Anesthetic considerations for lung resection: preoperative assessment, intraoperative challenges and postoperative analgesia

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Abstract: This article is intended to provide a general overview of the anesthetic management for lung resection surgery including the preoperative evaluation of the patient, factors influencing the intraoperative anesthetic management and options for postoperative analgesia. Lung cancer is the leading cause of death among cancer patients in the United States. In patients undergoing lung resection, perioperative pulmonary complications are the major etiology of morbidity and mortality. Risk stratification of patients should be part of the preoperative assessment to predict their risk of short-term *vs.* long-term pulmonary complications. Improvements in surgical technique and equipment have made video assisted thoracoscopy and robotically assisted thoracoscopy the procedures of choice for thoracic surgeries. General anesthesia including lung isolation has become essential for optimizing visualization of the operative lung but may itself contribute to pulmonary complications. Protective lung ventilation strategies may not prevent acute lung injury from one-lung ventilation, but it may decrease the amount of overall lung injury by using small tidal volumes, positive end expiratory pressure, low peak and plateau airway pressures and low inspired oxygen fraction, as well as by keeping surgical time as short as possible. Because of the high incidence of chronic post-thoracotomy pain syndrome following thoracic surgery, which can impact a patient's normal daily activities for months to years after surgery, postoperative analgesia is a necessary part of the anesthetic plan. Multiple options such as thoracic epidural analgesia, intravenous narcotics and several nerve blocks can be considered in order to prevent or attenuate chronic pain syndromes. Enhanced recovery after thoracic surgery is a relatively new topic with many elements taken from the experience with colorectal surgery. The goal of enhanced recovery is to improve patient outcome by improving organ function and decreasing postoperative complications, and therefore decreasing length of hospital stay.

Keywords: Acute lung injury; one-lung ventilation (OLV); chronic obstructive pulmonary disease (COPD); video-assisted thoracic surgery (VATS); ventilator induced lung injury

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Introduction

Lung cancer is the leading cause of death among cancer patients in the United States with surgical resection being the only potential cure. These patients have an increased risk of perioperative pulmonary complications (PPCs) and long-term respiratory impairment following lung resection. Since 1933, when Graham and Singer reported the first successful pneumonectomy for lung cancer, there have been attempts to define a comprehensive preoperative assessment that would identify patients at high risk for PPC (1). A PPC is defined as any pulmonary complication occurring during the post-operative period and resulting in significant dysfunction (2). After lung cancer surgery, PPC's develop in 3.9% to 32.5% of patients, even with the improvements in anesthetic and surgical management (3,4). PPCs are a major cause of morbidity, mortality, lengthy hospital stay, and increased medical costs (4). Several examples of PCCs include postoperative respiratory failure, pneumonia, atelectasis, bronchospasm, and pulmonary edema.

Independent risk factors for PPC are Anesthesia Physical Status Classification of 3 or more, age ≥75 years, smoking history, body mass index ≥30 kg/m^2 and chronic obstructive pulmonary disease (COPD) (5). Approximately 73% of men and 53% of women are diagnosed with both COPD and lung cancer (6). Patients with COPD, controlled or uncontrolled, are at a substantially increased risk of pulmonary complications after surgery. Risks of bronchial inflammation, airway hyperreactivity and bronchospasm are consequences of airway manipulation in patients with COPD. The effects of smoking in the intraoperative and postoperative periods are caused by nicotine, carbon monoxide, and other elements that induce inflammatory and oxidative stress. The pro-inflammatory effects of cigarette smoke increase the risk of cardiac and infectious complications (7).

Tobacco smoking is a shared risk factor for both lung cancer and COPD. In patients with lung cancer caused by cigarette smoking, cardiovascular disease is also common. The prevalence of underlying coronary artery disease in this patient population is about 11–17%. Postoperative cardiac complications, including cardiac arrest or pulmonary edema, occur as frequently as 2–3% following lung resection (8,9).

General anesthesia is also considered to be a risk factor for postoperative pulmonary complications due to the numerous effects on the respiratory system. Prolonged exposure to general anesthetics can cause a reduced production of surfactant, increased alveolar-capillary permeability, impaired alveolar macrophage function, and slow mucociliary clearance, leading to an alteration in gas exchange. Positioning and mechanical ventilation cause postoperative atelectasis in up to 90% of patients. The result of this atelectasis is ventilation-perfusion (V/Q) mismatch, a decrease in compliance and hypoxemia (10).

Pre-operative evaluation

In patients being evaluated for surgical resection of their lung cancer, there is a direct correlation between the extent of pulmonary resection and the potential perioperative morbidity and mortality. After pneumonectomy, the mortality is up to two times higher than after lobectomy and the mortality rate of segmentectomy is lower than that after lobectomy (11). Limited pulmonary resection provides the ability to reduce the risk of physiological impairment by preserving a greater amount of lung parenchyma. Identifying an individual's acceptable risk for postoperative complications is an impetus to pursue efforts to define the best predictive tests necessary in order to minimize surgical risk. Consequently, when considering whether a patient should undergo surgical resection of a lung cancer, the short-term risk from cardiopulmonary disease and the risk of chronic pulmonary impairment must be considered in comparison to the risk of decreased length of survival if surgery is not a viable option.

The function of the preoperative evaluation is to identify patients at an increased risk of perioperative complications and long-term disabling consequences from surgical resection of lung cancer. Preoperative evaluation of pulmonary disease may include: preoperative pulmonary function tests (PFTs), calculation of predicted postoperative (ppo) PFT, measures of gas exchange, and exercise testing (12). Evaluation of preoperative exercise tolerance can be a strong predictor of outcome, particularly in the geriatric population (13). The actual perioperative risks are affected by patient factors (age, comorbidities), management of complications and surgical procedure [thoracotomy *vs.* video-assisted thoracoscopic surgery (VATS)]. VATS is a less invasive surgical technique whereby multiple laparoscopic ports and instruments are introduced into the hemithorax instead of making a large incision for surgical access. The preoperative evaluation provides communication between physicians and patients about the risks and benefits of treatment options to allow for informed decision-making.

Although the Revised Cardiac Risk Index (RCRI) has been recommended as the preferable cardiac risk score for non-cardiac surgery by the American Heart Association/American College of Cardiology (14) and European Society of Cardiology/European Society of Anesthesiology (15), this score was recently recalibrated by Brunelli *et al.* to better predict the post-operative cardiac risk of candidates undergoing lung resection (9). The resulting score, named Thoracic RCRI (ThRCRI), is a simplified weighted score, in which four factors are associated with major cardiac morbidity. The four factors are: previous ischemic heart disease: 1.5 points, history of stroke or TIA: 1.5 points, serum creatinine level greater than 2 mg/mL: 1 point, and pneumonectomy: 1.5 points. Patients with the highest score and therefore the highest risk, experience major cardiac events as frequently as 23% *vs.* 1.5% in those with the lowest score. This recalibrated score has been validated by several studies to be more accurate than the traditional RCRI in this population (9,16,17). The American College of Chest Physicians (ACCP) has since updated their cardiac algorithm to include these parameters. Patients with ThRCRI ≥2 or a newly diagnosed or existing cardiac condition requiring medication or limited exercise tolerance should have a cardiac consultation including noninvasive testing (18).

According to both the ACCP and the British Thoracic Society (BTS), spirometry testing to measure the forced expiratory volume in one second (FEV1) is recommended in patients scheduled for pulmonary resection (18,19). In patients with a normal FEV1, the diffusing capacity of the lung for carbon monoxide (DLCO) was established for predicting postoperative complications (20). A reduced ppoDLCO correlates most closely with the risk of pulmonary complications and mortality following lung resection. In patients with compromised preoperative respiratory status, (ppoFEV1 between 30–40%) ppoDLCO is the best predictor of a patient's candidacy for surgical resection (21,22).

For patients requiring pneumonectomy, ventilation/perfusion scan (V/Q scan) method was suggested to calculate the ppo values of FEV1 or DLCO:

ppo values = Preoperative values × (1 − Fraction of total perfusion for the resected lung)

where the preoperative values are taken as the best measured post-bronchodilator values. For patients requiring lobectomy, ppo values of FEV1 or DLCO was calculated by segmental counting:

ppo values = Preoperative values × (1 – y/z)

where the preoperative values are taken as the best measured post-bronchodilator value, y is the number of functional or unobstructed lung segments to be removed and z is the total number of functional segments. The patient is considered to be at low risk if both the ppoFEV1 and ppoDLCO values are greater than 60% (19,23). This correlates to an expected risk of mortality below 1% for cardiopulmonary complications and perioperative death after lung resection, including pneumonectomy. However, if either the ppoFEV1 or the ppoDLCO values are within 30–60% of predicted, a low technology exercise test, such as the stair-climbing or shuttle-walking test should be performed to determine surgical risk.

If the ppoFEV1 or ppoDLCO is <30% or if the stair-climbing test or shuttle walking test is not satisfactory, a high technology test [e.g., cardiopulmonary exercise test (CPET)] is recommended. CPET evaluates exercise capacity and maximum oxygen consumption (VO_2max). According to the European Respiratory Society and the European Society of Thoracic Surgeons joint task force, CPET is inversely correlated with post-operative morbidity and mortality. VO_2max >20 mL/kg/min or >75% predicted indicates a low risk. If VO_2max is between 10 and 20 mL/kg/min or 35–75%, the patients are at moderate risk. The morbidity and mortality rates vary depending upon the extent of resection, exercise tolerance, and values of split lung functions Alternatively, VO_2max <10 mL/kg/min or <35% predicted implies a risk of mortality as high as >10%, which may cause significant risk of residual functional loss and severe cardiopulmonary morbidity. At this point, patients should be counseled about other available options such as minimally invasive surgery or nonsurgical options (19,23).

Neoadjuvant therapy

Patients with locally advanced lung cancer may require preoperative chemotherapy prior to surgical resection. Evidence suggests that chemotherapy can be associated with a 10% to 20% reduction in DLCO regardless of apparent improvement in spirometry values (24). Drug-induced structural lung damage has been linked to an increase in PPCs. Therefore, it is suggested to repeat PFTs with DLCO testing after completion of neoadjuvant therapy to reassess the operative risk after potentially damaging lung tissue (25).

Intraoperative anesthetic management for lung resection

The anesthesiologist's goal in addition to providing analgesia, loss of consciousness, stable hemodynamics, and when indicated, single lung ventilation should strive to minimize ventilator-associated lung injury (ALI) in surgical patients undergoing total or partial lung resection. As thoracic surgical procedures have become more minimally invasive, video-assisted laparoscopic and robotic-assisted procedures have become the preferred methods of thoracic surgery, necessitating more frequent use of one-lung ventilation (OLV). The rapid advances in VATS and robotics has increased the incidence of ALI that accompanies OLV, the primary cause of mortality following lung resection. Until the last decade, open thoracotomy for intrathoracic surgery allowed the surgeon to visualize the surgical field, manipulate the lung, and control movement within the surgical field, with or without intermittent ventilation. Insufflation of the hemithorax was not a concern and OLV had fewer absolute indications. The purpose of OLV is to collapse and isolate the operative lung in order to provide the surgeon with optimal surgical exposure. One of the effects of OLV is a significant shunt which can affect gas exchange. In the lateral decubitus position required for thoracic surgery, gravity primarily causes perfusion to go to the dependent lung. Ventilation will initially go to the operative lung with the patient in this position due to decreased compliance in the dependent lung. Commencing with OLV by collapsing the operative lung favorably influences this shunt through a process called hypoxic pulmonary vasoconstriction (HPV). HPV will cause a time-dependent decrease in blood flow to the poorly ventilated lung (the operative lung) and therefore will improve the (V/Q) mismatch. The alveolar partial pressure of oxygen prompts this physiologic response (26).

Historically, anesthesiologists sought to prevent hypoxia and ensure adequate gas exchange by using high tidal volumes, zero positive end expiratory pressure (PEEP), and high inspired oxygen fractions (FIO_2). Unfortunately, these practices have been implicated as contributing to barotrauma (high pressures on the lung), volutrauma (overdistention of the lung), atelectotrauma (repetitive opening and closing of alveoli), and biotrauma (local inflammatory mediators) (27). Independent risk factors including high intraoperative ventilatory pressure (high peak and plateau airway pressures), high intraoperative tidal volumes (with low or no PEEP), excessive fluid infusion with pneumonectomy, and preoperative alcohol abuse have also been implicated in contributing to acute lung injury (28,29).

The mechanisms of injury behind ALI do not end with high tidal volumes, excessive fluids, or hypoxia. The process is more complex, with mechanisms for ALI differing for the dependent and operative lungs in OLV, and requires additional research to identify etiologies leading to this major cause of morbidity in up to 15% of patients, determined by the extent of their lung resection surgery. Other stresses on the lungs during and immediately after OLV include oxidative stress, ischemia-reperfusion injury, as well as capillary shear stress secondary to hyperperfusion, can be seen in both the dependent and operative lung and may be unavoidable (30).

Although far more evidence exists regarding lung protective strategies in two-lung ventilation (TLV), particularly in critical care literature of acute respiratory distress syndrome (ARDS) patients, many studies are emerging with specific strategies for OLV (31). Much of the evidence surrounding lung injury is extrapolated from landmark trials in the ARDS Network (30). This evidence includes lung protective parameters that have largely become the standard of care among anesthesiologists, in OLV and TLV, such as low tidal volume ventilation based on ideal body weight (4–5 mL/kg) and relatively high PEEP to maintain oxygenation. Blank *et al.* suggested that large tidal volume (V_T), high peak inspiratory pressures and low or no PEEP during OLV are associated with increased post-operative pulmonary complications and a higher mortality (30,31). This study suggested that there is a reduction in pulmonary and systemic inflammation, lung edema, pulmonary complications, and hospital stay when utilizing protective OLV (reduced V_T and moderate PEEP), while others further expanded on this protective strategy, incorporating limiting ventilator pressures and recruitment maneuvers during OLV (32,33). These studies do not elucidate which ventilatory parameter, low V_T, moderate PEEP, lower airway pressure, or recruitment maneuvers, if any, is more likely to predict an improved outcome (32). In contrast, a recent prospective observational study by Amar *et al.* found no difference, for example, in the incidence of pneumonia and/or ARDS between patients undergoing lung resection with tidal volumes <8 or ≥8 mL/kg (predicted body weight), implying that the clinical impact of protective lung strategies is small (27). Until there is a consensus, our practice is to use V_T 5–7 mL/kg, PEEP 5–7 cmH_2O, and ventilatory plateau pressures below 30 cmH_2O whenever possible. We use recruitment maneuvers as needed. Minimizing surgical time and OLV time are also important factors in our goal to decrease the incidence of PPC.

The anesthetic management for lung resection surgery must incorporate several factors: the nature of the planned thoracic procedure, the percentage loss of functional lung parenchyma and the physiologic and hemodynamic effects of mechanical ventilation, particularly with respect to OLV. OLV poses many challenges, for example, atelectasis, V/Q mismatch, barotrauma and alveolar injury. Atelectasis is a significant consequence during all anesthetics and in mechanically ventilated patients, but during OLV its effects may be compounded due to the use of higher inspiratory oxygen fraction (absorption atelectasis) and the greater potential for dependent lung compression (compression atelectasis) (32,34). The presence of atelectasis has the potential to cause inflammation and alveolar injury in adjacent healthy lung parenchyma and can promote bacterial translocation, increasing the risk for pneumonia (35). Atelectasis can be attenuated by the presence of PEEP to promote lung protection and function and to decrease morbidity. It appears that the specific pairing of low V_T and moderate to high PEEP, has shown benefit in preventing pathophysiologic sequelae of atelectasis, overdistension, and tidal recruitment/decruitment (32).

When employing OLV during intrathoracic surgery, the anesthesiologist is at times faced with hypoxemia. Given the unavoidable Alveolar-arterial (A-a) gradient and V-Q mismatch created by OLV, it is essential that in patients with poor cardiopulmonary reserve, the preoperative hemoglobin and oxygenation be optimized prior to surgery (36). In our practice, preoperative oxygenation is evaluated on room air whenever possible, to determine baseline oxygen saturation and PaO_2. Patients undergoing lung resection may have significant pulmonary disease manifested by a decreased functional residual capacity, impaired gas exchange, and V/Q mismatch. Smoking cessation for 4–6 weeks, the use of an incentive spirometer and treatment of any underlying pulmonary disease, such as asthma or COPD, using steroids and Beta 2 agonists is recommended to improve lung function prior to surgery (37). Anemia can negatively impact demand ischemia, which may not be tolerated well by patients at risk for myocardial ischemia. A preoperative hemoglobin is determined for our patients and blood is readily available in the event of unanticipated blood loss or inadequate perfusion as determined by a rising lactate on arterial blood gas, a compensatory tachycardia or hypotension. We rarely transfuse preoperatively unless a patient is actively bleeding.

It may be necessary intraoperatively to intermittently reinstitute TLV to improve the oxygen saturation. Using TLV during a procedure is limited by the procedure and the degree of impairment of the surgeon's visualization of the field. Alternative options include increasing the inspired fraction of oxygen, checking and repositioning the DLT or endobronchial blocker, and decreasing the inhalational agent or starting vasopressors or inotropes to improve cardiac output. In addition, recruitment of the atelectatic zones of the dependent lung can be attempted (36) with PEEP being added to the dependent lung (38) and/or continuous positive airway pressure (CPAP) 1–2 cm H_2O being applied to the operative lung (39). While a high inspired oxygen concentration is often required to alleviate intraoperative hypoxemia, this is not without risk, since oxidative stress caused by a high FIO_2 for an extended period of time, has been implicated in ALI (31).

The inhaled volatile agents, commonly used as the mainstay of an anesthetic, when employed at greater than one minimum alveolar concentration (MAC) will interfere with HPV, a pulmonary compensatory mechanism relied on to reduce the V/Q mismatch caused by OLV (31,36). Sevoflurane potentially reduces ALI by inhibiting the release of proinflammatory mediators during OLV and lung resection and increases bronchodilation (40). de la Gala *et al.* demonstrated a lower one year mortality and PPC using Sevoflurane *vs.* a total intravenous anesthetic (TIVA) (41). Another study by Wigmore *et al.* showed that a propofol-based TIVA technique for general anesthesia may provide anti-inflammatory and anti-oxidant properties and may preserve natural killer cell function (42). Currently, there is no sufficient evidence to support one anesthetic technique as being definitively advantageous over the other.

Narcotics can be used an important adjuvant anesthetic in anesthetizing patients with compromised cardiac function by decreasing the agents administered that are myocardial depressants, particularly the volatile anesthetic agents. When using a short-acting narcotic, such as remifentanil, a more rapid emergence is facilitated. This can be invaluable when anesthetizing patients with cardiomyopathies, left ventricular hypertrophy, and valvular disease, in particular aortic stenosis. Pulmonary hypertension poses a dilemma and requires different anesthetic management when it involves right (pulmonary) *vs.* left heart disease. Ketamine can be useful in patients with right ventricular dysfunction and pulmonary hypertension secondary to COPD. It is known for its sympathomimetic effects and will maintain or increase contractility while avoiding a decrease in systemic vascular resistance (SVR) associated with inhaled anesthetics. Its effect on pulmonary vascular resistance (PVR) is controversial, although some studies have documented a decrease in PVR (43-45).

In patients with severe pulmonary hypertension, inhaled pulmonary vasodilators including nitric oxide (10–40 ppm) or nebulized prostaglandins (prostacyclin, 50 ng/kg/min) should be considered along with a vasoconstrictor to maintain SVR while improving the pulmonary artery pressure (PAP)/systemic blood pressure (SBP) ratio (36).

In addition to standard American Society of Anesthesiologists (ASA) non-invasive monitoring (46), an arterial line is often indicated intraoperatively to measure blood pressure as well as for arterial blood gas determination. It is controversial whether a dynamic preload indicator such as stroke volume variation (SVV) in conjunction with cardiac index, using a FloTrac System (Edward Lifescience, Irvine, CA, USA), can predict fluid responsiveness in OLV for thoracic surgery. SVV is a dynamic factor and is based on the arterial waveform in relationship to various factors such as positive pressure ventilation, OLV, changes in intrathoracic pressure, preload status, arrhythmias, tidal volume, chest wall compliance, lung manipulation and compliance, and vasopressor administration. Xu *et al.* used SVV and cardiac index goal directed fluid restriction to improve hemodynamics and lung mechanics during OLV. They found it decreased the incidence of PPC and the length of hospital stay, although it did not decrease the overall incidence of inflammation as indicated by measuring serum cytokines (47). Jeong *et al.*'s study found that SVV did not predict fluid responsiveness in OLV (48). Parenteral fluid administration is usually limited in lung resection surgery. In our practice, we primarily use crystalloid (Plasmalyte or Normal Saline) for maintenance fluid and have packed red blood cells available in case of significant blood loss to maintain hemodynamics and tissue perfusion. Pulmonary edema, particularly in pneumonectomy, is not uncommon after excessive fluid administration. The exact etiology has not been determined (31).

Infrequently, other invasive lines may be necessary. A central line may be considered for vasoactive drugs and central venous pressure or a pulmonary artery catheter for pulmonary artery pressures, cardiac output and for therapeutic guidance in pulmonary hypertension. However, these invasive monitors have not been shown to improve outcome (49). The use of intraoperative transesophageal or transthoracic echocardiography may be considered to monitor intraoperative cardiac function, although employing these point-of-care modalities may prove to be logistically difficult due to positioning and limited access to the patient.

Achieving lung isolation

For procedures in the thoracic cavity, the use of lung isolation techniques facilitates a collapsed lung for maximal surgical exposure and a motionless surgical field. Options to achieve this goal are the double lumen tube (DLT) (we use the Robertshaw DLT), considered the gold standard for lung separation, or the Univent tube (Fuji Corp., Tokyo, Japan), which is a 9-Fr endobronchial blocker with a steering mechanism. Alternatively, the EZ-Blocker (Teleflex Medical Inc., Research Triangle Park, NC, USA) can be used, which is a 7-Fr catheter designed with a Y shape and two distal extensions that ride over the carina, and each lung can be selectively deflated. Regardless of the system chosen to isolate the lung, a fiberoptic bronchoscope must be used by the anesthesiologist to ensure proper placement and adequate lung isolation, both after positioning the device and again after positioning the patient (26,36).

There are advantages and disadvantages to DLT's *vs.* the use of an endobronchial blocker. DLT's provide better isolation of each lung when a lung contaminated with blood or pus is involved. Pulmonary suctioning is more easily accomplished since each lung can be suctioned throughout the procedure, whereas an endobronchial blocker would need to be deflated in order to suction the operative lung. Bilateral procedures do not require replacement of or repositioning of the DLT. Disadvantages of the DLT to consider are: it takes longer and requires more skill to place a DLT as opposed to a single lumen endotracheal tube (SLT). Often patients coming to the operating room from an intensive care unit (ICU) already have a SLT in place through which an endobronchial blocker can be positioned. After using a DLT for a procedure, there may be laryngeal edema and replacement of the DLT with a SLT can be challenging. There is also a higher incidence of airway injury using a DLT including hoarseness, vocal cord injury, esophageal injury and tracheal or mainstem bronchial injury (36,50).

Post-operative management

The role of well-planned pain management cannot be overemphasized after major thoracic surgery for lung resection. Post thoracotomy pain is one of the most severe of all surgical procedures, ranking highest on the visual analog pain scale. There are many intraoperative factors which contribute to postoperative pain including surgical retraction, resection, dislocation of costovertebral joints, incidental rib fractures, injury of intercostal nerves, as well as pleuritic pain caused by chest tubes. Pain control, however, is of the utmost importance in both open thoracotomy and VATS procedures (although VATS are significantly less painful) to prevent postoperative complications as a consequence of splinting of expiratory muscles by patients. Patients experiencing severe pain postoperatively will have a poor respiratory effort and a decreased functional residual capacity. It will also be challenging for the recovering patient to cough and clear secretions. These pulmonary complications result in airway closure, atelectasis, shunting and tissue hypoxemia (51). Therefore, both an acute and chronic pain management plan is crucial for these high-risk patients in whom pain can potentially last for months to years. Even low levels of pain can affect a patient's quality of life, especially from chronic post thoracotomy pain syndrome (CPTPS) (52). The incidence of long-term post thoracotomy pain has been reported to be as high as 80% at 3 months, 75% at 6 months, and 61% at 1 year after surgery. Severe pain occurs in 3–5% of patients, and 50% of patients report pain that interferes with their daily routine (53).

There are a number of techniques available to help patients maintain their functional residual capacity by deep breathing and avoiding development of CPTPS. Continuous thoracic epidural analgesia (TEA) remains the gold standard for post thoracotomy pain control and has been shown to provide superior analgesia both at rest and during movement with highest degree of patient satisfaction (54). A thoracic epidural provides excellent continuous analgesia while allowing decreased use of parenteral opioids, and therefore can significantly decrease the incidence of pulmonary morbidity (55). In addition, epidural analgesia is associated with lower need of rescue analgesia. Limitations of TEA include hypotension, bradycardia, urinary retention, incomplete (or failed) block, neurological injury and rarely, paraplegia due to epidural hematoma. In addition, resulting hypotension with epidural analgesia must be carefully managed in patients who are at risk for cardiovascular complications (55,56).

Opioids are an important component of treatment regiments and can be administered via various routes. Intravenous patient-controlled analgesia (IV PCA) is the simplest and one of the most common methods for postoperative pain management (54). IV PCA is ideal in achieving a balance between comfort and respiratory depression. Parenteral narcotics, however, present a challenge in patients with marginal lung function and must be carefully titrated. Excessive sedation can also increase the risk of pulmonary complications such as respiratory depression, sputum retention and infection (57).

Intercostal nerve blockade (ICNB) is used routinely in some centers. The surgeons perform single shot injection of two dermatomes above, two below, and one at the site of the incision before closure. Since a single-shot ICNB is not very effective, some surgeons place indwelling catheters in a subpleural/extrapleural pocket. Intraoperative cryoneurolysis of the intercostal nerves prior to closure of the chest incision is another option. Endoneurial and perineural connective tissue are preserved using this technique, thereby allowing restoration of nerve structure occurs 1–3 months after freezing. Although this has been shown to be an effective method in decreasing the amount of postoperative pain and analgesics prescribed, in the long term, there was a high incidence of developing neuropathic pain, dysesthesia, and intercostal muscle paralysis (58,59).

There has been a renewed interest in paravertebral nerve blocks (PVB) in the last decade as an alternative technique that may offer comparable analgesic effectiveness with a more desirable side-effect profile. These blocks generally last 18–24 h and are considered by some authors nearly equivalent in efficacy to epidural analgesia in the first 24 h without the detrimental effects of bilateral sympathectomy (54,57). It proves most helpful in patients who are not candidates for TEA. The disadvantage of PVB includes a relatively high failure rate of up to 10%, possibly due to the interference by the endothoracic, fascia which may hinder diffusion of the local anesthetic (60). It should be noted that paravertebral catheter placement has the same contraindications in anticoagulated patients as does an epidural. Also, fewer practitioners are trained to perform PVB. Those clinicians who are proponents of PVB claim it is a simple, safe, and easy to learn block with a low incidence of complications (61,62).

In addition to PVB, some centers have been performing serratus anterior plane blocks (SAPB) as an alternative to TEA. The SAPB blocks the lateral branches of the intercostal nerves. The effectiveness was demonstrated in a small randomized control trial which compared serratus anterior block with TEA using mean arterial blood pressure after SAPB and TEA, as well as determination of level of pain, narcotic use and nausea and vomiting in the first 24 hours post-operatively. In addition, the SAPB avoids the autonomic complications of TEA (63).

Enhanced recovery after thoracic surgery (ERATS)

ERATS aims to decrease postoperative complications and hospital stay while improving organ function, using evidence-based perioperative recommendations for preadmission, admission, intraoperative and postoperative care of the patient, to achieve better patient outcomes. These recommendations are endorsed by the Enhanced Recovery after Surgery Society and the European Society for Thoracic Surgery. They include, but are not limited to, preoperative counseling, nutritional screening, smoking cessation, avoidance of fasting, use of preoperative carbohydrate drinks, avoidance of preoperative sedatives, venous thromboembolism prophylaxis, prevention of hypothermia, use of short-acting anesthetics, use of regional anesthesia, minimally-invasive procedures, and early postoperative mobilization. Many of these recommendations are based on enhanced recovery after surgery (ERAS) from established colorectal surgery guidelines, but it is quickly becoming evident that incorporating these elements into the care of thoracic patients, improves patient satisfaction and outcome (64).

Conclusions

Lung resection surgery is very complicated and requires a team effort including the surgeon, the anesthesiologist, the pulmonologist and other specialists, to choose the best therapy given an individual's presentation, comorbidities and risk stratification. The patient's preoperative assessment must include PFTs, a complete physical exam and an evaluation of independent indicators such as exercise tolerance, comorbidities, smoking and alcohol use. The extent and type of surgery must be taken into account to be able to stratify the patient's perioperative risk *vs.* the long-term pulmonary risk. Pain management is also a pertinent factor in determining a patient's postoperative comfort, morbidity, and ultimately, quality of life. Chronic pain syndromes can negatively affect a patient's daily activities but may be preventable with adequate, early pain control using a variety of techniques. Preoperative evaluation, intraoperative anesthetic management, postoperative analgesia and incorporating ERATS into the plan for lung resection are crucial elements to consider in ensuring the best care and outcome for the patient.

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Footnote

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