23 Anesthesia for Video-Assisted Thoracoscopic Surgery

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Key Points

- Limited options to treat hypoxemia during one-lung ventilation (OLV) compared to open thoracotomy. Continuous positive airway pressure (CPAP) interferes with surgical exposure during video-assisted thoracoscopic surgery (VATS).
- Priority on rapid and complete lung collapse.
- Possibility of prolonged periods of OLV. Particularly during the learning phase of the surgical team.
- Decreased postoperative analgesic requirements compared to open thoracotomy.
- Surgical delay in treating major intraoperative hemorrhage.
- The option of doing minor VATS procedures with local or regional anesthesia.

Historical Considerations of Video-Assisted Thoracoscopy

Thoracoscopy involves intentionally creating a pneumothorax and then introducing an instrument through the chest wall to visualize the intra-thoracic structures. Recent application of video cameras to thoracoscopes for high-definition magnified viewing coupled with the development of sophisticated surgical instruments and stapling devices has greatly expanded the endoscopist's ability to do increasingly more complex procedures by thoracoscopy. It was widely believed that the first to perform a documented thoracoscopy using a Nitze cystoscope in a human patient was the Swedish internist Hans Christian Jacobaeus Thoracoscopy, the introduction of an illuminated tube through a small incision made between the ribs, was first used in 1910 for the treatment of tuberculosis. In 1882 the tubercle bacillus was discovered by Koch, and Forlanini observed that tuberculous cavities collapsed and healed after patients developed a spontaneous pneumothorax. The technique of injecting approximately 200 cc of air under pressure to create an artificial pneumothorax became a widely used technique to treat tuberculosis [1].

Jacobaeus [2], however, was able to directly visualize pleural adhesions using thoracoscopy, and described a method for cutting them to facilitate lung collapse. Closed intrapleural pneumolysis, also called the Jacobaeus operation, consisted in inserting a galvanocautery into the pleural cavity through another small opening in the chest wall and dividing the adhesions under thoracoscopic control. Thus the two-point entry technique of medical thoracoscopy was born.

After the introduction of tuberculostatic medications this surgical approach was practically abandoned until the early 1990s when advancement in fibro-optic light transmission, image display and instrumentation made video-assisted thoracoscopic surgery (VATS) possible. The improvements in video endoscopic surgical equipment and a growing enthusiasm for minimally invasive surgical approaches, brought VATS to the practice of surgery for diagnostic and therapeutic procedures. Most of these procedures required general anesthesia, a well collapse lung and are an indication for one-lung ventilation (OLV).

A variety of medical and surgical procedures are performed by VATS [3] (see Table 23.1). The patient population tends to be either very healthy, undergoing diagnostic procedures, or

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TABLE 23.1. Spectrum of minimally invasive thoracic surgical procedures.

Diagnostic
a. Pleural disease
Biopsy, thoracentesis
b. Staging
Lung, pleural, esophageal cancer
c. Parenchymal disease
Fibrosis, solitary nodules, pneumonitis
d. Mediastinal tumors
Thymoma, lymphoma, sarcoma, germ cell
e. Pericardial disease
Pericarditis, tumors
Theraputic
a. Pleural disease
Pleurodesis, decortication
b. Parenchymal disease
Wedge resection, segmentectomy, lobectomy, pneumonectomy, bleb/bullae resection, lung volume reduction
c. Cardiovascular disease
Pericardial window, valve repair, coronary artery bypass, arrhythmia ablation
d. Mediastinal disease
Tumor excision, thymectomy, chylothorax
e. Esophageal surgery
Vagotomy, myotomy, antireflux surgery, esophagectomy
f. Sympathectomy
Hyperhidrosis, reflex sympathetic dystrophy
g. Spinal surgery

high-risk patients who are undergoing VATS to avoid the risks of thoracotomy. Patients with advanced cardiopulmonary disease, malignancies, and heavy smoking history deserve an extensive preoperative evaluation and optimization since conversion to an open procedure is always a possibility. Intraoperative monitoring in these high-risk patients should be the same as for thoracotomy.

Medical Thoracoscopy

Medical Thoracoscopy is mainly performed for diagnostic procedures. Initially it was limited to the use of rigid thoracoscope, however, with the introduction of optical fibers it was expanded to include diagnostic procedures with flexible thoracocscopy. Unlike VATS, which consist of multiple access ports, medical thoracoscopy involves the insertion of an endoscope through a single entry port into the thoracic cavity and pleural space. Medical Thoracoscopy is limited to diagnosis and biopsy of pleural disease, pleural effusions, infectious diseases, staging procedures, chemical pleurodesis, and occasionally for lung biopsy. It is often performed by the pulmonologist in the clinic rather then the operating room and is generally under local anesthesia. A small incision is made in through the lateral chest wall, and with the insertion of the instrument, fluid and biopsy specimens are easily obtained. Medical thoracoscopy has somewhat limited applications which are confined by the inability, in most cases, to perform more extensive therapeutic procedures such as wedge resection, lobectomy or pneumonectomy.

Surgical Thoracoscopy

VATS was introduced to thoracic surgical practice in the early 1990s and entails making multiple small incisions in the chest wall, which allow the introduction of a video camera and surgical instruments into the thoracic cavity through access ports. Most commonly, it is performed by a thoracic surgeon in the operating room under general anesthesia. In more recent years surgical techniques, instruments, and video technology have improved to permit a wide variety of therapeutic procedures to be performed using VATS.

Indications: In recent years, VATS has gained increasing popularity and continues to replace many procedures that formerly required thoracotomy. Clinicians offer less invasive approaches for complex surgical treatment of lung pathology and patients are appropriately drawn to the prospect of less postoperative pain and faster recovery. Whether VATS cancer surgery, which still may involve a limited thoracotomy, carries a higher risk of local recurrence, is still unclear [4]. Some large-scale studies found no differences in overall survival between patients undergoing lobectomy and those undergoing limited resection. In fact, there is a clear difference in the treatment approach between the European schools and those of North America. There is less popularity among the European schools regarding cancer treatment through a VATS approach. This is secondary to the belief that extensive malignant tumors are best approached via open thoracotomy and proper surgical field evaluation and appropriate lymph node dissection may be limited with the VATs approach [5].

Initially, when introduced to clinical practice, VATS was limited to diagnostic procedures of short duration and limited extension. Most surgeons were unfamiliar with technique and the available equipment. Increased familiarity with thoracoscopic techniques, as with laparoscopic techniques, had enabled surgeons to perform almost any major thoracic surgical procedure in a minimally invasive manner. VATS operations can be used for all structures in the chest and are not limited to the lungs, pleura, and mediastinum.

Diagnostic Procedures

With VATS, diagnosis of pleural disease, thoracentesis, and pleural biopsy of a specific area under direct vision can be performed. In many cases this is indicated for an undiagnosed pleural effusion, in which the cytology is inconclusive. VATS for parenchymal lung pathology such as biopsy, wedge resection for solitary lung nodules or for diffuse interstitial lung disease is a common indication. In the past, such a diagnosis was possible only by subjecting the patient to an open thoracotomy, despite the associated morbidity, or the patient was treated empirically. VATS, which offers an extensive visualization of the entire chest cavity, essentially has replaced the traditional mini-thoracotomy particularly in cases where percutaneous needle aspiration biopsy is inconclusive. Other diagnostic procedures are performed on the mediastinum for biopsy of lymph nodes not accessible via traditional mediastinoscopy such as the subcarinal lymph nodes or for mediastinal masses, either primary or metastatic. This procedure is essential when staging of the disease needs to be established. It is also useful for assessing resectability, to exclude direct invasion of the mediastinal structures. Lymphomas or germ-cell tumors that require a tissue diagnosis may benefit from a VATS approach. Diagnostic procedures involving the pericardium such as a pericardial biopsy and/or drainage of a pericardial effusion can be accomplished both for diagnosis and therapy with a VATS pericardial window.

Therapeutic Procedures

Therapeutic procedures using VATS have increased rapidly in recent years. In some institutions, the vast majority of the thoracic procedures are performed thoracoscopically.

Pleural disease can be managed by VATS including plurocentesis, pleural abrasion for recurrent pleural effusion from malignancy or pneumothorax, decortication, empyectomy, and lysis of adhesions. In the past, thoracotomy was performed for formal decortication to permit reexpansion of the lung. With VATS, thoracotomy can be avoided, particularly in the early stages of empyema. Malignant pleural effusions, particularly those with multiple loculated collections, are difficult to drain with tube thoracostomy and can be effectively treated with VATS.

Lung parenchymal disease such as wedge resection of a lesion, lobectomy or pneumonectomy can routinely be performed with VATS. These are better tolerated by the compromised patient with decreased pulmonary reserve [6]. VATS offers the opportunity to both diagnose and treat parenchymal lesions at the same time. Management of bullous disease, particularly giant bullae with significant compression of the adjacent lung, is frequently managed with VATS. Often these cases present with recurrent pneumothoraces or air-leaks associated with apical blebs. Lung volume reduction (LVR) performed by VATS is better tolerated by the patient with severe emphysema (see also Chap. 36). Resection of mediastinal masses such as thymoma or mediastinal cyst or resection of posterior mediastinal neurogenic tumors, treatment of chylothorax by ligation of the thoracic duct, bilateral sympathectomy are all possible with VATS.

A variety of esophageal procedures can be performed minimally invasively. Vagotomy, Heller myotomy, antireflux procedures, or staging of esophageal cancer are common procedures done with VATS. Finally, the dissection of the thoracic esophagus in cases of esophago-gastrectomy is increasingly performed with a combined VATS and laparotomy.

VATS sympathectomy is usually performed for hyperhidrosis or reflux sympathetic dystrophy. The sympathetic chain is visualized as it lies along the vertebral bodies. The magnification provided by VATS facilitates the procedure, which is usually done bilaterally during the same anesthetic.

Benefits

The incisions for a VATS are usually 3–5 ports to allow for the passage of a video camera stapling device and forceps. Because the ribs are not spread, patients have lower narcotic requirements for postoperative pain, reduced shoulder dysfunction, and decreased time until return to preoperative activities. There is a reduced risk of respiratory depression, reduced risk of atelectasis due to splinting, or reduced ability to sustain deep breathing and reduction in retained secretions. A review of 1,100 VATS lobectomies with lymph node sampling or dissection in patients who had a mean age of 71.2 years demonstrated low rates of mortality (1%) and morbidity, with 84.7% of patients exhibiting no significant complications [7].

The benefits of thoracoscopy should lead to greater patient satisfaction at a lower cost (as has been the experience with laparoscopic surgery). This view is supported by Weatherford et al. in his review of the experience of thoracoscopy vs. thoracotomy at a community hospital. Weatherford compared length of stay, morbidity, mortality, operative time, length of time to extubation length of intensive care unit stay, number of days of pleural drainage and found improvements in these categories with thoracoscopy [8]. A case–control study of lobectomies found a shorter hospital stay and fewer overall complications with VATS vs. open thoracotomy but no significant decrease in postoperative atrial fibrillation [9] (see Table 23.2). Elderly patient have been shown to have fewer pulmonary, but not cardiac, complications after VATS lobectomy [10] (see Table 23.3).

Surgical Technique

VATS is performed usually in the lateral position through three to five entry ports created in the chest wall on the side

Table 23.2. Postlobectomy complications VATS vs. open thoracotomy.

Outcome	VATS ($n = 122$)	Open ($n = 122$)	p value
Length of stay (days ± SD)	4.9 ± 2.4	7.2 ± 3.8	0.001
All complications	17%	28%	0.046
Atrial fibrillation	12%	16%	0.36
Prolonged air leaks	3.8%	5.7%	0.54
Pneumonitis	1.6%	4.1%	0.28

Based on data from Park et al. [9]

Table 23.3. Postlobectomy complications in elderly patients.

Outcome	VATS	Open	p value
Median length of stay (days)	5	6	0.001
No complications	72%	55%	0.04
Pulmonary	15%	33%	0.01
Cardiac	17%	23%	0.44

Based on data from Cattaneo et al. [10]

of the pathology (see Fig. 23.1). A video camera is inserted to allow for direct visualization of the entrance of trocars into the thorax. The lung is collapsed on the ipsilateral side by passive elastic recoil equilibrium of intrapleural and atmospheric pressure occurs through the access port. If the lung is not adequately collapsed, the surgeon is not able to appreciate the surgical field and identify a lung lesion when it is not located on the surface of the lung. Additionally, placing a stapler suture on a lung that is only partially deflated may result in inadequate closure lines which may be the source of continuous air-leak (see Fig. 23.2).

Fig. 23.1. Video-assisted thoracoscopic surgery as viewed from the foot of the operating table. A well collapsed lung on the side of surgery is necessary for any major procedure.

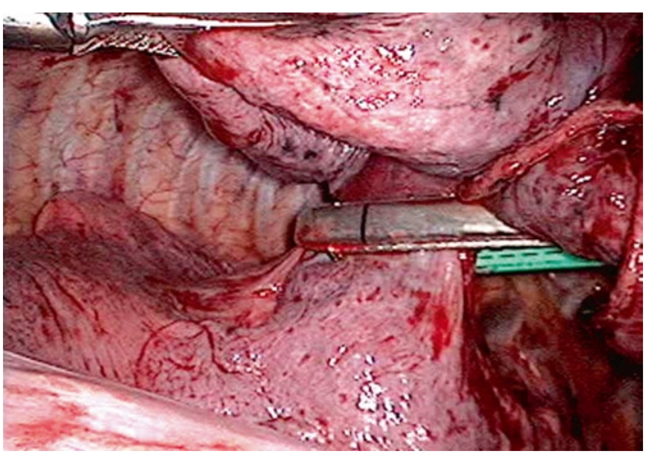

Fig. 23.2. A stapling devise is used to open the interlobar fissure as part of the initial surgical approach during a VATS lobectomy. If the lung is not well collapsed there is an increased risk of air-leaks from the staple lines.

Although rarely used in thoracoscopic procedures, unlike laparoscopic procedures, some surgeons may elect to insufflate CO_2 gas into the ipsilateral hemi-thorax to assist in collapsing the lung and breaking adhesions and to maintain the pneumothorax. There is no good evidence that a CO_2 insufflation has any benefit. Insufflation of CO_2 into the ipsilateral hemi-thorax can be associated with hemodynamic compromise and significant hypotension since the chest is a closed cavity and the increase in intra-thoracic pressure by insufflation of CO_2 will reduce venous return and cardiac output. The pressure inside the thorax must be measured and kept low. Keeping the intra-thoracic pressure below 10 cm of H_2O should minimize the negative hemodynamic effects. This is a period when communication between surgeon and anesthesiologist is crucial.

Anesthetic Management

After appropriate anesthesia and surgical evaluation, an anesthetic plan is devised to allow the patient to be safely anesthetized for the surgical procedure and to recover. Most patients find it reassuring to have a discussion with their anesthesiologist about the anesthetic and postoperative pain relief options. The choice of anesthetic technique is variable and dependent upon the wishes of the patient and the experience of the clinician. While simple diagnostic procedures can be performed under local anesthesia by infiltrating the chest wall accompanied by light sedation, more complex procedures that require sampling of tissue are best done under regional (epidural, intercostal blocks) or general anesthesia. The main disadvantage of local and regional anesthesia is that the patient is required to breathe spontaneously. While this is generally tolerated for brief periods of time, most VATS procedures today are performed under general anesthesia utilizing OLV techniques, which provides better exposure and guarantees a secure airway in the lateral decubitus position.

Each of the above techniques has its advantages and disadvantages. Decisions regarding postoperative pain relief should be made preoperatively. The management of an epidural vs. patient-controlled analgesia (PCA) vs. PRN medications given by the nurse with or without adjunctive agents is best evaluated on a daily basis by a specialist in the field of pain management. Additional considerations regarding postoperative pain management should be given to the likelihood of proceeding on to thoracotomy.

Local/Regional Anesthesia

The simplest technique is to use a local anesthetic to infiltrate the lateral thoracic wall and parietal pleura combined with appropriate sedation and supplemental oxygen. Preferably intercostal nerve blocks can be performed at the level of the incision(s) and at two interspaces above and below (see Chap. 46). Thoracic epidural anesthesia can also be used [11].

For VATS procedures under local or regional anesthesia, an ipsilateral stellate ganglion block is often performed to inhibit the cough reflex from manipulation of the hilum. To anesthetize the visceral pleura topical local anesthetics can be applied. Intravenous sedation with propofol may be needed to supplement regional nerve blocks.

For VATS performed under local or regional anesthesia with the patient breathing without assistance, partial collapse of the lung on the operated side occurs when air is allowed to enter the pleural cavity. The resulting atelectasis may provide suboptimal surgical exposure. The major disadvantage to VATS under local or regional anesthesia is that the patient must breathe spontaneously. This is usually tolerated for short periods of time, but for major VATS procedures, a general anesthetic with OLV is a better choice.

The collapse of the lung provides the surgeon with a working space, and a chest tube is placed at the conclusion of the surgery. Changes in PaO_2, $PaCO_2$, and cardiac rhythm are usually minimal when the procedure is performed using local or regional anesthesia. With local anesthesia, the spontaneous pneumothorax is usually well tolerated because the skin and chest wall form a seal around the thoracoscope and limit the degree of lung collapse. Occasionally, however, the procedure is poorly tolerated, and general anesthesia must be induced. The insertion of a double-lumen tube (DLT) with the patient in the lateral position may be difficult, in which case the patient may be temporarily placed in the supine position for the intubation.

If general anesthesia is required, a DLT is preferable to a single-lumen tube because positive-pressure ventilation via a single-lumen tube would interfere with endoscopic visualization. In addition, if pleurodesis is being performed, general anesthesia through a DLT allows for recontrolled reexpansion of the lung. A regional approach is well suited to a patient who is motivated to maintain control of their environment, a surgeon who can work gently and for a procedure that is short in duration. A benefit of regional anesthesia is that it wears off slowly over a few hours allowing for oral opioids and adjuvant analgesics to be added as needed with minimal discomfort to the patient. The risks of this approach include accidental intravenous, epidural or spinal injection with associated toxicity or cardiopulmonary embarrassment. In experienced hands, complications are rare enough to allow for the routine use of regional anesthesia for minor VATS procedures. Because the patient is not under general anesthesia and local anesthetic has only been applied to the rib cage, the patients may complain of discomfort during manipulation of lung tissue with pain referred to the shoulder. Referred shoulder pain may be difficult to differentiate from the anginal discomfort of cardiac disease.

General Anesthesia

Indications for OLV: "Lung isolation" includes the classical absolute indications for OLV, such as massive bleeding, pus, and alveolar proteinosis or bronchopleural fistula. The goal is to protect the nondiseased contra-lateral lung from contamination. "Lung separation," on the other hand, refers to cases with no risk of contamination to the dependent lung, and is performed primarily to improve surgical exposure such as for VATS. The inability to completely deflate the nondependent lung during VATS leads to poor surgical exposure, which in turn can jeopardize the success of the procedure, potentially requiring conversion to an open technique. Because of the increasing number of diagnostic and therapeutic procedures performed with VATS, the need to provide OLV has risen significantly. In my institution (EC), approximately 80% of the thoracic procedures either begin with or are performed entirely with VATS.

Treatment of Hypoxemia During VATS

The application of CPAP by oxygen insufflation to the nonventilated lung has traditionally been accepted as the best maneuver to treat hypoxemia during OLV [12] (see also Chap. 6). This maneuver is well accepted during open thoracotomy. Unfortunately, the application of CPAP is poorly tolerated by the surgeon during VATS because of the obstruction of the surgical field by the partially inflated lung [13] (see Fig. 23.3). Since most patients will develop atelectasis in the ventilated dependent lung during general anesthesia in the lateral position (see Fig. 23.4), recruitment maneuvers [14], and the application of PEEP to the ventilated-lung are useful in the majority of patients, except those with severe obstructive lung disease [15] (see Fig. 23.5). A useful method of improving oxygenation during OLV for VATS is the bronchoscopic-guided insufflation of oxygen into segments of the nondependent lung remote to the site of surgery [16] (see Chap. 6, Fig. 6.11).

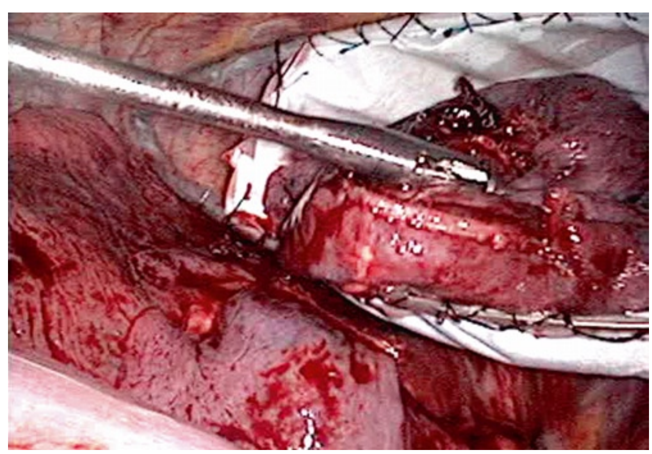

Fig. 23.3. During a VATS lobectomy the excised lobe is placed in a retrieval bag before being removed through a small chest wall incision. Good collapse of the operative lung is required for the surgeon to perform this operation.

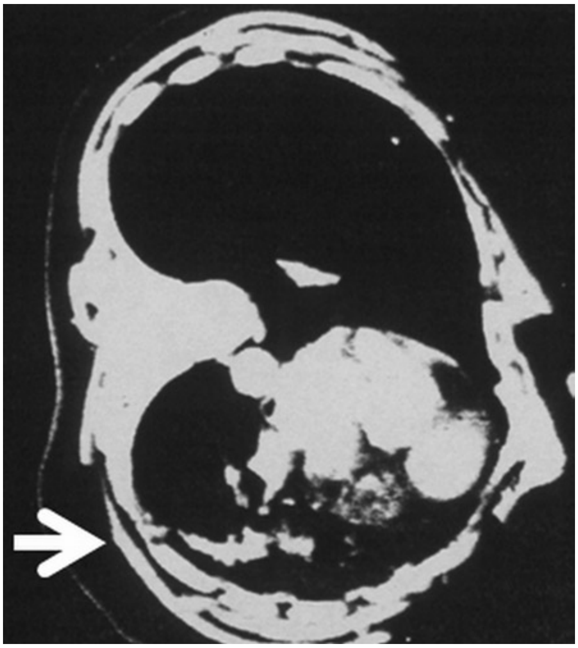

FIG. 23.4. Chest CT scan during general anesthesia in the lateral position. The white arrow points to a plaque of atelectasis in the dependent lung. Most patients develop atelectasis in the dependent lung during anesthesia.

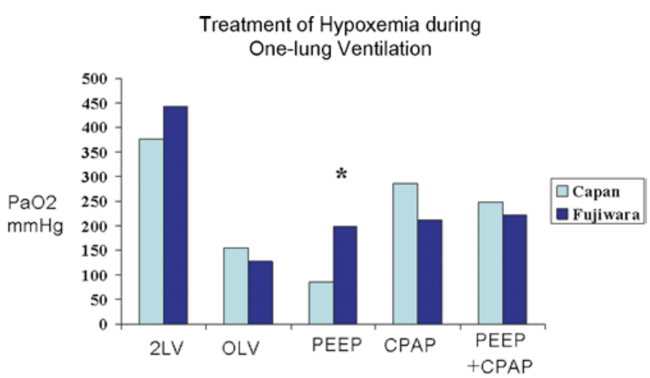

FIG. 23.5. A comparison of the effects of PEEP and CPAP on oxygenation during one-lung ventilation in patients with COPD (Capan) vs. normal pulmonary function (Fujiwara). PEEP improves PaO_2 for most patients with normal pulmonary function during OLV (*asterisk* significant improvement $p<0.05$) but decreases PaO_2 in patients with COPD (based on data from Thomsen [13] and Fujiwara et al. [15]).

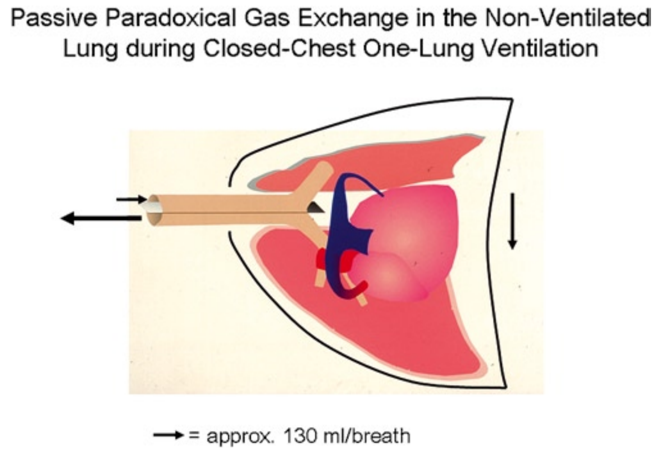

FIG. 23.6. Passive paradoxical gas exchange occurs in the nonventilated lung during OLV if the chest is closed. As the mediastinum falls during exhalation of the ventilated lung, the resultant negative pressure in the nonventilated hemi-thorax entrains room air into the nonventilated lung if the lumen of the DLT is open to atmosphere. This air is then expired during the inspiration phase of the ventilated lung. The passive tidal volumes depend on the size of the patient and cease once the initial VATS port allows atmospheric pressure to equilibrate in the nonventilated hemi thorax (based on data from Pfitzner et al. [18]).

Improving Lung Collapse During VATS

Since a collapsed immobile lung on the side of surgery is fundamental to VATS for major pulmonary resections, one of the Anesthesiologists responsibilities is to facilitate collapse of the nonventilated lung. There are three basic manuvers that will increase the rate of lung collapse.

1. Eliminate all nitrogen from the operative lung prior to the initiation of lung collapse. The poorlysoluble nitrogen in air delays collapse in nonventilated alveoli. Although the use of air–oxygen mixtures are desirable to prevent the development of atelectasis in the ventilated lung during one-lung anesthesia, if air is present in the nonventilated lung at the start of OLV it will delay collapse [17] (see Chap. 6, Fig. 6.6). It is best to ventilate with a FiO_2 of 1.0 for a period of 3–5 min immediately prior to the start of OLV to de-nitrogenate the operative lung. After a recruitment manuver of the ventilated dependent lung, air can then be reintroduced to the gas mixture after the start of OLV as tolerated, according to the arterial oxygen saturation.
2. Avoid entrainment of room air into the nonventilated lung during closed-chest OLV. Many anesthesiologists will begin OLV as soon as possible to encourage lung collapse prior to the start of surgery. However during closed-chest OLV, if the lumen of the DLT to the nonventilated lung is open to atmosphere, passive paradoxical ventilation of the nonventilated lung will occur (inspiration during the expiratory phase of the ventilated lung) and air will be drawn into the nonventilated lung delaying collapse (see Fig. 23.6). It has been shown that these passive tidal volumes are approximately 130 mL/breath [18] which far exceeds the deadspace of one side of a DLT (10–15 mL). These passive tidal volumes cease as soon as atmospheric pressure is allowed into the operative hemi-thorax.
3. Apply suction to the lumen of the DLT or bronchial blocker to the nonventilated lung at the start of OLV. Low suction (−20 cm H_2O) improves the rate of lung collapse for both open thoracotomy and VATS [19] (see Fig. 23.7). It is not clear whether the effect of suction is due to the negative pressure or simply due to a suction catheter preventing passive entrainment of air into the nonventilated lung (see Fig. 23.8).

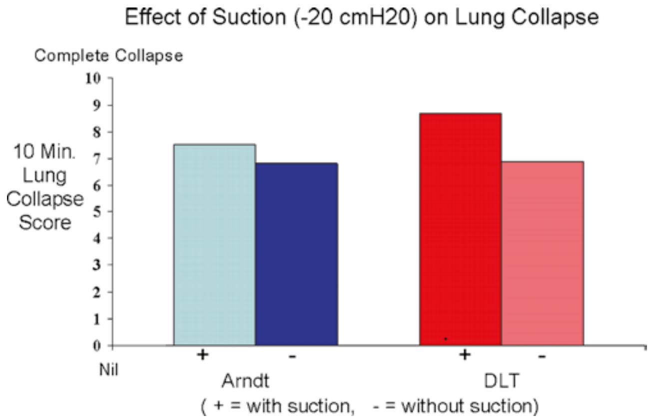

Fig. 23.7. The application of low suction to the channel of a bronchial blocker (in this case the Arndt blocker) or to the lumen of the DLT to the nonventilated lung significantly improves the speed of lung collapse measured both 10 min (shown here) and 20 min after the start of OLV (based on data from Narayanaswamy et al. [19]).

Fig. 23.8. Photograph of suction being applied via a catheter to the tracheal lumen of a left-sided DLT during a right-sided VATS procedure. Low suction (−20 cm H_2O) should be applied from the start of OLV until the nonventilated lung is completely collapsed.

Verifying Patency of Remaining Bronchi

During open thoracotomy for lobectomy, to ensure that the patency of a bronchus to a remaining lobe has not been compromised, the surgeon will often ask the anesthesiologist to temporarily reinflate the nonventilated lung after the stapling device has occluded the bronchus to the operative lobe or segment, just before the desired bronchus is cut and stapled. Reinflation of the ipsilateral remaining lobe(s) ensures the patency of their bronchi. However, during a VATS resection, this manuver impairs the surgeon's ability to visualize the surgical field and to proceed with the resection. To avoid this potential for compromise of noninvolved bronchi during VATS the anesthesiologist may be asked to perform fiberoptic bronchoscopy at this stage to ensure that the bronchi to the remaining ipsilateral lobe(s) is/are patent (see Fig. 23.9a, b). To perform this, the anesthesiologist needs a detailed knowledge endoscopic bronchial anatomy (see Chap. 16).

Lung Isolation

The use of DLT has classically been considered the "gold standard" for achieving OLV. Proper position of the DLT or endobronchial blocker is often confirmed in the supine position, but it is when the patient has been placed in the lateral decubitus position that matters most since the surgery will take place in that position and dislocation during position changes are not uncommon. A study conducted by Narayanaswamy et al. [19] showed in 104 patients undergoing left-sided lung surgery that, in regards to quality of surgical exposure, there was no difference between the use of bronchial blockers (Arndt wireguided, Cohen Flexi-tip, Fuji Uni-blocker) and a left-sided DLT. However, significant differences were found favoring the use of DLTs with regards to time to initial lung deflation and amount of repositioning required after initial placement of the lung isolation device. Since most VATS procedures require lung separation and not isolation, the insertion of a bronchial blocker to obtain OLV is an attractive alternative to a DLT, especially since multiple intubations of the trachea will not be necessary when using a bronchial blocker. Additionally, a difficult intubation is even more difficult much when using a DLT.

Management of One-Lung Ventilation

Peak airway pressure, delivered tidal volume (spirometry) and the wave-form of the capnogram, should be inspected to identify obstruction or reduced end-tidal carbon dioxide tension from inadequate gas exchange subsequent to DLT malposition. A peak airway pressure of up to 35 cm H_2O during OLV is acceptable. A sudden increase in the peak airway pressure (during volume-controlled ventilation) may be from DLT or endobronchial blocker dislocation. These tube or blocker movements are often a consequence of surgical manipulation. During pressure-controlled ventilation, this will present as a fall in tidal volume. When OLV is required, a FiO_2 of 1.0 provides the greatest margin of safety against hypoxemia. When using a FiO_2 of 1.0, assuming a typical HPV response, the expected PaO_2 during OLV should be between 150 and 210 mmHg. I typically ventilate OLV patients with a tidal volume of 6–7 mL/kg, PEEP 5 cm H_2O, and at a respiratory rate sufficient to maintain a $PaCO_2$ of 35 ± 3 mmHg. Following the initiation of OLV, PaO_2 can continue to decrease for up

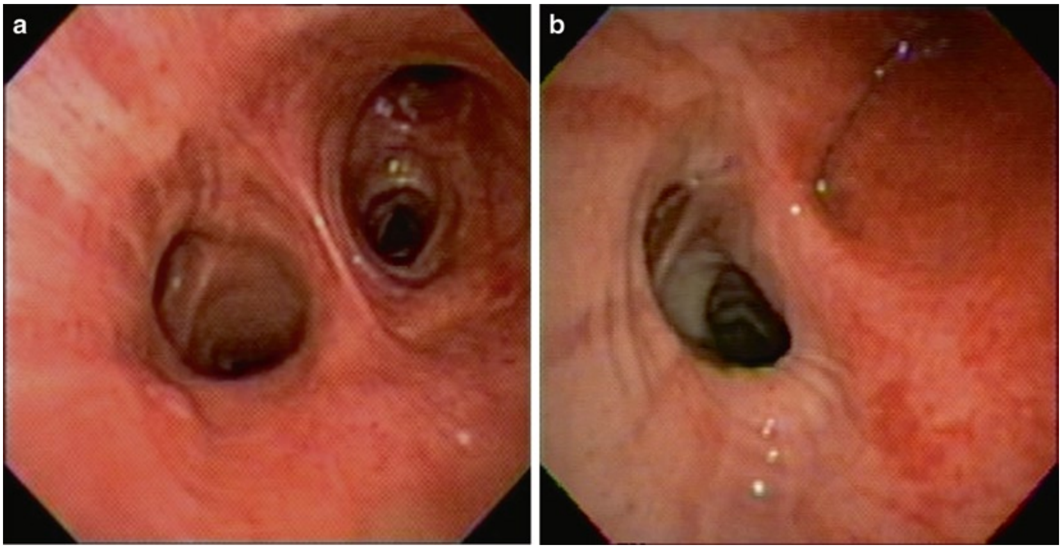

FIG. 23.9. (**a**) Normal anatomy of the secondary carina of the left lung as seen during fiberoptic bronchoscopy during VATS lobectomy. The left upper lobe orifice is at the upper right. The posterior wall of the mainstem bronchus is identified by the longitudinal elastic bundles, seen at 9 o'clock, which extend into the left lower lobe. (**b**) A surgical stapler has been applied to the left upper lobe bronchus. The anesthesiologist is asked to ensure that the bronchus to the left lower lobe remains patent, as seen in the photograph, prior to firing the stapler.

to 45 min; hence, a pulse oximeter is indispensable. Should hypoxia occur, proper positioning of the DLT should be reconfirmed using fiberoptic bronchoscopy.

Other Anesthetic Considerations for VATS

In addition to the usual complications related to intra-thoracic surgery and anesthesia, thoracoscopic procedures can be associated with massive hemorrhage and decreased inability to control large blood vessels. Maintaining stable hemodynamics can present a challenge until the surgeon gets control of the source of bleeding which may require conversion to an open thoracotomy. Therefore, large bore intravenous catheters are even more critical for VATS procedures than open thoracotomy where the hilar blood vessels can be controlled easier. Bleeding can be from placement of trocars into the lung or great vessels.

A false assumption that is made by patients coming for minimal invasive surgery is that the perioperative risk will also be "minimal." VATS is frequently described to the patient and their family as a simple entry into the chest. While VATS is associated with improved healing, lung function and shorter hospital length of stay, by no means should one be lured into thinking that the procedure is any less invasive than an open thoracotomy. Diagnostic VATS procedures are being increasingly performed on ASA III–IV patients, who historically would have been classified as inoperable using an open approach. An example would be a patient on the cardiac transplant list that needs a pretransplant tissue diagnosis of a lung lesion seen on a preoperative chest X-ray. Consequently, very ill patients requiring flawless lung separation techniques, who expect an uneventful perioperative course, pose an increased stress for the anesthesia team.

Postoperative Pain Management

Extensive discussion of the management of postthoracotomy pain can be found in Chap. 46. A commonly cited advantage of VATS when compared to open thoracotomy is a reduction in postoperative pain. While this is true in a relative sense, VATS procedures are still associated with a significant amount of postoperative pain, that is not only disturbing to patients, but may be associated with pain-related morbidities and prolonged hospital stays. The preponderance of literature suggests that VATS lung resection is associated with decreased postoperative pain compared with conventional thoracotomy. Sugiura and colleagues found a reduced duration of epidural catheter use, less narcotic use, decreased frequency of analgesic administration, and possibly a lower incidence of postthoracotomy pain syndrome in patients undergoing VATS compared with those undergoing thoracotomy [20].

Thoracic epidural analgesia has a long track-record of efficacy and safety and is considered by many anesthesiologists the gold standard in pain relief during the postoperative period for the thoracic patient. While other forms of postoperative analgesia are possible, many are associated with unwanted side effects. Systemic opioids are respiratory depressive and inhibit the cough reflex. Nonsteroidal antiinflammatory medication can inhibit coagulation and in isolation do not suffice to control the immediate postoperative pain experienced by this patient population. The utilization of paravertebral blocks has shown promise as an alternative to epidural analgesia.

The control of postoperative pain in patients after intrathoracic surgery is critical to the rehabilitation of their respiratory function. Postoperative pain in the chest wall can cause splinting which will impair couching, deep breathing leading to retention of secretions and a decrease in FRC. These problems have been shown to be a source of great morbidity and should be managed aggressively. The options for postoperative pain management should begin preoperatively and not postoperatively. A frank discussion with the patient will allow the patient to discuss their fears of anesthesia and postoperative pain. Pain control options include: Cognitive/behavioral (i.e., relaxation, distraction and imagery techniques), Intravenous administration of opioids and adjuvant agents (i.e., nonsteroidal antiinflammatory drugs, tri-cyclic agents) on an "around the clock" and or PRN basis, PCA intravenous pumps, neuraxial (epidural, intrathecal) agents (local anesthetics, opioids, ketamine, clonidine, alpha agonists), intermittent neural blockade (with local anesthetics, cryoprobe, neurolytic agents) or continuous neural blockade (with an intrapleural catheter), physical application of hot and cold compresses or TENS (transcutaneous electrical nerve stimulation). The surgical technique plays a very important part in the level of pain the patient will have postoperatively. There should be less pain associated with a VATS vs. open thoracotomy since there is less chest wall muscle damage. Controversy exists whether thoracic epidural analgesia is necessary for procedures performed with VATS since the pain experience is less dominated by the incisional component, compared to a thoracotomy. Thoracoscopy pain reflects more the visceral, pleural and diaphragmatic nociceptive components. Multimodal techniques involving a combination of intraoperative intercostal nerve blocks, pre and postoperative oral antiinflammatories and postoperative intravenous patient-controlled opioid analgesia is a common strategy for the majority of VATS patients in many centers. Thoracic epidural may be reserved for patients with severe pulmonary dysfunction who are at a high risk for postoperative respiratory complications.

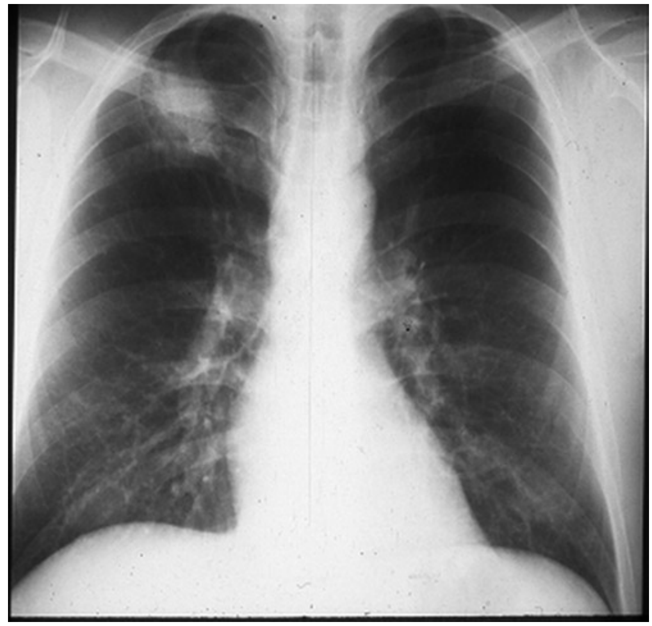

Fig. 23.10. Chest X-ray of a patient with a right upper lobe nonsmall cell lung cancer scheduled for VATS lobectomy. The patient has moderate COPD as evidenced by the hyperinflation of the lungs and the narrow cardiac silhouette.

Clinical Case Discussion

A 67-year-old-male with a right upper lobe nonsmall cell lung tumor is scheduled for VATS right upper lobectomy (see Fig. 23.10). He has COPD, preoperative FEV1 is 57% predicted and DLCO is 60%. No other comorbidities. After intravenous induction of anesthesia he is intubated with a left DLT. After turning the patient to the left lateral position and confirming the position of the DLT with fiberoptic bronchoscopy, one-lung anesthesia is begun with sevoflurane (1MAC) and a FiO_2 of 1.0, pressure-control ventilation, tidal volume 6 mL/kg, resp. rate 12/min. When the surgeon places the VATS camera in the right chest the lung is not completely collapsed. What can be done to improve lung collapse?

Answer: The position of the DLT should be reconfirmed with bronchoscopy. The adequacy of lung isolation should be confirmed by verifying that the inspired and expired tidal volumes of the left lung match using side-stream spirometry (the expired tidal volume is often a small percentage lower than the inspired volume due to the greater uptake of oxygen than the production of CO_2). The use of FiO_2 1.0 to the operative lung prior to the initiation of OLV will increase the rate of lung collapse and a low suction (20 cm H_2O) applied to the nonventilated lung will also speed collapse (see text).

With the onset of OLV the arterial oxygen saturation begins to slowly decrease. All other vital signs are stable: HR 78, BP 130/82 and $PetCO_2$ 32 mmHg. After 20 min of surgery the SpO_2 has fallen to 89% and continues to decline. What is the most appropriate next step?

Answer: After reconfirming the FiO_2 and the correct position of the DLT with bronchoscopy, a recruitment manuver of the left lung is performed and PEEP 5 cm H_2O is added to the left lung. In spite of these therapies the SpO_2 continues to fall and is now 87%. The Anesthesiologist suggests applying CPAP to the operative left lung. The Surgeon is adamant that he/she will not be able to complete the operation as a VATS procedure if CPAP is necessary and will have to convert to an open thoracotomy. Is there any other therapy that can improve oxygenation and will not interfere with surgical exposure?

Answer: Guided insufflation of oxygen at 5 L/min into the basilar segments of the right lower lobe is performed for 30 s. via the suction channel of the fiberoptic bronchoscope while the surgeon monitors the insufflation using the VATS camera (see Chap. 6, Fig. 6.11). After partial reinflation of the anterior and lateral basal segments of the right lower lobe the SpO_2 increases to 93% and surgery continues. The bronchoscopic segmental insufflation needed to be repeated once again 20 min later when the SpO_2 fell to <90%. Surgery was completed without complication or conversion to open thoracotomy. Management of hypoxemia during VATS procedures is outlined in Table 23.4.

Table 23.4. Management of hypoxemia during VATS.

Severe or acute desaturation
Resume two-lung ventilation
Gradual desaturation
1. Assure $FiO_2 = 1.0$
2. Check double-lumen tube or bronchial blocker placement with fiberoptic bronchoscopy
3. Optimize cardiac output
4. Recruitment maneuver of the ventilated lung
5. Apply PEEP 5 cm H_2O to ventilated lung (except moderate-severe COPD patients)
6. Partial ventilation of the nonventilated lung
(i) Segmental reinflation (with fiberoptic bronchoscopy)
(ii) High frequency jet ventilation

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