Intraoperative Anesthetic Management of the Thoracic Patient

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KEYWORDS

- One-lung ventilation complications • Double-lumen endobronchial tube • Bronchial blocker
- Hypoxic pulmonary vasoconstriction • Hypoxemia and one-lung ventilation

KEY POINTS

- Serious complications from one-lung ventilation include arterial hypoxemia, injury to the nonoperative lung, and right ventricular dysfunction.
- Understanding the effects of anesthetic agents on hypoxic pulmonary vasoconstriction is important for optimizing oxygenation during thoracic surgery.
- Individualized one-lung ventilation management strategies, influenced by the patient's risk for developing hypoxemia, the surgical approach, and the airway device selected, can improve postoperative outcomes.
- Goal-directed fluid therapy and perioperative pain management strategies can reduce morbidity after thoracic surgery.

INTRODUCTION

The concept of lung isolation dates back to the 1870s when experimental physiologists Edward Pflüger and Claude Bernard introduced the first example of a single-lumen endobronchial cannula.[1] The transition from single-lumen endobronchial cannulas to double-lumen cannulas that combined short-tracheal and long-bronchial segments in 1889 facilitated many advances in respiratory physiology and independent lung spirometry.[1] Over the years, these techniques led to a practical progression in human airway instrumentation devices, including two-cuff single-lumen endobronchial tubes (SLTs), double-lumen endobronchial tubes (DLTs), and bronchial blockers (BBs). This specialized armamentarium established the anesthetic practice of one-lung ventilation (OLV) and enabled the performance of complex lung, esophageal, mediastinal, and thoracic wall operations.

ONE-LUNG VENTILATION

OLV can be defined as the preferential ventilation of the nonoperative lung while deflating the operative lung to achieve an immobile surgical field and to prevent surgical debris, pus, or secretions from entering the contralateral lung (**Box 1**). The extent of lung deflation differentiates lung separation (adequate deflation) from lung isolation (complete deflation).[2] In routine practice, OLV is initiated intraoperatively by the anesthesiologist when the surgeon communicates that the pleura is opened; however, there is evidence to support preemptive OLV immediately after lateral positioning for expedited lung collapse.[3]

Double-Lumen Endobronchial Tubes

The modern version of the DLT stems from a breakthrough invention in 1949 by the Swedish

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Box 1
Common indications for one-lung ventilation

Surgical exposure

- Pulmonary resection
- Video-assisted thoracoscopic surgery
- Thoracoscopy
- Lung biopsy
- Lymph node biopsy
- Thoracic aortic surgery
- Esophageal surgery
- Mediastinal surgery
- Thoracic wall surgery

Protective lung isolation

- Malignancy
- Purulent material
- Massive hemoptysis

Differential lung ventilation

- Single-lung transplant
- Bronchopleural fistula
- Bronchial disruption
- Asymmetric parenchymal lung disease

Unilateral bronchial lavage

- Pulmonary alveolar proteinosis

physician Eric Carlens.[4] He advanced a red rubber tube with a cuff down to the left main bronchus to seal off the left lung. The tube had a carinal hook to stabilize against the carina. Above the carinal hook was an opening for ventilation of the right main bronchus. Proximal to this was the tracheal cuff. In 1962, Robertshaw[5] refined Carlen's design by eliminating the carinal hook, widening the D-shaped lumens to lower airflow resistance and facilitate suctioning, and incorporating a flatter extrusion to make it more stable and easier to handle. He designed both left-sided (angle of 45° at the carina) and right-sided (angle of 20° at the carina) DLTs.

Today's DLTs are the preferred device for OLV with the longest track record in clinical practice.[6] The consistent and more convenient design of left DLTs among manufacturers has led to their domination compared with the right DLTs. A DLT that is appropriately sized and placed is key to preventing airway injury and achieving proper lung isolation. The optimal DLT size is considered the largest size that will pass uneventfully through the glottis and trachea and whose bronchial component sits in the mainstem bronchus with only a small air leak. Still, appropriate DLT size selection based on patient factors remains controversial. Chest radiography,[7] computed tomography, and ultrasonography (US) to measure patient tracheal diameter have been suggested.[8] Roldi and colleagues[9] combined patient sex and height with US-derived tracheal measurements to predict DLT size. An undersized DLT can increase the risk of auto positive end-expiratory pressure (PEEP) and dynamic pulmonary hyperinflation, bronchial cuff hyperinflation, failed lung collapse, and possibly tube malposition.[10] Fiber-optic bronchoscopy remains the gold standard for confirming DLT placement; blindly placed DLTs can be malpositioned up to 48% of the time.[11]

Bronchial Blockers

The use of a BB for OLV is increasing worldwide. Various BB types are currently available (**Table 1**). The specific features of a BB dictate its utilization. Adult sizes are 9 French. Pediatric sizes are 5 French. **Table 2** provides a comparison between DLTs and BBs. For most patients, the BB is an appropriate option except for operations involving the main bronchus, distorted bronchial anatomy, or bronchopulmonary lavage. Some advantages of BBs over DLTs include use in patients with difficult airway anatomy where DLT placement may be impossible, patients at high risk for aspiration, patients with tracheostomy, children, surgical procedures with a high risk of left recurrent laryngeal nerve injury, or surgeries requiring postoperative mechanical ventilation.[12–14] Overall, the rate of major complications from BBs is low.[15] However, minor airway trauma, failure to achieve lung separation or isolation, balloon malpositioning, device technical malfunctioning (eg, fractured or bent tips, difficult balloon deflation and retrieval, asymmetrical balloon inflation), and inadvertent entrapment of the BB in the surgical staple line have been reported.[16,17]

The debate over which device is best for OLV is still ongoing.[18,19] For most thoracic procedures, either device can be used safely. The choice is usually based on the specific requirements of each case, patient airway anatomy, and the preference and experience of the anesthesiologist. A recent survey in the United Kingdom among anesthesiologists revealed a 98% preference rate for DLT use, and 64% of respondents reported rarely using a BB to provide lung isolation.[20] Although surgeons seem to also prefer DLTs, studies support similar quality in lung isolation between

Table 1
Types of bronchial blockers

Univent Torque Control (Fuji Systems, Tokyo, Japan)	First manufactured BB; contains a single lumen for ventilation and a channel that houses the BB; bulky tube for the size of its ventilating lumen. Out of favor
Cohen Flex-tip (Cook Medical Inc, Bloomington, IN, USA)	Has a wheel at the operator end that, when turned, flexes the tip; advancement of the BB is observed via a fiberscope, which also is passed through a multiport connector
Arndt (Cook Medical Inc, Bloomington, IN, USA)	Has a lumen through which a wire passes and exits in a loop, beyond its distal end. The fiberscope is passed through this loop and is advanced into the mainstem bronchus with the BB trailing. The wire snare is loosened and then is removed once the BB is in place. The position of the BB then is checked as the fiberscope is withdrawn. Somewhat cumbersome to use, with multiple steps needed for proper placement
Uniblocker (Fuji Systems, Tokyo, Japan)	The most newly released, simplest in design and usage. The BB has a bent tip and comes preinserted through a multiport connector. It is simply turned toward the side to be blocked and advanced under direct vision with the fiber-optic bronchoscope. Viable option for those with limited thoracic anesthesia experience, and placement actually may be easier than a DLT. It is also significantly less expensive, although more costly than a DLT
Rusch EZ (Teleflex Medical, Morrisville, NC, USA)	Y-shaped distal end with 1 blocker for each bronchus. Similar quality of lung isolation. Can be placed blindly if a fiberscope is not available or if visualization proves difficult. Lower incidence of airway injury than DLT

DLTs and BBs.[13,21] Successful utilization of BBs relies on the operator's skill and knowledge of airway anatomy, the device itself, and the fiberscope.[13] A systematic review and meta-analysis of 39 randomized controlled trials comparing DLTs and BBs for OLV concluded that DLTs were quicker to place and less likely to be positioned incorrectly, but had a higher complication rate. BBs appeared to have a lower incidence of sore throat, hoarseness, and severe airway injury.[15,22] Thus, for optimal patient care and maintaining technical skills, it is important to develop the skills needed to use both DLTs and BBs.

Two-Cuffed Single-Lumen Endobronchial Tubes

SLTs are another alternative to DLTs and BBs. They have a single lumen with a distal bronchial cuff and a proximal tracheal cuff and are guided either to the right or to the left mainstem bronchus. Both lungs can be ventilated when the upper cuff is inflated, and the tip of the tube remains in the trachea. When advanced to one of the main bronchi, OLV of the intubated lung is achieved by keeping the upper cuff deflated and the lower one inflated. Despite the efficient design of the SLT, it has fallen out of favor because of an inability to aspirate secretions from the operative lung, as well as the risk of right upper lobe orifice obstruction during right lung ventilation.[2]

COMPLICATIONS OF ONE-LUNG VENTILATION

Hypoxemia

During OLV, the operative lung is excluded from ventilation while it continues to be perfused. This large ventilation-to-perfusion (V/Q) mismatch creates an obligatory intrapulmonary shunt with resultant hypoxemia defined as oxygen saturation (Sp_{O_2}) less than 90% or partial pressure of arterial

Table 2
The advantages and disadvantages of double-lumen endobronchial tube and bronchial blocker

	DLT		BB
+ +	Applicable for every thoracic operation Only device suitable for bronchopulmonary lavage	–	Not suitable for thoracic operations that involve the main bronchus (eg, sleeve resection, major bronchopleural fistula, lung transplant, bronchopulmonary lavage, atypical bronchial anatomy)
+	Safe, easy, quick, accurate placement	–	Higher-risk incorrect positioning
+	Both lung separation and isolation	+	Both lung separation and isolation of similar quality with DLTs
+	Rapid lung deflation-reinflation as many times as needed (useful in short procedures)	–	Longer time to achieve lung separation or isolation
+	Less intraoperative displacement/ repositioning	–	Increased risk of balloon displacement with sequential inflation/deflation of the operated lung or patient position changes
+	Suitable for operation in both sides and for sequential surgery to both lungs during the same operation	–	Not recommended
+	Allows suctioning of both lungs without interrupting ventilation	–	Limited options for adequate suctioning without interrupting ventilation or contaminating the contralateral lung
+	Allows bronchoscopy of non–ventilated lung	–	Inability for visual examination of the non–ventilated lung
+	Allows application of CPAP to non–ventilated lung	–	Difficult application of CPAP to non–ventilated lung due to smaller BB lumen
+	Allows differential lung ventilation in ICU	–	Does not allow differential lung ventilation in ICU
+	Inexpensive disposable DLTs	–	More expensive than disposable DLTs
–	Only oral intubation	+	Both nasal and oral intubation
–	No available DLT for tracheostomies	+	Ability to pass through tracheostomies
–	Bulky device	+	Appropriate size to pass via SLT or laryngeal mask airway device
–	Inability to selective lobes or segments	+	Ability to deflate selective lobes or segments
–	Difficulties with endobronchial positioning	+	Easier endobronchial placement
–	Higher risk of airway trauma	+	Lower risk of airway trauma
–	Requires exchange to SLT for patients planned for postoperative ventilation	+	Obviates multiple tube exchanges; particularly useful in cases with difficult airway, airway edema, distorted upper and lower airway anatomy, long surgery, need for continued postoperative mechanical ventilation
–	Higher risk of adverse events	+	Slightly lower risk of adverse events
–	Risky tube exchange for patients already intubated with SLT	+	Safer option for patients already intubated with SLT

oxygen (Pa_{O_2}) less than 60 mm Hg. Furthermore, alveolar derecruitment of the nonoperative lung from general anesthesia and lateral positioning also contributes to arterial hypoxemia.[23] Wang and colleagues[24] estimated the shunt fraction after 30 and 60 minutes of OLV to be 35% and 37%, respectively, with an inverse correlation between Pa_{O_2} and V/Q mismatch.

In response, hypoxic pulmonary vasoconstriction (HPV) activates and redirects blood flow from poorly ventilated lung regions, operative lung, to well-ventilated lung regions, nonoperative lung, to decrease the intrapulmonary shunt.[25] Factors that inhibit HPV, such as inhaled anesthetics, hypotension, severe chronic obstructive pulmonary disease (COPD), and use of vasodilators or vasoconstrictors, will divert blood flow to the operative lung and worsen V/Q mismatch and hypoxemia. Factors that improve V/Q matching include lateral decubitus position and moderate COPD with air trapping. The likelihood of a patient developing hypoxemia during OLV is associated with several patient- and surgery-specific risk factors (**Table 3**).[26–29]

Thanks to improved lung isolation devices, improved positioning techniques, and newer anesthetics, the incidence of hypoxemia during OLV has decreased from 25% in the 1970s to 4% to 10% today.[30] Healthy individuals can tolerate hypoxemia during OLV,[31] and Sa_{O_2} as low as 85% to 90% may be acceptable.[31,32] Individuals with coexisting cardiovascular, cerebrovascular, or pulmonary disease, however, are at greater risk for hypoxemia-induced complications, including myocardial depression, atrial fibrillation, pulmonary hypertension, and cognitive dysfunction.[33]

Judicious delivery of oxygen is recommended to maintain adequate oxygenation yet minimize the deleterious effects of hyperoxia, such as inflammation, oxidative stress, alveolar wall thickening, absorption atelectasis, and coronary and peripheral vasoconstriction.[34]

Hypoxemia during OLV can be managed methodically and sequentially. First, the fraction of inspired oxygen (Fi_{O_2}) can be increased to 1.0. An alveolar recruitment maneuver (ARM), consisting of 10 consecutive breaths at a plateau pressure of 40 mm Hg, can be tried next. Notably, a preemptive ARM of both lungs before instituting OLV has been shown to decrease alveolar dead space and improve arterial oxygenation.[35,36] The high plateau pressure associated with an ARM can cause transient hemodynamic derangements and, therefore, should be considered carefully before routine use.[37]

Incremental increases in PEEP to the nonoperative lung to a maximum 20 cm H_2O can be attempted to open atelectatic alveoli.[35,38,39] Careful attention is warranted as PEEP is adjusted. When PEEP causes the end-expiratory pressure to approach the inflection point of the patient's static lung compliance curve, oxygenation is likely to improve. Conversely, if the equilibrium end-expiratory pressure increases beyond the inflection point, oxygenation is likely to deteriorate.[40] The application of PEEP to the nonoperative lung should be individualized by using a PEEP decrement trial; this can improve oxygenation, ventilation, and lung mechanics compared with a standard increase in PEEP of 5 cm H_2O.[41] Clinical trials examining the effect of individualized perioperative ventilator strategies[42] as well high versus low PEEP during OLV are ongoing.[43]

Apneic oxygen insufflation or continuous positive airway pressure (CPAP) to the operative lung should be considered to improve oxygenation by passive mechanics.[44] In the specific cases whereby CPAP may be contraindicated, including video-assisted thoracoscopic surgery, high-frequency jet ventilation to the operative lung has been used to assist with both oxygenation and ventilation, while maintaining an acceptable surgical field of vision.[45] Recently, differential lung ventilation has been described whereby the operative lung is ventilated with minimal tidal volumes (TV).[46]

If hypoxemia persists, two-lung ventilation should be restored to allow for fiber-optic assessment of the lung isolation device position and the presence of secretions. As a last resort, during

Table 3
Risk factors for developing hypoxemia during one-lung ventilation can be classified as patient specific and surgery specific

Patient-Specific Risk Factors	Surgery-Specific Risk Factors
• Normal preoperative spirometry • Body mass index >30 kg/m^2 • Low baseline Pa_{O_2} • History of lung-reducing operation	• Large, central lung mass • Right-sided thoracic surgery • Surgery performed in the supine position

open thoracotomy, the surgeon can clamp the pulmonary artery (PA) to the operative lung to reduce the shunt fraction and improve oxygenation.

Less common methods for improving refractory oxygenation involve the pharmacologic manipulation of pulmonary blood flow. Total intravenous anesthesia (TIVA) avoids volatile anesthetics and could theoretically preserve HPV, although significant improvements in hypoxemia have not been reported.[47] Selective dilation of the pulmonary vessels in ventilated lung regions with inhaled nitric oxide (iNO)[48] or selective constriction of pulmonary vessels in nonventilated regions with almitrine[49–51] have produced mixed results. Improved oxygenation has been achieved with small doses of iNO[52] in patients with pulmonary hypertension and hypoxemia during OLV.[53] Inhaled iloprost, a prostacyclin analogue, can also improve oxygenation by selectively vasodilating the pulmonary vascular bed and ameliorating V/Q mismatch.[54] The continuous infusion of dexmedetomidine has demonstrated clinical benefits by improving oxygenation and lung mechanics in patients with moderate COPD undergoing lung surgery,[55] which was further supported by a subsequent meta-analysis.[56]

For patients at high risk for developing hypoxemia during OLV, additional monitors can help. Oxygen reverse index is a novel noninvasive continuous monitor of real-time blood oxygenation. Based on multi-wavelength pulse cooximetry, its values correlate strongly with $Pa{O_2}$ and decrease earlier than $Sp{O_2}$, identifying hypoxemia earlier.[57–60] Cerebral oxygen saturation ($Sct{O_2}$) can also be monitored, especially in patients at higher risk for postoperative neurocognitive dysfunction. Studies investigating the role of cerebral oximetry in OLV, however, have had mixed results.[61–65] Interestingly, greater decreases in $Sct{O_2}$ during OLV were found in patients with good preoperative respiratory function compared with patients with poor respiratory function. Although reasons for this paradoxic finding remain unknown, it is theorized that chronic lung disease may induce an oxygen reserve enhancement in some patients.[62] More studies are needed to demonstrate the changes in $Sct{O_2}$ during OLV and their association with hypoxemic events measured by $Sp{O_2}$.

Acute Lung Injury

Acute lung injury (ALI) is characterized by a deleterious cascade of inflammatory and vascular permeability changes within the lung parenchyma that results in diffuse alveolar damage.[66] There are many factors that can cause postoperative ALI, such as interstitial lung disease, excessive fluid administration, and intraoperative transfusion.[67]

Surgical trauma to the operative lung from mechanical handling and reperfusion injury likely accounts for some lung injury noted after thoracic surgery. Less well recognized, however, are the injurious effects of OLV to the contralateral lung. In fact, OLV-associated ALI in the nonoperative lung is more common and can affect healthy lungs even after brief periods of OLV.[68] In a meta-analysis, the incidence of postoperative ALI was found to be 4.3%, and associated mortality was 26.5%.[69] Contributing factors included intraoperative ventilation strategies characterized by high inspiratory TV defined as greater than 10 mL/kg predicted body weight, and high peak inspiratory pressures defined as greater than 28 cm H_2O, both of which lead to abnormal stretching of the fibroelastic architecture of the lung and produce an inflammatory response.[70–72]

An intraoperative ventilation strategy aimed at maintaining adequate gas exchange while protecting the lungs from inflammation can improve postoperative outcomes. The traditional approach of high TV respirations (10–12 mL/kg) to prevent atelectasis, shunting, and oxygen desaturation during OLV has proven to be harmful.[73,74] TV of 6 mL/kg is an acceptable two–lung ventilation strategy. Halving TV to 3 mL/kg during OLV may result in unacceptably low TV and dead space ventilation. An approach that includes low TV (4–6 mL/kg) and high PEEP while achieving mean airway pressures less than 25 cm H_2O is proven to reduce volutrauma, barotrauma, and atelectrauma in patients with acute respiratory distress syndrome (ARDS).[75,76] A meta-analysis comparing low (4–6 mL/kg) versus high (8–12 mL/kg) TV strategies during OLV demonstrated preserved gas exchange, lower incidence of pulmonary infiltration, and lower incidence of ARDS in the low TV group without a significant change in postoperative pulmonary complication rate or hospital length of stay.[77] Applying this approach to OLV has been recommended,[78] although some anesthesiologists remain reluctant and continue to use strategies that prioritize reducing peak airway pressures.[79]

Avoiding high peak airway pressures (>25 cm H_2O) to achieve adequate TV is an important consideration. One way to achieve adequate TV with lower peak airway pressures is by using pressure-controlled ventilation (PCV) instead of volume-controlled ventilation (VCV).[80] A meta-analysis reported significantly higher $Pa{O_2}/Fi{O_2}$ ratio and lower peak airway pressure in the PCV group compared with the VCV group; however, no clinical difference was found in $Pa{CO_2}$, mean airway pressures, and postoperative pulmonary complications.[81] Overall, the advantages of PCV during OLV include lower peak airway pressures, lower intrapulmonary shunt, and improved oxygenation; however, how these advantages contribute to overall morbidity and mortality remains uncertain.

Excessive driving pressure, calculated as plateau pressure minus PEEP, is considered an independent risk factor for mortality in ARDS.[82] The benefit of targeting lower driving pressures during ventilation for thoracic surgery has been validated.[83] Compared with conventional ventilation strategies, targeting lower driving pressures led to fewer postoperative pulmonary complications, including lower rates of pneumonia and ARDS. Although low TV is an important component of lung protective ventilation strategies during OLV, evidence suggests that without adequate PEEP, low VT alone does not prevent postoperative pulmonary complications.[84] The optimal amount of PEEP that will prevent atelectasis and hypoxia from occurring is still debated. An individualized PEEP strategy that produces the lowest driving pressure may be favored.[83]

Technological advancements in extracorporeal lung assist systems, such as extracorporeal membrane oxygenation (ECMO), have expanded the potential for complex thoracic surgery in patients with insufficient pulmonary reserve and at significant risk of ALI.[85] ECMO has been used with good outcomes in thoracic surgery cases whereby patient-specific comorbidities or anatomic derangements confer infeasible or insufficient ventilation. It is indicated in cases of severe chest trauma warranting tracheoesophageal fistula repair or esophagectomy and in contralateral lung resection in the setting of previous pneumonectomy, lung transplantation, lung volume reduction surgery, difficult OLV, and difficult airway cases.

Right Ventricular Dysfunction

Thoracic surgery and OLV present a unique situation whereby the right ventricle (RV) is exposed to sudden changes in preload, afterload, and contractility; the summative effect can quickly escalate from insignificant morphologic changes to nonischemic RV injury, RV dysfunction, and eventual RV failure.[86] Intraoperative factors that can contribute to RV changes are numerous. V/Q mismatch and resultant hypoxemia and hypercapnia during OLV cause pulmonary vasoconstriction and substantial increases in RV afterload. Mechanical ventilation strategies that promote inflammation will negatively affect RV morphology. The mode of mechanical ventilation chosen intraoperatively can contribute. PCV has been shown to be more protective than VCV.[87] Thoracic epidural analgesia (TEA), if used for perioperative pain control, can cause loss of vasomotor tone and result in peripheral venous pooling, significantly decreasing RV preload. TEA also inhibits the native positive inotropic response of the RV to acute increases in pulmonary vascular resistance. The degree of RV dysfunction may be more severe in the setting of preexisting RV dysfunction or intraoperative factors, such as extensive thoracic surgery, bleeding, hypervolemia, or tachyarrhythmias. Several strategies exist to mitigate RV strain during OLV (**Table 4**).[86]

Vasoactive agents can be used to optimize RV function during thoracic surgery. Norepinephrine has been shown to improve RV-PA coupling, cardiac output, and RV performance in acute RV dysfunction with PA hypertension; however, high doses can increase pulmonary vascular resistance beyond systemic vascular resistance and should be avoided.[88] Vasopressin may be considered superior to norepinephrine because of endothelial nitric oxide stimulation in the pulmonary vascular

Table 4
Intraoperative strategies to protect right ventricular function during thoracic surgery and one-lung ventilation

Ventilation Strategies	Hemodynamic Strategies
Pressure control ventilation	Consider transesophageal echocardiography
Low TV (4–6 mL/kg)	Maintenance of sinus rhythm
Plateau pressure <25 cm H_2O	GDFT
Driving pressure <18 cm H_2O	Optimize RV preload
Avoid hypoxemia	Decrease RV afterload
Avoid hypercapnia	Increase RV contractility
	TEA
	Avoid hypothermia
	Avoid acidemia

tree at low doses (0.01-0.03 U/min), thus causing pulmonary vasodilation, but this effect is lost at higher doses, causing coronary vasoconstriction and significant reduction in RV stroke volume.[89] RV contractility can be enhanced by positive inotropes, such as epinephrine, or by inodilators, such as dobutamine, milrinone, enoximone, and levosimendan, with or without a peripheral vasoconstrictor. Lung transplantation–related RV dysfunction and pulmonary hypertension can be minimized by iNO and prostacyclin, 2 potent pulmonary vasodilators.[90]

INTRAOPERATIVE ANESTHETIC CONSIDERATIONS

Maintenance of Anesthesia

The pharmacologic choice to maintain general anesthesia has been widely debated. Inhaled anesthetics are known to inhibit HPV, whereas TIVA techniques do not. It has been theorized that TIVA would decrease V/Q mismatch and improve oxygenation, rendering TIVA the anesthetic of choice for OLV.[91] More recent data suggest that oxygenation during OLV is similar between propofol-based anesthesia and isoflurane.[92] Therefore, other factors must be considered when choosing an anesthetic. Volatile anesthetics have been shown to attenuate the inflammatory response and protect the glycocalyx of the lung parenchyma,[93–96] and do not appear to exacerbate hypoxemia.[97]

Fluid Management

A targeted fluid administration strategy for thoracic surgery is an important aspect of reducing postoperative ALI while minimizing end-organ injury.[98] Practice has changed since the deleterious effects of liberal fluid administration in pneumonectomy were first documented.[99] Today, euvolemia is the primary goal of intraoperative fluid management in lung resection and esophagectomy surgery. Attaining this goal entails navigating the balance between extreme ends of the fluid therapy spectrum to achieve an ideal lung water state.

Excessive fluid administration in lung resection can cause postoperative pulmonary edema, ARDS, reintubation, and pneumonia.[99–101] In esophagectomy, ARDS, pneumonia, prolonged intensive care unit (ICU) stays,[102] and increased morbidity[103] and mortality[104] correlate with fluid overload strategies.

Fluid restrictive strategies during major surgery are associated with a significant risk of perioperative acute kidney injury (AKI).[105] Colloid solutions that maximize the capillary oncotic load and minimize interstitial edema can inadvertently cause AKI.[106,107] AKI in both lung resection and esophagectomy is associated with greater morbidity.[107]

Ideal fluid management strategies remain controversial. The use of dynamic hemodynamic parameters to target fluid administration, called goal-directed fluid therapy (GDFT), has been adopted by fast-track surgery experts in elective lung surgery. GDFT is now a cornerstone of most perioperative strategies to expedite patient recovery while minimizing postoperative complications.[108] GDFT strategies driven by objective data, such as pulse pressure variation and stroke volume variation, are gaining favor, although some strategies rely on the relationship between heart and lung interactions and are not as reliable in open thoracotomy.[109]

Pain Management

Multimodal pain management strategies aim to provide adequate postoperative analgesia while reducing the reliance on opioids. In addition to oral and intravenous nonopioids, regional anesthesia is commonplace. TEA is the gold standard for controlling postoperative pain and a foundation of accelerated recovery pathways in thoracic surgery.[110] In routinely used doses, TEA does not significantly affect oxygenation and might prevent the development of ALI and associated postoperative pulmonary complications.[111] Alternative regional anesthesia techniques, such as paravertebral block, erector spinae block, and serratus anterior block, can provide adequate postoperative pain relief with less systemic hypotension, but require additional specialized training and may have limited efficacy.[112]

SUMMARY

Preoperative assessment and risk-stratification of the prospective thoracic surgery patient, including the risk of developing hypoxemia during OLV, are crucial in formulating an appropriate intraoperative anesthetic plan. Hypoxemia, ALI, and right ventricular dysfunction are significant complications of OLV. Anesthesiologists should be prepared to navigate these problems and methodically choose a patient-specific management plan that mitigates perioperative morbidity. Ventilator management strategy, GDFT, and perioperative pain control are important components for optimizing postoperative recovery after thoracic surgery.

DISCLOSURE

The authors have nothing to disclose.

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