and after a pneumonectomy. OLV is usually required for pneumonectomy. Preservation of lung capacity and function following a pneumonectomy decreases with increasing age. Consequently, babies do better than 20-year olds.\(^4\)

*Post pneumonectomy syndrome* is due to progressive hyperinflation of the remaining lung. This leads to increasing dyspnea, bronchomalacia, and recurrent lung infections. This syndrome is common after a right thoracotomy, due to counterclockwise rotation of mediastinal structures and compression of the left main stem bronchus or left lower bronchus between the aorta and spine posteriorly and pulmonary artery anteriorly. To correct this problem, mediastinal structures are sutured to the anterior chest wall to lift the vessels off of the bronchi.

**Chest Trauma & Pneumothorax**

*Pulmonary contusion* and rib fractures constitute 50% of pediatric chest trauma. Twenty percent of patients with chest trauma have a pneumothorax. If it impairs breathing and/or circulation, chest trauma can be life threatening. Life threatening injuries include tension pneumothorax, open pneumothorax, flail chest, and direct airway injuries.

A *tension pneumothorax* occurs when gas accumulates in the pleural space, is trapped there, and impairs both breathing and return of blood to the heart. The trachea is deviated and breath sounds are decreased on the affected side. The heart sounds are often shifted to the unaffected side. Hypotension and the need to use higher airway pressure to ventilate the lungs are often present. Relieving the high intrapleural pressure caused by the pneumothorax is the first priority. This can initially be accomplished by inserting a large-bore intravenous catheter into the pleura through the second intercostal space in the mid-clavicular line (Figure 11-8). This will immediately reduce the intrapleural pressure and improve ventilation and perfusion until a chest tube can be inserted. The cut-off finger of a glove can be attached to the catheter to act as a flap valve until a chest tube can be inserted. During inspiration the piece of glove is pulled over the end of the catheter. During expiration it is pushed away to allow the exit of gas.
A large bore needle is being inserted over a rib (to avoid injuring the intercostal vessels) to relieve a pneumothorax. The hand is steadied against the rib cage during needle insertion.

An open pneumothorax occurs when a chest injury produces a hole in the chest and allows the pressures between the pleural space and atmosphere to equalize. The lung beneath the hole collapses; air moves through the chest wall defect (hole) during breathing. An occlusive dressing should be placed over the defect and a chest tube inserted. If a chest tube is not immediately available, a dressing that is closed on three sides may act as a flap valve to prevent more air from entering the chest.

A flail chest occurs when multiple ribs are fractured. During inspiration, the fractured area moves inward while the remaining chest moves outward. This interferes with ventilation.

It is usually necessary and desirable to connect a chest tube to a suction bottle system to remove the drained gas or fluid/blood from the pleura and re-expand the collapsed lung. Below are three systems used for this purpose (Figures 11-9 to 11).
Figure 11-9: Single Bottle Under Water Seal

This is a schematic diagram of an underwater seal bottle containing sterile water. A chest tube is attached to the tube that is under water. The bottle is placed 100cm or more below the level of the patient to generate sufficient negative pressure to relieve the pneumothorax. A single bottle works well for an isolated pneumothorax when suction is not available. The collapsed lung may not re-expand as quickly as it would if suction is applied. Asking the patient to repeatedly perform the Valsalva maneuver (take in a deep breath and forcefully exhale) can aid in re-expanding the collapsed lung more quickly. [http://emedicine.medscape.com/article:1503275-overview - a09](http://emedicine.medscape.com/article:1503275-overview - a09)
A two-bottle drainage system is needed when fluid or blood must be drained from the chest. The bottle on the right is for fluid and/or blood collection. [Link](http://emedicine.medscape.com/article:1503275-overview) - a09
If suction is required and available, a third bottle is added to the system. The maximum amount of suction produced is determined by how far the atmospheric vent is placed underwater in the suction regulation bottle. The bottle on the right is for collecting fluid, and blood. The center bottle is a water seal. When the patient inhales and produces a negative pressure, fluid is drawn into the under tube and air is prevented from passing back into the pleural cavity. Applying suction to the bottle on the left helps remove gas and fluid from the lung. If there are gas bubbles in the center and left bottle, there is still a gas leak from a hole in the lung. [Link](http://emedicine.medscape.com/article:1503275-overview-a09)

**CONCLUSION**

Providing safe anesthesia for patients who require thoracic surgery requires an understanding of the surgical lesion and the effects of these lesions on lung function, oxygenation, and the ability to remove CO₂. This chapter has reviewed the neonatal thoracic surgery conditions of congenital diaphragmatic hernia, tracheoesophageal fistula, and congenital cystic lung disease. It has also reviewed childhood mediastinal tumors. The pathophysiology of one-lung ventilation has been explained, as well as practical advice on techniques and equipment needed to safely deliver OLV. Lastly, management of traumatic pneumothorax, including setting up a chest drainage system, has been discussed.
References