As the population ages, the number of patients in whom lung disease develops and who require surgical intervention will continue to rise. When compared with open thoracotomy, video-assisted thoracoscopic surgery (VATS) offers patients significant advantages. Decreased invasiveness results in less blood loss, a lower rate of infection, and less postoperative pain and allows for quicker recovery. A description of the significant physiologic changes related to pulmonary blood flow, ventilation, and perfusion when patients are placed in the lateral decubitus position is included.

A common method of providing one-lung ventilation during VATS is via a double-lumen endotracheal tube. Proper use, placement, ventilation strategies, and methods to minimize the incidence and treat hypoxia for a double-lumen tube are reviewed. One-lung ventilation poses significant challenges for anesthetists. As a result, adequate preparation during the preoperative, intraoperative, and postoperative phases is essential.

**Keywords:** Double-lumen endotracheal tube, one-lung ventilation, video-assisted thoracoscopic surgery.

## Objectives
At the completion of this course, the reader should be able to:
1. Describe the physiologic changes associated with the lateral decubitus position and one-lung ventilation.
2. Examine interventions used to correctly insert and confirm placement of a double-lumen endotracheal tube.
3. Identify methods to treat hypoxia during video-assisted thoracoscopic (VATS) surgery.
4. Discuss complications that can occur during VATS.
5. Discuss postoperative pain management strategies after VATS.

## Introduction
In an attempt to decrease postoperative pain and hospital stay and increase patient satisfaction, the use of minimally invasive approaches for lung surgeries is increasing. In thoracic surgery, minimally invasive techniques using operative telescopes and video technology are referred to as video-assisted thoracoscopic surgery (VATS). When first introduced into clinical practice, VATS was limited to short diagnostic procedures. However, improved technology coupled with increased familiarity with thoracoscopic techniques has enabled surgeons to perform many diagnostic and therapeutic thoracic surgeries in a minimally invasive manner. Most VATS procedures are performed...
using general anesthesia and one-lung ventilation (OLV) techniques, which provide optimal surgical exposure, a motionless surgical field, and a secure airway.

**Physiology**

During 2-lung ventilation, there is a ventilation/perfusion (V/Q) mismatch in an anesthetized, paralyzed, open-chest patient who is positioned in the lateral decubitus position. The 2 primary reasons for V/Q mismatch are that greater ventilation but less perfusion occurs to the nondependent lung and less ventilation but more perfusion is present in the dependent lung. Due to gravity, blood flow favors the dependent lung. The relatively poor ventilation is a result of suboptimal positioning, circumferential compression on the lungs by the mediastinum and abdominal contents, and the overall decreased lung volume associated with general anesthesia. Better ventilation to the nondependent lung is a result of muscle paralysis and improved compliance from opening the chest.3

Owing to the inability to retract the lung and permit adequate surgical exposure during VATS, there is a much greater need for OLV than with open thoracotomy. Varying degrees of respiratory dysfunction should be anticipated in patients undergoing this procedure. The principal physiologic change associated with OLV is the redistribution of lung perfusion between the ventilated (dependent) and nonventilated (nondependent) lung. Once the lungs are isolated and OLV is instituted, all blood flow to the nondependent lung becomes shunt flow. This aberration is compounded by increased shunt flow to the dependent lung, which further predisposes to a decreased PaO₂.3

Hypoxic pulmonary vasoconstriction (HPV) is an adaptive mechanism unique to the pulmonary circulation that allows redirection of blood flow to alveoli with higher oxygen tension, thereby reducing V/Q mismatch. Hypoxic pulmonary vasoconstriction has been shown to be of greatest benefit when 30% to 70% of the lung becomes hypoxic. Factors known to inhibit HPV and worsen right-to-left shunting and oxygenation include the following: (1) high mean airway pressures; (2) low fraction of inspired oxygen (FiO₂); (3) vasoconstrictor medications such as dopamine, epinephrine, and phenylephrine, causing greater vasoconstriction of normoxic vessels compared with vessels that are hypoxic; and (4) intrinsic PEEP from short expiratory times.4

**Preoperative Anesthetic Management**

Preoperative anesthetic management for VATS includes a thorough history and physical examination, preoperative laboratory and diagnostic testing, and optimization of the patient’s condition.5 Preoperative planning for VATS will include the following: (1) histologic type and stage of thoracic disease, (2) necessity for advanced intraoperative monitoring, (3) optimal OLV methods, (4) perioperative risk stratification based on the patient’s ability to tolerate VATS, (5) perioperative anesthetic plan, and (6) need for additional medical consultation.6,7 The preoperative assessment should focus heavily on the pathophysiological factors that are unique to the thoracic disease.

Laboratory testing before VATS is dependent on the patient’s age and surgical risk. These tests should provide thoughtful, efficient, and cost-effective care while ensuring that anesthetic management can proceed safely on the day of surgery. Laboratory testing for VATS may include complete blood cell count; basic metabolic panel, serum glucose level; renal, liver, and coagulation function tests and blood typing and crossmatching.

Right- and left-sided cardiac function is crucial in determining a patient’s ability to tolerate VATS. The American College of Cardiology and American Heart Association specify 4 high-risk conditions for which evaluation and preoperative treatment are necessary: (1) unstable coronary syndromes, (2) decompensated heart failure, (3) significant cardiac arrhythmias, and (4) severe valvular disease.8 Cardiac testing in a patient planning to undergo VATS should be based on cardiac risk stratification and may include electrocardiogram, echocardiogram, cardiac stress test, and cardiac catheterization.

The chest radiograph is the most common preoperative test used to evaluate thoracic disease. Anterior, posterior, and lateral chest radiographs provide information about the size, location, and density of the diseased area. In addition, the chest radiograph may allude to possible cardiopulmonary compression.6 Computerized tomography, magnetic resonance imaging, and positron emission tomography provide more accurate information regarding thoracic disease and metabolic activity. The degree of cardiopulmonary compression or metastases, which is not always obvious on chest radiograph, can be quantified. Tracheal compression greater than 50% of the predicted cross-sectional area increases the risk of perioperative risk of airway obstruction. Metastases to distal sites or invasion of the major vascular and mediastinal structures may preclude VATS.7

Pulmonary function testing is a valuable diagnostic
tool for evaluating the dynamic nature of thoracic disease and possible compression of tracheobronchial structures throughout the respiratory cycle. Pulmonary function testing may include arterial blood gas analysis, whole lung function spirometry, and carbon dioxide diffusion capacity. The findings associated with increased perioperative risk include a PaCO$_2$ of more than 45 mm Hg, a forced expiratory volume in 1 second (FEV1) of less than 2 L, a FEV1/forced vital capacity of less than 50% of predicted, a maximum breathing capacity of less than 50% of predicted, a residual volume/total lung capacity of more than 50%, and carbon dioxide diffusion in the lungs of less than 60% of predicted.

Preoperative bronchoscopic and mediastinoscopic examination is imperative for patients with bronchogenic carcinoma. Gross findings and pathologic examination provide insight regarding optimal OLV methods based on abnormalities in airway anatomy. When constructing the anesthetic plan, additional tests may be advantageous for staging, planning operative therapy, and deciding on the method for OLV. These tests include the following: (1) transthoracic echocardiography, (2) ultrasonography, (3) venography, (4) angiography, (5) radionuclide scan, and (6) biochemical marker testing.

The purpose of preoperative optimization is to treat or manage conditions that predispose a patient to perioperative complications (eg, atelectasis, pneumonia, and cardiac events), ideally decreasing morbidity and mortality in the process. Pulmonary optimization procedures include the following: (1) cessation of smoking, (2) bronchodilator therapy, (3) decreasing viscosity of secretions, (4) secretion mobilization, and (5) adjunct care (eg, pharmacologic and psychological). The pulmonary and cardiovascular systems are physiologically intertwined. Right and/or left ventricular dysfunction indicates the need for cardiovascular optimization (eg,

Table 1. Indications for Video-Assisted Thoracoscopic Surgery
(Adapted from Brodsky and Cohen$^{10}$ and Fischer and Cohen.$^{11}$)
medical management, percutaneous coronary intervention, or coronary artery bypass graft) before surgery.6,8

Patients with lung cancer typically have multiple risk factors. Preoperative interventions should be implemented with consideration of the 4 Ms: (1) mass effects (eg, bronchopulmonary and extrapulmonary intrathoracic symptoms), (2) metabolic effects (eg, endocrinopathies and paraneoplastic neurologic syndromes), (3) metastases, and (4) medications (eg, bleomycin and other antineoplastic drugs).3 Procedures such as tumor debulking, cystic aspiration, and tracheobronchial stenting may be used to alleviate extrinsic compression. Preoperative radiotherapy and chemotherapy have been used to reduce the size of the diseased area and thoracic compression.

Surgical Procedure

The terms video-assisted thoracotomy and video-assisted thoracic surgery have been used interchangeably when describing the use of operative telescopes and video imaging technology for visualizing the pleural space and mediastinal structures while avoiding fracturing of the ribs.9 Video-assisted thoracoscopic surgery is predominantly performed for diagnostic and therapeutic procedures involving the mediastinum, lungs, and pleura; it is quickly replacing surgeries that previously required a thoracotomy and/or sternotomy. With advances in technology and surgeon skill, VATS is being used for an increasing number of procedures. A comprehensive list of indications for VATS is found in Table 1.10,11 Video-assisted thoracoscopic surgery is not a feasible surgical approach for all patient populations. Contraindications to VATS procedures include inability to tolerate OLV or lateral decubitus position and hemodynamically unstable condition. Other relative contraindications specific to VATS pulmonary resection include a tumor larger than 6 cm; disease involving the chest wall, extensive tumor or lymph node involvement, and severe coagulopathies. A comprehensive list of contraindications is given in Table 2.12,13 Surgeon experience and procedural complexity may dictate the necessity to convert from VATS to an open thoracotomy.13

Depending on surgeon preference and the surgical procedure, the VATS approach involves creating small incisions in the chest wall for the placement of 2 to 4 ports. The first port is usually placed at the seventh or eighth intercostal space in the midaxillary line. This 10-mm port typically houses the thoracoscope, allowing visualization of the pleural cavity, and aids in the placement of the remaining ports to be used for instrumentation.9 Historically, this approach to port placement allows for triangulation of the instruments; all instruments should be aligned in the same direction, facing the target pathology within a 180° arc, as shown in the Figure. This approach provides ample spacing and visualization without instrument interference.12

Table 2. Contraindications for Video-Assisted Thoracoscopic Surgery

<table>
<thead>
<tr>
<th>Contraindication</th>
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<tr>
<td>Inability to tolerate one-lung ventilation</td>
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<tr>
<td>Inability to tolerate lateral decubitus position</td>
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<tr>
<td>Hemodynamic instability</td>
</tr>
<tr>
<td>Tumor &gt; 6 cm</td>
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<tr>
<td>Chest wall or mediastinal involvement</td>
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<tr>
<td>Coagulopathy</td>
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<tr>
<td>T3 tumor or N2 disease</td>
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<tr>
<td>Involvement of hilar structures</td>
</tr>
<tr>
<td>Preoperative chemotherapy or radiation therapy</td>
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<td>Expansive intrapleural adhesions</td>
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Once the disease has been confined and hemostasis achieved, the specimen can be extracted from the pleural space via a disposable trocar (Thoracoport). However, larger specimens (lung mass, lobectomy, wedge resection, and pneumonectomy) are removed via specimen bags through a utility incision of approximately 4 to 6 cm.12

As with any surgical procedure, there are specific complications associated with VATS. The complications of VATS are generally infrequent. The most frequent surgical complications are a prolonged air leak and bleeding.9,14 Other potential complications include cardiac arrhythmias, pneumonia, empyema, atelectasis, pneumothorax, respiratory failure, dissemination of tumor at the port site, surgical-site infection, and intercostal neurama.13

A prolonged air leak is more likely to occur after lung resection procedures. Small injuries to the visceral pleura from suturing, biopsies, and thermal electrocautery and the use of endoscopic graspers result in air leaks. The greater amount of lung tissue resected may increase the likelihood of air leaks. Normally, small air leaks resolve on reexpansion of the noninflated lung over a course of a few days. However, an air leak lasting more than 7 days is considered persistent or prolonged, and treatment includes extended chest tube placement.14

Since VATS is performed where surgical access is limited and pulmonary vasculature exists, hemorrhage can occur. Inadvertent injury to pulmonary vasculature and failure of mechanical staples may cause bleeding. Other sources of bleeding are the trocar access sites and dense adhesions or tumors that are near the pulmonary hilum.14 If attempts to control bleeding through the application of pressure, sutures, metal clips, stapling, or
electrocoagulation are unsuccessful, prompt conversion to open thoracotomy for definitive hemostasis is needed. Overall, the incidence of bleeding associated with major lung resection via VATS is infrequent, less than 1% among experienced surgeons.15

**Intraoperative Considerations**

One-lung ventilation with “lung isolation” is indicated to protect the nondiseased contralateral lung from contamination. One-lung ventilation with “lung separation” refers to cases with no risk of contamination to the dependent lung and is done primarily to improve surgical exposure, such as for VATS. This can be achieved by 3 methods: double-lumen tube (DLT), bronchial blocker, or single-lumen endobronchial tube (SLT). The most common technique is with a DLT. The DLT is a bifurcated tube with an endotracheal and an endobronchial lumen that can be used to achieve isolation of the right or the left lung. The second method involves blockade of a main-stem bronchus to allow lung collapse distal to the occlusion. These bronchial blockers can be used with a standard endotracheal tube or are contained within a separate channel inside a modified SLT such as the Univent tube. Last, advancing an SLT over a fiberoptic scope into the appropriate bronchus can facilitate OLV, although the ability to ventilate or suction the nonintubated lung is lost.

Although a left-sided DLT is more commonly used for elective thoracic procedures, there are specific clinical situations in which a right-sided DLT is indicated owing to distorted anatomy of the left main-stem bronchus or surgery involving the left main-stem bronchus. Because the right main-stem bronchus is shorter than the left and the bronchus of the right upper lobe originates at a small distance of 1.5 to 2 cm from the carina, left-sided DLTs are most commonly used to help ensure ventilation of the right upper lung lobe. Techniques using right endobronchial intubation must take into account the location and potential for obstruction of the orifice of the right upper lobe bronchus, causing desaturation. The right-sided DLT incorporates a modified cuff, or slot, on the endobronchial side that allows ventilation for the right upper lobe.

On direct laryngoscopy, the DLT is passed with the distal curve pointing anteriorly. Once the vocal cords are passed, the tube is rotated 90° toward the bronchus to be intubated and advanced to its proper depth.3 The optimal depth of insertion for a left-sided DLT is strongly correlated with height in average-sized adults. In adults, depth measured at the teeth, for a properly positioned DLT, will be approximately as follows: (patient height in cm/10) + 12 cm. Alternatively, the flexible fiberoptic bronchoscope may be used as a “guide wire” for DLT placement, in which the tip of the endobronchial lumen is guided into the correct bronchus after the DLT passes the vocal cords. Auscultation and fiberoptic bronchoscopy should be used when the DLT is initially placed and again after the patient is repositioned to confirm correct placement. The anesthetist should be able to isolate left- and right-sided breath sounds as the respective single lumen is ventilated. Correct positioning of the DLT is confirmed by using a fiberoptic bronchoscope by visualization. The blue cuff should be clearly visualized, yet advanced far enough to ensure that it will not herniate over the carina.3,16

The most common complications associated with the use of a DLT are malpositioning or migration and airway trauma. A malpositioned DLT will fail to allow collapse
of the lung, causing gas entrainment during positive-pressure ventilation, or may cause partial collapse of the ventilated lung, producing hypoxemia. A common cause of malposition is dislodgment of the endobronchial cuff because of overinflation, surgical manipulation, or extension of the head and neck during patient positioning. The techniques used to manage the ventilated lung during OLV have an important role in the distribution of pulmonary blood flow between the lungs. Suggested strategies for ventilation during OLV are summarized in Table 3. In addition to underlying pulmonary disease, V/Q mismatching caused by anesthesia and lateral decubitus positioning predisposes patients to desaturation. If desaturation occurs, the following steps can be used to improve $\text{Paco}_2$: (1) administer 100% $\text{FiO}_2$, (2) use hand ventilation, (3) ensure DLT positioning, (4) add continuous positive airway pressure to the nondependent nonventilated lung, (5) add PEEP at 5 cm of water pressure to the dependent ventilated lung, (6) intermittent 2-lung ventilation, and (7) ask the surgeon to clamp the pulmonary artery to the nondependent nonventilated lung.

Although some VATS procedures such as bilateral wedge resections or lung volume reduction may be performed with the patient in the supine position, most procedures are performed with the patient in the lateral decubitus position. The brachial plexus is the site that is at greatest risk for intraoperative nerve injury related to the lateral position. Most often, compression-related injuries of the brachial plexus occur in the dependent arm. Adequate placement of a chest roll below the axilla will aid in keeping the body weight off the dependent brachial plexus. The nondependent arm is most at risk if it is suspended from an independently fixed arm support or an “ether screen.” The arm should not be abducted, nor should the elbow be flexed greater than 90°. In addition, the arm should not be extended posteriorly, potentially causing nerve and vascular injury because of unnecessary stretch and rotation. Owing to hydrostatic effects, excessive administration of intravenous fluids can cause increased shunting and subsequently lead to pulmonary edema of the dependent lung. Since the ventilated dependent lung must maintain gas exchange during OLV, it is best to be conservative with fluid administration. Although the placement of arterial and central lines may be debated in patients with otherwise good health status (ASA class 1-3), a potential for intrathoracic organ injury is constantly present and requires immediate identification and treatment. Blood gases are not routinely monitored if the procedure is short and lung deflation is for only a brief period. However, for patients undergoing prolonged VATS procedures, such as lobectomy, and for patients with marginal pulmonary status, invasive monitoring with a central line, arterial line, and measurement of arterial blood gases may be required. Video-assisted thoracoscopic surgery carries the same risks related to any form of intrathoracic surgery, including massive hemorrhage. If this occurs, the surgeon may be unable to gain control of damaged vasculature and will need to rapidly perform an open thoracotomy.

The anesthetic medications used during the management of VATS procedures are chosen with consideration for their effects on lung function during OLV. The use of inhalation agents allows for rapid adjustment, depending on the patient’s hemodynamic status, and delivery of high oxygen concentrations. Nitrous oxide is usually avoided. Until recently, clinicians have focused on the fact that the inhalation anesthetics inhibit HPV and surmised that these medications may be detrimental to tissue oxygenation during OLV. The actual effects are more complicated. The inhalation anesthetics have a salutary effect on intrapulmonary perfusion and hypoxia and decrease the amount of inflammation and the release of inflammatory mediators, compared with anesthetic doses of propofol. Additional data suggest that thoracic epidural analgesia, when combined with a general anesthetic, does not significantly affect shunt and oxygenation and provides an excellent avenue for analgesia.

### Postoperative Considerations

Postoperative considerations for VATS should focus on providing adequate analgesia while remaining vigilant to the possibilities of postoperative complications, especially respiratory insufficiency. Although VATS is associated with a reduction in postoperative pain compared with an open thoracotomy, patients remain at risk for significant postoperative pain. Adequate postoperative analgesia facilitates improved respiratory effort, increases patient comfort, and decreases potential postoperative complications (eg, infection and respiratory insufficiency).

#### Table 3. Suggested Ventilator Modalities

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Suggested</th>
<th>Guidelines</th>
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<tbody>
<tr>
<td>Tidal volume</td>
<td>5-6 mL/Kg</td>
<td>Maintain peak airway pressure &lt; 35 cm H2O</td>
</tr>
<tr>
<td>Positive end-expiratory pressure</td>
<td>5 cm H2O</td>
<td>Except with patients with COPD</td>
</tr>
<tr>
<td>Respiratory rate</td>
<td>12-16/min</td>
<td>Maintain normal $\text{PaCO}_2$</td>
</tr>
<tr>
<td>Mode</td>
<td>Volume or pressure controlled</td>
<td>Pressure control for patients at risk for lung injury, such as pneumonectomy, bullae</td>
</tr>
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</table>

Abbreviation: COPD, chronic obstructive pulmonary disease.
A variety of analgesic therapies are available to treat postoperative pain following VATS procedures. Therapies such as continuous thoracic epidural analgesia with local anesthetic and/or opioid infusions, paravertebral block, intrapleural regional anesthesia, intercostal nerve block, site-specific local anesthetic infiltration, cryoaanalgesia, and systemic analgesia (eg, opioids and nonsteroidal anti-inflammatory medications) are all considerations.7

Thoracic epidural analgesia, with a catheter placed at the T6-T8 interspace, is the current standard analgesic therapy for the treatment of postthoracotomy and VATS pain.7,18 However, owing to the minimally invasive nature of VATS, adjunctive thoracic epidural analgesia is rarely required unless there is a high likelihood of conversion to an open procedure. The use of continuous paravertebral nerve block has been identified as an effective analgesic therapy and is associated with a reduced incidence of hypotension compared with continuous thoracic epidural analgesia. This pain management technique may be considered when a coagulopathy is possible. However, intrathecal and intercostal nerve blocks provide adequate analgesia and cause less respiratory depression compared with systemic opioids and nonsteroidal anti-inflammatory medications alone.19

A multimodal analgesic approach, such as systemic patient-controlled opioid and/or nonsteroidal anti-inflammatory administration, should be considered when pain is not adequately controlled.18 Nonsteroidal anti-inflammatory medications and acetaminophen can be administered to treat shoulder pain associated with thoracotomy procedures. Ipsilateral shoulder pain is common following a thoracotomy as a result of dividing the anterior serratus and latissimus dorsi muscles. Finally, respiratory insufficiency may occur when systemic opioid analgesia is used as the sole postoperative method for pain control.

Postoperative respiratory function should be monitored closely following a VATS procedure because patients are at risk for decreased functional residual capacity, opioid-induced respiratory depression, and atelectasis leading to impaired gas exchange. Factors that increase the risk for postoperative respiratory insufficiency are significant preexisting pulmonary dysfunction, large resections of the lung, pulmonary trauma, large amounts of pulmonary exudates, inadequate analgesia, and excessive opioid analgesia.7 Postoperative mechanical ventilation may be necessary if spontaneous ventilation is judged inadequate. If the decision is made to continue postoperative mechanical respiratory support and a DLT has been used for OLV, it should be replaced at the end of surgery with an SLT under direct laryngoscopy or with the assistance of an airway exchange catheter. In contrast, if a bronchial blocker has been used for OLV, the associated SLT or Univent tube can be used postoperatively.20

An arterial blood gas measurement and chest radio-

graph should be obtained to assess functional respiratory status. Chest tube(s) should be assessed for patency and remain connected to the appropriate amount of suction or water seal. Pulmonary recruitment maneuvers, such as incentive spirometry, should be implemented as soon as possible in the postanesthesia care unit.21

There are a number of potential postoperative complications. Along with inadequate pain management and respiratory insufficiency, other postoperative complications could include bleeding, prolonged air leak causing subcutaneous and/or mediastinal emphysema, pneumonia, pleural effusion, atrial fibrillation, intercostal neuritis or neuralgia, and chronic pain.7,22 Close observation and intensive monitoring are required in the immediate postoperative period following VATS.

REFERENCES


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