CHAPTER 25

Anesthesia for Thoracic Surgery

KEY CONCEPTS

1. During one-lung ventilation, the mixing of unoxygenated blood from the collapsed upper lung with oxygenated blood from the still-ventilated dependent lung widens the alveolar-to-arterial (A-a) O_2 gradient and often results in hypoxemia.
2. There are certain clinical situations in which the use of a right-sided double-lumen tube is recommended: (1) distorted anatomy of the left main bronchus by an intrabronchial or extrabronchial mass; (2) compression of the left main bronchus due to a descending thoracic aortic aneurysm; (3) left-sided pneumonectomy; (4) left-sided single lung transplantation; and (5) left-sided sleeve resection.
3. If epidural opioids are to be used postoperatively, their intravenous use should be limited during surgery to prevent excessive postoperative respiratory depression.
4. Postoperative hemorrhage complicates about 3% of thoracotomies and may be associated with up to 20% mortality. Signs of hemorrhage include increased chest tube drainage (>200 mL/h), hypotension, tachycardia, and a falling hematocrit.
5. Bronchopleural fistula presents as a sudden large air leak from the chest tube that may be associated with an increasing pneumothorax and partial lung collapse.
6. Acute herniation of the heart into the operative hemithorax can occur through the pericardial defect that is left following a radical pneumonectomy.
7. Nitrous oxide is contraindicated in patients with cysts or bullae because it can expand the air space and cause rupture. The latter may be signaled by sudden hypotension, bronchospasm, or an abrupt rise in peak inflation pressure and requires immediate placement of a chest tube.
8. Following transplantation, peak inspiratory pressures should be maintained at the minimum pressure compatible with good lung expansion, and the inspired oxygen concentration should be maintained as close to room air as allowed by a Pa_{O_2} >60 mm Hg.
9. Regardless of the procedure, a common anesthetic concern for patients with esophageal disease is the risk of pulmonary aspiration.

Indications and techniques for thoracic surgery continually evolve. Common indications now include thoracic malignancies (mainly of the lungs and esophagus), chest trauma, esophageal disease, and mediastinal tumors. Diagnostic procedures such as bronchoscopy, mediastinoscopy, and open-lung biopsies are also common. Anesthetic techniques for providing lung separation have allowed the refinement of surgical techniques to the point that many procedures are increasingly performed thoracoscopically.

Physiological Considerations During Thoracic Anesthesia

Thoracic surgery presents a unique set of physiological problems for the anesthesiologist. These include physiological derangements caused by placing the patient in the lateral decubitus position, opening the chest (**open pneumothorax**), and the need for one-lung ventilation.

THE LATERAL DECUBITUS POSITION

The lateral decubitus position provides optimal access for most operations on the lungs, pleura, esophagus, the great vessels, other mediastinal structures, and vertebrae. Unfortunately, this position may significantly alter the normal pulmonary ventilation/perfusion relationships. These derangements are further accentuated by induction of anesthesia, initiation of mechanical ventilation, neuromuscular blockade, opening the chest, and surgical retraction. Although perfusion continues to favor the dependent (lower) lung, ventilation progressively favors the less perfused upper lung. The resulting mismatch increases the risk of hypoxemia.

The Awake State

When a supine patient assumes the lateral decubitus position, ventilation/perfusion matching is preserved during spontaneous ventilation. The dependent (lower) lung receives more perfusion than does the upper lung due to gravitational influences on blood flow distribution in the pulmonary circulation. The dependent lung also receives more ventilation because: (1) contraction of the dependent hemidiaphragm is more efficient compared with the nondependent [upper] hemidiaphragm and (2) the dependent lung is on a more favorable part of the compliance curve (Figure 25–1).

Induction of Anesthesia

The decrease in functional residual capacity (FRC) with induction of general anesthesia moves the upper lung to a more favorable part of the compliance

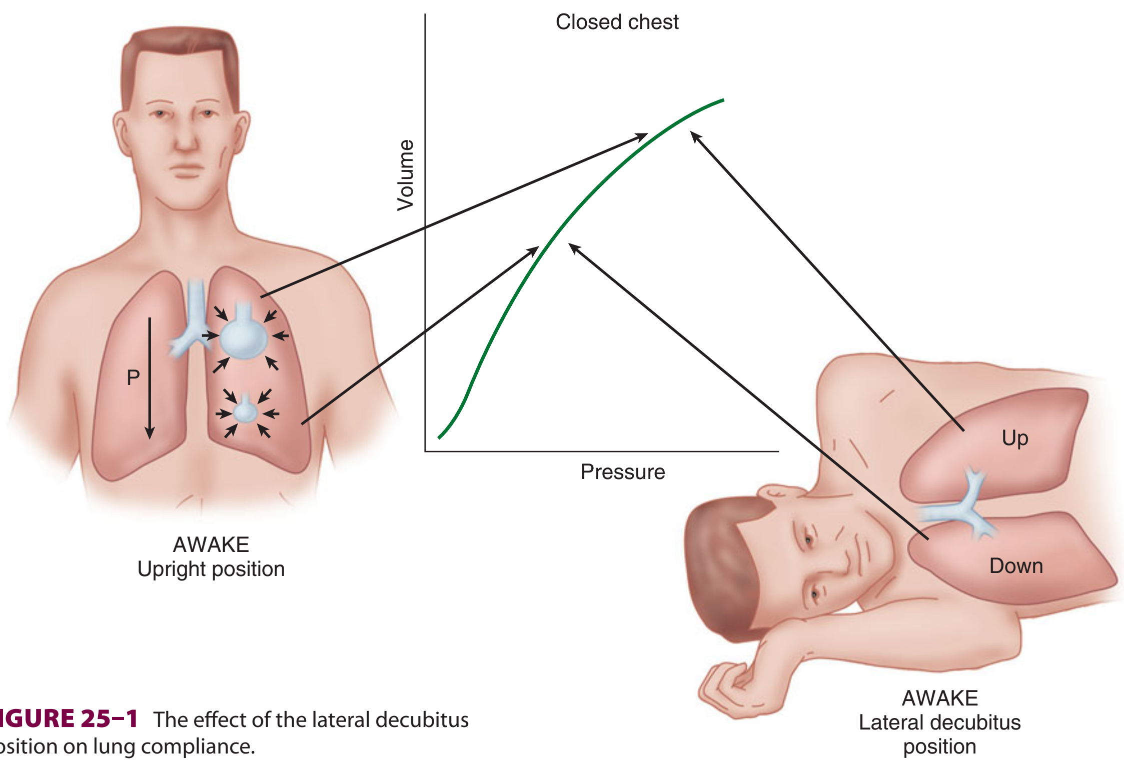

FIGURE 25–1 The effect of the lateral decubitus position on lung compliance.

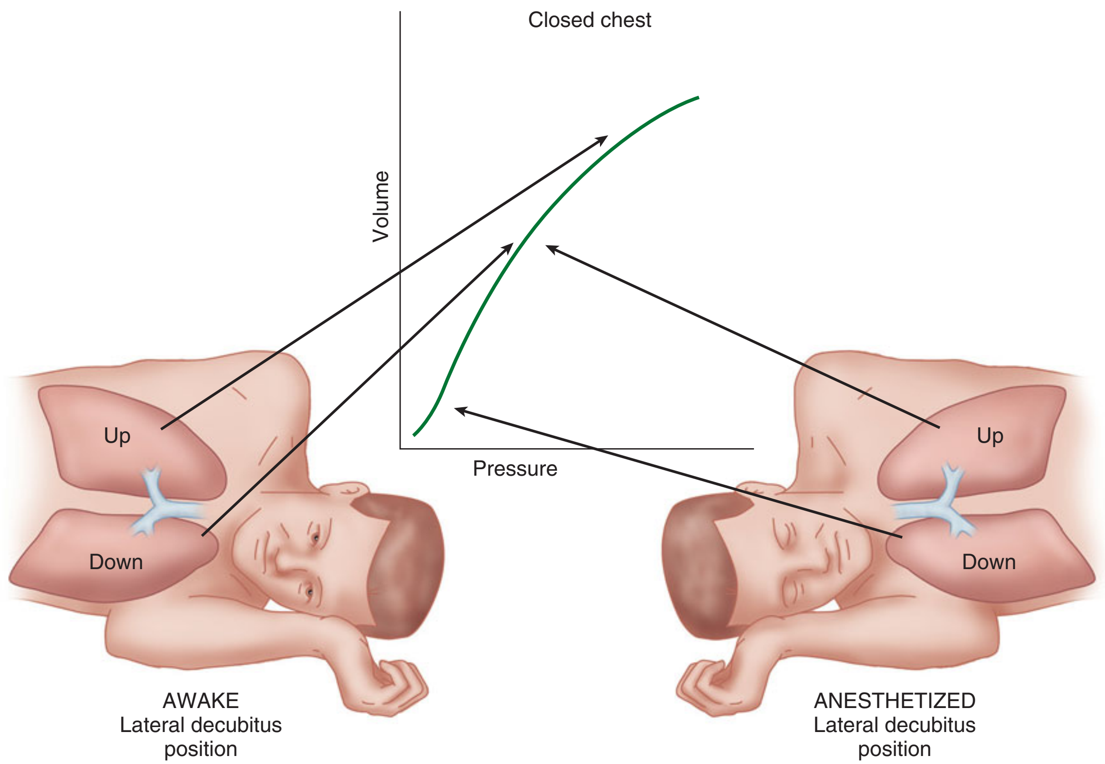

FIGURE 25–2 The effect of anesthesia on lung compliance in the lateral decubitus position. The upper lung assumes a more favorable position, and the lower lung becomes less compliant.

curve, but moves the lower lung to a less favorable-position (Figure 25–2). As a result, the upper lung is ventilated more than the dependent lower lung; ventilation/perfusion mismatching occurs because the dependent lung continues to have greater perfusion.

Positive-Pressure Ventilation

Controlled positive-pressure ventilation favors the upper lung in the lateral position because it is more compliant than the lower lung. Neuromuscular blockade enhances this effect by allowing the abdominal contents to rise up further against the dependent hemidiaphragm and impede ventilation of the lower lung. Using a rigid "bean bag" to maintain the patient in the lateral decubitus position further restricts movement of the dependent hemithorax. Finally, opening the nondependent side of the chest further accentuates differences in compliance between the two sides because the upper lung is now less restricted in movement. All of these effects worsen ventilation/perfusion mismatching and predispose the patient to hypoxemia.

THE OPEN PNEUMOTHORAX

The lungs are normally kept expanded by a negative pleural pressure—the net result of the tendency of the lung to collapse and the chest wall to expand. When one side of the chest is opened, the negative pleural pressure is lost, and the elastic recoil of the lung on that side tends to collapse it. Spontaneous ventilation with an open pneumothorax in the lateral position results in paradoxical respirations and mediastinal shift. These two phenomena can cause progressive hypoxemia and hypercapnia, but, fortunately, their effects are overcome by the use of positive-pressure ventilation during general anesthesia and thoracotomy.

Mediastinal Shift

During spontaneous ventilation in the lateral position, inspiration causes pleural pressure to become

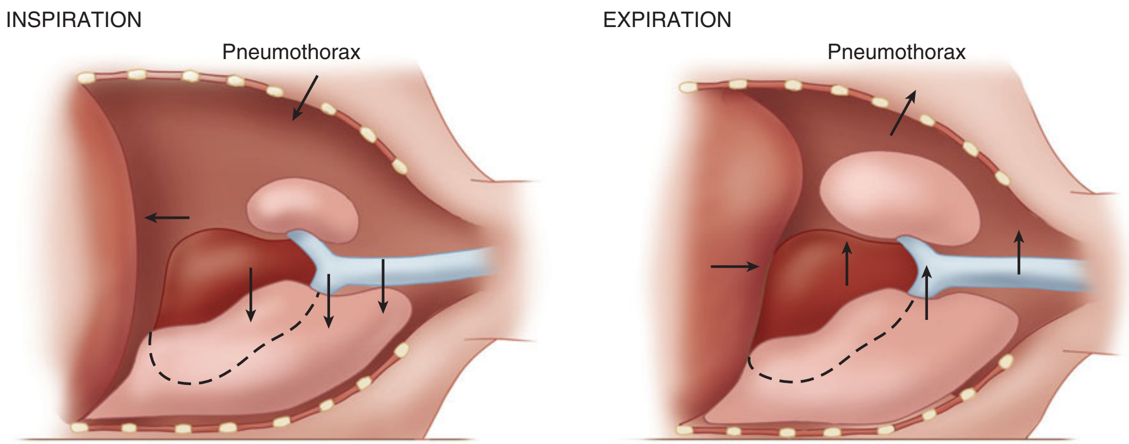

FIGURE 25–3 Mediastinal shift in a spontaneously breathing patient in the lateral decubitus position. (Reproduced, with permission, from Tarhan S, Moffitt EA: Principles of thoracic anesthesia. Surg Clin North Am 1973;53:813.)

more negative on the dependent side, but not on the side of the open pneumothorax. This results in a downward shift of the mediastinum during inspiration and an upward shift during expiration (Figure 25–3). The major effect of the mediastinal shift is to decrease the contribution of the dependent lung to the tidal volume.

Paradoxical Respiration

Spontaneous ventilation in a patient with an open pneumothorax also results in to-and-fro gas flow between the dependent and nondependent lung (paradoxical respiration [pendeluft]). During inspiration, the pneumothorax increases, and gas flows from the upper lung across the carina to the dependent lung. During expiration, the gas flow reverses and moves from the dependent to the upper lung (Figure 25–4).

ONE-LUNG VENTILATION

Intentional collapse of the lung on the operative side facilitates most thoracic procedures, but greatly complicates anesthetic management. Because the

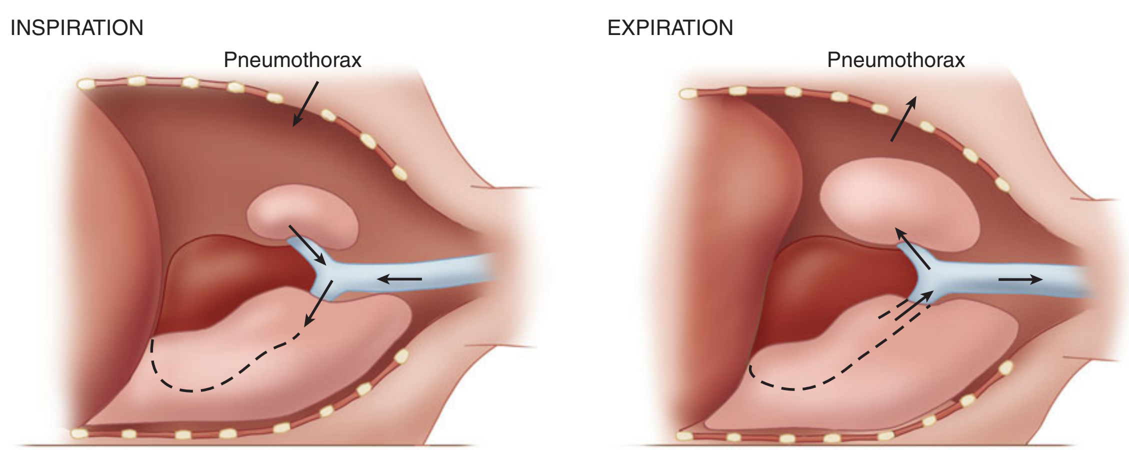

FIGURE 25–4 Paradoxical respiration in spontaneously breathing patients on their side. (Reproduced, with permission, from Tarhan S, Moffitt EA: Principles of thoracic anesthesia. Surg Clin North Am 1973;53:813.)

collapsed lung continues to be perfused and is deliberately no longer ventilated, the patient develops a large right-to-left intrapulmonary shunt (20% to 30%). During one-lung ventilation, the mixing of unoxygenated blood from the collapsed upper lung with oxygenated blood from the still-ventilated dependent lung widens the alveolar-to-arterial (A-a) O_2 gradient and often results in hypoxemia. Fortunately, blood flow to the nonventilated lung is decreased by hypoxic pulmonary vasoconstriction (HPV) and possibly surgical compression of the upper lung.

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Factors known to inhibit HPV (increasing venous admixture), and thus worsen the right-to-left shunting, include (1) very high or very low pulmonary artery pressures; (2) hypocapnia; (3) high or very low mixed venous Po_2; (4) vasodilators such as nitroglycerin, nitroprusside, phosophodiesterase inhibitors (milrinone and inamrinone), β-adrenergic agonists, calcium channel blockers; (5) pulmonary infection; and (6) inhalation anesthetics.

Factors that decrease blood flow to the ventilated lung can be equally detrimental; they counteract the effect of HPV by indirectly increasing blood flow to the collapsed lung. Such factors include (1) high mean airway pressures in the ventilated lung due to high positive end-expiratory pressure (PEEP), hyperventilation, or high peak inspiratory pressures; (2) a low FIO_2, which produces hypoxic pulmonary vasoconstriction in the ventilated lung; (3) vasoconstrictors that may have a greater effect on normoxic vessels than hypoxic ones; and (4) intrinsic PEEP that develops due to inadequate expiratory times.

Elimination of CO_2 is usually unchanged by one-lung ventilation, provided that minute ventilation is unchanged and that preexisting CO_2 retention was not present while ventilating both lungs; arterial CO_2 tension is usually not appreciably altered.

Techniques for One-Lung Ventilation

One-lung ventilation can also be utilized to isolate a lung or to facilitate ventilatory management under certain conditions (Table 25–1). Three techniques can be employed: (1) placement of a double-lumen bronchial tube; (2) use of a single-lumen tracheal tube in conjunction with a bronchial blocker; or (3) insertion of a conventional endotracheal tube into a mainstem bronchus. Double-lumen tubes are most often used.

TABLE 25–1 Indications for one-lung ventilation.

Patient-related
Confine infection to one lung
Confine bleeding to one lung
Separate ventilation to each lung
Bronchopleural fistula
Tracheobronchial disruption
Large lung cyst or bulla
Severe hypoxemia due to unilateral lung disease
Procedure-related
Repair of thoracic aortic aneurysm
Lung resection
Pneumonectomy
Lobectomy
Segmental resection
Thoracoscopy
Esophageal surgery
Single-lung transplantation
Anterior approach to the thoracic spine
Bronchoalveolar lavage

DOUBLE-LUMEN BRONCHIAL TUBES

The principal advantages of double-lumen tubes are relative ease of placement, the ability to ventilate one or both lungs, and the ability to suction either lung.

All double-lumen tubes share the following characteristics:

- A longer bronchial lumen that enters either the right or left main bronchus and another shorter tracheal lumen that terminates in the lower trachea
- A preformed curve that when properly "aimed" allows preferential entry into abronchus
- A bronchial cuff
- A tracheal cuff

Ventilation can be delivered to only one lung by clamping either the bronchial or tracheal lumen with both cuffs inflated; opening the port on the appropriate connector allows the ipsilateral lung to collapse. Because of differences in bronchial anatomy between the two sides, tubes are designed specifically for either the right or left bronchus. A right-sided double-lumen tube incorporates a modified cuff and a proximal portal on the endobronchial side for ventilation of the right upper lobe. The most commonly used double-lumen tube are available in several sizes: 35, 37, 39, and 41F.

Anatomic Considerations

On average, the adult trachea is 11–13 cm long. It begins at the level of the cricoid cartilage (C6) and bifurcates at the level of the carina behind the sternomanubrial joint (T5). Major differences between the right and left main bronchi are as follows: (1) the larger diameter right bronchus diverges away from the trachea at a less acute angle in relation to the trachea, whereas the left bronchus diverges at a more horizontal angle (**Figure 25–5**); (2) the right bronchus has upper, middle, and lower lobe branches, whereas the left bronchus divides into only upper and lower lobe branches; and (3) the orifice of the right upper lobe bronchus is typically about 1–2.5 cm from the carina, whereas the bifurcation of the left main bronchus is typically about 5 cm distal to the carina. There is considerable anatomic variation: for example, the right upper lobe bronchus will occasionally arise from the trachea itself.

As previously noted, right-sided double-lumen tubes must have a portal through the bronchial cuff for ventilating the right upper lobe (**Figure 25–6**). Anatomic variations among individuals in the distance between the carina and the right upper lobe orifice will occasionally result in difficulty ventilating that lobe with right-sided tubes. A left-sided double-lumen tube can be used in most surgical procedures, **2** irrespective of the operative side. There are certain clinical situations in which the use of a right-sided double-lumen tube is recommended:

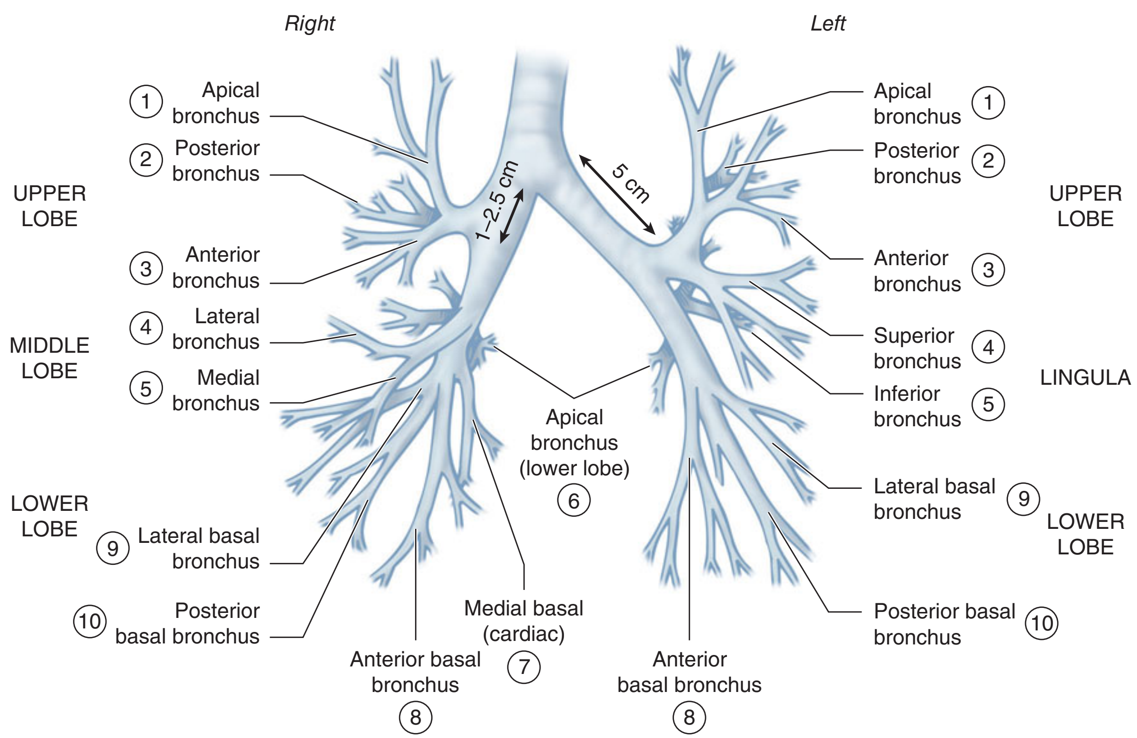

FIGURE 25–5 Anatomy of the tracheobronchial tree. Note bronchopulmonary segments (1–10) as numbered. (Adapted and reproduced, with permission, from Gothard JWW, Branthwaite MA: *Anesthesia for Thoracic Surgery.* Blackwell, 1982.)

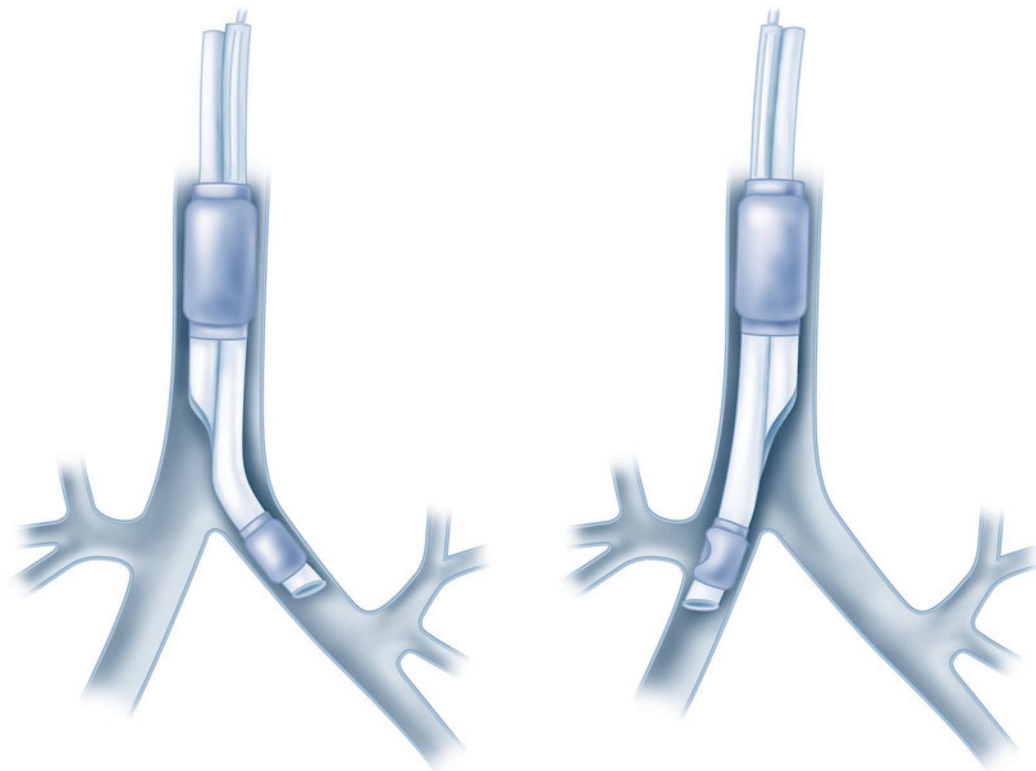

FIGURE 25–6 Correct position of a left- and right-sided double-lumen tube.

(1) distorted anatomy of the left main bronchus by an intrabronchial or extrabronchial mass; (2) compression of the left main bronchus due to a descending thoracic aortic aneurysm; (3) left-sided pneumonectomy; (4) left-sided single lung transplantation; and (5) left-sided sleeve resection. Finally, despite concerns about right upper lobe atelectasis and potentially difficult placement, studies have failed to detect differences in clinical performance of right- and left-sided double-lumen tubes when used clinically.

Placement of Double-Lumen Tubes

Laryngoscopy with a curved (MacIntosh) blade usually provides better intubating conditions than does a straight blade because the curved blade typically provides more room for manipulation of the large double-lumen tube. Video laryngoscopy can also be employed to facilitate tube placement. The double-lumen tube is passed with the distal curvature concave anteriorly and is rotated 90° (toward the side of the bronchus to be intubated) after the tip passes the vocal cords and enters the larynx (Figure 25–7). At this point, the operator has two options: the tube can be advanced until resistance is felt (the average depth of insertion is about 29 cm [at the teeth]), or alternatively, the fiberoptic bronchoscope can be inserted through the bronchial limb and advanced into the desired bronchus. The double-lumen tube can be advanced over the bronchoscope into the desired bronchus. Correct tube placement should be established using a preset protocol (Figure 25–8 and Table 25–2) and confirmed by flexible fiberoptic bronchoscopy. When problems are encountered in intubating the patient with the double-lumen tube, placement of a single-lumen endotracheal tube should be attempted; once positioned in the trachea, the latter can be exchanged for the double-lumen tube by using a specially designed catheter guide ("tube exchanger").

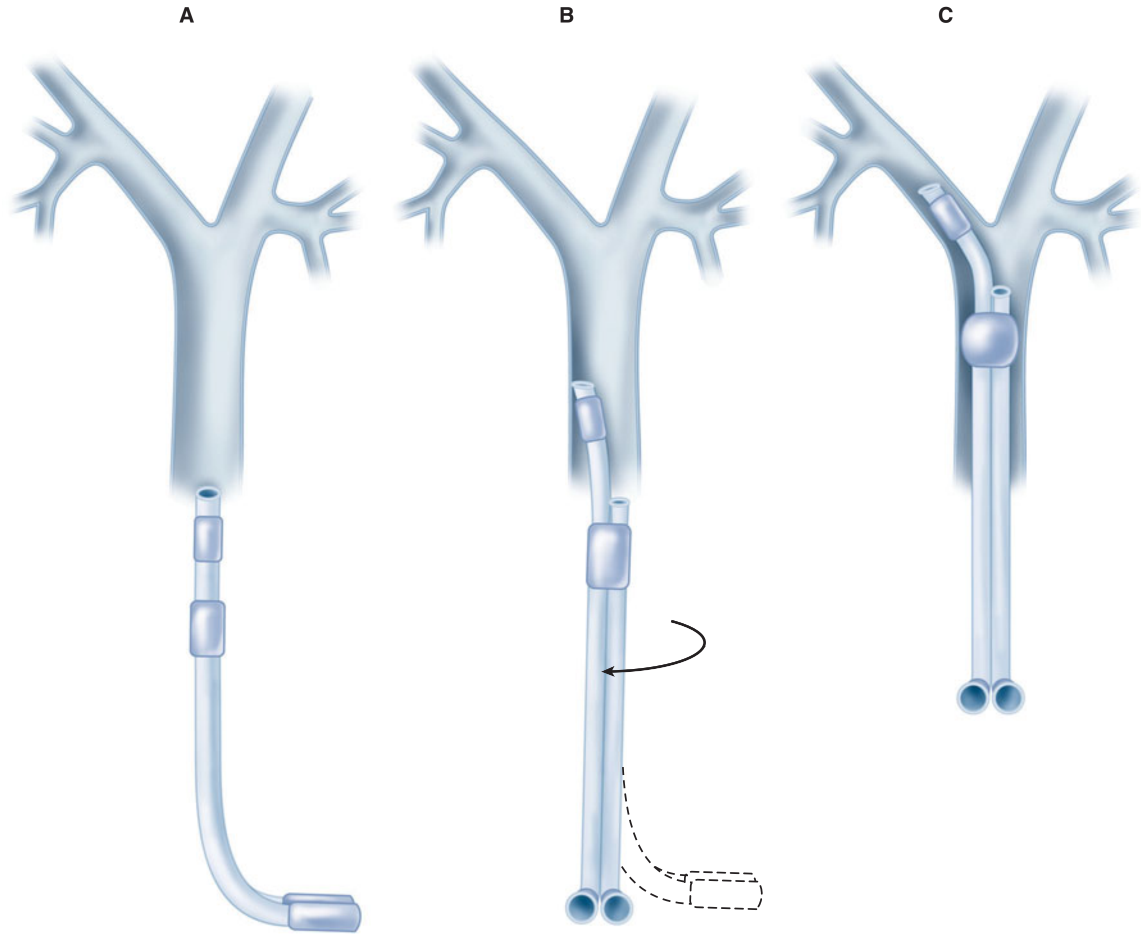

FIGURE 25–7 Placement of a left-sided double-lumen tube. Note that the tube is turned 90° as soon as it enters the larynx. **A**: Initial position. **B**: Rotated 90°. **C**: Final position.

Most double-lumen tubes easily accommodate bronchoscopes with a 3.6- to 4.2-mm outer diameter. When the bronchoscope is introduced into the tracheal lumen and advanced through the tracheal orifice, the carina should be visible (Figure 25–9), and the bronchial limb of the tube should be seen entering the respective bronchus; additionally, the top of the bronchial cuff (usually colored blue) should be visible, but should not extend above the carina. If the bronchial cuff of a left-sided double-lumen tube is not visible, the bronchial limb may have been inserted sufficiently far to allow the bronchial cuff to obstruct the orifice of the left upper or lower lobe; the tube should be withdrawn until the cuff can be identified distal to the carina. The optimal position of a right-sided double-lumen tube is confirmed by placing the fiberoptic scope through the endobronchial lumen, which should show alignment of the endobronchial side portal with the opening of the right upper lobe bronchus. The bronchial cuff should be inflated only to the point at which the audible leak from the open tracheal lumen disappears while ventilating only through the bronchial lumen. Tube position should be reconfirmed after the patient is positioned for surgery because the tube may move relative to the carina as the patient is turned into the lateral decubitus position. Malpositioning of a double-lumen tube is usually

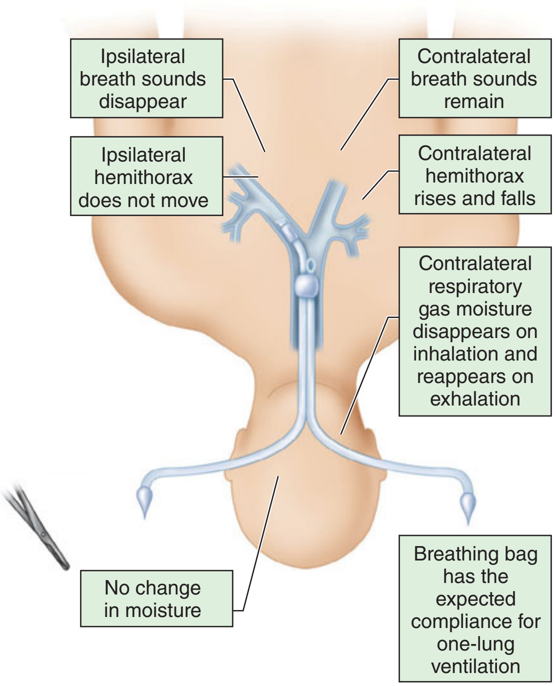

FIGURE 25–8 Results of unilateral clamping of the bronchial lumen tube when the double-lumen tube is in the correct position.

indicated by failure of the operative lung to collapse, poor lung compliance, and low exhaled tidal volume. Problems with left-sided double-lumen tubes are usually related to one of three possibilities: (1) the tube tip is too distal: (2) the tube tip is too proximal: or (3) the tube is in the right bronchus (the wrong side). If the tube tip is located too distally, the bronchial cuff can obstruct the left upper or the left lower lobe orifice, and the bronchial lumen can be inserted into the orifice of the left lower or left upper lobe bronchus, respectively. When the tube is not advanced distally enough, the inflated bronchial cuff may be above the carina and also occlude the tracheal lumen. In both instances, deflation of the bronchial cuff improves ventilation to the lung and helps to identify the problem. In some patients, the bronchial lumen may be within the left upper or left lower lobe bronchus but with the tracheal opening remaining above the carina; this situation is suggested by collapse of only one of the left lobes

TABLE 25–2 Protocol for checking placement of a left-sided double-lumen tube.

1. Inflate the tracheal cuff (5–10 mL of air).
2. Check for bilateral breath sounds. Unilateral breath sounds indicate that the tube is too far down (tracheal opening is bronchial).
3. Inflate the bronchial cuff (1–2 mL).
4. Clamp the tracheal lumen.
5. Check for unilateral left-sided breath sounds.
   a. Persistence of right-sided breath sounds indicates that the bronchial opening is still in the trachea (tube should be advanced).
   b. Unilateral right-sided breath sounds indicate incorrect entry of the tube in the right bronchus.
   c. Absence of breath sounds over the entire right lung and the left upper lobe indicates that the tube is too far down the left bronchus.
6. Unclamp the tracheal lumen and clamp the bronchial lumen.
7. Check for unilateral right-sided breath sounds. Absence or diminution of breath sounds indicates that the tube is not far enough down and that the bronchial cuff is occluding the distal trachea.

when the bronchial lumen is clamped. In the same situation, if the surgical procedure is in the right thorax, clamping of the tracheal lumen will lead to ventilation of only the left upper or left lower lobe; hypoxia usually develops rapidly.

Right-sided double-lumen tubes can be accidentally inserted into the left main stem bronchus, inserted too distally or too proximally, or have

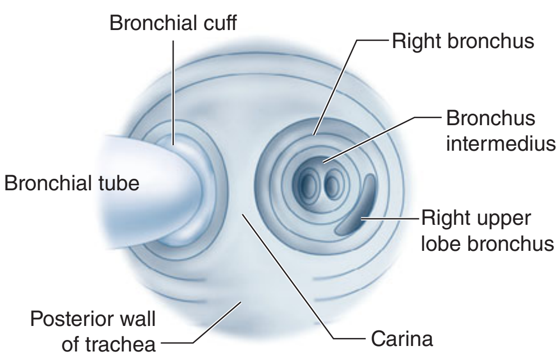

FIGURE 25–9 The view of the carina looking down the tracheal lumen of a properly positioned left double-lumen bronchial tube.

misalignment of the endobronchial side portal with the opening of the right upper lobe bronchus. If the tube inadvertently enters the wrong bronchus, the fiberoptic bronchoscope can be used to direct it into the correct side: (1) the bronchoscope is passed through the bronchial lumen to the tip of the tube; (2) under direct vision, the tube and the bronchoscope are withdrawn together into the trachea just above the carina; (3) the bronchoscope alone is then advanced into the correct bronchus; and (4) the double-lumen tube is gently advanced over the bronchoscope, which functions as a stylet to guide the bronchial lumen into the correct bronchus.

Complications of Double-Lumen Tubes

Major complications of double-lumen tubes include: (1) hypoxemia due to tube malplacement, tube occlusion, or excessive degrees of venous admixture with one-lung ventilation; (2) traumatic laryngitis; (3) tracheobronchial rupture resulting from traumatic placement or overinflation of the bronchial cuff; and (4) inadvertent suturing of the tube to a bronchus during surgery (detected as the inability to withdraw the tube during attempted extubation).

SINGLE-LUMEN TRACHEAL TUBES WITH A BRONCHIAL BLOCKER

Bronchial blockers are inflatable devices that are passed alongside or through a single-lumen tracheal tube to selectively occlude a bronchial orifice. A single-lumen tracheal tube with a built-in side channel for a retractable bronchial blocker is available. The tube is placed with the blocker fully retracted; its natural curve is such that turning the tube with the curve concave toward the right preferentially directs the bronchial blocker toward the right bronchus. Turning the tube with the curve concave toward the left usually directs the blocker toward the left bronchus. The bronchial blocker must be advanced, positioned, and inflated under direct visualization via a flexible bronchoscope.

The major advantage of a tube with an incorporated bronchial blocker is that, unlike a double-lumen tube, it does not need to be replaced with a conventional tracheal tube if the patient remains intubated postoperatively (below). Its major disadvantage is that the "blocked" lung collapses slowly (and sometimes incompletely) because of the small size of the channel within the blocker.

Another way to achieve lung separation is by using an independent bronchial blocker passed through a single-lumen endotracheal tube. There are several types of independent bronchial blockers. They come in different sizes (7Fr and 9Fr) and have a 1.4-mm diameter inner lumen. Bronchial blockers have a high-volume low-pressure cuff with either an elliptical or spherical shape. The spherical shape of the cuff facilitates adequate blockade of the right mainstem bronchus. The spherical or the elliptical cuff can be used for the left main stem bronchus. The inner lumen contains a nylon wire, which exits the distal end as a wireloop. The placement of the bronchial blocker involves inserting the endobronchial blocker through the endotracheal tube and using the fiberoptic bronchoscope and the distal loop of the guidewire to direct the blocker into a mainstem bronchus. The fiberoptic bronchoscope must be advanced beyond the bronchus opening so that the blocker enters the bronchus while it is being advanced. When the deflated cuff is beyond the entrance of the bronchus, the fiberoptic bronchoscope is withdrawn, and the blocker is secured in position. In order to obtain bronchial blockade, the cuff is fully inflated under fiberoptic visualization with 4 to 8 mL of air. The placement must be reconfirmed when the patient is placed in the lateral position. Bronchial blockers may be good choices for lung separation in intubated critically ill patients who require one-lung ventilation, patients who are difficult to intubate using direct laryngoscopy, patients with prior tracheostomies, and patients who may require postoperative mechanical ventilation. However, because bronchial blockers are more prone to dislodgement compared with double-lumen endotracheal tubes, and their small central lumens do not allow efficient suctioning of secretions or rapid collapse of the lung, some clinicians prefer not to use them.

In smaller children, an inflatable embolectomy (Fogarty) catheter can be used as a bronchial blocker in conjunction with a conventional tracheal tube (with the embolectomy catheter placed either inside or alongside the tracheal tube); a guidewire in the catheter can be used to facilitate placement. This technique is occasionally used to collapse one lung when other techniques do not work. As the embolectomy catheter does not have a communicating channel in the center, it also does not allow suctioning or ventilation of the isolated lung, and the catheter can be easily dislodged. Nonetheless, such bronchial blockers may be useful for one-lung anesthesia in pediatric patients and for tamponading bronchial bleeding in adult patients (see below).

Anesthesia for Lung Resection

PREOPERATIVE CONSIDERATIONS

Lung resections are usually carried out for the diagnosis and treatment of pulmonary tumors, and, less commonly, for complications of necrotizing pulmonary infections and bronchiectasis.

1. Tumors

Pulmonary tumors can be either benign or malignant, and, with the widespread use of bronchoscopic sampling, the diagnosis is usually available prior to surgery. Hamartomas account for 90% of benign pulmonary tumors; they are usually peripheral pulmonary lesions and represent disorganized normal pulmonary tissue. Bronchial adenomas are usually central pulmonary lesions that are typically benign, but occasionally may be locally invasive and rarely metastasize. These tumors include pulmonary carcinoids, cylindromas, and mucoepidermoid adenomas. They often obstruct the bronchial lumen and cause recurrent pneumonia distal to the obstruction in the same area. Primary pulmonary carcinoids may secrete multiple hormones, including adrenocorticotropic hormone (ACTH) and arginine vasopressin; however, manifestations of the carcinoid syndrome are uncommon and are more likely with metastases.

Malignant pulmonary tumors are divided into small ("oat") cell and non–small cell carcinomas. The latter group includes squamous cell (epidermoid) tumors, adenocarcinomas, and large cell (anaplastic) carcinomas. All types are more commonly encountered in smokers, but more "never smokers" die of lung cancer each year in the United States than the total number of people who die of ovarian cancer. Epidermoid and small cell carcinomas usually present as central masses with bronchial lesions; adenocarcinoma and large cell carcinomas are more typically peripheral lesions that often involve the pleura.

Clinical Manifestations

Symptoms may include cough, hemoptysis, wheezing, weight loss, productive sputum, dyspnea, or fever. Pleuritic chest pain or pleural effusion suggests pleural extension. Involvement of mediastinal structures is suggested by hoarseness that results from compression of the recurrent laryngeal nerve, Horner's syndrome caused by involvement of the sympathetic chain, an elevated hemidiaphragm caused by compression of the phrenic nerve, dysphagia caused by compression of the esophagus, or the superior vena cava syndrome caused by compression or invasion of the superior vena cava. Pericardial effusion or cardiomegaly suggests cardiac involvement. Extension of apical (superior sulcus) tumors can result in either shoulder or arm pain, or both, because of involvement of the C7–T2 roots of the brachial plexus (Pancoast syndrome). Distant metastases most commonly involve the brain, bone, liver, and adrenal glands.

Lung carcinomas—particularly small cell—can produce remote effects that are not related to malignant spread (paraneoplastic syndromes). Mechanisms include ectopic hormone production and immunologic cross-reactivity between the tumor and normal tissues. Cushing's syndrome, hyponatremia, and hypercalcemia may be encountered, resulting from secretion of ACTH, arginine vasopressin, and parathyroid hormone, respectively. Lambert–Eaton (myasthenic) syndrome is characterized by a proximal myopathy in which muscle strength increases with repeated effort (in contrast to myasthenia gravis). Other paraneoplastic syndromes include peripheral neuropathy and migratory thrombophlebitis.

Treatment

Surgery is the treatment of choice to reduce the tumor burden in nonmetastatic lung cancer. Various chemotherapy and radiation treatments are likewise employed, but there is wide variation among tissue types in their sensitivity to chemotherapy and radiation.

Resectability & Operability

Resectability is determined by the anatomic stage of the tumor, whereas operability is dependent on the interaction between the extent of the procedure required for cure and the physiological status of the patient. Anatomic staging is accomplished using chest radiography, computed tomography (CT) or magnetic resonance imaging (MRI), bronchoscopy, and (sometimes) mediastinoscopy. The extent of the surgery should maximize the chances for a cure but still allow for adequate residual pulmonary function postoperatively. Lobectomy via a posterior thoracotomy, through the fifth or sixth intercostal space, or thorough video assisted thoracoscopic surgery (VATS), is the procedure of choice for most lesions. Segmental or wedge resections may be performed in patients with small peripheral lesions and poor pulmonary reserve. Pneumonectomy is necessary for curative treatment of lesions involving the left or right main bronchus or when the tumor extends toward the hilum. A sleeve resection may be employed for patients with proximal lesions and limited pulmonary reserve as an alternative to pneumonectomy; in such instances, the involved lobar bronchus, together with part of the right or left main bronchus, is resected, and the distal bronchus is reanastomosed to the proximal bronchus or the trachea. Sleeve pneumonectomy may be considered for tumors involving the trachea.

The incidence of pulmonary complications after thoracotomy and lung resection is about 30% and is related not only to the amount of lung tissue resected, but also to the disruption of chest wall mechanics due to the thoracotomy. Postoperative pulmonary dysfunction seems to be less after VATS than "open" thoracotomy. The mortality rate for pneumonectomy is generally more than twice that of for a lobectomy. Mortality is greater for right-sided than left-sided pneumonectomy, possibly because of greater loss of lung tissue.

Evaluation for Lung Resection

A comprehensive preoperative pulmonary assessment is necessary to assess the operative risk, minimize perioperative complications, and achieve better outcomes. Preoperative assessment of respiratory function includes determinations of respiratory mechanics, gas exchange, and cardiorespiratory interaction.

Respiratory mechanics are assessed by pulmonary function tests. Of these parameters, the most useful is the predicted postoperative forced expiratory volume in one sec (FEV_1), which is calculated as follows:

$$\text{Postoperative } FEV_1 = \text{preoperative } FEV_1 \times (1 - \text{the percentage of functional lung tissue removed divided by } 100)$$

Removal of extensively diseased lung (nonventilated but perfused) does not necessarily adversely affect pulmonary function and may actually improve oxygenation. Mortality and morbidity are significantly increased if postoperative FEV_1 is less than 40% of normative FEV_1, and patients with predicted postoperative FEV_1 of less than 30% may need postoperative mechanical ventilatory support.

Gas exchange will sometimes be characterized by diffusion lung capacity for carbon monoxide (DLCO). DLCO correlates with the total functioning surface area of the alveolar–capillary interface. Predictive postoperative DLCO can be calculated in the same fashion as postoperative FEV_1. A predicted postoperative DLCO of less than 40% also correlates with increased postoperative respiratory and cardiac complications. Adequacy of gas exchange is more commonly assessed by arterial blood gas data such as Pao_2 >60 mm Hg and a $Paco_2$ <45 mm Hg.

Ventilation-perfusion ($\dot{V}/\dot{Q}$) scintigraphy provides the relative contribution of each lobe to overall pulmonary function and may further refine the assessment of predicted postoperative lung function, in patients where pneumonectomy is the indicated surgical procedure and there is concern whether a single lung will be adequate to support life.

Patients considered at greater risk of perioperative complications based on standard spirometry testing and calculation of postoperative function should undergo exercise testing for evaluation of

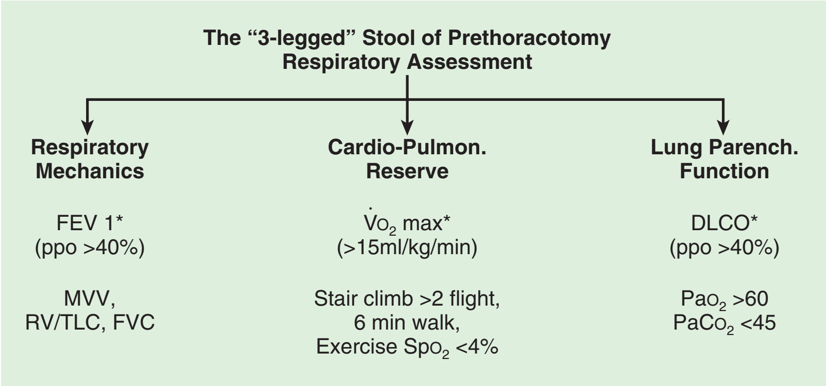

FIGURE 25–10 The "three-legged" stool of prethoracotomy respiratory assessment. *Most valid test. (Reproduced, with permission, from Slinger PD, Johnston MR: Preoperative assessment: an anesthesiologist's perspective. Thorac Surg Clin 2005;15:11.)

cardiopulmonary interaction. Stair climbing is the easiest way to assess exercise capacity and cardiopulmonary reserve. Patients capable of climbing two or three flights of stairs have decreased mortality and morbidity. On the other hand, the ability to climb less than two flights of stairs is associated with increased perioperative risk. The gold standard for evaluating cardiopulmonary interaction is by laboratory exercise testing and measurement of maximal minute oxygen consumption. A $\dot{V}O_2$ >20 mL/kg is not associated with a significant increase in perioperative mortality or morbidity, whereas a minute consumption of less than 10 mL/kg is associated with an increased perioperative risk.

A combination of tests to evaluate the three components of the respiratory function (ie, respiratory mechanics, gas exchange, and cardiopulmonary interaction) has been summarized in the so-called "three-legged" stool of respiratory assessment (Figure 25–10).

2. Infection

Pulmonary infections may present as a solitary nodule or cavitary lesion (necrotizing pneumonitis). An exploratory thoracotomy may be carried out to exclude malignancy and diagnose the infectious agent. Lung resection is also indicated for cavitary lesions that are refractory to antibiotic treatment, are associated with refractory empyema, or result in massive hemoptysis. Responsible organisms include both bacteria and fungi.

3. Bronchiectasis

Bronchiectasis is a permanent dilation of bronchi. It is usually the end result of severe or recurrent inflammation and obstruction of bronchi. Causes include a variety of viral, bacterial, and fungal pathogens, as well as inhalation of toxic gases, aspiration of gastric acid, and defective mucociliary clearance (cystic fibrosis and disorders of ciliary dysfunction). Bronchial muscle and elastic tissue are typically replaced by very vascular fibrous tissue. The latter predisposes to bouts of hemoptysis. Pulmonary resection is usually indicated for massive hemoptysis when conservative measures have failed and the disease is localized. Patients with diffuse bronchiectasis have a chronic obstructive ventilatory defect.

ANESTHETIC CONSIDERATIONS

1. Preoperative Management

The majority of patients undergoing pulmonary resections have underlying lung disease. It should be emphasized that smoking is a risk factor for both chronic obstructive pulmonary disease and coronary artery disease; both disorders commonly coexist in patients presenting for thoracotomy.

Echocardiography is useful for assessing baseline cardiac function and may suggest evidence of cor pulmonale (right ventricular enlargement or hypertrophy) in patients with poor exercise tolerance. Stress echocardiography (exercise or dobutamine) may be useful in diagnosing coronary artery disease in patients with suggestive signs and symptoms.

Patients with tumors should be evaluated for complications related to local extension of the tumor and paraneoplastic syndromes (above). Preoperative chest radiographs and CT or MR images should be reviewed. Tracheal or bronchial deviation can make tracheal intubation and proper positioning of bronchial tubes much more difficult. Moreover, airway compression can lead to difficulty in ventilating the patient following induction of anesthesia. Pulmonary consolidation, atelectasis, and large pleural effusions predispose to hypoxemia. The location of any bullous cysts or abscesses should be noted.

Patients undergoing thoracic procedures are at increased risk of postoperative pulmonary and cardiac complications. Perioperative arrhythmias, particularly supraventricular tachycardias, are thought to result from surgical manipulations or distention of the right atrium following reduction of the pulmonary vascular bed. The incidence of arrhythmias increases with age and the amount of pulmonary resection.

2. Intraoperative Management

Preparation

As with anesthesia for cardiac surgery, optimal preparation may help to prevent potentially catastrophic problems. The frequent presence of poor pulmonary reserve, anatomic abnormalities, or compromise of the airways, and the need for one-lung ventilation predispose these patients to the rapid onset of hypoxemia. A well thought-out plan to deal with potential difficulties is necessary. Moreover, in addition to items for basic airway management, specialized and properly functioning equipment—such as multiple sizes of single- and double-lumen tubes, a flexible (pediatric) fiberoptic bronchoscope, a small-diameter “tube exchanger” of adequate length to accommodate a double lumen tube, a continuous positive airway pressure (CPAP) delivery system, and an anesthesia circuit adapter for administering bronchodilators—should be immediately available.

Patients undergoing open-lung resections (segmentectomy, lobectomy, pneumonectomy) often receive postoperative thoracic epidural analgesia, unless there is a contraindication. However, patients are increasingly being treated with numerous antiplatelet and anticoagulant medications, which may preclude epidural catheter placement.

Venous Access

At least one large-bore (14- or 16-gauge) intravenous line is mandatory for all open thoracic surgical procedures. Central venous access (preferably on the side of the thoracotomy to avoid the risk of pneumothorax on the side that will be ventilated intraoperatively), a blood warmer, and a rapid infusion device are also desirable if extensive blood loss is anticipated.

Monitoring

Direct monitoring of arterial pressure is indicated for resections of large tumors (particularly those with mediastinal or chest wall extension), and any procedure performed in patients who have limited pulmonary reserve or significant cardiovascular disease. Central venous access with monitoring of central venous pressure (CVP) is desirable for pneumonectomies and resections of large tumors. Less invasive measures of cardiac output through use of pulse contour analysis and transpulmonary thermodilution provide better estimates of cardiac function and volume responsiveness (See Chapter 5). Pulmonary artery catheters are very rarely used. Measurement of pulmonary artery pressures may also not be accurate due to intrinsic and extrinsic PEEP, lateral decubitus, and open chest. In patients with significant coronary artery disease or pulmonary hypertension, intraoperative monitoring can be enhanced by the use of transesophageal echocardiography.

Induction of Anesthesia

After adequate preoxygenation, an intravenous anesthetic is used for induction of most patients. The selection of an induction agent should be based on the patient’s preoperative status. Direct laryngoscopy should generally be performed only after adequate depth of anesthesia has been achieved to prevent reflex bronchospasm and to obtund the cardiovascular pressor response. This may be accomplished by incremental doses of the induction agent, an opioid, or deepening the anesthesia with a volatile inhalation agent (the latter is particularly useful in patients with reactive airways).

Tracheal intubation with a single-lumen tracheal tube (or with a laryngeal mask airway [LMA]) may be necessary, if the surgeon performs diagnostic bronchoscopy (below) prior to surgery. Once the bronchoscopy is completed, the single-lumen tracheal tube (or LMA) can be replaced with a double-lumen bronchial tube (above). Controlled positive-pressure ventilation helps prevent atelectasis, paradoxical breathing, and mediastinal shift; it also allows control of the operative field to facilitate the surgery.

Positioning

Following induction, intubation, and confirmation of correct tracheal or bronchial tube position, additional venous access and monitoring may be obtained before the patient is positioned for surgery. Most lung resections are performed with the patient in the lateral decubitus position. Proper positioning avoids injuries and facilitates surgical exposure. The lower arm is flexed and the upper arm is extended in front of the head, pulling the scapula away from the operative field (Figure 25–11). Pillows are placed between the arms and legs, and an axillary (chest) roll may be positioned just beneath the dependent axilla to reduce pressure on the inferior shoulder (it is assumed that this helps to protect the brachial plexus); care is taken to avoid pressure on the eyes and the dependent ear.

Maintenance of Anesthesia

All current anesthetic techniques have been successfully used for thoracic surgery, but the combination of a potent halogenated agent (isoflurane, sevoflurane, or desflurane) and an opioid is preferred by most clinicians. Advantages of the halogenated agents include: (1) potent dose-related bronchodilation; (2) depression of airway reflexes; (3) the ability to use a high inspired oxygen concentration (FIO_2), if necessary; (4) the ability to make relatively rapid adjustments in anesthetic depth; and (5) minimal effects on hypoxic pulmonary vasoconstriction (see below). Halogenated agents generally have minimal effects on HPV in doses <1 minimum alveolar concentration (MAC). Advantages of an opioid include: (1) generally minimal hemodynamic effects; (2) depression of airway reflexes; and (3) residual

3 postoperative analgesia. If epidural opioids are used postoperatively, intravenous opioids should be limited during surgery to prevent excessive postoperative respiratory depression. Maintenance of neuromuscular blockade with a nondepolarizing neuromuscular blocker (NMB) during surgery facilitates rib spreading as well as anesthetic management. Intravenous fluids should generally be restricted in patients undergoing pulmonary resections. Excessive fluid administration in thoracic surgical patients has been associated with acute lung injury in the postoperative period. No fluid replacement for estimated "third space" losses should be administered during lung resection. Excessive fluid administration in the lateral decubitus position may promote a "lower lung syndrome" (ie, gravity-dependent transudation of fluid into the dependent lung). The latter increases intrapulmonary shunting and promotes hypoxemia, particularly

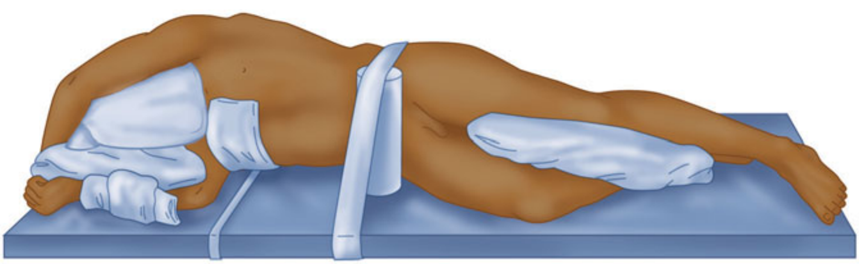

FIGURE 25–11 Proper positioning for a lateral thoracotomy. (Reproduced, with permission, from Gothard JWW, Branthwaite MA: *Anesthesia for Thoracic Surgery*. Blackwell, 1982.)

during one-lung ventilation. Moreover, the collapsed lung may be prone to acute lung injury due to surgical retraction during the procedure and possible ischemia–reperfusion injury. During lung resections, the bronchus (or remaining lung tissue) is usually divided with an automated stapling device. The bronchial stump is then tested for an air leak under water by transiently sustaining 30 cm of positive pressure to the airway. Prior to completion of chest closure, all remaining lung segments should be fully expanded manually under direct vision. Controlled mechanical ventilation is then resumed and continued until chest tubes are connected to suction.

Management of One-Lung Ventilation

Although still an intraoperative problem, hypoxemia has become less frequent due to better lung isolation methods, ventilation techniques, and the use of anesthetic agents with less detrimental effects on hypoxic pulmonary vasoconstriction. Attention has currently shifted toward avoidance of acute lung injury (ALI). Fortunately, ALI occurs infrequently, with an incidence of 2.5 % of all lung resections combined, and an incidence of 7.9% after pneumonectomy. However, when it occurs, ALI is associated with a risk of mortality or major morbidity of about 40%.

Based on current data, it seems that protective lung ventilation strategies may minimize the risk of acute lung injury *after* lung resection. This ventilatory strategy includes the use of lower tidal volumes (6–8 mL/kg), routine use of PEEP (5–10 cm H_2O), lower FIO_2 (50% to 80%), lower ventilatory pressures (plateau pressure <25 cm H_2O; peak airway pressure <35 cm H_2O) through the use of pressure-controlled ventilation and permissive hypercapnia. The use of lower tidal volumes may lead to lung derecruitment, atelectasis, and hypoxemia. Lung derecruitment may be avoided by application of external PEEP and frequent recruitment maneuvers. Although PEEP may prevent alveolar collapse and development of atelectasis, it may cause a decrease in PaO_2 due to diversion of blood flow away from the dependent, ventilated lung and an increase in total shunt. Thus, PEEP must be customized to the underlying disease of each patient, and a new application of PEEP will almost never be the appropriate way to treat hypoxemia that occurs immediately after the onset of one-lung ventilation. Patients with obstructive pathology may develop intrinsic PEEP. In these patients, the application of external PEEP may lead to unpredictable levels of total PEEP. Although the management of one-lung ventilation has long included the use of 100% oxygen, evidence of oxygen toxicity has accumulated both experimentally and clinically. Although there is no convincing evidence that outcomes are worsened with the use of 100% oxygen, some clinicians recommend titrating FIO_2 to maintain the oxygen saturation above 90%, especially in patients who have undergone adjuvant therapy and are at risk of developing ALI. Although there is no unequivocal evidence that one mode of ventilation may be more beneficial than the other, pressure-controlled ventilation may diminish the risk of barotrauma by limiting peak and plateau airway pressures, and the flow pattern results in a more homogenous distribution of the tidal volume and improved dead space ventilation.

At the end of the procedure, the operative lung is inflated gradually to a peak inspiratory pressure of less than 30 cm H_2O to prevent disruption of the staple line. During reinflation of the operative lung, it may be helpful to clamp the lumen serving the dependent lung to limit overdistension.

Periodic arterial blood gas analysis is helpful to ensure adequate ventilation. End-tidal CO_2 measurement may not be reliable due to increased dead-space and an unpredictable gradient between the arterial and end-tidal CO_2 partial pressure.

Management of Hypoxia

Hypoxemia during one-lung anesthesia requires one or more of the following interventions:

1. Adequate position of the bronchial tube (or bronchial blocker) must be confirmed, as its position relative to the carina can change as a result of surgical manipulations or traction; repeat fiberoptic bronchoscopy through the tracheal lumen can quickly detect this problem. Both lumens of the tube should also be suctioned to exclude excessive secretions or obstruction as a factor.
2. Increase FIO_2 to 1.0

3. Recruitment maneuvers on the dependent, ventilated lung may eliminate atelectasis and improve shunt.
4. Optimize PEEP to the dependent, nonoperative lung.
5. Ensure adequate cardiac output and adequate oxygen carrying capacity.
6. CPAP or blow-by oxygen to the operative lung will decrease shunting and improve oxygenation. However, inflation of the operative lung during VATS will make identification and visualization of the lung structures difficult for the surgeon; therefore, such maneuvers should be applied carefully and cautiously.
7. Two-lung ventilation should be instituted for severe hypoxemia. If possible, pulmonary artery clamp can also be placed during pneumonectomy to eliminate shunt.
8. In patients with chronic obstructive lung disease, one should always be suspicious of pneumothorax on the dependent, ventilated side as a cause of severe hypoxemia. This complication requires immediate detection and treatment by aborting the surgical procedure, reexpanding the operative lung, and immediately inserting a chest tube in the contralateral chest.

Alternatives to One-Lung Ventilation

Ventilation can be stopped for short periods if 100% oxygen is insufflated at a rate greater than oxygen consumption **(apneic oxygenation) into an unobstructed tracheal tube**. Adequate oxygenation can often be maintained for prolonged periods, but progressive respiratory acidosis limits the use of this technique to 10–20 min in most patients. Arterial P_{CO_2} rises 6 mm Hg in the first minute, followed by a rise of 3–4 mm Hg during each subsequent minute.

High-frequency positive-pressure ventilation and high-frequency jet ventilation have been used during thoracic procedures as alternatives to one-lung ventilation. A standard tracheal tube may be used with either technique. Small tidal volumes (<2 mL/kg) allow decreased lung excursion, which may facilitate the surgery but still allow ventilation of both lungs. Unfortunately, mediastinal "bounce"—a to-and-fro movement—often interferes with the surgery.

3. Postoperative Management

General Care

Most patients are extubated shortly after surgery to decrease the risk of pulmonary barotrauma (particularly "blowout" [rupture] of the bronchial suture line). Patients with marginal pulmonary reserve should remain intubated until standard extubation criteria are met; if a double-lumen tube was used for one-lung ventilation, it should be replaced with a regular single-lumen tube at the end of surgery. A catheter guide ("tube exchanger") should be used if the original laryngoscopy was difficult (above).

Patients are observed in the postanesthesia care unit, and, in most instances, at least overnight or longer in an intensive care unit or intermediate care unit. Postoperative hypoxemia and respiratory acidosis are common. These effects are largely caused by atelectasis and "shallow breathing ('splinting')" due to incisional pain. Gravity-dependent transudation of fluid into the intraoperative dependent lung may also be contributory. Reexpansion edema of the collapsed nondependent lung can also occur.

4 Postoperative hemorrhage complicates about 3% of thoracotomies and may be associated with up to 20% mortality. Signs of hemorrhage include increased chest tube drainage (>200 mL/h), hypotension, tachycardia, and a falling hematocrit. Postoperative supraventricular tachyarrhythmias are common and usually require immediate treatment. Routine postoperative care should include maintenance of a semiupright (>30°) position, supplemental oxygen (40% to 50%), incentive spirometry, electrocardiographic and hemodynamic monitoring, a postoperative chest radiograph (to confirm proper position of all thoracostomy tube drains and central lines and to confirm expansion of both lung fields), and adequate pain relief.

Postoperative Analgesia

The importance of adequate pain management in the thoracic surgical patient cannot be overstated. Inadequate pain control in these high-risk patients will result in splinting; poor respiratory effort; and the inability to cough and clear secretions, with an end result of airway closure, atelectasis, shunting, and hypoxemia. Irrespective of the modality used, there must be a comprehensive plan for pain management.

A balance between comfort and respiratory depression in patients with marginal lung function is difficult to achieve with parenteral opioids alone. Patients who have undergone thoracotomy clearly benefit from the use of other techniques (described below) that may reduce the need for parenteral opioids. If parenteral opioids are used alone, they are best administered via a patient-controlled analgesia device.

In the absence of an epidural catheter, intercostal or paravertebral nerve blocks with long-acting local anesthetics may facilitate extubation, but have a limited duration of action, so alternative means of pain management must be employed. Alternatively, a cryoanalgesia probe may be used intraoperatively to freeze the intercostal nerves (cryoneurolysis) and produce long-lasting anesthesia; unfortunately, maximum analgesia may not be achieved until 24–48 hr after the cryoanalgesia procedure. Nerve regeneration is reported to occur approximately 1 month after the cryoneurolysis. Infusion of local anesthetic through a catheter placed in the surgical wound during closure will markedly reduce the requirement for parenteral opioids and improve the overall quality of analgesia relative to parenteral opioids alone.

Epidural analgesia is the current optimal method for acute pain control following thoracic surgical procedures. It provides excellent pain relief, continuous therapy, and avoidance of the side effects associated with administration of systemic opioids. On the other hand, epidural techniques require attention from the acute pain team for the duration of the infusion and subject the patient to the long list of epidural-related side effects and complications. However, there is still much debate over the level of placement of the epidural catheter (thoracic versus lumbar), type of medication administered (opioid and/or local anesthetic), and timing of medication administration (before surgical incision vs before end of surgery). Most practitioners use a combination of opioid (fentanyl, morphine, hydromorphone) and local anesthetic (bupivacaine or ropivacaine), with the epidural catheter placed at a thoracic level.

Postoperative Complications

Postoperative complications following thoracotomy are relatively common, but fortunately most are minor and resolve uneventfully. Blood clots and thick secretions may obstruct the airways and result in atelectasis; suctioning may be necessary. Atelectasis is suggested by tracheal deviation and shifting of the mediastinum to the operative side following segmental or lobar resections. Therapeutic bronchoscopy should be considered for persistent atelectasis, particularly when associated with thick secretions. Air leaks from the operative hemithorax are common following segmental and lobar resections. Most air leaks stop after a few days.

5 Bronchopleural fistulae present as a sudden large air leak from the chest tube that may be associated with an increasing pneumothorax and partial lung collapse. When they occur within the first 24–72 hr, they are usually the result of inadequate surgical closure of the bronchial stump. Delayed presentation is usually due to necrosis of the suture line associated with inadequate blood flow or infection.

Some complications are rare, but deserve special consideration because they can be life-threatening and require immediate exploratory thoracotomy. Postoperative bleeding was discussed above. Torsion of a lobe or segment can occur as the remaining lung on the operative side expands to occupy the hemithorax. The torsion usually occludes the pulmonary vein to that part of the lung, causing venous outflow obstruction. Hemoptysis and infarction can rapidly follow. The diagnosis is suggested by an enlarging homogeneous density on the chest radiograph and a closed lobar orifice on bronchoscopy.

6 Acute herniation of the heart into the operative hemithorax can occur through the pericardial defect that may remain following a pneumonectomy. A large pressure differential between the two hemithoraces is thought to trigger this catastrophic event. Cardiac herniation into the right hemithorax results in sudden severe hypotension with an elevated CVP because of torsion of the central veins. Cardiac herniation into the left

hemithorax following left pneumonectomy results in sudden compression of the myocardium, resulting in hypotension, ischemia, and infarction. A chest radiograph shows a shift of the cardiac shadow into the operative hemithorax.

Extensive mediastinal dissections can injure the phrenic, vagus, and left recurrent laryngeal nerves. Postoperative phrenic nerve palsy presents as elevation of the ipsilateral hemidiaphragm together with difficulty in weaning the patient from the ventilator. Large chest wall resections may include part of the diaphragm, causing a similar problem, in addition to a flail chest. Paraplegia rarely follows thoracotomy for lung resection. There are reports of cellulose gauze and other debris migrating from the thoracic gutter into the spinal canal, resulting in spinal cord compression. If an epidural catheter has been placed, any loss of motor function or unexplained back pain should immediately trigger imaging to rule out epidural hematoma.

SPECIAL CONSIDERATIONS FOR PATIENTS UNDERGOING LUNG RESECTION

Massive Pulmonary Hemorrhage

Massive hemoptysis is usually defined as >500–600 mL of blood loss from the tracheobronchial tree within 24 hr. The etiology is usually tuberculosis, bronchiectasis, or a neoplasm, or complication of transbronchial biopsies. Emergency surgical management with lung resection is reserved for "potentially lethal" massive hemoptysis. In most cases, surgery is usually carried out on an urgent rather than on a true emergent basis whenever possible; even then, operative mortality may exceed 20% (compared with > 50% for medical management). Embolization of the involved bronchial arteries may be attempted. The most common cause of death is asphyxia secondary to blood in the airway. Patients may be brought to the operating room for rigid bronchoscopy when localization is not possible with fiberoptic flexible bronchoscopy. A bronchial blocker or Fogarty catheter (above) may be placed to tamponade the bleeding, or laser coagulation may be attempted.

Multiple large-bore intravenous catheters should be placed. Sedating drugs should not be given to awake, nonintubated, spontaneously ventilating patients because they are usually already hypoxic; 100% oxygen should be given continuously. If the patient is already intubated and has bronchial blockers in place, sedation is helpful to prevent coughing. The bronchial blocker should be left in position until the lung is resected. When the patient is not intubated, a rapid sequence induction (ketamine or etomidate with succinylcholine) is used. Patients usually swallow a large amount of blood and should be considered to have a full stomach. A large double-lumen bronchial tube is ideal for protecting the normal lung from blood and for suctioning each lung separately. If any difficulty is encountered in placing the double-lumen tube, or its relatively small lumens occlude easily, a large (>8.0-mm inner diameter) single-lumen tube may be used with a bronchial blocker to provide lung isolation.

Pulmonary Cyst & Bulla

Pulmonary cysts or bullae may be congenital or acquired as a result of emphysema. Large bullae can impair ventilation by compressing the surrounding lung. These air cavities often behave as if they have a one-way valve, predisposing them to progressively enlarge. Lung resection may be undertaken for progressive dyspnea or recurrent pneumothorax. The greatest risk of anesthesia is rupture of the air cavity during positive-pressure ventilation, resulting in tension pneumothorax; the latter may occur on either side prior to thoracotomy or on the nonoperative side during the lung resection. Induction of anesthesia with maintenance of spontaneous ventilation is desirable until the side with the cyst or bullae is isolated with a double-lumen tube, or until a chest tube is placed; most patients have a large increase in dead space, so assisted ventilation is necessary to avoid excessive hypercarbia. 7 The use of N_2O is contraindicated in patients with cysts or bullae because it can expand the air space and cause rupture. The latter may be signaled by sudden hypotension, bronchospasm, or an abrupt rise in peak inflation pressure and requires immediate placement of a chest tube.

Lung Abscess

Lung abscesses result from primary pulmonary infections, obstructing pulmonary neoplasms (above), or, rarely, hematogenous spread of systemic infections. The two lungs should be isolated to prevent contamination of the healthy lung. A rapid-sequence intravenous induction with tracheal intubation with a double-lumen tube is generally recommended, with the affected lung in a dependent position. As soon as the double-lumen tube is placed, both bronchial and tracheal cuffs should be inflated. The bronchial cuff should make a tight seal before the patient is turned into the lateral decubitus position, with the diseased lung in a nondependent position. The diseased lung should be frequently suctioned during the procedure to decrease the likelihood of contaminating the healthy lung.

Bronchopleural Fistula

Bronchopleural fistulas occur following lung resection (usually pneumonectomy), rupture of a pulmonary abscess into a pleural cavity, pulmonary barotrauma, or spontaneous rupture of bullae. The majority of patients are treated (and cured) conservatively; patients come to surgery when chest tube drainage has failed. **Anesthetic management may be complicated by the inability to effectively ventilate the patient with positive pressure because of a large air leak, the potential for a tension pneumothorax, and the risk of contaminating the other lung if an empyema is present.** The empyema is usually drained, prior to closure of the fistula.

A correctly placed double-lumen tube greatly simplifies anesthetic management by isolating the fistula and allowing one-lung ventilation to the normal lung. The patient should be extubated as soon as possible after the repair.

Anesthesia for Tracheal Resection

Preoperative Considerations

Tracheal resection is most commonly performed for tracheal stenosis, tumors, or, less commonly, congenital abnormalities. Tracheal stenosis can result from penetrating or blunt trauma, as well as tracheal intubation and tracheostomy. Squamous cell and adenoid cystic carcinomas account for the majority of tumors. Compromise of the tracheal lumen results in progressive dyspnea. Wheezing or stridor may be evident only with exertion. The dyspnea may be worse when the patient is lying down, with progressive airway obstruction. Hemoptysis can also complicate tracheal tumors. CT is valuable in localizing the lesion. **Measurement of flow–volume loops confirms the location of the obstruction and aids the clinician in evaluating the severity of the lesion (Figure 25–12).**

Anesthetic Considerations

Little premedication is given, as most patients presenting for tracheal resection have moderate to severe airway obstruction. Use of an anticholinergic agent to dry secretions is controversial because of the theoretical risk of inspissation. Monitoring should include direct arterial pressure measurements.

An inhalation induction (in 100% oxygen) is carried out in patients with severe obstruction. Sevoflurane is preferred because it is the potent anesthetic that is least irritating to the airway. Spontaneous ventilation is maintained throughout induction. NMBs are generally avoided because of the potential for complete airway obstruction following neuromuscular blockade. Laryngoscopy is performed only when the patient is judged to be under deep anesthesia. Intravenous lidocaine (1–2 mg/kg) can deepen the anesthesia without depressing respirations. The surgeon may then perform rigid bronchoscopy to evaluate and possibly dilate the lesion. Following bronchoscopy, the patient is intubated with a tracheal tube small enough to be passed distal to the obstruction whenever possible.

A collar incision is utilized for high tracheal lesions. The surgeon divides the trachea in the neck and advances a sterile armored tube into the distal trachea, passing off a sterile connecting breathing circuit to the anesthesiologist for ventilation during the resection. Following the resection and completion of the posterior part of the reanastomosis, the armored tube is removed, and the original tracheal tube is advanced distally, past the anastomosis (Figure 25–13). Alternatively, high-frequency jet ventilation may be employed during the anastomosis

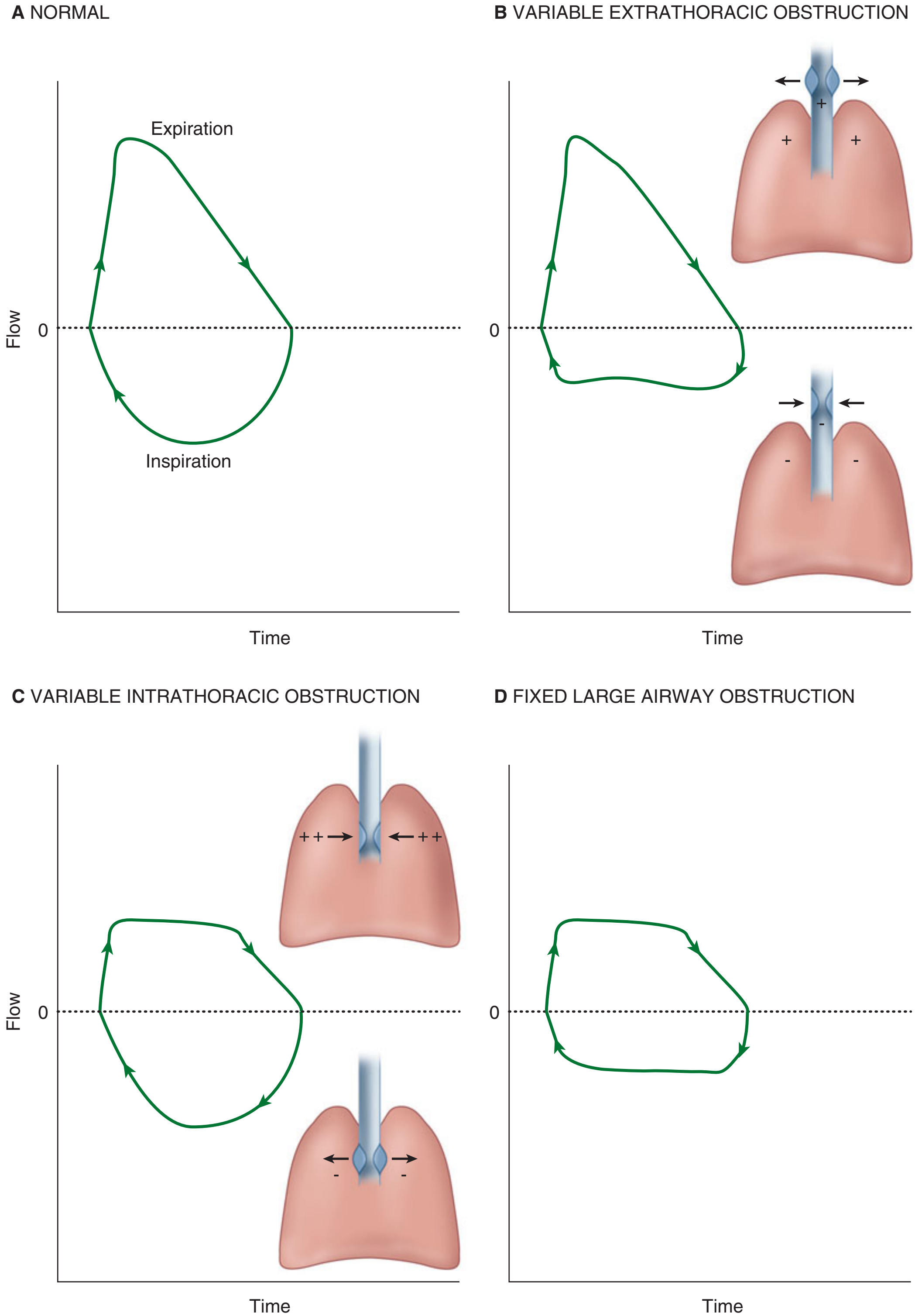

FIGURE 25–12 **A–D**: Flow–volume loops.

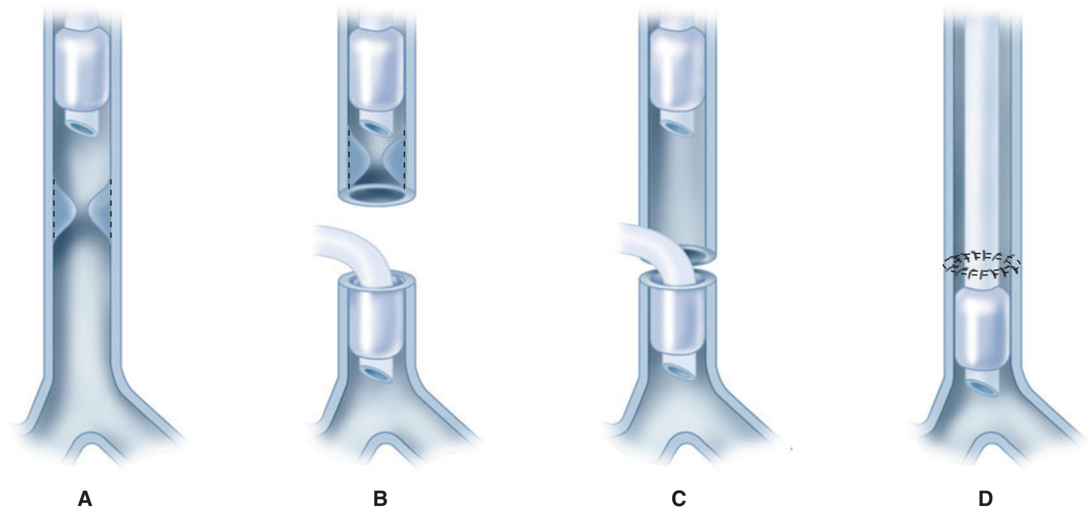

FIGURE 25–13 **A–D**: Airway management of a high tracheal lesion.

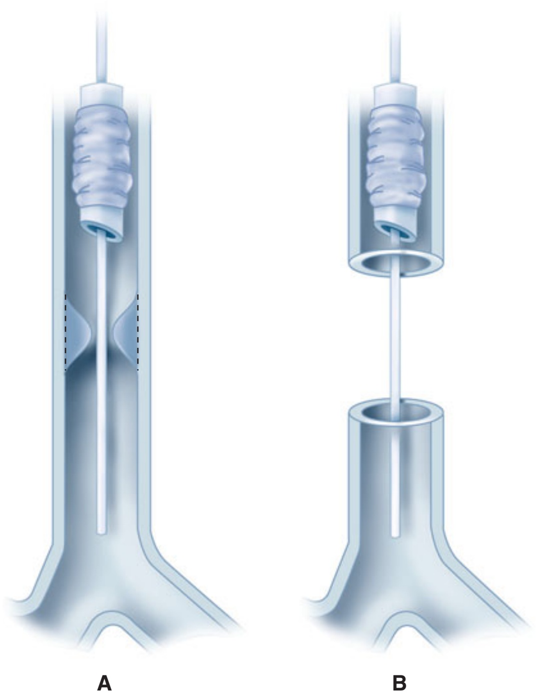

FIGURE 25–14 Tracheal resection using high-frequency jet ventilation. **A**: The catheter is advanced past the obstruction, and the cuff is deflated when jet ventilation is initiated. **B**: The catheter is advanced distally by the surgeon. Jet ventilation can be continued without interruption during resection and reanastomosis.

by passing the jet cannula past the obstruction and into the distal trachea (Figure 25–14). Return of spontaneous ventilation and early extubation at the end of the procedure are desirable. Patients should be positioned with the neck flexed immediately after the operation to minimize tension on the suture line (Figure 25–15).

Surgical management of low tracheal lesions requires a median sternotomy or right posterior thoracotomy. Anesthetic management is similar, but more regularly requires more complicated techniques, such as high-frequency ventilation or even cardiopulmonary bypass (CPB) in complex congenital cases.

Anesthesia for Video-Assisted Thoracoscopic Surgery (VATS)

VATS is now used for most lung resections that previously required open thoracotomy. The list of procedures that can be accomplished during VATS includes lung biopsy, segmental and lobar resections, pleurodesis, esophageal procedures, and pericardectomy. Most procedures are performed through three or more small incisions in the chest, with the patient in the lateral decubitus position.

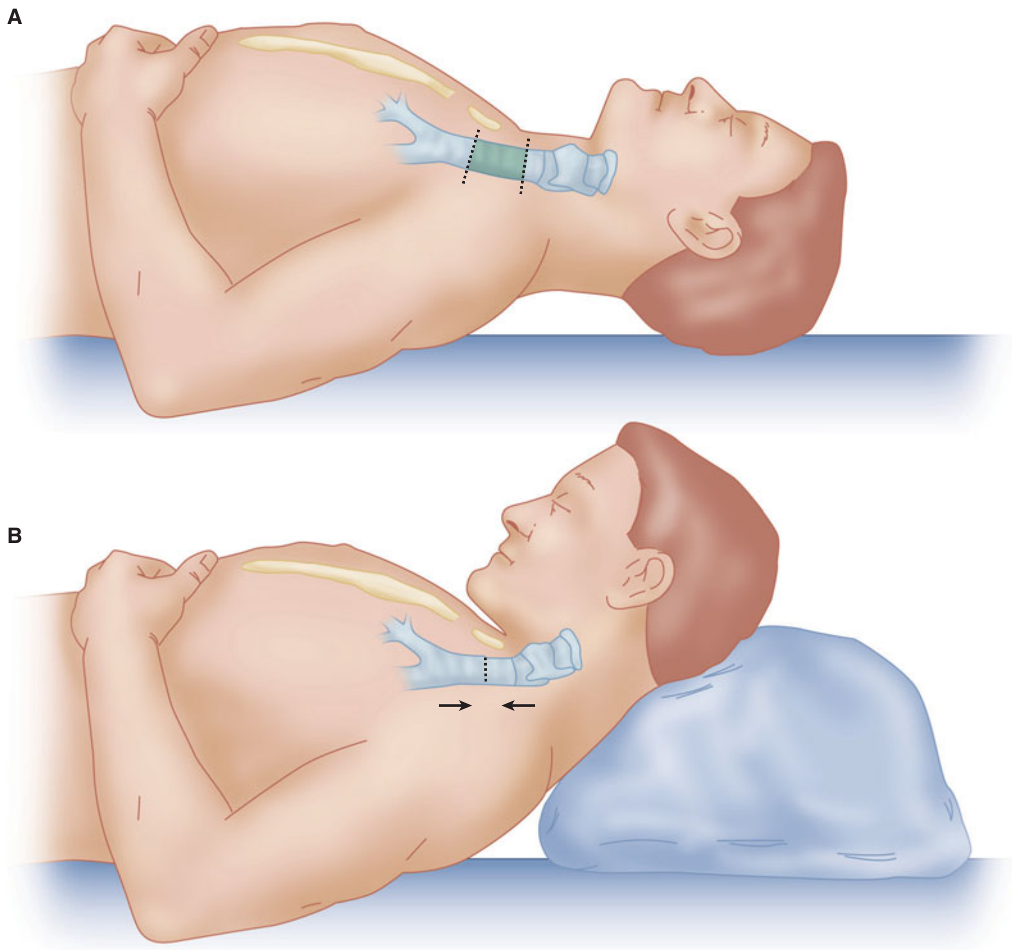

FIGURE 25–15 Position of the patient before (**A**) and after (**B**) tracheal resection and reanastomosis with the patient's neck flexed for the first 24–48 hr.

Anesthetic management is similar to that for open procedures, except that one-lung ventilation is required (as opposed to being desirable) for nearly all procedures.

Anesthesia for Diagnostic Thoracic Procedures

Bronchoscopy

Rigid bronchoscopy for removal of foreign bodies or tracheal dilatation is usually performed under general anesthesia. These procedures are complicated by the need to share the airway with the surgeon or pulmonologist; fortunately, they are often of short duration. After a standard intravenous induction, anesthesia is often maintained with total intravenous anesthesia, and a short- or intermediate-acting NMB. Brief airway procedures are among the few remaining indications for a succinylcholine infusion. One of three techniques can then be used during rigid bronchoscopy: (1) apneic oxygenation using a small catheter positioned alongside the bronchoscope to insufflate oxygen (above); (2) conventional ventilation through the side arm of a ventilating bronchoscope (when the proximal window of this instrument is opened for suctioning or biopsies, ventilation must be interrupted); or (3) jet ventilation through an injector-type bronchoscope.

Mediastinoscopy

Mediastinoscopy, much more commonly employed in the past than at present, provides access to the mediastinal lymph nodes and is used to establish either the diagnosis or the resectability of intrathoracic malignancies (above). Preoperative CT or MR imaging is useful for evaluating tracheal distortion or compression.

Mediastinoscopy is performed under general tracheal anesthesia with neuromuscular paralysis. Venous access with a large-bore (14- to 16-gauge) intravenous catheter is mandatory because of the risk of bleeding and the difficulty in controlling bleeding when it occurs. Because the innominate artery may be compressed during the procedure, blood pressure should be measured in the left arm.

Complications associated with mediastinoscopy include: (1) vagally mediated reflex bradycardia from compression of the trachea or the great vessels; (2) excessive hemorrhage (see above); (3) cerebral ischemia from compression of the innominate artery (detected with a right radial arterial line or pulse oximeter on the right hand); (4) pneumothorax (usually presents postoperatively); (5) air embolism (because of a 30° head elevation, the risk is greatest during spontaneous ventilation); (6) recurrent laryngeal nerve damage; and (7) phrenic nerve injury.

Bronchoalveolar Lavage

Bronchoalveolar lavage may be employed for patients with pulmonary alveolar proteinosis. These patients produce excessive quantities of surfactant and fail to clear it. They present with dyspnea and bilateral consolidation on the chest radiograph. In such patients, bronchoalveolar lavage may be indicated for severe hypoxemia or worsening dyspnea. Often, one lung is lavaged, allowing the patient to recover for a few days before the other lung is lavaged; the "sicker" lung is therefore lavaged first. Increasingly, both lungs are lavaged during the same procedure, creating unique challenges to ensure adequate oxygenation during lavage of the second lung.

Unilateral bronchoalveolar lavage is performed under general anesthesia with a double-lumen bronchial tube. The cuffs on the tube should be properly positioned and should make a watertight seal to prevent spillage of fluid into the other side. The procedure is normally done in the supine position; although lavage with the lung in a dependent position helps to minimize contamination of the other lung, this position can cause severe ventilation/perfusion mismatch. Warm normal saline is infused into the lung to be treated and is drained by gravity; treatment continues until the fluid returning is clear (about 10–20 L). At the end of the procedure, both lungs are well suctioned, and the double-lumen tracheal tube is replaced with a single-lumen tracheal tube.

Anesthesia for Lung Transplantation

PREOPERATIVE CONSIDERATIONS

Lung transplantation is indicated for end-stage pulmonary parenchymal disease or pulmonary hypertension. Candidates are functionally incapacitated by dyspnea and have a poor prognosis. Criteria vary according to the primary disease process. Common etiologies are listed in Table 25–3. Lung transplantation (as is true for all solid organ transplants) is limited by the availability of suitable organs, not by the availability of recipients. Patients typically have dyspnea at rest or with minimal activity and resting

TABLE 25–3 Indications for isolated lung transplantation.

Cystic fibrosis
Bronchiectasis
Obstructive
Chronic obstructive pulmonary disease
α_1-antitrypsin deficiency
Pulmonary lymphangiomatosis
Restrictive
Idiopathic pulmonary fibrosis
Primary pulmonary hypertension

hypoxemia (PaO_2 <50 mm Hg) with increasing oxygen requirements. Progressive CO_2 retention is also very common. Patients may be ventilator dependent. Cor pulmonale does not necessarily require combined heart–lung transplantation because right ventricular function may recover when pulmonary artery pressures normalize. Patients should have normal left ventricular function and be free of coronary artery disease, as well as other serious health problems.

Single-lung transplantation may be performed in selected patients with idiopathic pulmonary fibrosis, whereas double-lung transplantation is typically performed in patients with cystic fibrosis, bullous emphysema, or vascular diseases. Patients with Eisenmenger syndrome require combined heart–lung transplantation.

ANESTHETIC CONSIDERATIONS

1. Preoperative Management

Effective coordination between the organ-retrieval team and the transplant team minimizes graft ischemia time and avoids unnecessary prolongation of pretransplant anesthesia time. These procedures are performed on an emergency basis; therefore, patients may have little time to fast for surgery. Oral cyclosporine also may be given preoperatively. Administration of a clear antacid, an H_2 blocker, or metoclopramide should be considered. Patients are very sensitive to sedatives, so premedication is usually administered only in the operating room when the patient is directly attended. Immunosuppressants and antibiotics are also administered after induction and prior to surgical incision.

2. Intraoperative Management

Monitoring

Strict asepsis should be observed for invasive monitoring procedures. Central venous access might be accomplished only after induction of anesthesia because patients may not be able to lie flat while awake. Patients with a patent foramen ovale are at risk of paradoxical embolism because of high right atrial pressures.

Induction & Maintenance of Anesthesia

A rapid-sequence induction is utilized. Induction with ketamine, etomidate, an opioid, or a combination of these agents is employed, avoiding precipitous drops in blood pressure. An NMB is used to facilitate laryngoscopy. Hypoxemia and hypercarbia must be avoided to prevent further increases in pulmonary artery pressure. Hypotension should be treated with vasopressors instead of large fluid boluses (see below).

Anesthesia is usually maintained with total intravenous anesthesia or a volatile agent. Intraoperative difficulties in ventilation are not uncommon. Progressive retention of CO_2 can also be a problem intraoperatively. Ventilation should be adjusted to maintain a $PaCO_2$ as close to the patient's baseline as possible. However, in the presence of a reasonable cardiovascular reserve and normal right heart function, higher levels of $PaCO_2$ can be tolerated for short periods of time. Hypercarbia and acidosis may lead to pulmonary vasoconstriction and acute right heart failure, and hemodynamic support with inotropes may be required for these patients. Patients with cystic fibrosis have copious secretions and require frequent suctioning.

Single-Lung Transplantation

Single-lung transplantation is often attempted without CPB. The procedure is performed through a posterior thoracotomy. Whether to employ CPB during transplantation of one lung is based on the patient's response to collapsing the lung to be replaced and clamping its pulmonary artery. Persistent arterial hypoxemia (SpO_2 < 88%) or a sudden increase in pulmonary artery pressures necessitates CPB. Prostaglandin E_1, milrinone, nitroglycerin, and dobutamine may be utilized to reduce pulmonary hypertension and prevent right ventricular failure. Inotropic support may be necessary. After the recipient lung is removed, the pulmonary artery, left atrial cuff (with the pulmonary veins), and bronchus of the donor lung are anastomosed. Flexible bronchoscopy is used to examine the bronchial suture line after its completion.

Double-Lung Transplantation

A "clamshell" transverse sternotomy can be used for double-lung transplantation. The procedure is occasionally performed with CPB; sequential thoracotomies for double-lung transplantation can also be performed. Heart lung transplantation is performed through median sternotomy with CPB.

Posttransplantation Management

After anastomosis of the donor organ or organs, ventilation to both lungs is resumed. 8 Following transplantation, peak inspiratory pressures should be maintained at the minimum pressure compatible with good lung expansion, and the inspired oxygen concentration should be maintained as close to room air as allowed by a Pao_2 >60 mm Hg. Methylprednisolone and mannitol are usually administered prior to the release of vascular clamps. Hyperkalemia may occur as the preservative fluid is washed out of the donor organ. If transplantation has been performed on CPB, the patient is separated from CPB. Pulmonary vasodilators, inhaled nitric oxide, and inotropes (above) may be necessary. Transesophageal echocardiography is helpful in differentiating right and left ventricular dysfunction, as well as in evaluating blood flow in the pulmonary vessels, particularly after transplantation.

Transplantation disrupts the neural innervation, lymphatic drainage, and bronchial circulation of the transplanted lung. The respiratory pattern is unaffected, but the cough reflex is abolished below the carina. Bronchial hyperreactivity is observed in some patients. Hypoxic pulmonary vasoconstriction remains normal. Loss of lymphatic drainage increases extravascular lung water and predisposes the transplanted lung to pulmonary edema. Intraoperative fluid replacement must therefore be kept to a minimum. Loss of the bronchial circulation predisposes to ischemic breakdown of the bronchial suture line.

3. Postoperative Management

Patients are extubated after surgery as soon as is feasible. A thoracic epidural catheter may be employed for postoperative analgesia when coagulation studies are normal. The postoperative course may be complicated by acute rejection, infections, and renal and hepatic dysfunction. Deteriorating lung function may result from rejection or reperfusion injury. Occasionally, temporary extracorporeal membrane oxygenation may be necessary. Frequent bronchoscopy with transbronchial biopsies and lavage are necessary to differentiate between rejection and infection. Nosocomial Gram-negative bacteria, cytomegalovirus, *Candida, Aspergillus*, and *Pneumocystis carinii* are common pathogens. Other postoperative surgical complications include damage to the phrenic, vagus, and left recurrent laryngeal nerves.

Anesthesia for Esophageal Surgery

PREOPERATIVE CONSIDERATIONS

Common indications for esophageal surgery include tumors, gastroesophageal reflux, and motility disorders (achalasia). Surgical procedures include simple endoscopy, esophageal dilatation, cervical esophagomyotomy, open or thoracoscopic distal esophagomyotomy, insertion or removal of esophageal stents, and esophagectomy. Squamous cell carcinomas account for the majority of esophageal tumors; adenocarcinomas are less common, whereas benign tumors (leiomyomas) are rare. Most tumors occur in the distal esophagus. Operative treatment may be palliative or curative. Although the prognosis is generally poor, surgical therapy offers the only hope of a cure. After esophageal resection, the stomach is pulled up into the thorax, or the esophagus is functionally replaced with part of the colon (interposition).

Gastroesophageal reflux is treated surgically when the esophagitis is refractory to medical management or results in complications such as stricture, recurrent pulmonary aspiration, or Barrett's esophagus (columnar epithelium). A variety of antireflux operations may be performed (Nissen, Belsey, Hill, or Collis–Nissen) via thoracic or abdominal approaches, often laparoscopically. They all involve wrapping part of the stomach around the esophagus.

Achalasia and systemic sclerosis (scleroderma) account for the majority of surgical procedures performed for motility disorders. The former usually occurs as an isolated finding, whereas the latter is part of a generalized collagen–vascular disorder. Cricopharyngeal muscle dysfunction can be associated with a variety of neurogenic or myogenic disorders and often results in a Zenker's diverticulum.

ANESTHETIC CONSIDERATIONS

9 Regardless of the procedure, a common anesthetic concern in patients with esophageal disease is the risk of pulmonary aspiration. This may result from obstruction, altered motility, or abnormal sphincter function. In fact, most patients typically complain of dysphagia, heartburn, regurgitation, coughing, and/or wheezing when lying flat. Dyspnea on exertion may also be prominent when chronic aspiration results in pulmonary fibrosis. Patients with malignancies may present with anemia and weight loss. Esophageal cancer patients usually have a history of cigarette smoking and alcohol consumption, so patients should be evaluated for coexisting chronic obstructive pulmonary disease, coronary artery disease, and liver dysfunction. Patients with systemic sclerosis (scleroderma) should be evaluated for involvement of other organs, particularly the kidneys, heart, and lungs; Raynaud's phenomena is also common.

In patients with reflux, consideration should be given to administering metoclopramide, an H_2-receptor blocker, or a proton-pump inhibitor preoperatively. In such patients, a rapid-sequence induction should be used. A double-lumen tube is used for procedures involving thoracoscopy or thoracotomy. The anesthesiologist may be asked to pass a large-diameter bougie into the esophagus as part of the surgical procedure; great caution must be exercised to help avoid pharyngeal or esophageal injury.

Transhiatal (blunt) and thoracic esophagectomies deserve special consideration. These procedures often involve considerable blood loss. The former requires an upper abdominal incision and a left cervical incision, whereas the latter requires posterolateral thoracotomy, an abdominal incision, and, finally, a left cervical incision. Parts of the procedure may be performed using laparoscopy or VATS. Monitoring of arterial and central venous pressure is indicated. Multiple large-bore intravenous access, fluid warmers, and a forced-air body warmer are advisable. During the trans hiatal approach to esophagectomy, substernal and diaphragmatic retractors can interfere with cardiac function. Moreover, as the esophagus is freed up blindly from the posterior mediastinum by blunt dissection, the surgeon's hand transiently interferes with cardiac filling and produces profound hypotension. The dissection can also induce marked vagal stimulation.

Colonic interposition involves forming a pedicle graft of the colon and passing it through the posterior mediastinum up to the neck to take the place of the esophagus. This procedure is lengthy, and maintenance of an adequate blood pressure, cardiac output, and hemoglobin concentration is necessary to ensure graft viability. Graft ischemia may be heralded by a progressive metabolic acidosis.

Postoperative ventilation will often be used in patients undergoing esophagectomy, because so many of them will have coexisting cardiac and pulmonary disease. Postoperative surgical complications include damage to the phrenic, vagus, and left recurrent laryngeal nerves.

CASE DISCUSSION

Mediastinal Adenopathy

A 9-year-old boy with mediastinal lymphadenopathy seen on a chest radiograph presents for biopsy of a cervical lymph node.

What is the most important preoperative consideration?

Is there any evidence of airway compromise? Tracheal compression may produce dyspnea (proximal obstruction) or a nonproductive cough (distal obstruction).

Asymptomatic compression is also common and may be evident only as tracheal deviation on physical or radiographic examinations. A CT scan of the chest provides invaluable information about the presence, location, and severity of airway compression. Flow–volume loops will also detect subtle airway obstruction and provide important information regarding the location and functional importance of the obstruction (above).

Does the absence of any preoperative dyspnea make severe intraoperative respiratory compromise less likely?

No. Severe airway obstruction can occur following induction of anesthesia in these patients even in the absence of any preoperative symptoms. This mandates that the chest radiograph and CT scan be reviewed for evidence of asymptomatic airway obstruction. The point of obstruction is typically distal to the tip of the tracheal tube. Moreover, loss of spontaneous ventilation can precipitate complete airway obstruction.

What is the superior vena cava syndrome?

Superior vena cava syndrome is the result of progressive enlargement of a mediastinal mass and compression of mediastinal structures, particularly the vena cava. Lymphomas are most commonly responsible, but primary pulmonary or mediastinal neoplasms can also produce the syndrome. Superior vena cava syndrome is often associated with severe airway obstruction and cardiovascular collapse on induction of general anesthesia. The caval compression produces venous engorgement and edema of the head, neck, and arms. Direct mechanical compression, as well as mucosal edema, severely compromise airflow in the trachea. Most patients favor an upright posture, as recumbency worsens the airway obstruction. Cardiac output may be severely depressed due to impeded venous return from the upper body, direct mechanical compression of the heart, and (with malignancies) pericardial invasion. An echocardiogram is useful in evaluating cardiac function and detecting pericardial fluid.

What is the anesthetic of choice for a patient with superior vena cava syndrome?

The absence of signs or symptoms of airway compression or superior vena cava syndrome does not preclude potentially life-threatening complications following induction of general anesthesia. Therefore, biopsy of a peripheral node (usually cervical or scalene) under local anesthesia is safest whenever possible. Although establishing a diagnosis is of prime importance, the presence of significant airway compromise or the superior vena cava syndrome may dictate empiric treatment with corticosteroids prior to tissue diagnosis at surgery (cancer is the most common cause); preoperative radiation therapy or chemotherapy may also be considered. The patient can usually safely undergo surgery with general anesthesia once airway compromise and other manifestations of the superior vena cava syndrome are alleviated.

General anesthesia may be indicated for establishing a diagnosis in young or uncooperative patients who have no evidence of airway compromise or the superior vena cava syndrome, and, rarely, for patients unresponsive to steroids, radiation, and chemotherapy.

How does the presence of airway obstruction and the superior vena cava syndrome influence management of general anesthesia?

1. *Premedication*: Only an anticholinergic should be given. The patient should be transported to the operating room in a semiupright position with supplemental oxygen.
2. *Monitoring*: In addition to standard monitors, an arterial line is helpful, but it should be placed after induction in young patients. At least one large-bore intravenous catheter should be placed in a lower extremity, as venous drainage from the upper body may be unreliable.
3. *Airway management*: Difficulties with ventilation and intubation should be anticipated. Following preoxygenation, awake intubation with an armored tracheal tube may be safest in a cooperative patient. Use of a flexible bronchoscope is advantageous in the presence of airway distortion and will define the site and degree of obstruction. Coughing or straining, however, may precipitate complete airway obstruction because the resultant positive pleural pressure increases intrathoracic

tracheal compression. Passing the armored tube beyond the area of compression may obviate this problem. Uncooperative patients require a sevoflurane inhalation induction.

4. *Induction*: The goal should be a smooth induction maintaining spontaneous ventilation and hemodynamic stability. The ability to ventilate the patient with a good airway should be established prior to use of an NMB. Using 100% oxygen, one of three induction techniques can be used: (1) intravenous ketamine (because it results in greater hemodynamic stability in patients with reduced cardiac output); (2) inhalational induction with a volatile agent (usually sevoflurane); or (3) incremental small doses of propofol or etomidate.

   Positive-pressure ventilation can precipitate severe hypotension, and volume loading prior to induction may partly offset impaired ventricular filling secondary to caval obstruction.
5. *Maintenance of anesthesia*: The technique selected should be tailored to the patient's hemodynamic status. Following intubation, neuromuscular blockade prevents coughing or straining.
6. *Extubation*: At the end of the procedure, patients should be left intubated until the airway obstruction has resolved, as determined by flexible bronchoscopy or the presence of an air leak around the tracheal tube when the tracheal cuff is deflated.

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