Anesthetic Management for Pulmonary Resection

Current Concepts and Improving Safety of Anesthesia

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KEYWORDS

• Thoracic anesthesia • Lung resection • Thoracic ERAS • Non-intubated VATS • Anesthesia safety

KEY POINTS

- Perioperative management of the pulmonary resection candidate is evolving to incorporate prehabilitation as well as enhanced recovery after surgery (ERAS) pathways to facilitate recovery.
- With a shift toward less invasive surgical procedures, the avoidance of general anesthesia through approaches incorporating regional anesthesia and spontaneous ventilation are being explored.
- ERAS protocols to improve patient recovery and minimize hospital length of stay are being developed and adopted more broadly.

INTRODUCTION

Lung resection surgery presents a unique set of challenges for anesthesiologists. Significant advances in surgical techniques have dramatically increased the scope and complexity of the patients presenting for surgery. This article provides an evidence-based update on anesthetic care for these patients.

PREANESTHETIC EVALUATION AND OPTIMIZATION

The goal of preoperative evaluation is to determine the risk of postoperative morbidity and mortality, and to identify opportunities for risk modification. A number of global risk scores have been developed that can assist in risk stratification and to provide guidance regarding preoperative testing.

The Eurolung risk score was developed from data in the European Society of Thoracic Surgeons (ESTS) database, containing more than 82,000 lung resections. The score is based on patient and surgical variables and can stratify patients with respect to 30-day mortality as well as long-term survival.[1,2]

The Thoracic Revised Cardiac Risk Index (ThRCRI) was developed to address the poor performance of the Revised Cardiac Risk Index (RCRI) in predicting adverse cardiac events in patients within 30 days of lung resection.[3] Compared with the original RCRI, the ThRCRI has been shown to have a greater degree of discrimination (c index 0.72 vs 0.62; $P = .004$).[3]

Further preoperative cardiac assessment is conducted based on the recommendations of the 2014 American College of Cardiology/American Heart Association Guideline on Perioperative Cardiovascular Evaluation and Management of Patients Undergoing Noncardiac Surgery.[4] In general, patients with lung resection with poor (<4 metabolic equivalents [METS]) or unknown functional capacity should undergo functional cardiac testing if the test results will impact perioperative care, otherwise, they should proceed with surgery with goal-directed medical therapy. Recent

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studies have shown that the subjective assessment of functional capacity by physicians has low sensitivity for identifying the inability to achieve 4 METS and that the use of the Duke Activity Status Index can be used to identify patients at greater risk for cardiac complications.[5,6]

Preoperative B-type natriuretic peptide concentrations (BNP) and N-terminal fragment of proBNP (NT-proBNP) are independent predictors of postoperative complications.[7–9]

Preoperative pulmonary assessment is conducted based on the guidelines published by the American College of Chest Physicians and the European Respiratory Society/European Society of Thoracic Surgery (ERS/ESTS).[10,11] Both sets of guidelines advocate for further testing for patients with forced expiratory volume in 1 second or diffusing capacity of the lung for carbon monoxide less than 80% predicted; however, they differ with respect to the order in which they prioritize quantitative lung scintigraphy and exercise testing.[10,11]

Prehabilitation

Prehabilitation is a multifaceted approach of improving a patient's functional capacity to allow them to better withstand the stresses associated with the entire perioperative period. In its most advanced and comprehensive iterations, prehabilitation involves (1) personalized strength, flexibility and balance training; (2) dietary modifications designed to favorably modify the balance of catabolism associated with the immediate postoperative period with the anabolism needed for improved recovery; (3) interventions designed to support the patient's resiliency, reduce anxiety, and promote self-efficacy; and (4) cease deleterious habits such as smoking and alcohol abuse. The utilization of such programs is recommended as a component of the current ERAS Society/European Thoracic Surgery guidelines for enhanced recovery after lung surgery with a recommendation grade of "strong" albeit with an evidence level of "low."[12]

A recent meta-analysis identified 10 randomized controlled trials (RCTs) with a total of 676 participants investigated the effects of preoperative exercise training on postoperative pulmonary complications. Pooled data analysis showed a significant reduction in postoperative pulmonary complications (respiratory rate 0.5; 95% confidence interval [CI] 0.39–0.66) and length of stay (LOS) as well as improvements in walking endurance and peak exercise capacity.[13] The quality of evidence was graded as low because of the small number of studies, small sample sizes, and significant risks of bias in the study designs. Furthermore, the type, frequency, and intensity of the exercise programs varied across the different studies, making it challenging to recommend a specific intervention. In the studies included for meta-analysis, interventions ranged from 1 week to 4 weeks, training sessions ranged from twice daily to 3 to 7 per week, and training programs varied from aerobic training only to aerobic training with some combination of inspiratory muscle training, strength training, and flexibility training. Another potential challenge for interpretation and application of these findings is that the included studies made no distinction between patients undergoing open lung resections and those undergoing thoracoscopic resections. Significant questions remain with respect to the widespread implementations of prehabilitation programs, including the minimum amount of intervention that is necessary, the necessity of hospital-based or clinic-based intervention, as opposed to home-based programs, as well as the specific patient populations for which the programs offer the greatest benefit.[14]

Enhanced Recovery after Surgery for Thoracic Surgery

As in other surgical fields, there is growing interest in enhanced recovery after surgery (ERAS) pathways, which are evidence-based, protocolized pathways aimed at simultaneously improving perioperative outcomes while increasing cost savings. Guidelines for ERAS after lung surgery were published by the ERAS and ESTS in 2019.[12] The suggested pathway spans the entire care continuum, from preadmission through recovery and includes recommendations for 45 items in total, including an assessment of each item's level of supporting evidence and the Society's strength of recommendation. Recommendations unique to the thoracic ERAS include interventions such as using lung protective ventilation while avoiding overly restrictive fluid resuscitation, muscle-sparing and nerve-sparing surgical techniques, and early removal of chest tubes. Emerging data from clinical studies indicate significant benefits of adoption of ERAS protocols for lung resection.[15–18] Some studies show decreased hospital LOS by 1 to 2 days, decreased cardiopulmonary complications, decreased opioid use, and significant cost savings per patient. Interestingly but perhaps unsurprisingly, these benefits are more pronounced in patients undergoing thoracotomy and open lung resection as opposed to video-assisted thoracoscopic surgery (VATS).[12,18] Still, there may be additional benefits that traditional outcome measures fail to capture that are most important from the patient's perspective; that is, patient-reported outcomes that measure elements of a patient's physical and psychological well-being.[18,19]

ANESTHETIC TECHNIQUE

The anesthetic technique used for lung cancer operations is tailored to the nature of the surgical procedure and the patient's comorbidities. The overarching objective is to provide the safest anesthetic while minimizing complications and improving the patient experience.

Regional and Neuraxial Anesthesia

Thoracic epidural analgesia is typically used intraoperatively and postoperatively to manage the pain associated with thoracotomy. Meta-analyses show that thoracic epidurals reduce pulmonary complications, decrease stress responses, and are consequently associated with better short-term outcomes in thoracic surgery.[20,21] Thoracic epidural should be considered for all patients undergoing thoracotomy unless contraindicated, although some studies suggest paravertebral blocks (PVBs) and catheters provide nearly equivalent analgesia.[22–24] A recent Cochrane Review concluded that thoracic epidural and PVB had equivalent survival, LOS, rates of major complications, and treatment of acute perioperative pain, but there were fewer minor complications in patients receiving PVB.[25] However, due to heterogeneity of available studies and local expertise of practice, this issue remains a subject of considerable debate.[26,27]

Minimally invasive procedures such as VATS usually do not require epidural anesthesia, but PVB, intercostal nerve blocks, or other regional techniques can be used effectively, likely with a better margin of safety compared with epidural anesthesia.[28–32] Intercostal nerve blocks significantly decrease postoperative opioid consumption in patients undergoing VATS; however, they may be inferior to PVB with respect to analgesia and the preservation of pulmonary mechanics.[33,34] Serratus anterior plane and erector spinal plane blocks have also been demonstrated to control pain and improve outcomes in thoracic surgery.[35–38] Despite these compelling findings, whether or not regional anesthesia is even necessary in VATS is also a matter of controversy, with one study showing equivalent outcomes in patients managed with epidural or PVBs compared with intravenous analgesics alone.[39]

Multiple different types of local anesthetics have been used in studies of regional anesthesia for thoracic surgery. Liposomal bupivacaine with its slow-release property and the potential for prolonged pain relief has received considerable attention in thoracic surgery. Although initial retrospective studies appeared promising, the beneficial results have not been reproduced in a clinical trial (NCT 01802411).[40,41] A recent meta-analysis of studies also cast doubt about the superiority of liposomal bupivicaine.[42,43]

Nonintubated Thoracic Surgery with Sedation

General anesthesia with endotracheal intubation and lung isolation remains the standard in anesthesia care for lung resection. A secured airway and controlled 1-lung ventilation (OLV) provide ideal surgical conditions. Nevertheless, before the introduction of double lumen tubes and modern anesthetic agents, thoracic surgery had been successfully performed using local and regional anesthesia.[44] The advancement of imaging technology, minimally invasive approaches, and improved monitoring has rekindled interest in the use of this technique. Reports in the literature have described the use of this approach for a wide array of cases from lung biopsy to pneumonectomy, as well as tracheal and carinal resection and reconstruction.[45–47]

Appropriate patient selection is critical to the success of this approach. Contraindications include anticipated difficult airway management, high risk of aspiration, respiratory failure, elevated intracranial pressure, need for contralateral lung isolation to protect from contamination, contralateral phrenic nerve palsy, and obesity.

A variety of regional anesthetic techniques have been used to control afferent nerve input from the chest wall. These include intercostal nerve block (ICB), thoracic PVB, and thoracic epidural, although the optimal approach has yet to be identified. These techniques can provide adequate anesthesia and analgesia for small peripheral lung cancer resections and pleural surgeries. However, the bronchial tree is innervated by the vagus nerve and sympathetic nerves and thus manipulation of the airway may stimulate strong cough reflexes that interfere with the surgical procedure. Intrathoracic vagus nerve block, preemptive lidocaine nebulization, or ipsilateral phrenic nerve block can all be used in attempt to minimize the cough reflex.[48,49]

Although selective lung cancer resections can be performed using regional anesthesia while the patient is fully awake, in practice some level of sedation is frequently required in nonintubated patients to minimize movement, excessive diaphragmatic motion, and mediastinal swing. Multiple sedatives, including midazolam, propofol, dexmedetomidine, fentanyl, and remifentanil have all been used successfully. Target control infusion of propofol titrated to a Bispectral index value 40 to 60 and respiratory rate of 12 to 20 have been advocated by some high-volume centers.[45,50,51] Our own experience favors the use of propofol and remifentanil infusions because of their titratability as well as analgesic and antitussive effects.

Nonintubated VATS poses a unique challenge to anesthesia providers who battle between keeping patients safe and providing an ideal surgical field. With the creation of surgical pneumothorax and OLV, patients frequently require oxygen supplementation with a face mask or venturi mask to correct hypoxia. Interestingly, early studies have demonstrated that nonintubated patients have equal or even improved oxygenation while undergoing VATS compared with intubated patients.[52,53] Intraoperative hypercapnia is also a common phenomenon, with reports of $Paco_2$ values as high as 80 mm Hg. However, it seems to be well tolerated by most patients.[49]

Intubation may be necessary if patients become unstable or surgeons encounter significant technical difficulties. Close communication between the anesthesia and surgical teams is imperative. Because patients remain in a lateral position, supraglottic devices can be easily placed to deliver additional oxygen and inhalation agents. If a more secured airway is necessary, video laryngoscopy can be used to intubate patients laterally. Alternatively, patients can be intubated through supraglottic devices with the assistance of a fiberoptic bronchoscope. Lung isolation can be achieved through the insertion of a bronchial blocker either through the endotracheal tube or supraglottic airway device.

To date, the largest RCT to compare nonintubated VATS with intubated VATS enrolled 354 patients with a variety of surgical indications.[54] The study demonstrated a significant reduction in overall postoperative morbidity (6.7% vs16.7%, $P = .004$) as well as a reduction in respiratory complications (4.2% vs 10.0%, $P = .039$) in patients undergoing nonintubated VATS. In patients undergoing nonintubated VATS, there were 4 adverse effects related to thoracic epidural, including back pain, dizziness, nausea, and vomiting. In the control group, there were 10 minor events attributable to orotracheal intubation.[54] A recent meta-analysis of 14 randomized controlled studies of nonintubated versus intubated VATS demonstrated equal surgical field satisfaction but decreased air leak from operation, better pain control, and decreased hospital stay for 1.4 days in the nonintubated patient.[55] Common issues with the included trials were small sample sizes and the potential for selection bias of nonintubated patients. Patients undergoing nonintubated VATS tended to have lower body mass index, minimal airway secretions, and preserved cardiopulmonary function at baseline. Furthermore, there was heterogeneity in the type and extent of thoracic diseases. Nonetheless, the use of nonintubated VATS merits further study in the era of enhanced recovery protocols.

Lung Isolation Techniques and Methodology

Surgical procedures for lung cancer often require lung isolation techniques to facilitate surgical exposure and resection. This is achieved most commonly via several strategies, including the use of left-sided or right-sided double lumen tubes (DLTs), a standard endotracheal tube plus bronchial blocker, or specialized endobronchial tubes.[56,57] Each of these methods has unique advantages and disadvantages. For example, DLTs provide excellent lung isolation and can be used to efficiently change from OLV to 2-lung ventilation, but the tubes are large and require additional expertise to place. Moreover, the large diameter of DLTs can make them very challenging to place in patients with history of difficult intubation. Limited evidence suggests that the most effective means of DLT size can be ascertained by measuring tracheal diameter or main bronchus diameter using computed tomography (CT) scan.[58–60] Bronchial blockers, on the other hand, can be placed through standard endotracheal tubes. In small trials, bronchial blockers have also been associated with lower risk of bronchial or tracheal injury and lower incidence of sore throat compared with DLT.[61,62] However, alternating between OLV and 2-lung ventilation can be time-consuming due to their small orifices for gas efflux and associated delay in lung collapse.

Ventilation Strategies

Current ventilation strategies for 1-lung ventilation (OLV) are adapted from the acute respiratory distress syndrome literature and use lung protective ventilation (LPV), usually defined as tidal volume of 6 mL/kg of ideal body weight or less.[57,63] LPV decreases the incidence of ventilator-induced lung injury (VILI) by reducing the mechanical stress on the alveoli and decreasing the local production of cytokines, chemokines, and other inflammatory mediators.[64–67] Although some studies comparing LPV and conventional ventilation for OLV show fewer postoperative pulmonary complications (PPCs) and shorter hospital LOS with LPV, other studies have failed to show a benefit.[68–70] The use of positive end expiratory pressure and/or recruitment maneuvers in conjunction with LPV might be an important factor explaining this discrepancy.[68]

In patients with severe pulmonary disease, complex masses near the heart or major blood vessels, those who have had prior pneumonectomy or other complex comorbidities, lung resection surgery can be performed using extracorporeal life support (ECLS) modalities, such as venovenous or venoarterial extracorporeal membrane oxygenation.[71,72] These techniques can allow procedures to be completed with minimal or no ventilation, while still achieving adequate CO_2 removal and oxygenation, and are an alternative to conventional cardiopulmonary bypass. As with other interventions, the risks and benefits of using ECLS for lung resection must be carefully considered, and local expertise is a critical determinant of favorable outcomes.

Fluid Management

Lung resections, particularly pneumonectomies and multilobar resections, are typically managed with a highly conservative fluid management strategy (about 1 mL/kg per hour intraoperatively), aimed at minimizing capillary hydrostatic pressure and interstitial and alveolar edema.[73–75] This is particularly important because OLV is associated with significant risk of VILI, leading to capillary membrane injury with increased fluid extravasation and pulmonary edema. However, there are a paucity of studies testing the veracity of this dogma. Recent data from retrospective studies of VATS and open thoracotomy suggest that both overly restrictive and liberal fluid management strategies are associated with increased PPCs, favoring a moderately conservative strategy between 2 and 6 mL/kg per hour of crystalloid on an individually managed basis.[76,77] Presumably, a moderately conservative strategy strikes the balance of avoiding fluid overload while minimizing the risk of organ hypoperfusion.

Maintenance of Anesthesia

There is ongoing debate regarding the benefit of propofol-based, total intravenous anesthesia (TIVA) when compared with volatile anesthetics with respect to improved long-term survival in patients undergoing cancer operations.[78,79] One small prospective RCT in lung cancer resection suggests that the use of volatile anesthetics, not TIVA, may be favorable, with more PPCs (28.4% vs 14.0%, odds ratio [OR] 2.44; 95% CI 1.14–5.26) and increased 1-year mortality (12.5% vs 2.3%, OR 5.37; 95% CI 1.23–23.54) in the TIVA group compared with patients receiving volatile anesthesia.[80] A metanalysis of small RCTs comparing TIVA and volatile anesthetics similarly found that volatile anesthetics were associated with shorter LOS, fewer PPCs, and, interestingly, lower levels of the proinflammatory cytokines tumor necrosis factor-alpha, interleukin (IL)-6, and IL-8 during OLV. However, the inhalational anesthetics can interfere with hypoxic pulmonary vasoconstriction during OLV, and patients were found to have lower Pa_{O_2} at 30 minutes after the initiation of OLV compared with patients maintained with TIVA.[81] Additional trials are needed to definitively address the question.

Pain Management

Thoracic surgery, including minimally invasive approaches like VATS and robotic surgeries are considered to cause moderate to severe pain, with a large fraction of patients developing a chronic pain condition known as post-thoracotomy pain syndrome.[82] Intrathoracic procedures also negatively alter respiratory mechanics, resulting in atelectasis, decreased functional residual capacity, decreased compliance, and physical trauma and ischemia/reperfusion injury. Inadequate postoperative analgesia further worsens respiratory mechanics, resulting in splinting with reduced tidal volumes, impaired cough and clearance of secretions, and increased risk of postoperative pulmonary complications.[83,84] Severe postoperative pain is related to nociceptive, neuropathic, inflammatory, and ischemic sources, including incisional pain, disruption of chest wall and intercostal muscles, costovertebral joint disruption, intercostal nerve damage related to retraction and trocar insertion, and pleural disruption and inflammation.[85] Multiple neural pathways mediate nociception from the chest wall, including intercostal nerves, long thoracic and thoracic dorsal nerves for somatic pain, and the vagus and phrenic nerves for visceral pain.[86]

Optimal postoperative pain management begins in the preoperative period, and often involves a multidisciplinary approach.[87] Pain management plans that allow for the minimum use of opioid analgesics are preferred due to the avoidance of their deleterious side-effect profiles. Numerous metanalyses and RCTs support the use of opioid-sparing regimens, and these are therefore a major component of ERAS protocols for thoracic surgery.[12,88] Indeed, patients managed with ERAS protocols after lung resection use fewer opioids than those managed with traditional approaches like patient-controlled analgesia.[89,90] Numerous nonopioid analgesics are used as part of multimodal analgesic strategies for thoracic ERAS protocols, including acetaminophen, nonsteroidal anti-inflammatory drugs, ketamine, dexmedetomidine, local anesthetics including nerve blocks (see preceding section on regional anesthesia) and others. A detailed discussion of each analgesic agent is beyond the scope of this review, as this topic has been extensively reviewed elsewhere.[90,91] An underlying principle in multimodal analgesia is the use of multiple agents that target a range of receptors involved in nociceptive transmission. This not only interrupts nociception from multiple pathways but also may decrease potential side effects of each medication, because smaller doses can be used. At a basic level, ideal strategies rely heavily on regional anesthetic interventions including neuraxial anesthesia, because these can theoretically provide total analgesia with complete or near complete avoidance of opioids.

SUMMARY

Increasingly complex procedures are routinely performed using minimally invasive approaches, allowing cancers to be resected with short hospital stays, minimal postsurgical discomfort, and improved odds of cancer-free survival. Along with these changes, the focus of anesthetic management for lung resection surgery has expanded from the provision of ideal surgical conditions and safe intraoperative patient care to include preoperative patient training and optimization and postoperative pain management techniques that can impact pulmonary outcomes as well as patient lengths of stay.

CLINICS CARE POINTS

- Prehabilitation has been shown to improve postoperative outcomes; however, the specific type of program and the frequency and intensity of exercise that is most effective remains to be determined.
- ERAS pathways specific to pulmonary resection have been shown to improve patient outcome and reduce hospital LOS.
- Regional anesthesia techniques such as serratus anterior plane block and erector spinae block can improve postoperative pain control.

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