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Thoracic Surgery

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Introduction—Surgeon's Perspective

Airway and Lung Access Conflicts

As in Chapter 3, induction and maintenance of anesthesia for thoracic surgery requires interdisciplinary cooperation. Perioperative communication between the surgeon and anesthesiologist is required for a satisfactory outcome. For example, during periods of OLV, significant hypoxia and hypotension may occur. Surgery may need to be stopped temporarily while the hypoxia is corrected by reinflation of the unventilated lung. Hypotension in the absence of bleeding can be corrected by less vigorous retraction of the lung and heart by the surgeon. Quick and timely communication between the anesthesiologist and the surgeon can be life-saving. Occasionally, during critical parts of the dissection, cessation of all respiration for short periods of time can make the surgeon's job much easier. Testing the changes is an option.

Tubes and Tube Sizes

Although the size of the ETTs may not be particularly critical for most types of surgery, thoracic surgical procedures are often different. Fiber optic bronchoscopy (FOB) through the ETT is a common event. The standard FOB just fits through an 8.0 ETT. The fiber optic laryngoscope (FOL) used for difficult intubations will fit smaller ETTs and DLTs. Proper lubrication of the bronchoscope with a polyethylene glycol-based ointment (e.g., Carbowax rather than an aqueous jelly, which will dry out quickly) makes manipulation quite easy. The FOL can be used for correct positioning of the DLT. If the bronchial portion of the DLT cannot be advanced into the left main bronchus, the bronchoscope can be advanced through the bronchial side of the DLT into the left main bronchus. Then, through use of the bronchoscope as a stent, the DLT can be advanced over the bronchoscope into the left bronchus. The depth of the tube can be determined by bronchoscopic observation of the right main bronchus through the tracheal side of the DLT. If a laser is to be involved, have a laser-compatible ETT available, keep FiO_2 to < 0.3 and do not use N_2O.

Patient Positioning and Surgical Incisions

Patient positioning for these procedures is dictated by the type of incision used. The incisions used most often by thoracic surgeons are the **posterolateral thoracotomy** (and its variations) (Fig. 5-1A), the **median sternotomy** (Fig. 5-1B), and the anterior thoracotomy (often bilateral) (Fig. 5-1C). For procedures where excellent exposure of both lungs is mandatory (e.g., bipulmonary lung transplantation), the **"clamshell" incision** (Fig. 5-2) has become popular. Generally, patients are in the **supine position** for anterior incisions (sternotomy, cervical, and anterior thoracotomy) and in the **lateral position** for lateral and posterolateral thoracotomies. Thoracoscopic procedures (VATS) typically are performed in the lateral position. (Note: A review of a recent CXR in the OR will help ensure that the thoracotomy is performed on the correct side.)

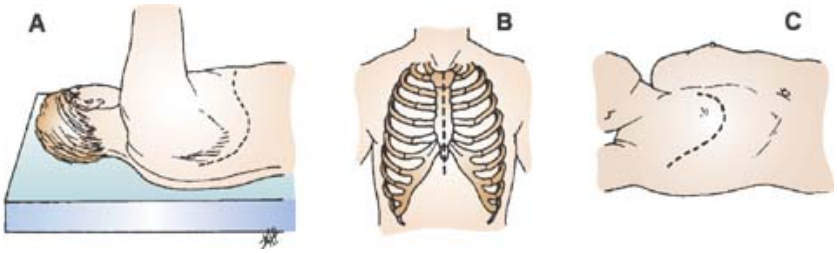

Figure 5-1. Primary incisions for thoracic surgery. **A.** Posterolateral thoracotomy, in lateral position. The incision curves in an S shape, passing under the tip of the scapula over in the fifth interspace anteriorly. **B.** Median sternotomy, in supine position, arms at side: the incision is made from the suprasternal notch to a point between the xiphoid process and umbilicus. **C.** Anterior thoracotomy in supine position. (Reproduced with permission from Fry WA: Thoracic

incisions. In *General Thoracic Surgery,* 5th edition. Shields TW, LoCicero J III, Ponn RB, eds. Lippincott Williams & Wilkins, Philadelphia: 2000.)

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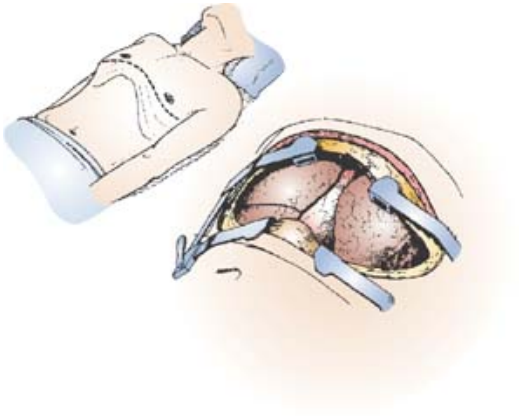

Figure 5-2. The "clamshell" incision, in classic supine position, affords excellent exposure, especially for bilateral lung procedures. (Reproduced with permission from Fry WA: Thoracic incisions. In *General Thoracic Surgery*, 5th edition. Shields TW, LoCicero J III, Ponn RB, eds. Lippincott Williams & Wilkins, Philadelphia: 2000.)

Patients undergoing surgery in the **lateral position** are initially placed on a bean bag. When GA is induced, the patient is rolled onto his/her side with the kidney rest being positioned at the level of the lower ribs. An axillary roll is placed to prevent axillary compression, and the table is flexed to assist in spreading the ribs. The head and neck must be aligned in a neutral position to avoid brachial plexus injuries. The lower arm can be either extended on an arm board or flexed and placed next to the patient's head (Fig. 5-3A). The upper arm is *(Print pagebreak 270)* then extended and held in position with either an airplane holder or an arm board with several pillows (Fig. 5-3B). The lower leg should be flexed and the upper leg should be left extended and supported by pillows. The back is kept in a vertical position while the beanbag is evacuated of air (blanket bolsters may be placed next to the patient). Wide adhesive tape is placed across the hips to further secure the patient. A lower-body warming blanket (e.g., Bair Hugger) should be used to avoid hypothermia. To facilitate closure, the table can be returned to the flat position. Ideally, this is accompanied by inflation, and subsequent deflation, of the beanbag. The anesthesiologist may be asked to exert downward pressure on the patient's shoulder to diminish tension on the latissimus dorsi closure.

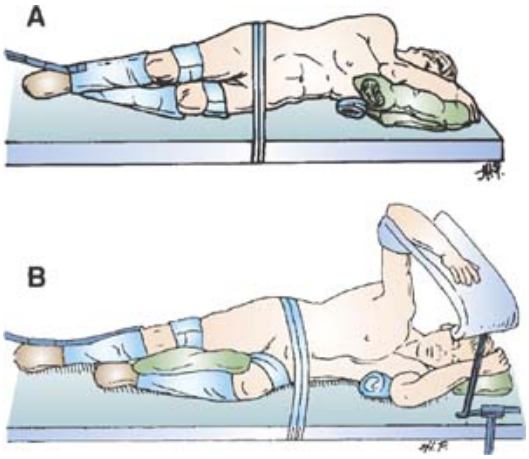

Figure 5-3. Lateral positioning for thoracic lateral and posterolateral procedures. **A.** Patient on his side, with kidney rest, axillary roll, pillows between knees, and padding under elbows. Wide adhesive tape secures the position. **B.** Upper arm abducted 90% on arm board. (Reproduced with permission from Fry WA: Thoracic incisions. In *General Thoracic Surgery,* 5th edition. Shields TW, LoCicero J III, Ponn RB, eds. Lippincott Williams & Wilkins, Philadelphia: 2000.)

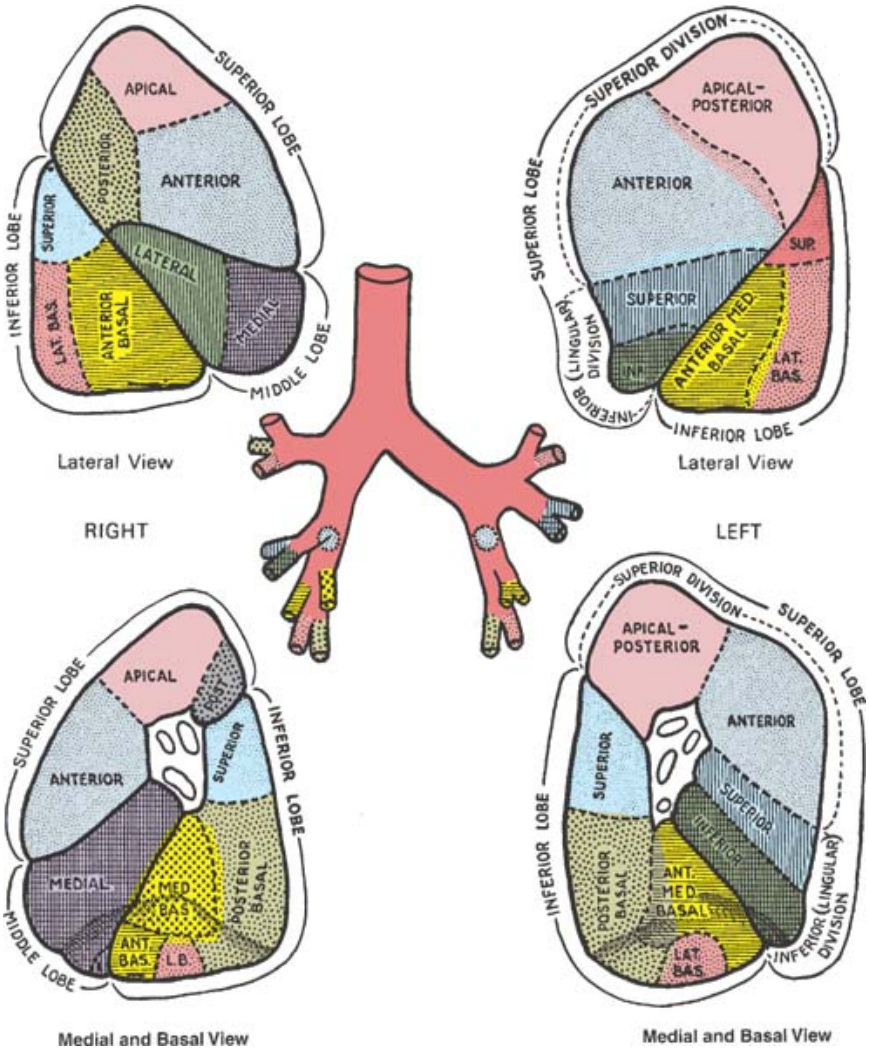

Figure 5-4. Segmental anatomy of the lungs. (Reproduced with permission from Clemente CD: *Gray's Anatomy,* 30th American edition. Williams & Wilkins, Philadelphia: 1985.)

Although the standard posterolateral thoracotomy involves division of the latissimus dorsi and serratus anterior muscles, **muscle-sparing incisions**—either transverse or vertical—are gaining in popularity because they are perceived *(Print pagebreak 271)* to decrease pain and provide a more rapid recovery. Variations on the posterolateral thoracotomy all have position requirements similar to those of the standard posterolateral incision.

For an anterior incision, the patient is placed supine. A small roll placed under the shoulder blades will serve to extend the neck and facilitate access to the upper mediastinum. This is particularly important for an operation on the upper trachea, and improves visualization for cervical mediastinoscopy. In general, the arms should be tucked at the patient's sides. Having an arm extended during a sternotomy can place undue stretch on the brachial plexus → injury.

The probability of DVT in general thoracic cases is controversial, whereas the risks of prophylaxis are minimal. Given that patients undergoing thoracotomy often have protracted periods of immobility, both during and after surgery, and often have a Dx of a malignant disease (hypercoagulability), use of DVT prophylaxis is good practice. We use SCDs for all patients, except those undergoing short video-assisted procedures, and reserve subcutaneous heparin for those at higher than normal risk (e.g., with prolonged postop immobility).

Postoperative Issues

The most common postop issues relevant to anesthesiologists are:

- The need for postop mechanical ventilation;
- Airway management;
- Hemodynamic instability; and

- Pain control.

The majority of patients undergoing thoracotomy can be extubated immediately postop. The most common exceptions are patients requiring preop mechanical ventilation, lung transplant patients, and those with "difficult" airways. Patients undergoing prolonged surgery may require postop mechanical ventilation. With shorter procedures, and those performed using minimally invasive techniques, even patients undergoing lung-volume-reduction surgery for severe emphysema generally can be extubated at the conclusion of the procedure.

Because DLTs are larger than standard ETTs, there is greater potential for laryngeal trauma and airway edema → loss of airway following extubation. By exchanging the DLT for a single-lumen ETT over a tube changer, this potentially catastrophic complication can be avoided.

Hemodynamic instability following surgery may be 2° several causes, the most important being ongoing blood loss (or inadequate intraop fluid replacement) and cardiac dysfunction. Use of epidural anesthesia may accentuate ↓ BP both intraop and postop.

With the use of epidural anesthesia and systemic analgesics (e.g., ketorolac) postop pain can be managed effectively. It is important for the anesthesiologist to communicate to the surgeon (and postop care team) which agents have been used, how the patient responded to them, and what types of hemodynamic, pulmonary, and neurological effects can be expected in the postop period.

Lobectomy, Pneumonectomy

Surgical Considerations

Description: Surgery remains the most appropriate form of treatment for early-stage lung cancer. Other less common indications include infection (particularly mycobacterial disease and bronchiectasis), developmental abnormalities such as sequestrations, and trauma. Patients with Stage I or II non–small-cell lung cancer (disease confined to the lung or those with intrapulmonary node involvement only) generally are offered surgery, unless their pulmonary function is prohibitively poor or their comorbidities pose an unacceptable risk. Patients with Stage IIIA disease often receive preop chemotherapy and/or radiation; and those with Stage IIIB or IV disease are rarely offered an operation.

Regardless of the underlying disease, the preoperative evaluation should include an assessment of pulmonary function (Table 5-1). Spirometry is adequate for most patients with little or no functional impairment, but more elaborate tests—such as measurement of diffusion capacity, quantitative ventilation/perfusion scans, or formal exercise testing (Fig. 5-5)—are appropriate for others.

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Table 5-1. Spirometric Criteria for Pulmonary Resection

Spirometry	Operable	Further Study Suggested
Forced vital capacity (FVC)	> 60% predicted	< 60% predicted
Forced expired volume in 1 see (FEV_1)	> 60% predicted	< 60% predicted
FEV_1FVC ratio	> 50%	< 50%
Maximum voluntary ventilation	> 50% predicted	< 50% predicted
Gas exchange		
Diffusing capacity for carbon monoxide	> 60% predicted	< 60% predicted
Articrial carbon dioxide tension	< 45 mmHg	> 45 mmHg

Used with permission from Olson GN: Pulmonary physiologic assessment of operative risk. In: *General Thoracic Surgery*, 5th edition. Shields TW, LoCicero J III, Ponn RB, eds. Lippincott Williams & Wilkins, Philadelphia, 2003.

Following induction of general anesthesia, many surgeons perform a preoperative bronchoscopy. In patients with tumors in the trachea or mainstem bronchi, this step may be important in determining whether the patient should undergo a lobectomy, sleeve lobectomy, or pneumonectomy. Most patients undergoing **lobectomy** or **pneumonectomy** are placed in the lateral decubitus position. This approach permits a lateral or posterolateral thoracotomy (Fig. 5-1A)—the incision that provides optimal exposure of the pulmonary hilum. A more limited, **muscle-sparing incision** may be used; however, the exposure may be somewhat limited. Occasionally, a **median sternotomy approach** (Fig. 5-1 B) is used–particularly when there is significant involvement of the anterior mediastinum by the tumor.

Over the past several years, video-assisted thoracoscopic lobectomy (VATS-lobectomy) has become more widely available. Although the anesthetic and surgical details of VATS techniques are described later in the chapter, early experiences with this procedure have demonstrated similar outcomes to those associated with the more traditional open techniques. Although a limited "access" thoracotomy is necessary to remove the mobilized lobe from the chest cavity, the technique has the advantages of minimizing soft tissue trauma and the pain associated with spreading the ribs.

Following entry into the chest, the lung on the operative side is allowed to deflate. If the lung remains inflated, a flexible bronchoscope should be used to verify correct positioning of the ETT (Fig. 5-6). Alternatively, the surgeon may be able to feel the tip of the ETT and guide it into the correct position. After stable OLV has been obtained, the lung is mobilized and the bronchovascular structures are identified. Generally, the vascular structures are divided first, although when exposure is limited, it may be best to divide the bronchus first. Hypotension and arrhythmias may occur when the hilar structures or pericardium are retracted vigorously. Such aberrations generally resolve quickly on restoration of normal anatomic relationships. Inadvertent entry into a branch of the pulmonary artery during dissection can result in rapid blood loss. Because these vessels are usually under low pressure, bleeding generally can be controlled with direct pressure on the bleeding site, while the anesthesiologist resuscitates the patient and the surgeon obtains more definitive vascular control. During a lobectomy, the surgeon will ask the anesthesiologist to reinflate the lung while the bronchus leading to the lobe that will be removed is occluded. This will ensure that the remaining lobes inflate appropriately. Thorough suctioning immediately before the lobectomy eliminates secretions as a cause of continued atelectasis. Once the lung or lobe has been resected, positive pressure is applied to the bronchial stump (and lobe) to check that there is no significant postop air leak. Large air leaks are best addressed at the time of surgery, rather than waiting for them to resolve postop.

Chest drainage is standard following lobectomy and involves placement of one or two 28–36 Fr chest tubes attached to underwater seal or suction. Placing the tubes to suction typically increases observed air leak, whereas extubating the patient in the supine position typically decreases the leak. Following pneumonectomy, chest drainage is not uniformly carried out; however, if a chest tube is to be placed, a balanced drainage system must be used or the *(Print pagebreak 273)* mediastinum will shift to the operative side, thus creating adverse hemodynamic consequences. An alternative to drainage (after the patient is placed supine) is to aspirate air from the operative pleural space until a slight negative pressure is obtained.

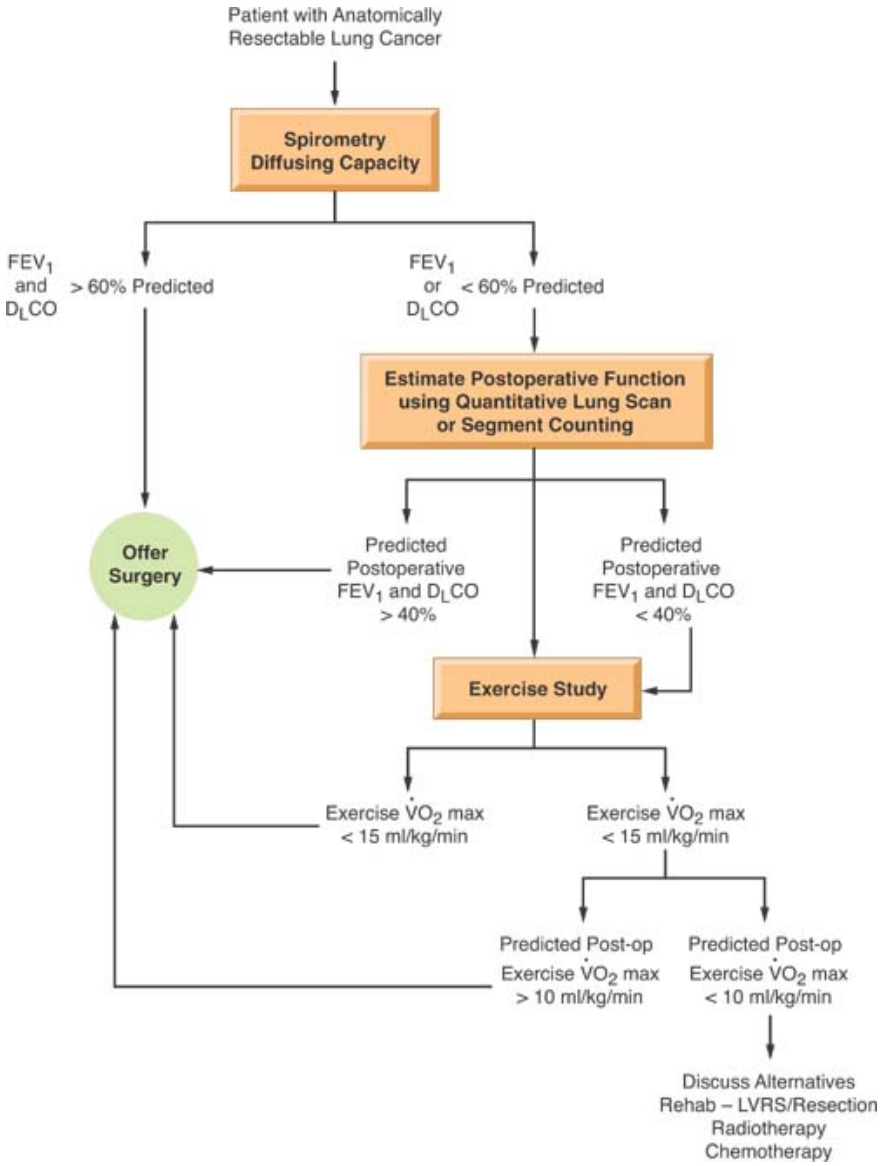

Figure 5-5. Physiologic assessment of patients with compromised lung function. (Reproduced with permission from Olson GN: Pulmonary physiologic assessment of operative risk. In *General Thoracic Surgery*, 5th edition. Shields TW, LoCicero J III, Ponn RB, eds. Lippincott Williams & Wilkins, Philadelphia, 2000.)

Usual preop diagnosis: Carcinoma of the lung; infection; developmental abnormalities; trauma

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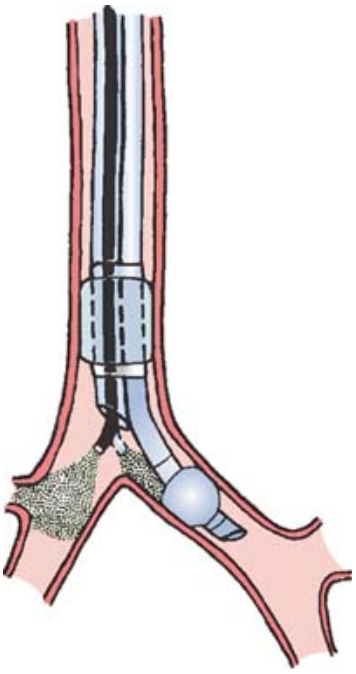

Figure 5-6. Use of a fiber optic bronchoscope to assure correct positioning of a left-side DLT. (Reproduced with permission from Ovasspian A: Conduct of anesthesia. In *General Thoracic Surgery,* 5th edition. Shields TW, LoCicero J III, Ponn RB, eds. Lippincott Williams & Wilkins, 2000. With permission from Fry WA: Thoracic incisions. In: *General Thoracic Surgery*, 5th edition. Shields TW, LoCicero J III, Ponn RB, eds. Lippincott Williams & Wilkins, Philadelphia, 2000.)

Summary of Procedures

	Lobectomy	Pneumonectomy
Position	Lateral/supine	
Incision	Posterolateral/median sternotomy/VATS	
Special instrumentation	DLT; SCD or TED hose	
Antibiotics	Cefazolin 1 g	
Surgical time	2–3 h	
EBL	< 500 mL (more in redo or inflammatory cases)	
Postop care	PACU ± IIC; careful attention to pulmonary toilet; chest tube output	+ Special balanced drainage tube
Mortality	± 1%	± 5%
Morbidity	Dysrhythmias: 10–20% DVT: 5–20% ARDS PE MI Bronchopleural fistula Chylothorax Subcutaneous emphysema Phrenic nerve injury Recurrent laryngeal nerve injury	30–40%
Pain score	7–8	7–8

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Patient Population Characteristics

Age range	0–80 yr
Male:Female	15:1
Incidence	Common thoracic procedure; increasing in females
Etiology	Smoking
Associated conditions	Cardiopulmonary disease; PVD

Anesthetic Considerations

Preoperative

The main indication for lung resection is neoplasm. Other indications include infection, hemorrhage, or air-leak. The majority of patients have a Hx of cigarette smoking with associated emphysema and/or chronic bronchitis. As most patients are older, other comorbidities are common (CAD, DM). Morbidity and mortality following thoracotomy is increased with pre-existing pulmonary, cardiovascular, and neurologic disease. Lung resections are increasingly being performed via thoracoscopy, which decreases patient morbidity. Lung isolation (DLT or BB) and OLV are mandatory for surgical exposure.

Respiratory	Question patient about exercise tolerance, dyspnea, productive cough and cigarette smoking. Examine patient for cyanosis, clubbing, RR, and pattern. Listen to chest for wheezes, rhonchi, rales. Timely cessation of smoking (> 8 wk), adequate management of bronchospasm with bronchodilator treatment ± steroids, and prompt treatment of pre-existing lung infections are important to reduce postop pulmonary complications. **Tests:** PFT (see below and Table 5-2); CXR; chest CT (if available), always examine chest imaging re: ease of lung isolation; ABG (only if indicated from H&P).
Pulmonary function	Nonsmoker with normal lungs may not require any studies for simple lobectomy. Any pre-existing respiratory disease (or possibility of pneumonectomy) should trigger lung function studies. Whole-lung tests (ABG, spirometry) are sufficient in most cases. Split-function lung tests (V/Q scan) should be considered if the patient has heterogeneous disease, or a planned pneumonectomy or borderline lung resection is planned. Many variables have been shown to correlate with poor outcome. The most important are FEV_1, D_LCO, and VO_2max, which focus on different aspects (mechanics, parenchymal function, and cardiopulmonary reserve, respectively). Postoperative predictive values of FEV_1 < 40%, D_LCO < 40%, or baseline VO_2max < 15 mL/kg/min predict ↑ risk for postop complications following pulmonary resection. Preop hypercapnia or PHTN/ RV dysfunction are relative contraindications to lung resection, except for specific circumstances (e.g., combined with LVRS in severe emphysema). Trial pneumonectomy with PA balloon occlusion is frequently discussed, but not used in clinical practice. Preop optimization of respiratory function with bronchodilator therapy should be routine.
Cardiovascular	RV dysfunction is a relative contraindication to lung resection (particularly pneumonectomy). Prophylactic digoxin or amiodarone to ↓ risk of postop atrial fibrillation have limited efficacy. **Tests:** ECG—look for evidence of RV hypertrophy, conduction problems, ischemia, and prior MI. ECHO to evaluate ventricular function; others as indicated from H&P.
Neurological	Hx of previous back surgery, peripheral neuropathy. Examine thoracolumbar area for skin lesions, infection, deformities.

Musculoskeletal	Patients with lung cancer may have myasthenic (Eaton-Lambert) syndrome with resistance to depolarizing muscle relaxants and ↑ sensitivity to NDMRs. Monitor relaxation with peripheral nerve stimulator.
Hematologic	Adequate O_2carrying capacity is important. Optimize Hb preoperatively if possible (iron, EPO), consider transfusion with Hb < 7 g/dl (<10 g/dl with CAD), depending on vital signs. Although rare, bleeding can be profuse, so blood should be immediately available. Coagulopathy may preclude neuraxial anesthesia.
Laboratory	**Tests:** Hct; PT; PTT (if epidural anesthesia planned) Other tests as indicated from H&P.
Premedication	Midazolam 0.5–2 mg iv if patient anxious (unless respiratory compromise). When epidural opioids are planned, avoid additional systemic opioid or sedative premedication that can potentiate postop respiratory effects of neuraxial opioids.

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Table 5-2. Assessment of Risk of Postop Pulmonary Complications Following Thoracic and Abdominal Procedures

Category	Point
1. Expiratory Spirogram	
1. Normal (%FVC + %FEV 1/FVC > 150)	0
2. %FVC + %FEV 1/FVC = 100–150	1
3. %FVC + %FEV 1/FVC < 100	2
4. Preop FVC < 20 mL/kg	3
5. Post-bronchodilator FEV 1/FVC < 50%	3
2. Cardiovascular System	
1. Normal	0
2. Controlled HTN, MI sequelae for more than 2 yr	0
3. Dyspnea on exertion, orthopnea, paroxysmal nocturnal dyspnea, dependent edema. CHF, angina	1
3. ABGs	
1. Acceptable	0
2. $PaCO_2$ >50 mmHg or $PaCO_2$ < 60 mmHg on room air	1
3. Metabolic pH abnormality > 7.50 or < 7.30	1
4. Nervous System	
1. Normal	0
2. Confusion, obtundation, agitation, spasticity, discoordination, bulbar malfunction	1
3. Significant muscular weakness	1
5. Postop Ambulation	
1. Expected ambulation (minimum, sitting at bedside) within 36 h	0
2. Expected complete bed confinement for at least 36 h	1

0 Points = Low Risk; 1–2 Points = Moderate Risk; 3 Points = High Risk

Shapira BA, Harrison RA, Kacmarek RM, Cane RD: *Clinical Application of Respiratory Care.* 3rd edition. Year Book Medical Publishers, Chicago: 1985. (With permission.)

Intraoperative

Anesthetic technique: Combined GA with continuous regional technique (epidural or paravertebral). Anesthesia for lobectomy/pneumonectomy relies on OLV techniques to improve surgical exposure and minimize damage to the operative lung in the case of lobectomy or bi-lobectomy. The challenges to the anesthesiologist include maintaining adequate oxygenation in patients

with poor pulmonary reserve and ensuring that the patient is comfortable, warm, and awake at the end of surgery.

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Preinduction	Placement of a regional analgesia catheter is important for postop pain control. Continuous epidural (lumbar or thoracic) and paravertebral blocks have been shown to be effective. Epidural catheters should be placed in the awake patient, whereas paravertebral catheters can be sited asleep or intraop under direct vision. The catheter tip should be as close as possible to the level of incision in order to minimize the sympathectomy. Intraop use of regional analgesia reduces the amount of systemic anesthetics/analgesics required and, therefore, facilitates rapid emergence. An adequate block can be established with lidocaine or bupivacaine; however, higher concentrations will be required for intraop anesthesia than postop analgesia.
Induction	Standard induction (p. B-2). If flexible bronchoscopy is planned prior to lung resection, intubate with an ETT (≥ 8 mm), which will be replaced with DLT after bronchoscopy (see below). Otherwise, proceed to intubation with an appropriate sized DLT (check imaging, rough guideline: adult male, 39–41 Fr; adult female, 35–37 Fr) after induction.
Maintenance	Air/$O_2$and isoflurane/desflurane/sevoflurane (around 0.5–0.7 MAC if neuraxial block established). Avoid N_2O. Use high FiO_2= 0.8–1.0 at onset of OLV; titrate to lowest possible after HPV well established and operative lung collapsed. A local anesthetic (e.g., 2% lidocaine or 0.25–0.5% bupivacaine) can be infused or injected hourly into a thoracic (1–3 mL) or lumbar (5–10 mL) epidural catheter. Continuous infusion of local anesthetic generally provides better hemodynamic stability than hourly bolus injection. To enhance the effect of epidural analgesia, a loading dose of epidural opiate (e.g., hydromorphone 200–500 mcg [thoracic] or 1–1.5 mg [lumbar]) can be administered prior to incision. Epidural hydromorphone has a superior side-effect profile over morphine at equipotent doses. IV (compared to inhalational) anesthetics have a clinically insignificant benefit on OLV oxygenation (particularly if volatile agents are limited to < 1 MAC) and are, therefore, not necessary in the majority of cases.
Emergence	Before chest closure, lungs are inflated gradually to 20–30 cmH_2O pressure to reinflate atelectatic areas and to for significant air leaks. Surgeon inserts chest tubes to drain pleural cavity and aid lung re-expansion. Patient is extubated in OR. If postop ventilation is required (rare), DLT exchanged for single-lumen ETT. Patient transferred in head-elevated position to PACU or ICU, breathing mask O_2 If hemodynamically unstable, monitor ECG, pulse oximetry, and arterial pressure during transfer.
Blood and fluid requirements	IV: 18 ga × 1 + 14 or 16 ga × 1 Maintain stable hypovolemia, Limit fluid to 10–15 mL/kg if possible Blood: available, but rarely required; use vasopressor (ephedrine 5–10 mg iv bolus or phenylephrine 50–100 mcg iv bolus) if hypo- tensive. Postop, PVR is increased in proportion to the amount of lung tissue removed. An overhydrated patient is at risk of RV failure and pulmonary edema. Replace blood loss with colloid (1:1) to minimize volume load. Third-space loss is negligible and need not be replaced. Use of epidural local anesthetics can cause ↓ BP in a volume-restricted patient; vasopressor may be needed.
Monitoring	Standard monitors (p. B-1) Arterial line Urinary catheter ± CVP line ± PA line or TEE (rare) It is mandatory to follow oxygenation continuously during OLV. Typically, this can be done with pulse oximetry, although continuous intraarterial PO_2monitoring is now commercially available. CVP and/or PA line optional for pneumonectomy and for patients with coexisting cardiac disease. CVP monitoring may be inaccurate intraop and is mostly placed for postop care. PA lines are rarely necessary and may interfere with PA stapling or endanger the PA stump. TEE may be of benefit in the borderline pneumonectomy to check for RV tolerance of PA cross-clamp.

Positioning	Axillary roll, “airplane” for upper arm Avoid hyperextending arms. and pad pressure points. eyes, ears, genitals.	radial pulses to ensure correct placement of axillary roll (if misplaced, will compromise distal pulses). Placing the oximeter probe on the down arm may assist in monitoring arm perfusion.
Fiber optic bronchoscopy	FOB performed immediately before thoracotomy to evaluate resectability of lesion. Patient intubated with large ETT (≥ 8 mm), replaced with DLT or BB following bronchoscopy (see Bronchoscopy, p. 306).	Use the largest DLT that atraumatically passes through the glottis (typically, 39–41 Fr for men, 35–37 Fr for women). DLT can be placed accurately by careful auscultation ±confirmation by FOB. Fiberoptic confirmation is most commonly done through the tracheal lumen, but can be performed through the bronchial lumen via trans-illumination. For small children, the balloon of a Fogarty embolectomy catheter is used as a BB; for adults, either a BB or a Univent tube may be used if the proper size DLT cannot be placed. BB not ideal as FOB always needed to confirm placement, lung collapse delayed, suction and CPAP not effective and repeated inflation and collapse may be difficult.
Lung isolation	Separate lungs to prevent contralateral contamination (infection, pus, blood, tumor), allow selective ventilation and facilitate operation.	
OLV	Two lung vent: Vt = 8–10 mL/kg, normocapnia, PEEP 3–5 cm H_2O OLV: Vt = 4–8 mL/kg, permissive hypercapnia ($PaCO_2$ 50–70 mmHg), PEEP 3–8 cm H_2O (unless BPF), FiO_2 0.6–1.0, PIP < 35 cm H_2O and plateau pressures < 25 cm H_2O, consider PCV.	Issues during OLV are: oxygenation, ventilation and lung injury. Oxygenation is rarely an issue if the DLT is adequately placed and derecruitment is avoided in the nonoperative lung. Ventilation is impaired by the smaller lumen of the DLT and the fact that only one lung is ventilated, resulting in higher ventilatory pressures. However, permissive hypoventilation allows for limiting the ventilatory stress. Acute lung injury may result in post-pneumonectomy pulmonary edema, which may occur even after lesser resections. Limiting Vt, peak and plateau pressures, FiO_2 duration of OLV and atelectasis formation help to minimize the risk.
	Hypoxemia	Hypoxemia is now relatively infrequent due to better lung isolation techniques and anesthetic agents with less suppression of HPV. If hypoxemia occurs, tube position should immediately be confirmed and FiO_2 increased towards 1.0. Suctioning of secretions and lung recruitment maneuvers are often all that is required. If derecruitment has occurred, higher levels of PEEP should be employed; however, this may potentially worsen oxygenation. CPAP to the (recruited) operative lung is always helpful, as is clamping of the PA to exclude shunt flow. Return to two-lung ventilation (if possible) will always improve oxygenation (even if used intermittently only) and should be considered with

		refractory hypoxemia.
Complications	Hypercarbia	Mild hypercarbia is well tolerated except in the setting of severe PHTN. CO_2 levels above 70 mmHg may be associated with tachycardia, dysrhythmias and cardiac depression. Treat with higher minute ventilation.
	Arrhythmia	for mechanical compression of heart or great vessels.
	Hypotension	volume status (but always hypovolemic) and cardiac function. Consider neosynephrine for BP support if ↓ BP is 2° epidural.
	Airway rupture	integrity of intubated bronchus after re-expanding lung.
	DVT	Preventive measures: TED hose or SCD.
	Airway trauma from intubation, tracheobronchial rupture	Force should NEVER be used during insertion of a DLT, as it may result in catastrophic airway disruptions. Do not overdistend bronchial balloon or DLT cuffs. DLT bronchial cuff usually requires < 2 mL air for airtight seal, if an appropriate (large) DLT is used.

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Postoperative

		Pressure damage to ear, eye, nose, deltoid muscle, iliac crest, brachial plexus, and radial, ulnar, common peroneal, and sciatic nerves have all been reported.
		Neurologic (phrenic and recurrent laryngeal nerves), thoracic duct, spinal cord; bronchopleural fistula, tracheobronchial disruption
	Injuries related to lateral positioning	
Complications	Structural injuries related to thoracotomy Surgical complications	Cardiac herniation, tension pneumothorax, bleeding, torsion of residual lobe, acute lung injury/ARDS
	Cardiopulmonary complications	Supraventricular dysrhythmias, SVT, acute RV failure, atelectasis, BPF, pneumonia, PE. For SVT, treat underlying cause and correct electrolyte abnormalities. Most postop SVTs are 2° atrial fibrillation or 2° catecholamine surge and may resolve spontaneously. Hemodynamically unstable patients will require cardioversion. Beta blockers, amiodarone, Ca^{+} channel blockers, and over-drive cardiac pacing are effective in patients with unstable AF.
		Effective analgesia via epidural or paravertebral route is essential in order for patient to cough, deep breathe, and ambulate early. Epidural infusions consist of a local anesthetic + opioid mixture

Pain management	Neuraxial opioids—epidural or intrathecal Parenteral opioids (iv, im, continuous iv, PCA [p. C-3]) Intercostal blocks. Interpleural analgesia Epidural local anesthetics Cryoanalgesia NSAID (ketorolac)	(smaller volume and higher concentration with thoracic placement). Paravertebral infusions are local anesthetic only, thereby avoiding opioid side-effects. Paravertebral analgesia interferes less with postop lung function than epidural analgesia. Ketorolac (10–15 mg) is helpful as adjunct analgesic, particularly with referred shoulder pain.
Tests	Hct, CXR, ABG and others as indicated.	

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2. Amar D: Perioperative atrial tachyarrhythmias. *Anesthesiology* 2002; 97(6):1618–23.

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5. Brodsky JB, Macario A, Mark JBD: Tracheal diameter predicts double-lumen tube size: a method for selecting left double-lumen tubes. *Anesth Analg* 1996; 82:861–4.

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8. Kavanagh BP, Katz J, Sandler AN, et al: Pain control after thoracic surgery. A review of current techniques. *Anesthesiology* 1994; 81:737–59.

9. Lohser J: Evidence-based management of one-lung ventilation. *Thorac Anesth Anesthesiol Clin North America* 2008; 26(2): accepted.

10. McKenna RJ Jr, Houck W, Fuller CB: Video-assisted thoracic surgery lobectomy: experience with 1,100 cases. *Ann Thorac Surg* 2006; 81(2):421–5; discussion 425–6.

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12. Slinger PD: Postpneumonectomy pulmonary edema: good news, bad news. *Anesthesiology* 2006; 105(1):2–5.

Wedge Resection of Lung Lesion

Surgical Considerations

Description: Wedge resection (removal of a mass in a manner that does not remove an entire anatomical pulmonary segment) may be carried out for a number of reasons. A known or suspected cancer may be removed by this limited resection. There is general agreement that this is an appropriate operation for patients with peripheral non–small-cell tumors and who have pulmonary reserve limited to the point that they are unable to tolerate lobectomy. Wedge resection also is used for resection of single- or multiple-metastatic lesions from various primary neoplasms. A single metastasis may be removed through a limited thoracotomy incision. At the other extreme, a **median sternotomy** may be used to remove bilateral lesions. Wedge resection also is indicated for diagnostic and therapeutic purposes in lesions which defy diagnosis by less invasive techniques. Incisions vary with location, number of lesions, and technique used. **Limited thoracotomy, standard thoracotomy,** or **median sternotomy** may be used under different circumstances. **Stapling** (Fig. 5-7), **clamp and suture** technique, or **excision and *(Print pagebreak 281)* suture** technique may be used for lesions in different locations. Wedge resection is best performed in the lateral position and with OLV. Small nodules on the edge of the lung and diagnostic biopsies for interstitial lung disease often can be performed with the thoracoscope, thereby avoiding a thoracotomy. In patients who cannot tolerate OLV (e.g., with ARDS), it may be necessary to keep the patient supine and ventilate both lungs. The wedge resection itself generally is carried out with a surgical stapling device (Fig. 5-7) that simultaneously staples the lung parenchyma and cuts between staple lines. Alternatively, the lung tissue can be clamped and oversewn—a technique applicable to particularly indurated lung tissue that is too thick for a stapler. A final option is to perform a pneumonotomy, enucleate the nodule, and suture the lung closed. A single chest tube usually is placed for postop chest drainage.

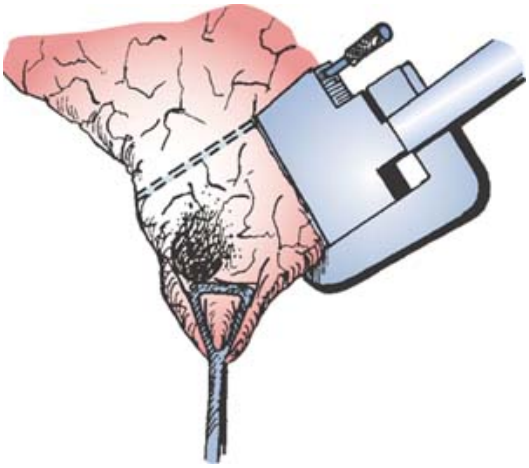

Figure 5-7. Stapler used to perform wedge incision. (Reproduced with permission from Scott-Conner CEH, Dawson DL: *Operative Anatomy.* Lippincott Williams & Wilkins, Philadelphia, 2003.)

Variant approach: Video-assisted thoracoscopy surgery (VATS) (see p. 313).

Usual preop diagnosis: Metastatic tumor to the lungs; primary lung cancer (typically, lobectomy); unknown pulmonary lesion

Summary of Procedures

Position	Lateral or supine
Incision	Limited and related to location of solitary lesion; sternotomy for bilateral lesions
Special instrumentation	DLT
Antibiotics	Cefazolin 1 g (or other antibiotic as indicated from culture and sensitivity)
Surgical time	< 1–3 h, depending on number of lesions
EBL	< 500 mL
Postop care	PACU ± ICU; careful attention to pulmonary toilet, chest tube output
Mortality	Minimal

Morbidity	Air leaks Cardiac dysrhythmias
Pain score	2–6

Patient Population Characteristics

Age range	30–60 yr most common
Male:Female	1:1
Incidence	Common thoracic procedure
Etiology	Variable – neoplasm or inflammatory disease
Associated conditions	COPD; cardiovascular disease; malignancy; infection

Anesthetic Considerations

Preoperative

The anesthetic considerations for this procedure are very similar to those for lobectomy/ pneumonectomy, although most wedge resections are easily accomplished via thoracoscopy. Wedge resection of the lung may be performed for diagnosis of interstitial process/lesion or for resection of neoplasm in patients with poor pulmonary reserve, who may not tolerate an anatomic resection.

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Respiratory	PFTs similar to major thoracotomy. Further evaluation directed toward an underlying disease (e.g., immuno-compromised patient for open-lung biopsy, patient with metastatic lesions, etc.). **Tests:** PFTs (see Lobectomy, Pneumonectomy, p. 275); CXR; chest CT (if available), always examine chest imaging for airway problems that might interfare with lung isolation, airway compression/obstruction; ABG (only if indicated from H&P).
Cardiovascular	**Tests:** ECG—look for evidence of RV hypertrophy, conduction problems, ischemia, and previous MI.
Neurological	Hx of previous back surgery or peripheral neuropathy. Examine thoracolumbar area for skin lesions, infection, deformities. The placement of an epidural catheter in patients with neurologic problems is controversial.
Musculoskeletal	Patients with lung cancer may have myasthenic (Eaton-Lambert) syndrome with resistance to depolarizing muscle relaxants and ↑ sensitivity to NMRs. Monitor relaxation with a peripheral nerve stimulator.
Hematologic	Patients are often anemic from primary disease. Consider preop blood transfusion or erythropoietin therapy. **Tests:** Hct
Laboratory	Other tests as indicated from H&P.
Premedication	Midazolam 0.5–2 mg iv if patient anxious. When epidural opioids are planned, avoid additional systemic opioid or sedative premedication, which can potentiate postop respiratory effects of central neuraxial opioids.

Intraoperative

Anesthetic technique: GETA, often combined with epidural or paravertebral blocks for thoracotomy approach. Thoracoscopy approach does not usually require a regional anesthetic. DLT or BB required for lung isolation.

Induction	Standard induction. Short acting paralytic (succinylcholine 1–1.5 mg/kg or vecuronium 0.1 mg/kg or rocuronium 0.3–0.6 mg/kg for tracheal intubation)	
Maintenance	**Balanced technique:** Air-O_2 isoflurane, and iv opioids (usually fentanyl). No N_2O. Pain is highly variable after thoracoscopic procedures, dependent on degree of lung dissection. If a regional catheter is used, management should be similar to pneumonectomy/lobectomy (consider lower dose of opioid). If parenteral analgesia is insufficient, useful adjuncts include intercostal block, paravertebral block and/or intrapleural local anesthetic (given through the chest tube after the lung is inflated [maximum 0.5 mL/kg of bupivacaine 0.25% with epinephrine]).	
Emergence	Ensure complete recruitment of operative lung. Extubate in OR, transfer in head-up position to PACU or ICU, breathing O_2 by mask.	
Blood and fluid requirements	IV: 16–14 ga × 1 NS/LR @ 2 mL/kg/h (maintenance fluid)	Replace blood loss with colloid (1:1). Third-space loss is negligible and does not need to be replaced.
Monitoring	Standard monitors (p. B-1) ± Arterial line	Depending on comorbidities.
Positioning	Lateral decubitus or supine, with wedge under back on operated side. and pad pressure points. eyes, ears, genitals.	
Ventilation	Lung isolation (DLT or BB) usually required, except for easily accessible/peripheral lesions. DLT superior in regards to rapidity of lung collapse.	For OLV technique, see Anesthetic Considerations for Lobectomy/Pneumonectomy, p. 275.
Complications during OLV	See OLV under Intraop Anesthetic Considerations for Lobectomy/Pneumonectomy, p. 278.	

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Postoperative

Complications	Same as for lobectomy, pneumonectomy Pain	See Postop Complications for Lobectomy, Pneumonectomy, p. 279. Pain may at times be poorly controlled with parenteral agents alone. May require neuraxial technique for rescue. More common with extensive resections than simple wedge
Complications during OLV	See OLV under Intraop Anesthetic Considerations for Lobectomy/Pneumonectomy, p. 279.	
Pain management	Parenteral opioids (iv, im, continuous iv, PCA [p. C-3]). Epidural Intercostal blocks Interpleural analgesia NSAID (ketorolac 10–15 mg)	See Pain Management for Lobectomy, Pneumonectomy, p. 279.

Suggested Readings

1. McKenna RJ Jr, Mahtabifard A, Pickens A, et al: Fast-tracking after video-assisted thoracoscopic surgery lobectomy, segmentectomy, and pneumonectomy. *Ann Thorac Surg* 2007; 84(5):1663–7.

2. See Pneumonectomy/ Lobectomy Suggested Readings p. 279–280.

3. Shah JS, Bready LL: Anesthesia for thoracoscopy. *Anesthesiol Clin North Am* 2001; 19(1):153–71.

Chest-Wall Resection

Surgical Considerations

Description: Removal of portions of the thoracic cage may be required under several circumstances with the two most common indications being (a) lung cancer that has invaded the chest wall and (b) primary chest-wall tumors (the notable exceptions being Ewing's sarcoma and rhabdomyosarcoma). Although preoperative chemotherapy is not standard treatment for chest-wall sarcomas, some patients may have received Adriamycin, which is associated with cardiotoxicity at high doses. If the tumor process involves the skin, an appropriate area of skin—typically, 4 cm around the tumor—must be resected along with the specimen. Underlying subcutaneous tissue and muscle should always be resected in continuity; however, the tumor itself must not be exposed. Wide skin flaps are frequently necessary as well. Limited resection (1–5 cm segments of one or two ribs) generally requires no specific reconstructive measures, but resection of larger areas of the chest wall may require extensive reconstruction including the use *(Print pagebreak 284)* of plastic mesh replacement with or without methylmethacrylate, rib grafts and muscle, or myocutaneous flaps. Removal of anterolateral or anterior portions of the chest wall, particularly resections that include the sternum, are associated with greater postoperative instability than are resections of posterior portions of the chest wall, which are protected by the back muscles and scapula. Larger defects can be tolerated posteriorly without reconstruction, as the scapula provides chest-wall stabilization and prevents lung herniation. If a prosthesis is required, it must be covered by viable muscle so as to avoid erosion through the skin. Extensive reconstruction of the chest wall is often carried out in conjunction with plastic surgeons.

Usual preop diagnosis: Lung cancer with a chest-wall attachment; primary tumor of the chest wall (bone, cartilage, or soft tissue); radiation necrosis

Summary of Procedures

Position	Supine or lateral
Incision	Over mass to be resected
Special instrumentation	Bone instruments; Marlex (or other) mesh; methylmethacrylate
Antibiotics	Cefazolin 1 g (or as indicated by culture and sensitivity)
Surgical time	1–8 h
Closing considerations	May require help of plastic surgeon in extensive cases.
EBL	100–2000 mL
Postop care	PACU or ICU; some patients require temporary ventilatory support.
Mortality	< 5%
Morbidity	Paradoxical chest-wall motion (less in posterior resections) Pneumothorax Wound complications
Pain score	3–8

Patient Population Characteristics

Age range	Adults of all ages; children, rarely
Male:Female	1:1
Incidence	Relatively rare
Etiology	Unknown
Associated conditions	Lung cancer; metastatic disease; smoking-related diseases; cardiovascular disease

Anesthetic Considerations

See Anesthetic Considerations following Repair of Pectus Excavatum or Carinatum, p. 287.

Suggested Readings

1. Baue AE, ed: *Glenn's Thoracic and Cardiovascular Surgery*, 6th edition, Volume II. Geha AS, Hammond GL, Laks H, et al., eds. Appleton & Lange, Norwalk: 1996.

2. Sellke FW, Swanson S, del Nido P: *Sabiston & Spencer: Surgery of the Chest*. *Section I: Chest Wall*, 7th edition. Elsevier Saunders, Philadelphia: 2004.

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Repair of Pectus Excavatum or Carinatum

Surgical Considerations

Description: Standard bony and cartilaginous repair of a pectus excavatum (funnel chest) or carinatum (pigeon breast) deformities is usually elective surgery with the aim of improving contour and body image. Evidence that these repairs have any positive effect on cardiopulmonary function is controversial, although some surgeons feel that it can be more than a cosmetic procedure–particularly in patients with prominent deformities. Recent evidence suggests that, although resting cardiopulmonary function tests do not improve after pectus repairs, maximal exercise capacity may improve.

To **repair pectus excavatum,** enough pairs of costal cartilages—usually four to six—must be removed to be able to mobilize and elevate the sternum. Depending on the severity of the defect and patient's age, fixation of the sternum in the corrected position may be necessary. **Repair of pectus carinatum** is somewhat more complicated because the defects are more varied–often with a rotational component as well as anteroposterior displacement; however, removal of cartilages and correction of the position of the sternum are still the mainstays of treatment.

A midline incision provides the most satisfactory access to the cartilages and sternum. For cosmetic reasons, however, it may be important to use a curvilinear transverse incision, particularly in females. This incision requires extensive mobilization of subcutaneous and muscle flaps. The wound complication rate is somewhat greater after transverse incisions. The costal cartilages are moved by subperichondrial dissection. This may be tedious and time-consuming, especially because four or five, or even more, pairs of cartilages need to be removed. The elevation of the sternum is usually fairly straightforward, and usually is accompanied by a transverse sternal osteotomy (Fig. 5-8). Intercostal muscle bundles may be left attached to the sternum or may be detached and reattached for *(Print pagebreak 286)* better positioning of the sternum. Sternal support normally is not used in infants, but may be used in older children. One common method of support is the use of a temporary transverse metal strut resting on the ribs, but beneath the sternum. The final position of the sternum is easier to predict following repair of the pectus carinatum than following repair of pectus excavatum. Because of the negative intrathoracic pressure, it is easier to hold the sternum down than up. Ideally, patients for repair of pectus excavatum are just under school age. Satisfactory repair, however, may be carried out at almost any time during childhood. As full growth is attained, results tend to be less favorable. Pectus carinatum generally has its onset during adolescence, and it is well to let the patient complete his or her growth spurt prior to undertaking repair. (Also see Repair of Pectus Excavatum/Carinatum in Pediatric General Surgery, p. 1270.)

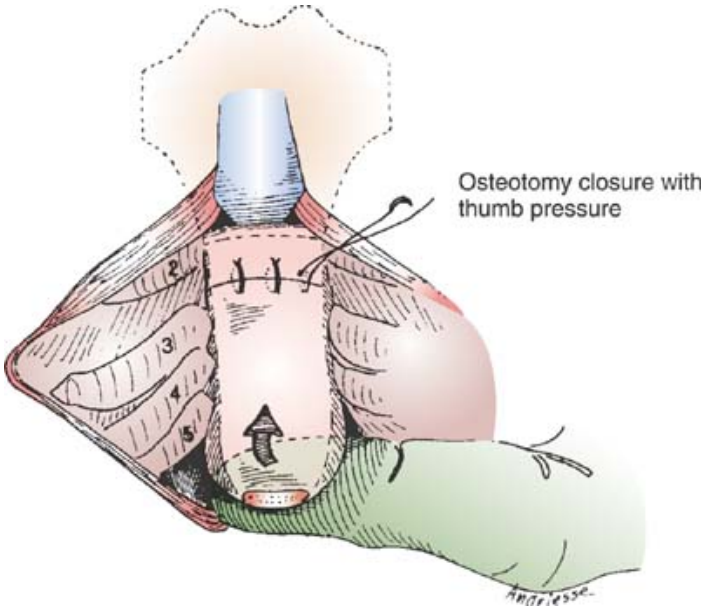

Figure 5-8. Correction of a pectus excavatum defect in a child. After subperichondrial resection of the involved costal cartilages, a wedge osteotomy permits anterior mobilization of the lower portion of the sternum. (Reproduced with permission from Shamberger RC: Chest wall deformities. In *General Thoracic Surgery*, 5th edition. Shields TW, LoCicero J III, Ponn RB, eds. Lippincott Williams & Wilkins, Philadelphia: 2000.)

Variant procedure or approaches: In certain circumstances, particularly in teenage girls and patients who do not engage in strenuous sports, subcutaneous, custom-made implants may be placed to improve body contour without necessitating major bony and cartilaginous repairs. These are usually carried out by plastic surgeons.

Usual preop diagnosis: Pectus excavatum or carinatum

Summary of Procedures

Position	Supine
Incision	Transverse or vertical
Special instrumentation	Bone instruments; sometimes metal struts or wires for reconstruction
Antibiotics	Cefazolin 1 g iv q 8 h × 36–48 h
Surgical time	2–3 h
Closing considerations	Pleural and wound drainage common
EBL	100–500 mL
Postop care	ICU
Mortality	Minimal
Morbidity	Pneumothorax: 5–10% Wound infection Sternum necrosis Immigration of strut Paradoxical chest-wall motion → hypoventilation/atelectasis
Pain score	4–5

Patient Population Characteristics

Age range	Usually children, 5–10 yr; teenagers, sometimes; adults, rarely
Male:Female	1:1
Incidence	Unusual

Etiology	Unknown
Associated conditions	Marfan syndrome; MVP

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Anesthetic Considerations

(Procedures covered: chest-wall resection; repair of pectus excavatum/carinatum)

Preoperative

Patients for chest-wall resection often have extensive cancer and may be weak and debilitated. A very large resection may create a "flail chest" situation, compromising postop ventilation.

Respiratory	Mild pectus seldom interferes with ventilation; no special studies indicated. Severe pectus deformity can be associated with restrictive lung defects. **Tests:** CXR; PFT, ABG, if indicated from H&P.
Cardiovascular	With severe pectus, the heart is displaced to the left and compressed; arrhythmias and RVOTO can occur 2° impaired filling, especially during exercise or in upright position. ECG may show right axis deviation, atrial and ventricular arrhythmias. A functional murmur may be detected. ECHO may reveal ↓ SV with MVP. **Tests:** ECG; cardiac catheterization if indicated. Echocardiogram if symptoms or signs suggest MVP or RVOTO.
Hematologic	**Tests:** Hct
Musculoskeletal	Chest-wall resection performed for invasive or metastatic cancer; patient may be markedly debilitated: pectus repair of chest-wall deformity for cosmetic, orthopedic, or cardiopulmonary indications: pectus deformity usually asymptomatic.
Laboratory	Other tests as indicated from H&P.
Premedication	Consider anxiolysis with short acting benzodiazepine. When epidural opioids are planned, minimize systemic opioid or sedative premedication to avoid potentiating postoperative respiratory depression from central neuroaxial opioids.

Intraoperative

Anesthetic technique: GETA, occasionally combined with epidural for minimal chest-wall resection; however, epidural anesthesia is an excellent adjunct for extensive chest-wall resections or repair of pectus deformities.

Induction	Standard induction (see p. B-2). In the setting of RVOTO avoid myocardial depressants, hypovolemia and a short diastolic filling time (e.g., tachycardia). Lung isolation (DLT or BB) usually required for chest wall resections.	
Maintenance	Standard maintenance (see p. B-2) or high-dose opioid technique (fentanyl 10–25 mcg/kg) for patient with severe RVOTO. Patients with MVP will require prophylactic antibiotics for bacterial endocarditis. OLV, if necessary, as outlined for lobectomy/pneumonectomy.	
Emergence	Extubate in OR; if high-dose opioid →ICU for later extubation.	
Blood and fluid requirements	IV: 18–16 ga × 1 NS/LR @ 1–2 mL/kg/h	Usually minimal blood loss. Fluid restriction unnecessary as this is extrapulmonary operation.
	Standard monitors (p. B-1)	Close monitoring with arterial and central

Monitoring	± Arterial line	venous catheters may be required in patients with significant cardiopulmonary compromise.
Positioning	and pad pressure points. eyes.	
Complications	Pneumothorax	Unintentional pleural tear can cause pneumothorax. Intraop deterioration characterized by ↑ ventilatory pressure, hypotension, and hypoxemia suggests pneumothorax. Increase FiO_2; D/C N_2O. Ensure pleural space is decompressed appropriately with needle or tube thoracostomy.
	Cardiac perforation	Rare, catastrophic event reported with aberrant bar placement during minimally invasive approach. Heralded by signs of hemorrhagic or obstructive shock. Supporting bar may interfere with external cardiac compressions.

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Postoperative

Complications	Hypoventilation Flail chest Atelectasis/pneumonia	Although most patients do not require postop ventilatory support, with extensive chest-wall resection, patient may hypoventilate. Respiratory stimulants, such as doxapram, should be avoided as they may → deep inspirations that can → severe sternal retractions. Paradoxical chest-wall movement may occur during spontaneous ventilation with flail chest; postop atelectasis 20 splinting. Obtain postop CXR.
	Pericarditis	Similar to post pericardotomy syndrome; usually responsive to NSAIDs though occasionally corticosteroids or percutaneous drainage required.
	Bar displacement	Following minimally invasive repair (Nuss) the bar may become displaced and require repositioning. Inadequate analgesia and absence of a stabilizing bar often cited as contributing factors.
Pain management	Depends on site and extent of chest wall resected. Parenteral or epidural opioids with local anesthetic.	Epidural opioids and local anesthetics are particularly useful if flail chest is present—reduces need for ventilatory support.

Suggested Readings

1. Baue AE, ed: *Glenn's Thoracic and Cardiovascular Surgery,* 6th edition, Volume II. Geha AS, Hammond GL, Laks H, et al., assoc. eds. Appleton & Lange, Norwalk: 1996.

2. Garcia VF, Seyfer AE, Graeber GM: Reconstruction of congenital chest-wall deformities. *Surg Clin North Am* 1989; 69(5):

1103–18.

3. Ghory MJ, James FW, Mays W: Cardiac performance in children with pectus excavatum. *J Pediatr Surg* 1989; 24(8):751–5.

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5. Jacobs JP, Quintessenza JA, Morell VO, et al: Minimally invasive endoscopic repair of pectus excavatum. *Eur J Cardiothorac Surg* 2002; 21(5): 869–73.

6. Mansour KA, Thourani VH, Odessey EA, et al: Thirty-year experience with repair of pectus deformities in adults. *Ann Thorac Surg* 2003;76(2):391–5; discussion 395.

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11. Shamberger RC: Chest wall deformities. In: *General Thoracic Surgery,* 5th edition. Shields TW, LoCicero J III, Ponn RB, eds. Lippincott Williams & Wilkins, Philadelphia: 2000, 535–62.

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Thoracoplasty

Surgical Considerations

Description: The objective of a **thoracoplasty** (removal of several ribs) is to permanently obliterate an existing pleural space or to collapse a portion of the lung. Formerly, this operation was used in the treatment of tuberculosis (TB); however, because of better drug therapy, appropriate pulmonary resection and the decrease in incidence of TB, thoracoplasty is now rare. The procedure also was used for obliterating empyema spaces and helping to close bronchopleural fistulas (BPFs). The use of **pedicled muscle flaps** (serratus anterior, pectoralis major, and latissimus dorsi are the most common) or an **omental transposition** have largely replaced thoracoplasty for filling empyema spaces and encouraging closing of BPFs. These operations are less deforming and better tolerated physiologically because they do not result in paradoxical motion of the chest wall.

For patients whose lungs will never expand to fill the space—such as those who have had a pneumonectomy or who have a permanently noncompliant lung—resection of multiple overlying ribs may be necessary (Fig. 5-9). Thoracoplasty is accomplished by removing several ribs in a subperiosteal fashion, allowing the underlying chest wall to collapse. This collapse is aided by the normally negative intrapleural pressure. Because the periosteum is left intact, the ribs will regenerate, resulting in a permanent, bony collapse of the chest wall. If the objective of the thoracoplasty is to obliterate a relatively small space (meaning that segments of only two to three ribs need be removed), the procedure may be done in a single stage, with little postop physiologic impairment of respiration. If extensive thoracoplasty is necessary, however, the procedure may be done in stages to minimize postop chest-wall instability and resultant respiratory problems.

Usual preop diagnosis: Pulmonary TB; BPF; empyema

Summary of Procedures

Position	Usually lateral
Incision	Along rib line
Special instrumentation	Bone instruments
Unique considerations	TB or fungal infection may be present
Antibiotics	As indicated by culture and sensitivity
Surgical time	2–3 h
EBL	500 mL or more
Postop care	ICU
Mortality	Minimal
Morbidity	Paradoxical chest-wall motion → atelectasis → hypoxemia: 10% Pneumothorax: Rare
Pain score	7–8

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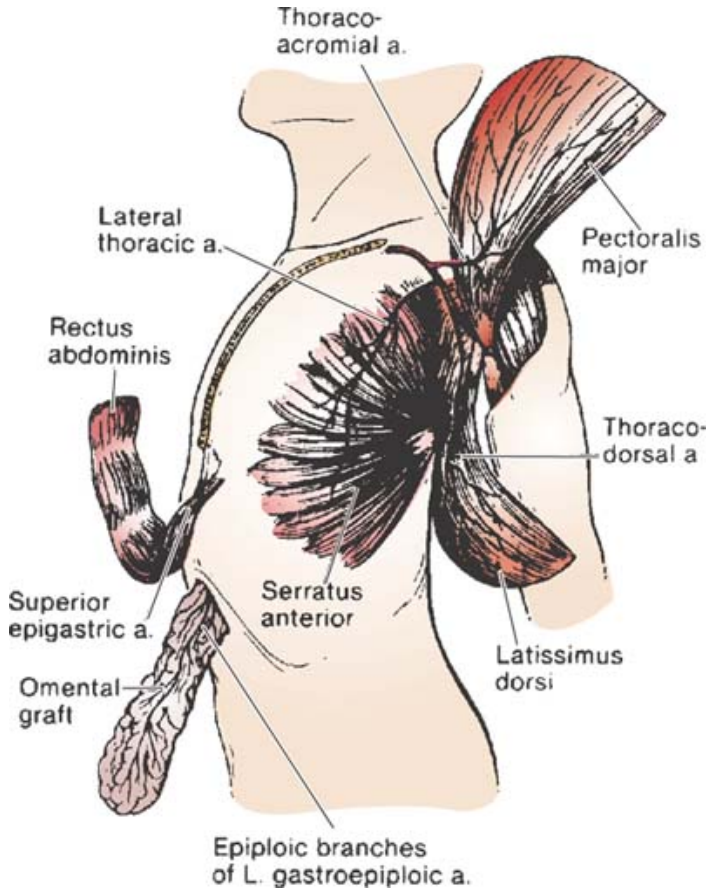

Figure 5-9. Extrathoracic muscle flaps that may be used to obliterate a postpneumo-nectomy empyema cavity. (Reproduced with permission from Miller JI Jr: Postsurgical empyema. In *General Thoracic Surgery,* 5th edition. Shields TW, LoCicero J III, Ponn RB, eds. Lippincott Williams & Wilkins, Philadelphia: 2000.)

Patient Population Characteristics

Age range	Middle-aged or older adults

Male:Female	1:1
Incidence	Rare
Etiology	TB; pneumococcal infection; neoplasm; complication of pneumonectomy
Associated conditions	Immunosuppression

Anesthetic Considerations

See Anesthetic Considerations following Drainage of Empyema, p. 292.

Suggested Readings

1. Baue AE, ed: *Glenn's Thoracic and Cardiovascular Surgery,* 6th edition, Volume II. Geha AS, Hammond GL, Laks H, et al., assoc. eds. Appleton & Lange, Norwalk, CT: 1996.

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Drainage of Empyema

Surgical Considerations

Description: Empyema is infection within the pleural space, and the primary treatment for it is drainage. Patients may be acutely ill or they may have a history of prolonged infirmity. The most common cause of empyema is extraparenchymal extension of a pneumonia, although other causes include trauma, iatrogenic, and esophageal perforation. The three phases of an empyema are the exudative phase, the fibrinopurulent phase, and the organized phase. The early, or exudative, phase of an empyema is usually associated with fever, dyspnea, and a pleural effusion, with the diagnosis generally being made by thoracentesis. In more established infections, patients may complain of chronic symptoms, such as pain, dyspnea, and chest heaviness, and their medical history may include several previous courses of antibiotics.

Treatment of empyemas is based on the stage and the underlying cause of the infection. Except in its earliest phase, chest tube drainage alone rarely provides adequate therapy. In the fibrinopurulent stage, thoracoscopic drainage with disruption of loculations and removal of the fine peel on the lung is enough to drain the infected fluid and allow the underlying lung to expand. This procedure typically is done with the patient in the lateral position and involves three thoracoscopy ports. Blood loss is generally small, although large volumes of irrigation fluid may be necessary to thoroughly débride the thoracic cavity.

As the empyema becomes more established, the peel becomes thicker and more difficult to remove thoracoscopically. In such cases, an **open thoracotomy** is necessary. Due to the extensive intrapleural inflammation, blood and fluid losses may be substantial. To identify the correct plane between the lung and the thickened pleura, the lung may need to be re-expanded frequently throughout the procedure. Satisfactory drainage is accomplished when the infected fluid is removed and the lung expands freely. Because the peel often intimately adheres to the underlying lung, there may be a moderate postop air leak.

In patients too ill to undergo thoracotomy, **rib resection** with subsequent open drainage tube will permit the underlying lung to expand over a period of several weeks. Although this may be done under local anesthesia, a brief general anesthetic is often easier on the patient. In this operation, the patient is placed in the lateral position and an incision is made over the rib corresponding to the most dependent portion of the empyema cavity. A 6-cm length of the rib is excised and a large-diameter (≥ 50 Fr) tube is inserted into the empyema cavity. More permanent open drainage is obtained by fashioning an **Eloesser flap.** In this procedure, a U-shaped flap of skin is rotated into the empyema cavity after rib resection. This creates a long-term, skin-lined tube that will last indefinitely. A varient of this procedure—the **Claggett procedure—** is carried out for empyema (with or without bronchopleural fistula) following pneumonectomy, since closed drainage rarely suffices in that situation. The principle is the same: drainage is

accomplished through an epithelial-lined permanent opening. The opening is made anterolaterally and dependently so that drainage is effective and the patient can handle dressing changes without assistance. Segments of 2-3 ribs are removed and the skin is sutured to the parietal pleura, leaving a permanent opening for drainage and irrigation. Without an underlying lung, and with a relatively fixed mediastinum, this procedure is well tolerated physiologically.

Usual preop diagnosis: Nontuberculosis empyema (typically pneumococcal)

Summary of Procedures

	Eloesser or Clagett	Tube Thoracostomy
Position	Usually lateral	Lateral
Incision	Over empyema pocket for Eloesser	Lateral
Special instrumentation	None	Large tubes
Unique considerations	Patient may have BPF	Local or GA
Antibiotics	As indicated by culture and sensitivity	
Surgical time	1 h; occasionally more	< 1 h
Closing considerations	Wound left open	None
EBL	100 mL	Minimal
Postop care	PACU → room	
Mortality	Minimal	
Morbidity	Fluid drainage Bleeding: Rare	Air leak
Pain score	3–4	2–3

(Print pagebreak 292)

Patient Population Characteristics

Age range	Usually adults
Male:Female	1:1
Incidence	Decreasing
Etiology	Pneumonia; esophageal or bronchial leak; lymphatic or hematogenous spread of infection; post-trauma or thoracic surgery
Associated conditions	Bronchopleural fistula (BPF); sepsis; malnutrition

Anesthetic Considerations

(Procedures covered: thoracoplasty; drainage of empyema)

Preoperative

The guiding principle in the anesthetic management of empyema is to protect the nonaffected lung from soiling by the affected side. These patients are often chronically ill with sepsis and cachexia; and there is usually an underlying BPF (which may require awake intubation).

Patients usually have pre-existing pulmonary disease. Preop pulmonary findings may include collapse of the ipsilateral lung, impaired hypoxic pulmonary vasoconstriction 2° infection, and mediastinal shift to the ipsilateral side. Procedure often is performed for empyema in the presence of BPF following lung

Respiratory	resection (particularly pneumonectomy), penetrating injury to chest, or rupture of a cyst or bulla. When possible, surgeon should drain empyema under local anesthesia before induction, with patient sitting upright. If empyema is loculated, complete drainage may not be possible. **Tests:** Consider PFTs; ABG; obtain CXR to determine efficacy of preop chest drainage; if chest CT available, look for airway obstruction that could interfere with DLT placement.
Cardiovascular	There may be ECG changes because of mediastinal shift to the affected side. **Tests:** As indicated from H&P.
Neurological	Hx of back surgery, peripheral neuropathy. Examine lumbar area for skin lesions, infection, deformities. Avoid placement of epidural catheter in patient with neurologic problems or if obviously bacteremic or septic.
Musculoskeletal	Patients with lung cancer may have myasthenic (Eaton-Lambert) syndrome with resistance to depolarizing muscle relaxant and ↑ sensitivity to NDMRs. Monitor relaxation with peripheral nerve stimulator.
Hematologic	Transfuse patients with preop Hct < 25% or Hct < 30% in patients with CAD. (Hb level necessary to maintain adequate O_2content.) Obtain autologous blood during the month before surgery or consider preop erythropoietin therapy in anemic patients.
Laboratory	Other tests as indicated from H&P.
Premedication	Midazolam 0.5–2 mg iv if patient anxious. When epidural opioids are planned, avoid systemic opioid or sedative premedication, which can potentiate postop respiratory effects of central neuraxial opioids.

(Print pagebreak 293)

Intraoperative

Anesthetic technique: GETA; combined with epidural anesthesia/analgesia if thoracotomy is indicated and patient is not bacteremic or septic.

(Print pagebreak 294)

Induction	Consider inhalational induction (e.g., sevoflurane) if patient has significant BPF. Rapid-sequence induction with cricoid pressure is an alternative (p. B-4). Intubate with DLT; isolate lungs to protect from aspiration and tension pneumothorax. Consider using DLT with bronchial lumen to side opposite BPF. Contamination of the healthy lung from aspiration of pus is a major concern; thus, proper tube position should be verified by FOB, and adequate cuff inflation should be checked. Large DLT provides snug fit in bronchus and limits aspiration. Pus may appear in tracheal lumen (lumen to the diseased lung); suction frequently to avoid soiling good lung.
Maintenance	$O_2$and isoflurane (1.0–1.5%); less required if epidural local anesthetics used. No N_2O. Use FiO_2= 0.5–1.0. A local anesthetic (e.g., 2% lidocaine with 1:200,000 epinephrine or 0.25% bupivacaine) can be infused or injected hourly into a thoracic (3–5 mL) or lumbar (5–10 mL) epidural catheter. Continuous infusion of local anesthetic generally provides better hemodynamic stability than hourly bolus injection. To enhance the effect of epidural analgesia, a loading dose of opiate (e.g., hydromorphone 0.4–1 mg [thoracic] or 1–1.5 mg [lumbar]) can be administered early in the surgery and at least 1 h before conclusion. Following intubation, isolate lung with DLT or BB. The chest tube is then removed while the chest is prepped for the operation. Ventilate only the healthy lung. Because BPF is an abnormal communication between the bronchial tree and pleural cavity, if no chest tube is present, conventional intubation with IPPV can produce tension pneumothorax. Keep unclamped and do not remove a functioning chest

	tube until the lung is isolated and ventilation to the diseased lung is stopped. After the chest is opened, there is no chance of pneumothorax, but the large air leak through BPF may prevent satisfactory ventilation of that lung. High-frequency ventilation (HFV) is recommended by some, but studies show no benefit; in some patients the BPF is actually increased with HFV. See OLV Management under Anesthetic Considerations for Lobectomy, Pneumonectomy, p. 278.	
Emergence	Before closing the chest, lungs are inflated gradually to 30 cmH_2O pressure to reinflate atelectatic areas and to check for significant air leaks. The surgeon will insert chest tubes to drain pleural cavity and aid lung re-expansion. Patient is extubated while still in OR. If postop ventilation is required (rare), the DLT is exchanged for an ETT. If BPF is still open, consider selective ventilation postop through DLT. It may be necessary to ventilate each lung separately; use smaller TVs to lung with BPF. Alternatively, pressure-controlled ventilation may be used to avoid major air leaks through BPF.	
Blood and fluid requirements	IV: 16–18 ga × 1 Avoid hypervolemia. Use vasopressor (ephedrine 5–10 mg iv bolus or phenylephrine 50–100 mcg iv bolus) if hypotensive.	An overhydrated patient is at increased risk of right-heart failure and pulmonary edema. Replace blood loss with crystalloid (1:3) or colloid (1:1). Third-space losses are negligible and do not need to be replaced. Use of epidural local anesthetics can cause ↓ BP in a volume-restricted patient; vasopressor often needed.
Monitoring	Standard monitors (p. B-1) ± CVP and/or PA line ± Arterial line	
Positioning	Axillary roll, “airplane” for upper arm Avoid hyperextending arms. and pad pressure points. eyes, ears, genitals.	Placing the oximeter probe on the down side may help detect inadequate perfusion from compression.

Postoperative

Complications	Tension pneumothorax Aspiration pneumonia (“down” lung)	Functioning chest tube necessary to prevent tension pneumothorax.
Pain management	Analgesic requirements minimal Parenteral opioids (iv, im, PCA [p. C-3]), epidural, NSAID	See Pain Management under Anesthetic Considerations for Lobectomy, Pneumonectomy, p. 279.

Suggested Readings

1. Baue AE, ed: *Glenn's Thoracic and Cardiovascular Surgery,* 6th edition, Volume II. Geha AS, Hammond GL, Laks H, et al., assoc. eds. Appleton & Lange, Norwalk: 1996.

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Tracheal Resection

Surgical Considerations

Description: The primary indications for **tracheal resection** are benign stricture and primary tracheal neoplasm. Benign strictures often are related to previous intubation or tracheostomy, whereas the most common malignant tumors include squamous cell carcinoma and adenoid cystic carcinoma. Proximal tracheal resections may also be required for trauma or idiopathic laryngotracheal stenosis. The preoperative assessment of patients with tracheal disease generally involves imaging with either CT or MRI. Important considerations include the length and position of the lesion and the caliber of the airway. Although up to 50% of the trachea can be resected with a successful primary anastomosis, shorter segment resections are technically simpler and do not require special techniques to maximize tracheal mobility.

(Print pagebreak 295)

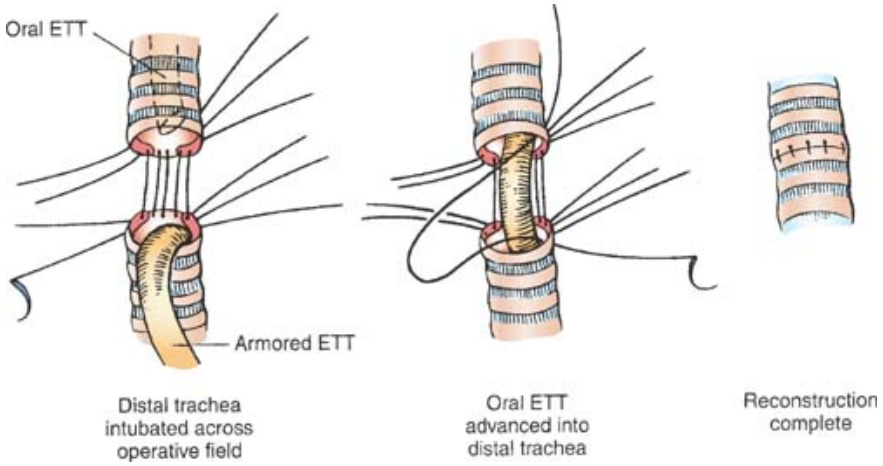

Figure 5-10. Stages of tracheal reconstruction. Note ETT in distal trachea. (Reproduced with permission from Grillo HC: *Current Problems in Surgery*. Year Book Medical Publishers, 1970.)

Lesions of the upper and midtrachea can be approached through the neck, whereas lesions of the lower trachea and carina must be approached through the right chest. When using the **cervical approach,** the patient is positioned with the neck extended. A transverse collar incision is used and subplatysmal planes are developed. The trachea is then extensively mobilized anteriorly and posteriorly. To minimize the risk of devascularizing the trachea, only the region to be removed should be circumferentially dissected. During this portion of the operation, care is taken to avoid injury of the recurrent laryngeal nerves. The trachea is then opened, the oral ETT is withdrawn into the proximal trachea, and a sterile armored ETT is passed across the operative field. Fine, interrupted, absorbable sutures are placed, but not tied. Once all sutures are in place, the armored tube is removed and the oral ETT is positioned across the anastomosis. The ends of the trachea are approximated with minimal tension and the sutures are tied (Fig. 5-10). To provide minimal tension, it may be necessary to flex the neck for this portion of the procedure. A suture may be placed from the chin to the chest wall to maintain neck flexion for several days postop. At the end of the procedure, the patient should be extubated to minimize airway irritation and disruption of the anastomosis.

Lesions of the lower trachea must be approached thought the right chest, where the same techniques as discussed above are used. To facilitate exposure of the distal trachea, OLV using either a DLT or a single-lumen tube advanced into the left main bronchus is helpful.

As is apparent from the above discussion, all tracheal procedures require cooperation and frequent communication between the surgeon and anesthesiologist. Occasionally, special techniques, such as jet ventilation or CPB, may be necessary for tracheal surgery.

Usual preop diagnosis: Tracheal stenosis or tumor (adenoid cystic carcinoma or squamous cell carcinoma most common)

Summary of Procedures

	Cervical Approach	Sternotomy	Right Thoracotomy
Position	Supine		Left lateral decubitus
Incision	Transverse low cervical	Cervical + sternotomy	Right thoracotomy
Antibiotics	Cefazolin 1 g		
Surgical time	3 h	3–4 h	4 h
Closing considerations	Neck flexion (chin stitch)		
EBL	200 mL	350 mL	350–500 mL
Postop care	ICU		
Mortality	< 5%	5%	
Morbidity	Retained secretions Dehiscence Recurrent stenosis Recurrent/superior laryngeal nerve injury Granuloma		
Pain score	3–4	5–6	7–9

(Print pagebreak 296)

Patient Population Characteristics

Age range	Wide variation
Male:Female	1:1
Incidence	Rare
Etiology	Stenosis usually 2° to intubation or injury; tumor, either primary (e.g., smoking) or secondary (e.g., esophageal, lung, thyroid cancer)
Associated conditions	Carcinoid syndrome; cardiopulmonary disease; tracheoesophageal fistula (TEF)

Anesthetic Considerations

Preoperative

Respiratory	Initial presentation may involve Sx of airway obstruction (stridor, cough, dyspnea), which may be misdiagnosed as asthma or pneumonitis. Patients presenting for tracheal resection almost exclusively have fixed obstruction, but may have an associated dynamic component. A careful preop evaluation of the airway usually includes bronchoscopic delineation of lesion site and size. This in combination with a review of CT images will help to determine a plan including type of induction, size of ETT and location of ETT tip.
Laboratory	**Tests:** PFT with flow/volume loops; bronchoscopy; CT scan to determine extent of tracheal obstruction Other tests as indicated from H&P.
Premedication	Patients with stridor or critical airway lesions should not receive preop sedation. It is probably best to avoid sedation in all patients. Patients may be unable to lie flat 2° respiratory distress. Low-density helium-oxygen mixtures (Heliox) have the clinical advantage of reducing airway resistance to flow past the obstruction, which may be beneficial in optimizing the patient

prior to the procedure.

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Intraoperative

Anesthetic technique: GETA, combined with epidural or paravertebral catheter if sternotomy or thoracotomy approach is used. Surgery is divided into five phases: induction, dissection, open trachea, closure and emergence. Induction, open trachea, and emergence are the critical and potentially dangerous stages. Close communication between surgeon and anesthesiologist is required.

Induction	Be prepared for airway emergency. Surgeon must be present and prepared for emergency rigid bronchoscopy and/or to perform tracheostomy below lesion. Induction depends on the site and degree of airway narrowing. Proximal or narrow lesions usually require inhalation induction or awake FOI, whereas distal or mild lesions may be approached with a rapid sequence i.v. induction. Sevoflurane/$O_2$is preferred for smooth inhalation induction with depression of cough reflex; avoid N_2O. High concentrations of sevoflurane may be necessary. Heliox (79% helium in oxygen) has been recommended to decrease resistance to flow past the obstruction; however, helium is not widely available and limits the FiO_2that can be administered. Have a variety of laryngeal blades and uncut ETTs of various sizes, including small 5 mm tubes available. If ETT passes beyond lesion, can begin IPPV. If ETT cannot be passed, spontaneous ventilation with 100% $O_2$and sevoflurane will be required if there is a dynamic obstruction, while patients with fixed lesions will tolerate PPV through a proximal tube. Careful and gradual dilation of the stenotic lesion may be required, using different sizes of ETTs or rigid bronchoscopy to facilitate placement of an adequate size ETT for ventilation. For carinal resections, use a sterile ETT, which can be placed by surgeon directly into each bronchus during resection for cross-field ventilation. An armored tube is preferable because it avoids kinking during repeated manipulations by the surgeon. Another option is to place jet ventilation catheters into the mainstem bronchi and jet-ventilate the patient during the open trachea stage.
Maintenance	Inhalational anesthesia can be unreliable (and may pollute the OR environment) due to frequent tube changes and intermittent apnea. TIVA is preferable: use propofol (25–100 mcg/kg/min) and remifentanil (0.05–0.2 mcg/kg/min) infusions. After the airway is secured, muscle relaxation should be given to avoid movement or coughing during the procedure. Standard maintenance (p. B-2). FiO_2= 1.0 if using apneic oxygenation; continuous monitoring with pulse oximetry mandatory. Consider HFJV through a small-diameter catheter if ETT interferes with operation. HFJV will require iv anesthesia, because inhalational agents cannot be delivered predictably; CPB can be used (rare). Analgesia requirements are highly dependent on surgical approach. Standard parenteral opioids are sufficient for the cervical approach, whereas epidural of paravertebral analgesia (similar to lobectomy) are used for open intrathoracic procedures.
Emergence	Early extubation; presence of ETT and IPPV can disrupt fresh suture line. Remove ETT as soon as patient is awake enough to protect airway and breathing spontaneously, but before bucking and coughing occur. Presence of a “guardian suture” (chestwall to chin) will make reintubation more difficult. Assess integrity of recurrent laryngeal nerve after high tracheal resections.+
Blood and fluid requirements	IV: 16–18 ga × 1 (left arm) NS/LR @ 3 mL/kg/h
Monitoring	Standard monitors (p. B-1) ± Arterial line and pad pressure points.

innominate artery compression, affects a right arm perfusion.

Left radial artery cannulation permits uninterrupted monitoring of BP during periods of innominate artery compression. Placement of iv in left arm allows unimpeded infusion. Right-extremity pulse oximetry will help detect innominate artery occlusion (which otherwise could lead to stroke.)

Positioning	eyes.	
Airway management	ETT replaced with sterile ETT and circuit intraop.	Ater the trachea is divided, the surgeon places a sterile ETT in the distal trachea. The original ETT is withdrawn above the surgical site. The surgeon attaches a sterile anesthesia circuit to distal ETT for ventilation. Then, the surgeon places a suture through the distal tip of the original ETT. Before reanastomosis of trachea, the distal trachea is suctioned to remove accumulated blood and secretions. After a posterior suture line is completed, the original ETT is pulled through the trachea and the distal tube (which is below the resection) is removed. Reattach and ventilate patient through original ETT.
Complications	Tracheal edema	Corticosteroids (dexamethasone 6–8 mg iv) to ↓ tracheal edema.
	Injury to neck	Any structure in the neck can be damaged, including superior and recurrent laryngeal nerves, trachea, and thoracic duct.

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Postoperative

Complications	Tracheal disruption	Neck swelling, subcutaneous emphysema, and inability to ventilate indicate loss of air-tight anastomosis. Immediate re-exploration of neck is essential. May be fatal.
	Recurrent laryngeal nerve injury	Bilateral (occasionally unilateral) laryngeal nerve damage may → airway obstruction, necessitating reintubation. Mask ventilation may be ineffective.
Position	Airway edema Keep head flexed to reduce tension on tracheal suture line.	Place patient in head-up, neck-flexed position. Treat with nebulized racemic epinephrine if airway compromise occurs. If reintubation is required, a small ETT should be placed under direct vision or fiberoptic guidance, to avoid disruption of the anastomosis.
Pain management	Parenteral opioids (p. C-2) ± Epidural	After patient is fully awake.

Suggested Readings

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Excision of Mediastinal Tumor

Surgical Considerations

Description: Mediastinal tumors are characterized by their location (anterior, middle, and posterior) and their size. Common anterior mediastinal tumors include thymic tumors (benign or malignant thymoma and thymic carcinoma), germ-cell tumors, lymphoma, and substernal goiters. Typically, thymic and germ-cell tumors are resected, whereas lymphomas are biopsied. Substernal goiters usually can be resected through the neck. Tumors in the anterior mediastinum *(Print pagebreak 299)* usually are removed through a **median sternotomy,** whereas tumors in the middle and posterior mediastinum usually are removed through a **lateral thoracotomy or thoracoscopy (VATS).** Although middle and posterior mediastinal tumors usually do not present airway management problems, the issue of functioning neuroendocrine tissue must be considered. Mediastinal pheochromocytomas are uncommon middle mediastinal tumors however, as with pheochromocytomas arising in other locations, appropriate preop adrenergic management is necessary. Some cysts or small tumors may be excised using **video thoracoscopy** (see Video-Assisted Thoracoscopy, p. 313).

Mediastinal tumors that are well encapsulated generally are removed in a straightforward fashion. If anterior mediastinal tumors are not well encapsulated and are attached to pericardium or lung on either side, appropriate portions of these attached structures may be removed in continuity with the tumor. If there is attachment to phrenic nerves on either side, one nerve may be sacrificed if necessary to remove the tumor completely. In patients with anterior mediastinal tumors, invasion of the major vascular structures, particularly the aorta and arch vessels, presents an even greater problem.

Germ-cell tumors of the anterior mediastinum–particularly nonseminomatous tumors–are often treated with chemotherapy initially. A common regimen for these patients consists of cisplatin, etoposide, and bleomycin, and because bleomycin is associated with pulmonary toxicity–particularly in conjunction with high concentrations of inhaled oxygen–care must be taken to keep the FiO_2 < 40% when conducting these operations.

Another common issue with patients with large anterior mediastinal masses is that of intrathoracic airway obstruction at the time of anesthetic induction. Although most mediastinal masses do not cause obstruction of the trachea or tracheobronchial tree, large mediastinal masses in the anterior mediastinum, in conjunction with muscle relaxation, can lead to complete obstruction of the airway with inability to ventilate the patient. Although rigid bronchoscopy may permit ventilation through the obstruction, it cannot be counted on to relieve the obstruction; therefore, only short-acting or no muscle relaxants (spontaneous ventilation) should be used in these patients.

Usual preop diagnosis: Thymoma; teratodermoid; ganglioneuroma; lymphoma; schwannoma; substernal goiter

Summary of Procedures

Position	Supine or lateral
Incision	Median sternotomy or lateral thoracotomy
Special instrumentation	Sternal or rib retractors
Antibiotics	Cefazolin 1 g
Surgical time	≥ 2 h
EBL	< 500 mL
Postop care	Frequently ICU
Mortality	Minimal
Morbidity	Bleeding
Pain score	5–8

Patient Population Characteristics

Age range	All ages
Male:Female	1:1
Etiology	**Anterior mediastinum:** Thymoma; teratoma; pericardial cyst; lymphoma; parasternal (Morgagni) hernia; lipoma **Superior mediastinum:** Goiter; aneurysm; parathyroid tumor; esophageal tumor; angiomatous tumor **Middle mediastinum:** Lymphoma; lymph node inflammation; bronchogenic tumor; bronchogenic cyst **Posterior mediastinum:** Neurogenic tumor; aneurysm (enteric cyst); esophageal tumor; bronchogenic tumor
Associated conditions	SVC syndrome; myasthenia gravis; recurrent laryngeal nerve damage; airway obstruction; dyspnea; Horner's syndrome

(Print pagebreak 300)

Anesthetic Considerations

See Anesthetic Considerations following Mediastinoscopy, p. 302.

Suggested Readings

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Mediastinoscopy

Surgical Considerations

Description: Mediastinoscopy is used for biopsy of mediastinal lymph nodes. The most common indication for this procedure is bronchogenic carcinoma, although lymphadenopathy associated with lymphoma, sarcoidosis, and infectious granulomatous diseases are also indications for mediastinoscopy. **Cervical mediastinoscopy** provides access to the pretracheal, paratracheal, and anterior subcarinal nodes (Fig. 5-11), whereas **transthoracic mediastinoscopy** (also known as **anterior mediastinotomy** or **Chamberlain's procedure**) provides access to the aortopulmonary lymph nodes. Previous mediastinoscopy and radiation are relative contraindications to this procedure. If *(Print pagebreak 301)* a thoracic aneurysm is present or SVC is obstructed, mediastinoscopy is contraindicated, because the anatomy is distorted and vessels can be punctured inadvertently by the

mediastinoscope.

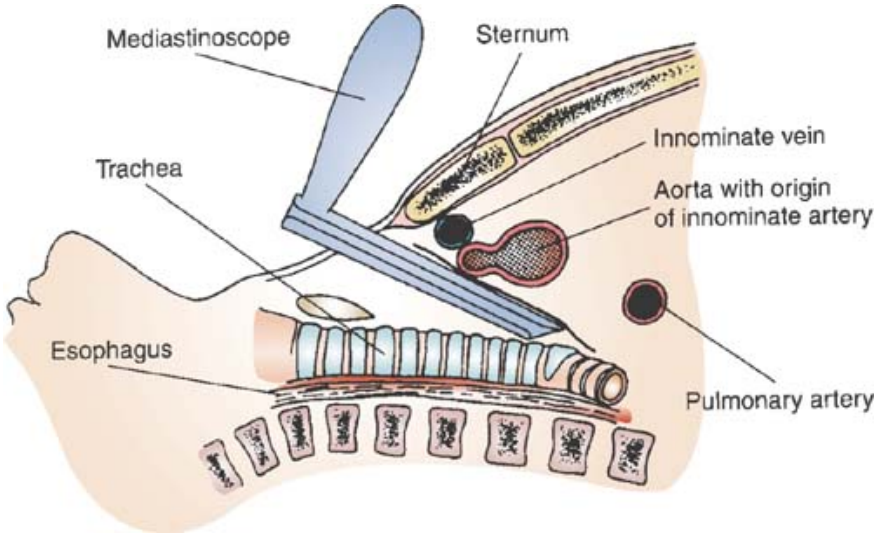

Figure 5-11. Mediastinoscope is inserted through a small cervical incision into the middle mediastinum, along the pretracheal plane. (Reproduced with permission from Baker RJ, Fischer JE: *Mastery of Surgery.* Lippincott Williams & Wilkins, Philadelphia: 2001.)

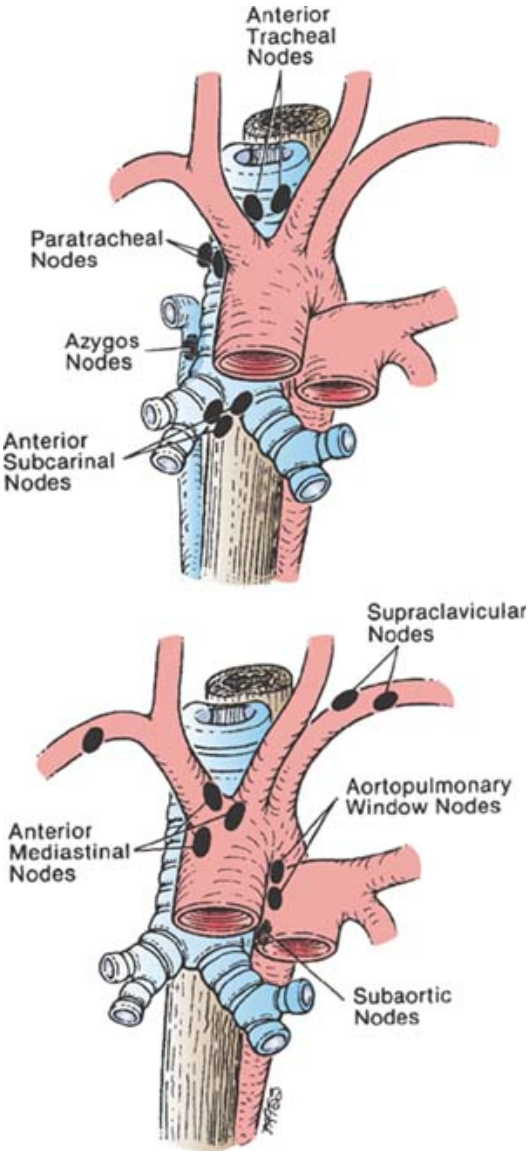

Figure 5-12. Lymph node sites accessible to mediastinoscope biopsy. Many of these can be reached by standard

cervical mediastinoscopy. Anterior and aortopulmonary window nodes, however, require extended or anterior mediastinoscopy, VATS, or needle biopsy. (Reproduced with permission from Bocage J-P, Mackenzie JW, Nosher JL: Invasive diagnostic procedures. In *General Thoracic Surgery,* 5th edition. Shields TW, LoCicero J III, Ponn RB, eds. Lippincott Williams & Wilkins, Philadelphia: 2000.)

Variant procedure or approaches: For nodes on the left side of the mediastinum, **transthoracic mediastinoscopy** is performed through a limited anterior thoracotomy. In the classic **Chamberlain's procedure,** the 3rd costal cartilage is resected and the mediastinum is explored without entering the pleural space. As with cervical mediastinoscopy, visualization is often limited and lymph nodes should be aspirated before biopsy. If the pleural space is entered during the course of the procedure, either a chest tube can be placed postop or the pleural space can be aspirated immediately before wound closure. Patients should be extubated at the end of the operation. Cervical *(Print pagebreak 302)* mediastinoscopy is usually an outpatient procedure, whereas patients undergoing transthoracic mediastinoscopy are usually hospitalized overnight.

Usual preop diagnosis: Carcinoma of the lung with enlarged mediastinal nodes; mediastinal node enlargement 2° lymphoma, thymoma, or other

Summary of Procedures

Position	Supine
Incision	For mediastinoscopy, suprasternal; usually left 2nd interspace for anterior mediastinotomy.
Special instrumentation	Mediastinoscope
Antibiotics	Cefazolin 1 g
Surgical time	≥ 1 h
EBL	Minimal (but risk of significant blood loss if major vascular injury occurs).
Postop care	PACU → room
Mortality	< 0.1%
Morbidity	Bleeding Pneumothorax: Rare Vocal cord paralysis: Rare Esophageal perforation: Rare Pleural tear: Rare Tracheal laceration: Rare
Pain score	2 (mediastinoscopy); 2–3 (anterior mediastinotomy)

Patient Population Characteristics

Age range	Adults, usually > 50 yr
Male:Female	Male > female
Incidence	Frequently part of evaluation for patients with lung cancer.
Etiology	Lung cancer; lymphoma; thymoma; retrosternal goiter
Associated conditions	Airway obstruction

Anesthetic Considerations

Preoperative

(Procedures covered: excision of mediastinal tumor; mediastinoscopy)

Typically, these patients can be divided into two populations, depending on the presence or absence of a significant mediastinal

mass (with the potential for catastrophic airway obstruction or cardiovascular collapse on induction of anesthesia). The preop assessment must focus on the differentiation of these two populations. Close consultation with the surgeon is essential in formulating the anesthetic plan. On occasion, patients with critical airway or cardiac compression may require a tissue biopsy for diagnostic purposes only. If general anesthesia poses a significant physiologic threat to the patient, search for an alternative, less invasive biopsy site.

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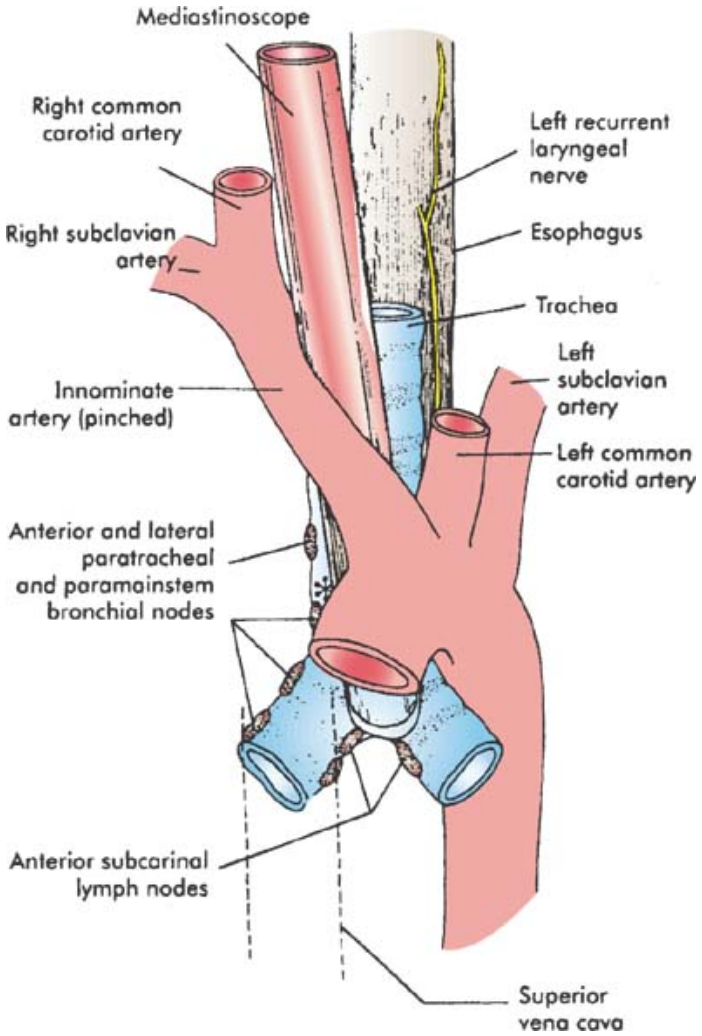

Figure 5-13. Relationship of mediastinoscope to trachea and great vessels. (Reproduced with permission from Petty C: Right radial artery pressure during mediastinoscopy. *Anesth Analg* 1979; 58:428. Modified in Rogers MC: *Principles & Practices of Anesthesiology.* Mosby-Year Book, St. Louis: 1993.)

Respiratory

Question patient with anterior mediastinal mass about ability to lie supine and the presence of cough or dyspnea. Change in position may cause superior vena caval obstruction or cardiac and airway compression by mediastinal mass (which may be apparent only following induction or on emergence from anesthesia). On PE, for the presence of cyanosis, wheezing, or stridor in the upright and supine positions. If significant airway compression or SVC obstruction is present, the surgeon may delay surgery for radiation or chemotherapy. Patients with SVC syndrome (edema; venous engorgement of head, neck, and upper body; supine dyspnea; ± headache; mental status change) may have significant airway edema.

Tests: Classic teaching has recommended PFTs with flow volume loops in upright and supine positions (Fig. 5-14 shows flow volume loop) in patients with suspected central airway obstruction. These investigations demonstrate airflow obstruction

	during inspiration in patients with an extrathoracic mass and during expiration in patients with an intrathoracic mass. CT scans obtained with the patient supine delineate the location and extent of both airway and cardiac ± vascular compression. These images may predict patients at higher risk (> 50% tracheal compression).
Cardiovascular	Intrathoracic vascular structures (e.g., right heart, PA, SVC) may be compressed → ↓ BP, hypoxia, SVC syndrome. Involvement of the pericardium may → tamponade. **Tests:** ECHO, CT/MRI if indicated by H&P.
Musculoskeletal	Patients with lung cancer may have myasthenic (Eaton-Lambert) syndrome with resistance to depolarizing agents and ↑ sensitivity to NDMRs. Monitor relaxation with peripheral nerve stimulator.
Neurologic	Patient may have ↑ ICP if SVC is obstructed. Consider neurology consultation. Patients with pre-existing carotid disease are at risk for stroke if there is significant compression of the innominate artery during the procedure.
Endocrine	Due to the diverse causes of an anterior mediastinal mass, consider comorbid thyroid disease and paraneoplastic syndromes.
Laboratory	Other tests as indicated from H&P.
Premedication	Avoid sedation in patients with the potential for airway obstruction; otherwise, midazolam 1–2 mg iv may be appropriate. Antisialogogue may facilitate awake intubation. In patients with critical airway obstruction, heliox may prove useful.

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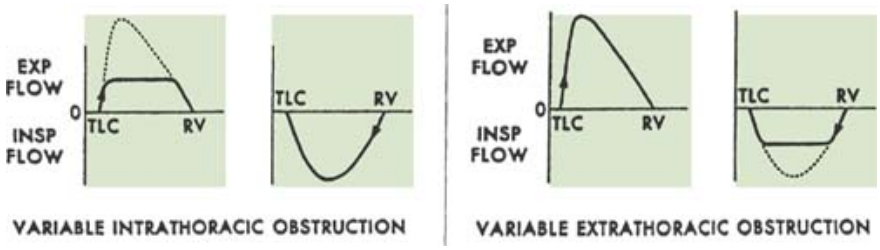

Figure 5-14. Flow volume loop: with variable extrathoracic lesion, the alteration in the flow volume loop is seen by flow limitation and a plateau on inspiration. The reverse occurs with variable intrathoracic lesions. (Reproduced with permission from Acres J, Kryger MH: Clinical significance of pulmonary function tests. *Chest* 1981; 80:207–11.)

Intraoperative

Anesthetic technique: GETA, combined with epidural if thoracotomy is planned.

Induction	Consider awake FOI (e.g., if symptomatic in supine position). Alternatively, a mask induction with sevoflurane/O_2 in a spontaneously breathing patient may be safe. Use of neuromuscular blockers in high risk patients may precipitate airway obstruction and CV collapse. Select a reinforced endotracheal tube when intubating patients with airway compression. Complete or partial airway obstruction by anterior mediastinal mass can also be due to changes in lung and chest-wall mechanics associated with changes in the patient's position (sitting to supine during procedure) or to muscle relaxation. Consider placing the patient in the lateral or prone position in the event of central airway compression. A surgeon familiar with rigid bronchoscopy must be in the OR ready to bypass any obstruction. In rare instances, percutaneous cardiopulmonary bypass (CPB) may be necessary to complete the procedure safely. If this is indicated, it must be employed electively, not as a rescue measure. Salvage or emergent use of CPB in these patients is rarely successful.
Maintenance	O_2 (100%) and isoflurane (1–1.5%) or sevoflurane (1.5–2.5%). Avoid N_2O, especially during OLV. Short-acting muscle relaxant and opioid as indicated.
Emergence	Extubation in OR

Blood and fluid requirements	IV: 14–16 ga × 1 NS/LR @ 1–2 mL/kg/h Blood in OR	Have blood for transfusion available in OR prior to surgery. Patients with SVC syndrome may have impaired venous return from upper-limb iv's. In these patients a large-bore iv cannula should be placed in lower limb for fluid and blood transfusions.
Monitoring	Standard monitors (p. B-1) ± Arterial line ± CVP/PA	Invasive monitors are appropriate in patients with large mediastinal masses. In the presence of SVC syndrome, CVP/PA catheters should be placed, using the femoral vein. BP cuff on left arm; radial artery line (if used) and pulse oximeter on right. Mass or mediastinoscope can compress innominate artery, causing reduction in right-radial pulse and right-arm BP. If only right-arm BP is measured, patients may be treated inappropriately for "hypotension" or cardiac arrest. Suspect great vessel compression if right-arm pressure is lower than left or if right-arm BP disappears in the presence of a normal ECG. Arterial compression can compromise cerebrovascular perfusion → cerebral ischemia → stroke.
Positioning	Head-up position and pad pressure points. eyes.	In patients with an anterior mediastinal mass, the head-up position reduces mass compression effect on airway and vascular structures, but may subject the patient to ↑ risk of VAE if venous bleeding occurs during the procedure. Patients with SVC obstruction, if placed in head-down position with IPPV (further impedes venous return of thoracic cavity), are at ↑ risk of airway edema and airway obstruction following extubation.
Complications	Bleeding	Surgical tamponade through mediastinoscope may be indicated. For major hemorrhage, emergency thoracotomy or median sternotomy may be required to stop bleeding. Can occur from laceration of mediastinal vein.
	Air embolism	Head elevation increases risk of embolism, particularly if patient breathes spontaneously. Monitor $ETCO_2$ and ETN_2
	Airway rupture or obstruction Tracheal collapse	Requires immediate thoracotomy. Acute obstruction may require rigid bronchoscope to reopen airway.
	Recurrent laryngeal nerve injury	If recurrent laryngeal nerve injury is suspected, the vocal cords should be examined during spontaneous breathing at the time of extubation.

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Postoperative

Complications	Pneumothorax	(see Postop Complications for Cervical Neurosurgical Procedures, p. 108).
	Phrenic/recurrent laryngeal nerve damage	Bilateral laryngeal nerve damage may result in airway obstruction, necessitating reintubation. Mask ventilation may be ineffective.
	Bleeding	
	Tracheomalacia	May occur in patients with longstanding mediastinal mass (e.g., retrosternal goiter)
Pain management	Parenteral opioids (p. C-2) ± Epidural	
Tests	CXR on all patients to r/o pneumothorax.	See Postop Complications for VATS, p. 315.

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Bronchoscopy—flexible and Rigid

Surgical Considerations

Description: Bronchoscopy can be performed using either rigid or flexible instrumentation. **Flexible fiber optic bronchoscopy (FOB)** is used for the diagnosis and evaluation of a variety of pulmonary conditions and can be accomplished using topical anesthesia and sedation without an anesthesiologist. Transbronchial biopsies can be performed in sedated patients, although more extensive interventions—such as laser ablation of a tumor, stent placement, and balloon dilation—generally require general anesthesia. When performed under general anesthesia, the bronchoscope should be passed through a size 8 or larger ETT.

Rigid bronchoscopy is more appropriate for evaluating hemoptysis and for intrabronchial procedures such as mechanical dilation of tracheal or bronchial strictures, laser or mechanical tumor debridement, and removal of foreign bodies that cannot be extracted with basket forceps through a flexible bronchoscope. Rigid bronchoscopy is performed under general anesthesia. With the patient's head and neck extended, the eyes, teeth, and gums must be protected, and the bronchoscope is inserted into the posterior pharynx until the epiglottis is visualized. The epiglottis is lifted anteriorly, with care being taken not to use the patient's teeth as a fulcrum. The bronchoscope is then advanced into the trachea (Fig. 5-15) and the diagnostic or therapeutic procedure is carried out. Ventilation is through the side-arm of the bronchoscope and, as there is no cuff to prevent escape of anesthetic gases, high ventilatory volumes may be required. Because interventions (e.g., biopsy or tumor debridement) require removal of the bronchoscope viewing lens, the anesthesiologist must time ventilation appropriately. A Venturi ventilator may be useful when the viewing lens must be off for prolonged periods.

Laser bronchoscopy can be performed using either flexible or rigid bronchoscopes. The CO_2 laser is characterized by limited tissue penetration. As such, it is useful for superficial lesions of the upper airway. The Nd:YAG lasers use higher energies, can be directed by fiber optic light guides, and can be used for tumor ablation. As both of these types of lasers rely on thermal damage to tissues, precautions—particularly $FiO_2 \geq 40\%$—must be taken to prevent the devastating complication of airway fire. **Photodynamic therapy** uses visible light to activate a photosensitive compound into a locally toxic drug. Because no thermal energy is involved, airway fires are not an issue.

Usual preop diagnosis: Carcinoma of the lung, primary or recurrent; hemoptysis; obstruction; foreign body; benign tumor; respiratory papillomatosis

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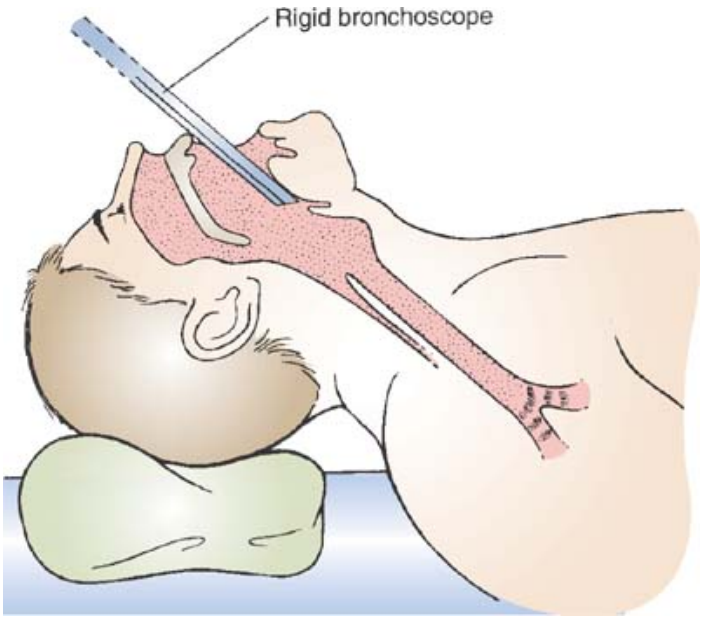

Figure 5-15. Patient positioning for rigid bronchoscopy.

Summary of Procedures

	Fiber Optic Bronchoscopy	Rigid Bronchoscopy	Laser Bronchoscopy
Position	Supine	(see fig 5-15)	
Special instrumentation	FOB and instruments	Rigid bronchoscope and instruments	Nd:YAG laser and bronchoscope
Unique considerations	None	Shared airway	+ Keep $FiO_2 \geq 0.4$ during use of laser.
Antibiotics	Usually none	± Cefazolin 1 g	
Surgical time	< 30 min		1 hr
EBL	Minimal		
Postop care	PACU → room		
Mortality	Minimal		5%
Morbidity	Barotrauma Airway obstruction Pneumothorax	Tooth damage Tracheal laceration Pneumomediastinum Esophageal perforation	Airway fire Hemorrhage Perforation
Pain score	1	1	1

Patient Population Characteristics

Age range	Usually adults > 50 yr
Male:Female	1:1
Incidence	Common
Etiology	Smoking; hemoptysis; aspiration of foreign body
Associated conditions	Lung cancer or metastatic spread to tracheobronchial tree; airway obstruction 2° tumor or FB; lung infiltrates

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Anesthetic Considerations

Preoperative

Patients presenting for bronchoscopy range from asymptomatic to those in severe respiratory distress. Fiberoptic bronchoscopy is performed most commonly as it is less invasive, usually easily done under sedation and allows for more distal airway examination. Rigid bronchoscopy is mostly reserved for specific interventional procedures such as hemorrhage control, foreign body removal, tumor debulking, and stent placement.

Respiratory	H&P to focus on underlying condition. Evaluate for acute and chronic pulmonary problems by H&P and lab and radiologic studies. **Tests:** Consider ABG in patient with respiratory distress, SOB at rest, or poor exercise tolerance. $PaO_2 < 70$ mmHg and/or $PaCO_2 > 45$ mmHg indicate significant respiratory impairment and predict increased risk); PFT with flow-volume loop (for airway lesions); CXR.

Cardiovascular	Many patients have Hx of cardiac disease. Cardiology consultation should be obtained for active/unstable cardiac issues or for patient with poorly controlled chronic disease. **Tests:** Consider ECG; others as indicated from H&P.
Musculoskeletal	Patients with lung cancer may have myasthenic (Eaton-Lambert) syndrome with resistance to depolarizing muscle relaxants and ↑ sensitivity to NDMRs. Monitor relaxation with peripheral nerve stimulator.
Hematologic	Type & cross rarely required unless high risk of hemorrhage from biopsy (with surgeon). Adequate O_2 carrying capacity (Hct) important. **Tests:** Hb/Hct
Laboratory	Other tests as indicated from H&P.
Premedication	Antisialagogue (glycopyrrolate 0.2 mg iv, avoids central anticholinergic effects). Light sedation with midazolam 1–2 mg iv and/or fentanyl, 50–100 mcg iv. Avoid heavy sedation that might impair postop ventilation.

Intraoperative

Flexible bronchoscopy: Anesthetic technique for flexible FOB requires sedation or GA. Anxious patients and those with respiratory compromise may not tolerate sedation for awake FOB; and patients with Hx of gastric reflux or aspiration are not candidates for awake FOB. Local anesthetic toxicity is a distinct possibility; ensure availability of resuscitative equipment.

Sedation with topical anesthesia	Sedate patient as necessary to ensure comfort and cooperation (midazolam 1–2 mg iv and/or fentanyl 50–100 mcg iv). Bronchoscopy often better tolerated if using nasal route. Airway anesthesia can be provided with direct nerve blocks or topical anesthesia. **Nerve blocks:** Transtracheal local anesthesia; Pass needle through cricothyroid membrane, aspirate air into syringe, and then inject lidocaine (2%) 2 mL. Remove needle quickly because injection causes cough (spreads the anesthetic). Perform superior laryngeal nerve blocks: Insert needle anterior to superior cornu of thyroid cartilage. After resistance is felt, aspirate gently, then inject lidocaine (2%) 2 mL; repeat on other side. **Topical anesthesia:** Spray palate, pharynx, larynx, vocal cords, and trachea with lidocaine (4%), using nebulizer, or have patient gargle viscous lidocaine (4%). hold base of tongue forward and, using Krause's forceps, place pledgets soaked in local anesthetic in each pyriform fossa to block the internal branch of superior laryngeal nerve. Laryngeal structures are well topicalized with having the patient gargle 4% lidocaine. The trachea can be topicalized by administering 1% lidocaine through the working channel of the fiberoptic scope. Patient can hold a suction catheter in the mouth to remove oral secretions. A special face mask (Patil-Syracuse) incorporates a diaphragm through which the FOB can pass while patient breathes 100% O_2 Use a special oral airway (Ovassapian) to guide FOB over back of tongue into trachea to prevent damage to FOB by teeth. Limit amount of suctioning by surgeon, because suctioning through FOB decreases FiO_2 and FRC, → ↓ PaO_2

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General anesthesia: Almost any anesthetic technique is acceptable, including use of an LMA. A large ETT has less resistance to air flow; minimum size is 8 mm (ID) for adult FOB. If patient requires ETT < 8 mm, use a pediatric FOB. Placing an LMA allows for examination of the proximal airway and a size 2.5 or larger ProSeal LMA has an airway caliber equivalent to or larger than a size

8.0 ETT. Presence of a FOB in the ETT or LMA increases airway resistance and may result in intrinsic PEEP and dynamic hyperinflation/ pulmonary tamponade (hypotension).

Rigid bronchoscopy: Requires relatively deep GA and usually paralysis for scope insertion.

Induction	Preoxygenate well. Standard induction. Consider short-acting paralytics (e.g., succinylcholine 1 mg/kg or rocuronium 0.3–0.6 mg/kg). Use only small amount of iv opioids, because postop analgesic requirements are minimal; consider remifentanil (1 mcg/kg) to avoid postop respiratory depression.	
Maintenance	Commonly inhalation anesthesia with isoflurane, or sevoflurane and 100% O_2 however, the adequacy of inhaled agent delivery may be hampered by ongoing suctioning. TIVA is an alternative (p. B-2): propofol (50–150 mcg/kg/min) and remifentanil (0.1–0.3 mcg/kg/min). Paralysis is usually used for ETT placement and is required during rigid bronchoscopy. May be provided with short-acting, nondepolarizing agents (atracurium, vecuronium, or rocuronium) or alternatively a succinylcholine drip (1 g/250 mL NS, titrated to effect; be aware of onset of phase II block at doses > 5–6 mg/kg). Manual IPPV through side-arm of rigid bronchoscope. High flow (up to 20 L/min) to compensate for leak. Hyperventilate patient in preparation for periods of apnea. Ventilation must be interrupted whenever surgeon removes eyepiece to suction or biopsy. Manually ventilate to compensate for compliance changes that occur when bronchoscope is in trachea (ventilating both lungs) and when it is in bronchus (ventilating one lung). O_2flush is used to compensate for leak; bypasses anesthetic vaporizer. Frequent flushing lowers anesthetic concentration. Sanders Jet Ventilator using Venturi effect—is an alternative. Allows for uninterrupted ventilation and may shorten the length of the procedure (fewer interruptions). Requires TIVA (p. B-2). Entrainment of air results in variable FiO_2 Adequacy of ventilation is hard to determine as no $EtCO_2$monitoring is available; prolonged procedures may require intermittent blood gas analysis or transcutaneous CO_2monitoring.	
Emergence	Place ETT or LMA at conclusion of rigid bronchoscopy. Patient must be fully awake before extubation with no residual neuromuscular blockade. Emergence can be "stormy." Patient may cough violently to clear secretions and blood. Wake-up from remifentanil infusion tends to be smoother, other considerations include early suctioning of the airway, lidocaine (1 mg/kg iv) to decrease airway reactivity. Provide postop O_2supplementation (preferably humidified).	
Blood and fluid requirements	Blood usually not required. IV: 18 ga × 1 NS/LR @ 2 mL/kg/h	Transfusion unnecessary unless complicated by massive hemorrhage; may require emergency thoracotomy. Usually restrict iv fluids to avoid fluid overload.
Monitoring	Standard monitors (p. B-1)	***NB:** $ETCO_2$not accurate during rigid bronchoscopy because of dilution effect at sample port.
Positioning	and pad pressure points. eyes. Shoulder roll for rigid bronchoscopy	
Complications	Hypoxemia	Monitor pulse oximetry continuously. If patient hypoxemic, surgeon must withdraw bronchoscope into trachea. If problem persists, remove bronchoscope and ventilate by mask or ETT.
	Hypercapnia	Common, due to hypoventilation. Mild hypercarbia is well tolerated except for the setting of severe pulmonary HTN. CO_2 levels above 70 mmHg may be associated with tachycardia, dysrhythmias and cardiac depression. Easily treated with higher minute ventilation/hyperventilation. IV lidocaine for dysrhythmias.
	Bleeding Tracheobronchial injury Aspiration of debris	Requires frequent suctioning. For major

		hemorrhage, place uncut ETT down healthy bronchus and ventilate good lung. Consider DLT. May require thoracotomy using DLT or BB to isolate and/or tamponade bleeding site.

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Postoperative

Complications	Hypoxemia	Rx: Supplemental O_2 Nebulized racemic epinephrine and steroids may ↓ airway edema. Humidified O_2may ↓ airway irritation.
	Hypoventilation Dental damage Airway trauma Pneumothorax Hemorrhage Risk of aspiration Airway obstruction (bronchospasm, bleeding, dislodged tumor, FB)	Incomplete reversal of muscle relaxants or opioid overdosage can cause hypoventilation. Obtain ABG if patient has difficulty breathing or is oversedated. Be prepared to reintubate patient. If nerve blocks used to depress gag reflex, no eating or drinking for several hours postbronchoscopy.
Pain management	Minimal pain; easily treated with iv opioids.	
Tests	CXR	Obtain CXR in recovery room to for atelectasis, pneumothorax, mediastinal emphysema.

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Airway Laser Surgery

Anesthetic Considerations

Preoperative

Patients usually present with complications related to long-term smoking and an airway mass (endobronchial, carinal, or tracheal). Resection tends to be a misnomer, as the laser is most commonly used for debulking of an unresectable lesion. Central airway obstruction is a primary concern when providing anesthesia.

Respiratory	It is imperative to define the exact location and magnitude of any central airway obstruction. This helps to estimate an appropriate ETT size and quantify the potential for obstruction during induction. CXR and CT scan must be studied. PFTs and flow volume loops may also characterize the lesion. **Tests:** PFTs; ABGs; CXR; CT scan (to delineate airway anatomy, including site and severity of airway lesion)
Musculoskeletal	Although there may be no clinically detectable muscle weakness, some of these patients will have Eaton-Lambert syndrome → ↓ sensitivity to NDMRs and ↑ resistance to depolarizing muscle relaxants.
Hematologic	Transfuse patients with preop Hct < 25% (or < 30%, if CAD present). **Tests:** Hct
Laboratory	Other tests as indicated from H&P.
Premedication	Minimal; avoid respiratory depressants; consider antisialagogue (e.g., glycopyrrolate).

Intraoperative

Anesthetic technique: Usually GA. Unexpected patient movement may be disastrous, which is why sedation and local anesthesia are rarely practical. Nd:YAG laser can be transmitted through a flexible quartz monofilament passed through either a rigid bronchoscope or FOB. Rigid bronchoscope provides improved visibility and better debris retrieval. It also maintains the airway with less chance of fire, although it can reflect the laser beam, causing tissue damage. Manual ventilation through the side-arm may be difficult. FOB is used with local anesthesia or through ETT under GA. Laser-safe ETTs (required for surgery in the proximal trachea) include regular ETTs wrapped in metallic tape or commercially available “laser” tubes (usually some combination of aluminum, stainless steel, Teflon, and/or silicon). Fill cuff with saline (+ methylene blue to facilitate leak detection) and avoid any petroleum-based lubricants on ETT. Steps also must be taken to protect the OR staff from laser injury. These include safety glasses to avoid ocular damage and specially designed and properly fitted filter face masks to protect from inhalation of vaporized viral particles. Photodynamic therapy is simpler in its considerations and risks: routine GETA with large ETT, immobile patient, and no risk of fire.

Induction	**Without or with distal airway obstruction** (past carina): Standard induction (see p. B-2). **With proximal airway obstruction:** Awake bronchoscopy may help to determine the feasibility of tracheal intubation. Awake fiberoptic intubation is the safest route. In patients with less severe obstruction, an inhalation induction with spontaneous ventilation may be appropriate. Avoid muscle relaxants until the airway has been secured. Several special laser ETTs are available though none guarantee against airway fire. The risk is minimized with Nd:YAG lasering of central airway lesions as the beam is directed distal to the tip of the ETT.

Maintenance	**With rigid bronchoscopy:** GA with standard or rapid sequence induction. Use isoflurane/desflurane/sevoflurane, air–O_2mixture. Keep FiO_2< 0.4. Avoid N_2O, which supports combustion. TIVA (p. B-2) with propofol (50–150 mcg/kg/min) and remifentanil (0.1–0.3 mcg/kg/min) infusion is preferable during rigid bronchoscopy as it avoids anesthetic contamination of the OR. Frequent suctioning during bronchoscopic examination may make inhalation techniques unreliable. Short-acting, nondepolarizing relaxant or succinylcholine infusion should be used to provide an immobile patient during laser use. If the patient becomes hypoxemic, ventilate the lungs with higher FiO_2 and ask the surgeon to stop.	
Emergence	Following rigid bronchoscopy, the patient usually is intubated until awake and breathing well and protective airway reflexes have returned. Emergence can be “stormy, ” with bleeding and secretion clearance a problem. Patient should be recovered in the sitting position.	
Blood and fluid requirements	IV: 14–16 ga × 1–2 NS/LR @ 1–2 mL/kg/h	There is a potential for massive blood loss following inadvertent perforation of a major blood vessel.
Monitoring	Standard monitors (p. B-1).	Continuous pulse oximetry essential; monitor $ETCO_2$to assess adequacy of ventilation ($ETCO_2$value may be inaccurate, consider ABG during long cases). Keep alveolar PAO_2< 40%.
Positioning	and pad pressure points. eyes and laser shields.	
Complications		From tumor, blood, tissue debris, etc. From inadequate ventilation. Can be massive from perforation of blood vessel by laser. Apply topical epinephrine following laser photocoagulation to control bleeding.
	Airway obstruction Hypoxemia/hypercarbia Bleeding	May be catastrophic secondary to pneumothorax/ pneumomediastinum, cardiac tamponade; lung isolation may be life saving.
	Perforation of tracheobronchial tree Airway fire	Rx: stop ventilation, remove O_2source, extubate trachea to decrease inhalation of toxic products. Douse fire with saline. Suction all debris from airway. Ventilate patient by mask, then reintubate. Prior to extubation, perform bronchoscopy to re-evaluate airway damage and suction debris. Consider steroids.
	Venous Air Embolism	Rx: Inform surgeon, d/c laser, prevent further entrainment. If access present, attempt to aspirate air. Immediately volume load and support circulation with vasopressors.

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Postoperative

Edema formation is difficult to appreciate simply based on epithelial changes during bronchoscopy. May progress dramatically

Complications	Airway edema	after the procedure resulting in airway obstruction and need for emergency reintubation. Steroids are routinely given to minimize edema formation (dexamethasone 6–8 mg iv). Nebulized racemic epinephrine is helpful. Complications such as hemorrhage or obstruction can be delayed up to 48 h.
Pain management	Minimal pain; rarely requires analgesic.	
Tests	Continuous pulse oximetry.	

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Video-Assisted Thoracoscopy Surgery (VATS)

Surgical Considerations

Description: Video-assisted thoracoscopy surgery (VATS) refers to the extension of laparoscopic and other minimally invasive techniques to thoracic surgery. Although initially used for the assessment of pleural processes of unknown etiology (e.g., pleural effusion that has defied diagnosis), VATS techniques are now accepted for treatment of spontaneous pneumothorax due to apical blebs, biopsy of peripheral infiltrates or nodules, talc pleurodesis, drainage of pleural effusions and other fluid collections, decortication of early empyemas, evaluation and evacuation of traumatic hemothorax, and standard pulmonary resections, such as wedge resection and lobectomy. Although not appropriate for all non–small-cell lung cancers, small, peripheral tumors without significant hilar of mediastinal lymph node involvement are often appropriate for VATS lobectomy. VATS also has been used for lung-volume reduction surgery (see p. 323), **esophageal (Heller) myotomy**, and **upper dorsal sympathectomy**. Less well-accepted procedures include **pneumonectomy** and **esophagectomy.**

In all VATS cases, use of a DLT to provide collapse of the ipsilateral lung is mandatory, because satisfactory visualization of the pleural cavity is impossible without this collapse of the lung. The patient is usually in the lateral position. Several small incisions are used—usually three, sometimes four or more. The video thoracoscope is placed through the first incision and the pleural cavity is inspected. Other small incisions are then made for insertion of instruments. The position of the video thoracoscope and instruments may be interchanged, depending on the location of the problem.

Usual preop diagnosis: Pleural disease (e.g., effusions); recurrent empyema; recurrent pneumothorax; localized lung masses; achalasia; pulmonary infiltrates; hyperhidrosis; reflex sympathetic dystrophy (RSD)

Summary of Procedures

Position	Lateral
Incision	Usually 3 to 5 small incisions (portals) (Fig. 5-16)
Special instrumentation	Video thoracoscope with thoracoscopy instruments; DLT required.
Antibiotics	Cefazolin 1 g
Surgical time	1–3 h
Closing considerations	Chest tube placed
EBL	Minimal, although there is a risk for major bleeding.
Postop care	Chest tube
Mortality	Minimal
Morbidity	Major vascular injury: Rare Conversion to open thoracotomy: 4% Pneumothorax/persistent air leak
Pain score	2–3

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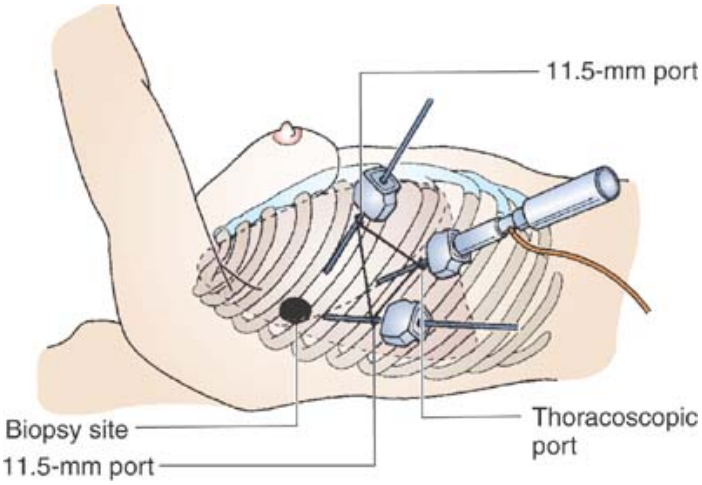

Figure 5-16. Example of thoracoscopic port placement. Positioning varies for individual need, but the principle of triangulation used for laparoscopic surgery is equally applicable in the thorax. (Reproduced with permission from Greenfield LJ, Mulholland MW, Oldham KT, et al., eds: *Surgery: Scientific Principles and Practice.* Lippincott-Raven Publishers, Philadelphia: 1997, 741.)

Patient Population Characteristics

Age range	All age groups
Male:Female	1:1
Associated conditions	Pleural effusions; lung mass; pneumothorax

Anesthetic Considerations

Preoperative

As VATS is used for both diagnostic and therapeutic purposes, this patient population is quite diverse: patients may be of any age group and may present with an asymptomatic mass or be in respiratory distress due to undiagnosed interstitial disease. VATS is also used for nonthoracic procedures such as sympathectomy, pericardial window and minimally invasive cardiac surgery.

The preop evaluation should focus on the patient's ability to

Respiratory	tolerate OLV, as well as the postop effects of the planned surgery. PFTs and ABG are useful prognostic tests. Question patient about dyspnea, productive cough, and cigarette smoking; examine for cyanosis, clubbing, RR, and pattern. Listen to chest for wheezes, rhonchi, and rales. Preop lung function may be improved by treating respiratory tract infections, stopping smoking for several weeks, and treatment with bronchodilators and steroids, as indicated. **Tests:** PFT; CXR; if chest CT available, look for airway anomalies that could interfere with DLT placement; ABG.
Cardiovascular	Directed at any underlying disease process.
Laboratory	As indicated from H&P.
Premedication	Standard premedication (see p. B-1). Avoid heavy sedation that might impair postop respiratory function.

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Intraoperative

Anesthetic technique: GETA, typically with OLV, using DLT or BB (see OLV, p. 278). OLV may be difficult to achieve in pediatric patients, so chest insufflation with CO_2 has been described, but is fraught with risks. Thoracoscopy has also been described in the awake, sedated patient under local or regional anesthetic technique. Although tissue trauma is significantly less than with the open thoracotomy, pain scores are not insignificant and chronic pain syndromes are common. Referred pain due to lung dissection, chest wall pain due to decortication and intercostal nerve impingements secondary to trocar insertion may cause marked postop pain. Multimodal therapy with opioid and NSAID is sufficient in many, but PCA may on occasion be required. Regional techniques (epidural or paravertebral) should be considered in compromised patients, in procedures with high conversion risk or in procedures with significant tissue trauma (e.g., decortication).

Regional anesthesia: The incision site is infiltrated with local anesthetics, and intercostal nerve blocks are performed at the level of incision and at several levels above and below incision. The same effect can be accomplished by multiple-level single-shot paravertebral nerve blocks which can be performed awake or asleep in the lateral position. Alternatively, continuous paravertebral or epidural catheters can be placed.

General anesthesia: The patient is intubated with DLT or BB to selectively collapse the operative lung. Anesthetic choice optional, but $FiO_2 = 1$ in anticipation of OLV to accelerate lung collapse. Lung collapse is slower than with thoracotomy due to lack of surgical pneumothorax. High FiO_2, early OLV, gentle suction and opening of trocar (to allow air inflow) can help to accelerate lung collapse. GA allows IPPV with complete re-expansion of lung without pain, if pleurodesis performed.

Induction	Standard induction (see p. B-2). Placement of DLT is discussed on p. 278.
Maintenance	O_2(60–100%) and isoflurane, desflurane or sevoflurane (0.6–1 MAC). No N_2O. Shortacting muscle relaxant and opioids as required. Consider remifentanil infusion (0.1–0.2 mcg/kg/min).
OLV	See pneumonectomy/lobectomy for OLV technique. p. 278
Emergence	Extubation in OR
Blood and fluid requirements	IV: 16–18 ga × 1 NS/LR @ 2 mL/kg/h

Monitoring	Standard monitors (p. B-1) ± Arterial line	Arterial catheter generally not required, unless indicated by patient's medical condition.
Positioning	and pad pressure points. eyes, ears, genitals.	See p. 268 for proper positioning.
Complications	Air leak from lung Hemorrhage Injury to intrathoracic structures Air embolism	Air leak observed on re-expansion of lung. Excessive blood drainage via chest tube; falling Hct Repair may require open thoracotomy.

Postoperative

Complications	Tension pneumothorax	In the absence of chest tube, air leak can → pneumothorax that can progress to tension pneumothorax if not treated. This may manifest as hyperresonance, ↓ chest-wall movement, dyspnea, subcutaneous emphysema, tracheal shift, dysrhythmias, cardiovascular collapse, ↓ PO_2 and ↓ SaO_2 CXR diagnostic, but need to diagnose clinically if hemodynamically unstable. Requires immediate decompression of tension pneumothorax with 14-ga iv catheter through 2nd intercostal space @ midclavicular line, followed by chest tube and continuous suction.
Pain management	IV opioids, ketorolac (30 mg) Intrapleural anesthesia Epidural or paravertebral	Analgesic requirements less than for lateral thoracotomy, but moderate to severe pain may occur and chronic pain is not uncommon. Intrapleural local anesthetics (0.25% bupivacaine + 1:200,000 epinephrine 0.5 mL/kg) via thoracostomy drainage tube after lung is reinflated but before chest tube suction applied. Indicated in patients with significant comorbidities and/or for procedures with significant tissue trauma (decortication, lobectomy).
Tests	CXR postop	

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Thymectomy

Surgical Considerations

Description: The two most common indications for **thymectomy are myasthenia gravis** and **thymoma.** The severity of myasthenia gravis can be classified using the Osserman scheme, which assigns Stage I to patients with ocular symptoms only, with Stages II-IV for progressive degrees of bulbar and systemic symptoms. Indications for surgery versus medical management remain controversial, with some neurologists referring nearly all patients with myasthenia gravis for surgery, whereas others referring only those with the most refractory symptoms. Patients referred for surgery often take a combination of pyridostigmine (Mestinon) and immunosuppressants (steroids and azathioprine). In cases of severe myasthenia gravis, preop plasmapheresis may be helpful in minimizing periop muscle weakness. Patients with thymoma may be asymptomatic, although 10–20% of them have a Hx of myasthenic symptoms.

Thymectomy can be a performed through a **complete sternotomy,** an upper sternal split (manubrium only), or via a cervical approach. The value of a complete sternotomy is that it allows for removal of all anterior mediastinal tissue that may harbor small thymic rests. This is the most invasive approach, however, and the one associated with the greatest degree of intraop tissue injury. An **upper sternal split** is performed with the neck extended and a roll placed under the shoulder blades. Either a short vertical incision or a transverse incision at the level of the sternal angle may be used. Division of only the manubrium provides adequate exposure for identification, dissection, and removal of the thymus. Mobilization of the thymus can be accomplished without entering the pleural space. Care must be taken to avoid injuring the phrenic nerves. In contrast with the removal of anterior mediastinal tumors, thymectomy usually does not require OLV.

Transcervical thymectomy is performed through a collar incision similar to that used for thyroidectomy (Fig. 7.11-3). The cervical extensions of the thymus are identified and the dissection is advanced progressively into the neck. Attachments of the gland are cauterized, and a clip is placed on the thymic vein (which drains directly into the innominate vein). Exposure is aided by a special retractor that elevates the sternum anteriorly and exposes the anterior mediastinum.

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At the conclusion of the operation—whether it is done through the chest or the neck—the thymic bed is drained with a small suction drain. Preop medications should be resumed as soon as possible.

Usual preop diagnosis: Myasthenia gravis; thymoma

Summary of Procedures

	Sternotomy	Cervical Approach
Position	Supine	
Incision	Median sternotomy	Suprasternal
Special instrumentation	None	Special sternal retractor
Antibiotics	Cefazolin 1 g	
Surgical time	1–2 h	
EBL	< 500 mL	
Postop care	ICU — special attention to muscle strength, related to respiratory function	
Mortality	< 5%	
Morbidity	Infection Pneumothorax Hemothorax	
Pain score	5–7	2

Patient Population Characteristics

Age range	Usually young adults
Male:Female	Females > males
Incidence	Infrequent
Etiology	Unknown
Associated conditions	Myasthenia gravis; benign or malignant thymoma; other autoimmune diseases (e.g., rheumatoid arthritis)

Anesthetic Considerations

Preoperative

Patients presenting for thymectomy may have myasthenia gravis, an autoimmune disease of the neuromuscular junction characterized by muscle weakness and easy fatiguability. Thymomas (benign or malignant) also may be associated with myasthenia gravis. The anesthesiologist needs to be aware of the possible compression effects of the tumor (see Excision of Mediastinal Tumor, p. 298), the potential for respiratory failure, and anticipate complications of various treatment modalities.

Respiratory	Patient may have marked reduction in VC 2° muscle weakness; establish baseline spirometry values. Classic (Leventhal) criteria predicting the need for postop ventilation include: duration of disease > 6 yr; chronic comorbid pulmonary disease; pyridostigmine dose > 750 mg/d; VC < 2.9 L. Others include preop use of steroids; and previous episode of respiratory failure. These predictors have not been widely validated. Inform the patient of the potential requirement for prolonged ventilation. **Tests:** PFTs, others as indicated from H&P.
Cardiovascular	There is a rare association between myasthenia gravis and cardiomyopathy. Consider ECG and cardiac consult if indicated from H&P.
Neurological	Review neurological assessment. Patients often exhibit diplopia, ptosis, and easy fatiguability of muscles. Difficulties with swallowing and speech are common. Review tests (EMGs, Tensilon test) done by neurologist to evaluate the adequacy of drug therapy (steroids, anticholinesterases, azathioprine, and cyclosporin A). Azathioprine (Imuran) may actually antagonize neuromuscular blockade by inhibiting phosphodiesterase. Cyclosporin A is reserved for severe disease because of the side effects of renal insufficiency and HTN. It may prolong neuromuscular blockade. 10–50% of the patients with thymomas will have myasthenia gravis and >85% of myasthenics will have thymus abnormalities.
Musculoskeletal	Determine adequacy of anticholinesterase medication. Evaluate hand strength, inspiratory efforts and PFTs. Note that an excess of anticholinesterase agents can cause weakness and respiratory failure (cholinergic crisis). A deleterious response (weakness) to Tensilon®; administration (10 mg), as well as the presence of cholinergic side effects (e.g., pupil constriction), characterize a cholinergic crises. Plasmapheresis may offer temporary (days to weeks) improvement in symptoms. Typically, patients with worsening symptoms receive 4–8 treatments prior to surgery. There should be a 24-h delay between the last plasmapheresis and surgery to restore clotting factors and immunoglobulins. Plasmapheresis also may transiently decrease plasma

	cholinesterase, which could prolong the effects of succinylcholine, mivacurium, and ester-type local anesthetics.
Endocrine	Other autoimmune phenomena occur in 10–15% of myasthenic patients. Elucidate symptoms of thyroid or adrenal disease.
Laboratory	Tests: TSH; evaluate screening test if indicated from H&P. Other tests as indicated from H&P.
Premedication	Avoid premedication; for the anxious patient, give a small dose of midazolam (0.5–1 mg); avoid opioids or any other sedatives that may depress ventilation. Current recommendations for anticholinesterases suggest that, in mild disease without physiological dependence, the morning dose can be held or halved. Patients with severe disease or with marked anticholinesterase dependence should receive their regular morning dose. For patients on steroids—depending on dosage and duration of steroid therapy—hydrocortisone (up to 100 mg iv bolus) before induction, then 100 mg q 8 h × 24 h, may be helpful. Note that acute steroid exposure in naïve patients may paradoxically exacerbate neuromuscular weakness. Consider aspiration prophylaxis.

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Intraoperative

Anesthetic technique: GETA, combined with thoracic or lumbar epidural if transsternal thymectomy. DLT may be requested by surgeon.

Induction	Inhalational induction with sevoflurane to avoid muscle relaxants entirely; however, patients with profound muscle weakness are at risk for aspiration 2° inadequate airway protective mechanism. Alternatively, iv propofol induction with remifentanil 1–2 mcg/kg (without muscle relaxants). If absolutely necessary, succinylcholine may be used to facilitate intubation, although myasthenic patients are considered resistant and require a dose of 1.5–2.0 mg/kg to obtain adequate conditions, which then will result in prolonged muscle weakness. Anticholinesterase therapy may prolong the duration of action of succinylcholine.
Maintenance	Standard maintenance (see p. B-2). Patients with myasthenia gravis have ↑ sensitivity to nondepolarizing NMBs, which are rarely ever needed, as maintenance with inhalational agents provides adequate neuromuscular relaxation when combined with the existing baseline weakness. If relaxants are needed, titrate small amounts (1/10 ED_{95}) of drug, using a peripheral nerve stimulator to maintain a single twitch. Cisatracurium (20–30 mcg/kg q 15–20 min or infusion 1–3 mcg/kg/min) is useful because it is rapidly eliminated. Alternatively, potent inhalation agents may provide adequate muscle relaxation, and avoid the need for any muscle relaxant. Avoid drugs with neuromuscular blocking effects (e.g., antidysrhythmics, calcium channel blockers, diuretics, aminoglycosides, Mg^{++}, iodinated contrast agents). Extremes of temperature, hypokalemia and hypophosphatemia may also aggravate neuromuscular weakness and should be prevented. If the patient has normal ventilatory function, then spontaneous ventilation during cervical thymectomy may be appropriate. Patients undergoing sternotomy, and any patient with ↓ pulmonary reserve, require mechanical ventilation.
Emergence	Criteria for extubation include: head lift (5 sec); MIF > -25 cmH_2O; TV > 5 mL/kg; and full reversal evidenced by twitch monitor. Extubate when fully awake; usually immediate postop ventilation is not necessary. Because of the variable response to muscle relaxation and delayed benefits of the surgery, some patients may require postop ventilation. Whether intubated or not, monitor patient for pulmonary function by measuring MIF and spirometry (Vt). Avoid residual pharmacologic neuromuscular blockade, which will → hypoventilation and ↑ risk of gastric aspiration if protective airway reflexes are inadequate.

Blood and fluid requirements	IV: 18 ga × 1 NS/LR @ 1–2 mL/kg/h	Consider lower extremity iv access when hemorrhage anticipated.
Monitoring	Standard monitors (p. B-1)	Avoid muscle relaxants if possible; use nerve stimulator.
Positioning	and pad pressure points. eyes.	
Complications	Hemorrhage Dysrhythmia Compression of mediastinal structures Pneumothorax	

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Postoperative

Complications	Pneumothorax Respiratory failure Phrenic nerve damage Myasthenic or cholinergic crises	Pleura can be entered–usually the right side; if so, chest tube needed. (For Dx and Rx, see VATS, p. 315)
Pain management	Parenteral opioids (p. C-2) Epidural opioids (p. C-2)	Avoid respiratory depression; parenteral opioids for cervical incision; epidural opioids for median sternotomy. Of note, anticholinesterases are reported to potentiate the effect of morphine.
Drug management	Usually ↓ anticholinesterase requirement in the immediate postop period.	Reduce daily anticholinesterase by 20%. Beware of 'cholinergic' crisis. Sx include ↑ salivation, sweating, lacrimation, abdominal cramps, urinary frequency, fasciculations, and weakness 2° anticholinesterase overdose. Rx: anticholinergic agent (e.g. atropine) ± intubation and mechanical ventilation.
	Tensilon (edrophonium)	Tensilon test may differentiate between myasthenic (↑ strength) and cholinergic (↓ strength) crises.
Tests	Muscle strength	Determine muscle strength postop (grip strength and sustained head lift).
	Pupil exam	Pupil dilation (myasthenic crisis); pupil constriction (cholinergic crisis).

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Excision of Blebs or Bullae

Surgical Considerations

Description: Pulmonary blebs or bullae requiring surgical treatment may vary from small, apical blebs—most usually seen in young people with spontaneous pneumothorax—to expanding, giant bullae causing respiratory distress. Specific indications for bullectomy include large size (> 30% of the lung), recurrent pneumothorax, dyspnea in conjunction with compressed adjacent parenchyma, and recurrent infection of the bullae. The small blebs can be excised through **video thoracoscopy** (see p. 313), although some surgeons still prefer an open technique for this procedure. Giant bullae are generally removed by **open thoracotomy,** although these lesions also may be excised by VATS techniques. In either case, the goal is to resect the nonfunctional bullae and allow the compressed, yet relatively preserved lung tissue to re-expand and contribute to gas exchange. The surgical technique generally involves **stapling** across the base of the bulla with reinforcing strips being applied to the staple line to minimize air leak. Alternatively, a **clamp and suture** technique may be used. However the most important point is that an airtight closure should be obtained as a prolonged air leak can be very debilitating. Patients undergoing operation for giant bullae frequently have limited pulmonary reserve and present formidable operative risks. Because the operation is planned to improve their pulmonary function, however, these patients frequently do well following operation. **Pleural abrasion** or, rarely, **pleurectomy** may accompany the excision of blebs or bullae. The blebs in young patients with recurrent spontaneous pneumothorax usually are located at the apex of the upper lobe. Bullae in patients with emphysema are usually in the upper lobe, but may be anywhere in the lung. Preop localization by CT scan is usually sufficient. If a thoracotomy is done, the approach is usually lateral.

Variant procedure or approaches: Patients with more generalized emphysema may be candidates for lung-volume reduction surgery (see p. 323).

Usual preop diagnosis: Spontaneous pneumothorax 2° ruptured blebs; giant bullae causing respiratory distress

Summary of Procedures

Position	Usually lateral
Incision	Axillary
Special instrumentation	Staplers
Antibiotics	Cefazolin 1 g
Surgical time	1–3 h
EBL	< 500 mL
Postop care	PACU → room; ICU or IIC for giant bullae
Mortality	Minimal

Morbidity	Air leak: 20% or more in giant bullae
Pain score	5–7

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Patient Population Characteristics

Age range	Young adults (blebs/small bullae); elderly (large bullae)
Male:Female	3:1
Incidence	Not uncommon
Etiology	Emphysema (usually 2° smoking); congenital; infectious
Associated conditions	Spontaneous pneumothorax; emphysema; long smoking Hx; a-antitrypsin deficiency

Anesthetic Considerations

Preoperative

Patients with apical blebs tend to be young with normal lung function and otherwise healthy. Bleb resection in these patients tends to be a routine thoracoscopic wedge-resection procedure. Patients with bullous emphysema on the other hand, may have end-stage lung disease, often with pulmonary hypertension and RV dysfunction. The risk of rupture of a bulla/bleb on the nonoperated side, with resultant tension pneumothorax, must be considered throughout the procedure. The majority of considerations and concerns therefore relate to the patient with bilateral disease. Most procedures are done thoracoscopically.

Respiratory	Cysts may be bronchogenic, postinfective, infantile, or emphysematous. With blebs, elicit Hx of repeat pneumothoraces. Bullae usually result from destruction of alveolar tissue; they represent end-stage emphysematous disease associated with severe COPD. Patients may have incapacitating dyspnea and limited pulmonary reserve. CO_2 retention ± hypoxia may be present. Obtain PFTs and ABG for baseline. **Tests:** CXR; presence of pneumothorax; if chest CT available, look for bilateral bullous disease and rule out airway anomalies that could interfere with DLT placement; ABG, as indicated from H&P.
Cardiovascular	**Tests:** ECG
Neurological	Hx for previous back surgery, peripheral neuropathy. Examine thoracolumbar area for skin lesions, infection, deformities.
Hematologic	Transfuse patient with preop Hct < 25% (Hct < 30% if patient has CAD). Cross-match 2 U of blood or obtain 1–2 U of autologous blood during the month before surgery, or consider erythropoietin therapy in patients who are anemic. **Tests:** Hct
Laboratory	Other tests as indicated from H&P.
Premedication	Midazolam 1–2 mg iv if patient anxious and not in respiratory distress. Minimize sedation if planning epidural placement, as the combination of parenteral sedation and epidural opioid may result in significant respiratory depression.

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Intraoperative

Anesthetic technique: GETA—combined with regional technique if open thoracotomy.

Induction	**Minor Bleb:** standard induction (see p. B-2) **Major bullae (particularly bilateral):** main issue is risk of pulmonary tamponade/tension pneumothorax secondary to bulla expansion by PPV. Best to establish lung isolation prior to instituting PPV (DLT essential in bilateral disease, to allow for ventilation/exclusion of either side; BB sufficient for unilateral disease). Strategies include awake intubation (difficult with DLT), spontaneous ventilation induction (inhalational or iv), or, in patients with easy airway anatomy, a true rapid sequence intubation. Lung isolation should immediately be confirmed with FOB prior to providing PPV. Rapid placement of a chest tube is essential should a bulla rupture.	
Maintenance	Patients with severe COPD may have significant auto-PEEP. To avoid worsening dynamic hyperinflation of lung, treat bronchospasm aggressively and allow adequate expiratory time (↓ I:E ratio, low RR). Caution with applied PEEP: it may increase total PEEP (and therefore air trapping). Minimize risk of bulla rupture by reducing ventilatory pressures (low tidal volumes, permissive hypercapnia and pressure-control ventilation @ < 20cmH_2O). Inhalational anesthesia supplemented with epidural, local anesthetics, or iv opioids. Avoid N_2O at all times, because bullae may be filled with air.	
Emergence	Re-expand lung under direct vision to check for major air leaks. Extubate patient early. Post-bullectomy, unlike other lung resections, patients have greater functional lung tissue than preop.	
Blood and fluid requirements	IV: 16 ga × 1 NS/LR @ 1–2 mL/kg/h Use vasopressors if hypotensive.	Excess fluid predisposes to right heart failure. Epidural local anesthetics can ↓ BP in a volume-restricted patient; vasopressor often needed (e.g. ephedrine 5–10 mg iv bolus or phenylephrine 50–100 mcg iv bolus).
Monitoring	Standard monitors (p. B-1) Arterial line ± CVP, ± PA line, ± TEE	for patients with coexisting severe cardiac disease
Positioning	and pad pressure points. eyes, ears, genitals. Axillary roll; “airplane” for upper arm	See Positioning, p. 268.
Ventilation	DLT or BB needed to separate the lungs.	Allows PPV of the nonoperative lung. Use gentle PPV (pressure control) with low Vt, permissive hypercapnea ($PaCO_2$ 50–70 mmHg). Inspiratory pressure should be as low as possible (10 cmH_2O), to reduce likelihood of rupture of bullae in nonoperative lung. Treat intraop hypoxemia with CPAP to “up” lung. In extreme cases consider CPB (rare).
Complications	Tension pneumothorax	Can occur on either side during induction, only on nonoperated side after chest is open, and again on either side postop. Presents with ↑ ventilatory pressure, progressive tracheal deviation, wheezing, cardiovascular collapse. CXR to r/o tension pneumothorax. Rx: insertion of chest tube.
	Broncho-pleural-cutaneous fistula	Placement of a chest tube can create a broncho-pleural-cutaneous fistula. Rx: low Vt, spontaneous ventilation; may require DLT for differential ventilation.
	Hypoxia Hypercardia Dysrhythmias	position of DLT, suction DLT, avoid hypo-ventilation.

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Postoperative

Complications	Hypoventilation Dental damage Airway trauma Pneumothorax Hemorrhage Risk of aspiration Airway obstruction (bronchospasm, bleeding, dislodged tumor, FB)	Ensure complete reversal of muscle relaxants, and patient wide-awake with good respiratory effort prior to extubation. Obtain ABG if patient has difficulty breathing or is overly sedated. If nerve blocks used to depress gag reflex for awake FOI, keep patient NPO for several hours postop.
Pain management	Epidural opioids (see p. C-2). Parenteral opioids	Parenteral opioids + intrapleural local anesthetics (0.5% bupivacaine + 1:200,000 epinephrine, 0.5 mL/kg) + single-shot paravertebral blocks are adequate for thoracoscopy.
Tests	CXR	ABG if indicated.

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Lung-Volume Reduction Surgery

Surgical Considerations

Description: Lung-volume reduction surgery (LVRS) was initially described by Brantigan in 1958 but reintroduced by Joel Cooper in 1995 for the treatment of severe emphysema. Typically, patients referred for LVRS are chronically ill, requiring steroids, bronchodilators, and supplemental O_2. With appropriate preoperative selection and perioperative care, these patients survive surgery and demonstrate improved pulmonary function. Physiologically, reducing the volume of the lung by resecting diseased tissue improves elastic recoil and decreases airway resistance. The chest cavity also is reduced in size, thereby improving chest-wall and diaphragmatic function.

The procedure can be carried out either through a median sternotomy or endoscopically. The **open approach** begins with a median sternotomy. OLV is initiated following opening of the pleurae. Often the diseased portions of the lung remain inflated, whereas healthy areas develop absorption atelectasis. These diseased portions are resected with the aid of a linear stapler. The visceral pleura

are very thin; the stapling is done with bovine pericardium to bolster the staple line; and high inspiratory pressures (> 20 cmH_2O) must be avoided. From 15–30% of the lung volume may be removed. Following careful examination for air leaks, the pleurae and chest wall are closed.

The **endoscopic approach** is carried out using standard VATS techniques and instrumentation. Diseased tissue will have been identified preop using V/Q and CT scans. Endoscopic forceps are used to guide this diseased tissue into the jaws of the stapler. Again, 15–30% of lung tissue may be removed by this means. At *(Print pagebreak 324)* some centers, the anesthesiologist may be asked to measure inspiratory and expiratory volumes. Any difference between these volumes may represent an air leak requiring further exploration. Following this, access ports and the thoracotomy are closed, and chest tubes are placed. The patient is turned over to the opposite side, reprepped and redraped, and the surgery is repeated. With either approach, patients should be extubated in the OR so that no unnecessary ventilatory pressures are put on the lungs. There is usually no suction on the chest tubes and, thus, a water seal is the primary method of controlling the pleural cavity pressures. A small pneumothorax (≥ 10%) is acceptable if the patient is not in respiratory distress. A functional epidural catheter, early extubation, and the avoidance of chest tube suction are important to the success of this procedure, especially in the very ill patient. Pleural drainage consists of two chest tubes per side; in contrast with lobectomy, however, they are often left to water seal so as not to exert excessive negative pressure on the lung and disrupt the staple lines. Ideally, patients are extubated at the conclusion of the operation. Because their respiratory status is often tenuous, close monitoring, vigorous pulmonary toilet, and good pain control are essential in the postop period.

Usual preop diagnosis: COPD (emphysema)

Summary of Procedures

	Open LVRS	Endoscopic LVRS
Position	Supine	Lateral decubitus
Incision	Sternotomy	Minilateral thoracotomy
Special instrumentation	Stapling devices; DLT	+ Endoscopic instrumentation
Unique considerations	Bovine pericardium to bolster staple line	
Antibiotics	Cefazolin 1 g	
Surgical time	2 h	45–60 min/side
Closing considerations	Avoid high PIPs (> 20 cmH_2O)	
EBL	Minimal	
Postop care	Extubated in OR; avoid chest tube suction	
Mortality	≥ 5–10%	
Morbidity	Pneumothorax Infection Tearing of suture line Wound healing problems	
Pain score	6–8	4–6

Patient Population Characteristics

Age range	> 50 yr
Male:Female	Male > female
Incidence	Although the incidence of emphysema is high in the general population, only a fraction of these patients will be candidates for LVRS.
Etiology	Smoking; genetic factors
Associated conditions	CAD; pulmonary HTN; PVD; cerebrovascular disease

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Medical history	Severe COPD (emphysema rather than chronic bronchitis) Age < 75 yr No cigarette smoking for 6 mo Lowest effective prednisone dose No previous chest surgery
Pulmonary function	FEV_1>30–35% of predicted $PaCO_2$< 50 mmHg TLC > l20% of predicted
Cardiac function	Mean PAP < 35 mmHg (if pulmonary HTN is suspected). No evidence of LV dysfunction on dobutamine stress testing (if Hx of angina or CHF is present)
Radiographic	Hyperinflation; flatted diaphragm (CXR) Decreased upper lobe perfusion (Ventilation-Perfusion scan) Emphysema, with upper lobe predominance (CT scan)
Relative exclusion criteria	Continued smoking Illness other than emphysema that may cause severe dyspnea (e.g. CAD; CHF; cancer; interstitial lung disease; bronchiectasis) Severe malnutrition Obliteration of pleural space (e.g., pleurodesis or pleurectomy) Previous thoracic surgery Morbid obesity Severe pulmonary HTN (mean PAP > 35) Chest-wall deformity with restrictive lung disease (e.g. kyphoscoliosis; severe pectus deformity; $PaCO_2$> 55 mmHg

Anesthetic Considerations

Preoperative

LVRS involves either laser thermal contraction or surgical resection of emphysematous lung tissue. Patients have end-stage emphysema with associated pulmonary HTN and RV dysfunction. These patients are a great challenge to the anesthesiologist, because it may be difficult to maintain relatively normal physiologic parameters intraop, and to have an awake, comfortable, and spontaneously breathing patient at the completion of surgery.

Respiratory	These patients have advanced pulmonary emphysema. Examine patient for cyanosis, clubbing, RR and pattern. Listen to chest—breath sounds are often very distant or absent. Hx should include use of O_2supplementation, recent infection, severe bronchospasm, prior surgery on the chest, and other associated diseases, such as CAD or CHF. **Tests:** PFT (± bronchodilators). Hyperinflation usually is indicated by TLC and RV value > 120%; V/Q scan; CXR; chest CT scan; noninvasive exercise test (6-min walk); preop ABG—check for hypoxemia, hypercarbia.
Cardiovascular	These patients often have coexisting cardiac disease with pulmonary HTN. **Tests:** right heart function can be determined by echocardiography or selective right heart catheterization, if indicated by H&P.
Premedication	Avoid premedication with sedative or opioids—cannot have respiratory depressants' patients have severe COPD, often are CO_2 retainers.

Intraoperative

Anesthetic technique: GETA (with DLT or BB) ± epidural anesthesia. Place and test epidural catheter before surgery. (See Lobectomy, Pneumonectomy, pp. 276–279.)

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Induction	Standard induction (see p. B-2). DLT or BB absolutely necessary during surgery to selectively ventilate each lung. DLT preferable if severe bilateral disease with increased risk of pneumothorax (See Lobectomy, Pneumonectomy, p. 277).
Maintenance	Inhalational agent and/or propofol. IV opioids and sedative agents should not be used (exception, remifentanil infusion intraop). Anesthesia may be supplemented by continuous or bolus administration of epidural anesthetics. Mechanical ventilation with O_2 and inhalation agent only. During TLV: Vt = 6–10 mL/kg, limit PIP to < 25 cmH_2O (best to use PCV). Respiratory rate and inspiratory flow should be adjusted to minimize air trapping (low RR, long E-time). Beware of overinflation and 'breath stacking,' which can → pulmonary tamponade with severe ↓ BP and ↑ airway resistance. ABG to determine $ETCO_2$ $PaCO_2$ gradient. During OLV use PCV for Vt = 4–8 mL/kg, long E-time, RR 6–10, and permissive hypercapnia ($PaCO_2$ 50–70 mmHg); monitor lung compliance closely because the ventilated lung also has emphysema/bullous disease. Avoid overdistention with hyperinflation (→ pneumothorax) on ventilated, nonoperated lung. Patients with severe COPD may have significant auto-PEEP. To avoid dynamic hyperinflation of lung, treat bronchospasm aggressively, allow adequate expiratory time (↓ I:E ratio), limit PIP to 15–20 cmH_2O, and cautiously use applied PEEP, as it may increase total PEEP (best managed with in-line spirometry). Moderate hypercapnia is well tolerated, but higher levels may result in significant pulmonary HTN, RV dysfunction, and tachydysrhythmias. CPAP to nonventilated lung may be necessary to maintain oxygenation. Maintenance of hemodynamic stability may require pressor support (e.g., ephedrine, phenylephrine, dopamine). Dynamic hyperinflation of the lung (pulmonary tamponade) during mechanical ventilation should be suspected if ↓ BP with ↑ PIP occurs.
Emergence	Emergence is a critical time for these patients. All physiologic parameters need to be optimized. Air leaks are common and may be worsened by prolonged mechanical ventilation, coughing or straining on the ETT. Different options are available to achieve those goals, including deep extubation or deep conversion to spontaneous pressure-support ventilation. Either way, ventilation has to be assisted until patients are wide-awake, comfortable, warm and maintaining adequate respiration with minimal support. These patients are critically dependent on good analgesia, upright/sitting position, and suctioning to ↓ mucous plugging (can be catastrophic). Recovery from GA occurs in the OR and may take 1–2 h. Ventilatory assistance via face mask with supplemental O_2 is usually necessary. ABG and CXR may be useful. When spontaneous ventilation and analgesia are satisfactory, the patient is transported to ICU. If postop mechanical ventilation is required, consider using pressure support ventilation with low levels of CPAP. The CPAP may help minimize the inspiratory work of breathing caused by lung hyperinflation. The pressure support mode of ventilation will permit control of airway pressure, while allowing patient control of $PaCO_2$ If postop intubation is anticipated, changing from DLT to ETT is required.
Blood and fluid requirements	IV: 14–16 ga × 1 LR @ 1–2 mL/kg/h Autologous PRBC	Fluid management to restore preop deficit and provide maintenance fluid, but restrict fluids similar to lung resection surgery. Replace minor blood loss with colloid. Transfuse autologous blood for Hct < 30. (See Lobectomy, Pneumonectomy, p. 277).
Monitoring	Standard monitors (see p. B-1). Arterial line Urinary catheter CVP and/or PA line	ABGs: baseline (preop) during sternotomy; 15 min after initiation of OLV; 15 min after initiation of OLV on the second lung; during closure of sternotomy; prior to extubation.

		Useful for postop fluid management. Depending on level of PHTN, RV dysfunction and co-morbid CAD
Positioning	and pad pressure points. eyes, ears, genitals.	Axillary roll and support for upper airway is necessary for the lateral decubitus position. (See Lobectomy, Pneumonectomy, p. 277.)

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Postoperative

Complications	Hypercarbia Hypoxemia Air leak/pneumothorax Hemorrhage	
Pain management	Lumbar or thoracic epidural opioids ± local anesthetics (see p. C-2).	Essential that patient be comfortable. Begin infusion of epidural opioids and local anesthetics (see Lobectomy, Pneumonectomy, p. 279). Breakthrough pain treatment options include iv hydromorphone (cautious boluses of 0.2–0.5 mg) and/or ketorolac (10–30 mg).

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Bronchopulmonary Lavage

Surgical Considerations

Description: Whole-lung bronchopulmonary lavage is occasionally required for patients with pulmonary alveolar proteinosis–a condition characterized by excessive (or abnormal) surfactant production with resultant flooding of the lungs with proteinaceous fluid. Although the underlying cause of the condition is unclear, treatment consists of periodic whole lung lavage and, more recently, GM-CSF administration. It is our practice to perform **unilateral lavage** only, although single-session, bilateral lavage has been reported. After induction of GA, a DLT is placed, and the correct position is confirmed bronchoscopically. The lung is then lavaged in aliquots of 500–1000 mL NS or 0.5–1.0 L NS to dilute and wash out excess alveolar surfactant, pus, or mucus, and to obtain material for cytological and histochemical examination. Care should be taken not to overdistend the lung, and a running tally of fluid instilled and withdrawn should be performed to avoid overhydrating the patient. Frequently, 9–12 L of fluid are used, with the initial effluent being very cloudy and the final effluent being clear. Techniques that may improve the distribution of the lavage fluid include external chest percussion and tilting the operating table (laterally as well as in the craniocaudal directions).

Usual preop diagnosis: Pulmonary alveolar proteinosis; refractory asthma; cystic fibrosis; bronchiectasis; lipoid pneumonitis; silicosis; alveolar microlithiasis; inhalation of radioactive dust

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Summary of Procedures

Position	Supine or lateral decubitus
Special instrumentation	Bronchoscope; DLT; lavage fluids
Antibiotics	None
Surgical time	45 min/side
EBL	None
Postop care	PACU → home
Mortality	Rare
Morbidity	Aspiration of lavage fluid Pneumothorax/hydrothorax Atelectasis
Pain score	1–2

Patient Population Characteristics

Age range	17–35 yr
Male:Female	1:1
Incidence	Uncommon
Etiology	Pulmonary alveolar proteinosis; cystic fibrosis; bronchiectasis; lipoid pneumonitis; silicosis
Associated conditions	Asthma and other abnormalities of lung function

Anesthetic Considerations

Preoperative

Although whole-lung lavage is primarily a treatment for pulmonary alveolar proteinosis, it is also used as a therapeutic modality for many other lung-related conditions (see Usual preop diagnosis, above). Respiratory dysfunction of variable symptomatology is expected in these patients. Indications for whole-lung lavage include dyspnea on exertion, resting room air PaO_2 < 60 mmHg, or shunt fraction > 10–12%. Because the procedure requires GA with OLV, it is recommended that preop V/Q scans be obtained so that unilateral lung irrigation can be performed first on the more severely affected lung. If both lungs are equally diseased, lavage should be performed on the left lung initially to allow the larger right lung to be used for ventilation to provide better gas exchange. Patients then return in subsequent days or weeks for therapeutic lavage of the contralateral lung. A nonoperative treatment option for pulmonary alveolar proteinosis using granulocyte-macrophage colony-stimulating factor (GM-CSF), has shown promise for some patients with the acquired form of pulmonary alveolar proteinosis.

Respiratory	Patients with pulmonary alveolar proteinosis generally present with cough (nonproductive > productive), dyspnea, and fatigue. Physical findings consist of diffuse rales ± clubbing or cyanosis. CXR typically reveals diffuse bilateral patchy airspace consolidation. Pulmonary compliance is reduced 2° the restrictive disease pattern. PFTs show ↓ TLC, ↓ RV, ↓ VC, and ↓ D_LCO. Though nonspecific, baseline ABGs classically demonstrate respiratory alkalosis and hypoxemia, with a calculated elevation in A-a DO_2gradient. Some patients may be O_2dependent or have concomitant COPD 2° Hx of smoking. Secondary infections, especially in the respiratory tract, are well recognized risks in these patients. Cessation of smoking (> 6–8 wk) and prompt treatment of any underlying infections before whole-lung lavage may be prudent. **Tests:** CXR; PFT; ABG; V/Q scans; ± CT
Cardiovascular	Directed at any underlying disease process.
Laboratory	Abnormal elevation of serum LDH has been reported in some patients and has been shown to correlate with the severity of A-a DO_2 Tests: LDH; other tests as indicated from H&P.
Premedication	Standard premedication (see p. B-1). Avoid heavy sedation that might impair adequate gas exchange before induction. O_2 supplementation may be required after premedication.

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Intraoperative

Anesthetic technique: GETA is required with OLV (see p. 278) using a DLT. In pediatric patients or small adults where appropriate sized DLT is not available, and in patients who cannot tolerate OLV, the use of partial venoarterial CPB, venovenous bypass, or even ECMO has been reported. In some cases, sequential lobar lavage with smaller volume of lavage fluid has been achieved under conscious sedation for those patients in whom OLV is not possible.

Induction	Standard induction (see p. B-2) with thorough preoxygenation. The largest DLT should be used to facilitate infusion and drainage of the lavage fluid. (Placement of DLT is discussed on p. 278.) Due to the underlying impaired respiratory function in these patients, instituting OLV will further compromise gas exchange. It is imperative to avoid spillage of lavage fluid into the ventilated lung during the procedure. This is achieved by verifying the correct position of the DLT with FOB and confirming the competency of the cuff seal by testing it against pressures as high as 50 cmH_2O. Baseline individual lung compliance, airway pressures, and ABG should be ' d after DLT placement.
Maintenance	100% $FiO_2$with inhalational agent (e.g., sevoflurane) or TIVA using propofol and remifentanil infusions. Muscle relaxation is necessary to avoid movement or coughing that can cause leakage of lavage fluid into the ventilated lung. Because chest physiotherapy, including vibration and percussion, is required after each cycle of lavage filling, any deleterious change from baseline lung compliance decrease or airway pressure increase of the ventilated lung should prompt the anesthesiologist to look for

	evidence of spillage. Filling the nonventilated lung with lavage fluid can → ↓ pulmonary shunting (→ improved O_2sat) and ↑PVR (→↓ CO). Draining the lavage fluid can → → pulmonary shunting (→↓ O_2sat) and ↓ PVR (→ → CO). Accurate inflow and outflow volume of the lavage fluid should be recorded to ensure return volumes are 90%.
Emergence	At the conclusion of surgery, the lavaged lung should be adequately suctioned to remove any residual fluid. Bilateral lung ventilation should be reinstituted. Because the compliance of the lavaged lung is greatly reduced, higher airway pressures are required to re-expand it, but at the risk of causing barotrauma to the nonlavaged lung. A brief period of OLV to the lavaged lung, using large TVs or ↑ airway pressure, may be necessary to recruit the collapsed alveoli (higher pressure, including PEEP, is needed to counter the increase in surface tension after the removal of significant amounts of surfactant). The patient's trachea should be extubated after adequate reversal of muscle relaxation; however, if prolonged postop ventilation is anticipated (e.g., in those who aspirated lavaged fluid to the ventilated lung), changing the DLT to single lumen tube is indicated. DLT should be maintained for patients in whom differential lung ventilation is required postop.
Blood and fluid requirements	IV: 18 ga × 1 NS/LR @ 1–2 mL/kg/h
Monitoring	Standard monitors (p. B-1) Arterial line ± CVP line ± PA line
Positioning	Supine and pad pressure points. eyes.
Complications	Hypoxemia

Although warmed lavage fluid is used, some patients may become hypothermic after several hours of lavage under GETA.

CVP or PA line only needed as indicated by comorbid conditions. Consider fluoroscopic or TEE guided positioning of a PA catheter to the lavaged lung. In doing so, the therapeutic potential of the catheter may be realized. Selective occlusion of pulmonary arterial blood flow can improve matching of blood flow to ventilation.

Some prefer the lavaged lung to be dependent to minimize the risk of contaminating the contralateral lung with lavage fluid. Others prefer the lavaged lung to be nondependent because, in this position, perfusion will more closely match ventilation in the dependent lung. As a compromise, we perform lavage with the patient supine. However, intermittent manipulation of the patient position may be required to facilitate the lavage and drainage of any retained fluid. Prevention of DLT displacement during repositioning is paramount.

Hypoxemia during OLV is most commonly 2° luminal obstruction (by blood or pulmonary secretions) of the DLT, worsening of shunting, or malposition of DLT. Rx: suctioning of the DLT; PEEP to ventilated lung (may ↑ shunting); return to two-lung ventilation; and DLT position. In extreme cases, temporarily inflating the balloon of the PA catheter (if available) may be necessary to improve shunting and, thus, oxygenation. Inadequate positioning of the DLT demands stopping further installation of fluid. Most authors recommend suspending the lavage fluid 30 cm above the midaxillary line. Instilling

		fluid from excessive height or under pressure may precipitate pulmonary edema. Ensure adequate TV and RR.
	Hypercarbia Aspiration	
		DLT position. Turn patient to lavaged side down and head down, suction the ventilated lung, reinstitute bilateral lung ventilation with PEEP, after the lavaged lung is thoroughly drained and suctioned. Termination of procedure may be needed in severe cases. Patient may need to be kept intubated after the procedure.

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Postoperative

Complications	Pneumothorax Hydrothorax Atelectasis	Obtain CXR; conservative measures if small pneumothorax or hydrothorax. Otherwise, chest tube placement will be required. Decrease in surfactant after lavage will → airspace collapse. Most patients will experience moderate coughing, which will help re-expand the atelectatic lung units.
Pain management	Parental opioids or NSAID (ketorolac 30 mg iv)	Some patients may experience chest pain due to vigorous intraop percussion.

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Lung Transplant

Surgical Considerations

Description: The most common indications for lung transplantation include emphysema, pulmonary fibrosis, cystic fibrosis, and pulmonary hypertension. Patients with the first three of these diagnoses have marked abnormalities in mechanical pulmonary function, whereas patients with pulmonary HTN often have normal lung mechanics but very abnormal cardiac function. Patients with emphysema and pulmonary fibrosis often receive single-lung transplants, and those with cystic fibrosis require double-lung transplants. The best operation for patients with pulmonary hypertension continues to be debated, with options including single-lung, double-lung, and heart-lung transplantation (see p. 456). Although candidates for lung transplantation, by definition, have end-stage lung disease, their overall state of health and functional abilities vary considerably. Furthermore, although these patients all have poor pulmonary function, many with multisystem disease are eliminated during the preop screening process. Thus, the remaining patients are generally well motivated and free of significant cardiac, renal, and vascular disease.

Single-lung transplants generally are carried out through a thoracotomy incision. Patients with emphysema as the underlying disease rarely require CPB, whereas those with pulmonary fibrosis ↓ pulmonary reserve and ↑ incidence of pulmonary HTN) more commonly require bypass. Although the need for bypass can be assessed at the outset of the operation by instituting OLV, a CPB circuit and perfusionist should always be available. The route for vascular access for bypass (transthoracic or through the groin vessels) must be considered by the surgeon at the start of the case.

Double-lung transplants generally are done through bilateral anterior thoracotomies or a single bilateral ‘clamshell’ incision (Fig. 5-2). Mobilization of the lung is facilitated by use of a DLT. If the patient does not tolerate OLV, CPB can be established using aortic and atrial cannulation. Some surgeons routinely use a single-lumen ETT, with a defined plan for using CPB.

The procedure for both single- and double-lung transplantation is the same for each side. The native lung is mobilized, and the bronchovascular structures are divided. Mediastinal adenopathy and extensive pleural adhesions are the rule, rather than the exception, for patients with cystic fibrosis. Such pneumonectomies take significantly longer than those for emphysema. Once the native lung is removed, the donor lung is brought into the surgical field. The bronchial anastomosis is created first, and the lung is allowed to fall into the posterior costovertebral gutter. The venous anastomosis (atrial cuff anastomosis) is fashioned next. The final sutures are placed but left untied for later deairing. The arterial anastomosis is created last. Upon removal of the arterial clamp, the lung is perfused and deaired. The venous sutures are then tied and the atrial clamp is removed. After ensuring that the vascular anastomoses are hemostatic and that there is no air leak at the bronchial site, the incision is closed or, in the case of double-lung transplant, attention is directed to the other side.

The anesthesiologist should be aware that hypotension is not uncommon on reperfusion of the donor lung, but that it usually resolves spontaneously. Specific immunosuppression protocols vary from institution to institution, but intravenous administration of steroids immediately before lung reperfusion is a common practice. Lung transplant patients typically are left intubated following surgery; however, changing from a DLT to a single-lumen tube at the conclusion of the operation facilitates postop ET suctioning.

Usual preop diagnosis: COPD; pulmonary fibrosis; cystic fibrosis; pulmonary HTN; Eisenmenger's syndrome.

For Summary of Procedure and Anesthetic Management, see Surgery for Lung and Heart/Lung Transplantation, p. 456, and Anesthetic Considerations for Lung Transplantation, p. 458.