One-Lung Ventilation in Anesthesia

13

Giorgio Della Rocca and Luigi Vetrugno

13.1 Introduction

The purpose of one-lung ventilation (OLV) is to provide a good surgical exposure of a collapsed lung while ensuring adequate gas exchange with the other. Currently, double-lumen tubes (DLTs) or bronchial blockers (BBs) are used to obtain it. *The separation of the lungs today means a completed "anatomical" sealing with DLTs, and the isolation of the lung means a "functional" sealing with BBs* [1–3]. In the first case, there are some *absolute indications in which a* protective strategy for the contralateral lung *is needed*, including life-threatening conditions such as massive bleeding, pneumonia with pus, and bronchopleural and bronchocutaneous fistulae, since they offer a low-resistance pathway during positive pressure ventilation, as well as giant unilateral bullae that may blow. Some surgical interventions as sleeve pneumonectomy or bronchopulmonary lavage for alveolar proteinosis or cystic fibrosis still require lung separation. In all the other situations, in which lung *separation* is a relative indication, lung *isolation* could be used [4, 5].

G. Della Rocca, MD (✉)
Department of Anesthesia and Intensive Care Medicine, Department of Medical and Biological Science, University of Udine, P. le S.M. Misericordia 15, Udine 33100, Italy
e-mail: Giorgio.dellarocca@uniud.it

L. Vetrugno, MD
Department of Anesthesia and Intensive Care Medicine, Department of Medical and Biological Science, University of Udine, P. le S.M. Misericordia 15, Udine 33100, Italy

Department of Anesthesia, Azinda Ospedaliera Unversitaria, P. le S.M. Misericordia 15, Udine 33100, Italy
e-mail: Vetrugno.luigi@aoud.sanita.fvg.it

D. Chiumello (ed.), *Topical Issues in Anesthesia and Intensive Care*,
DOI 10.1007/978-3-319-31398-6_13

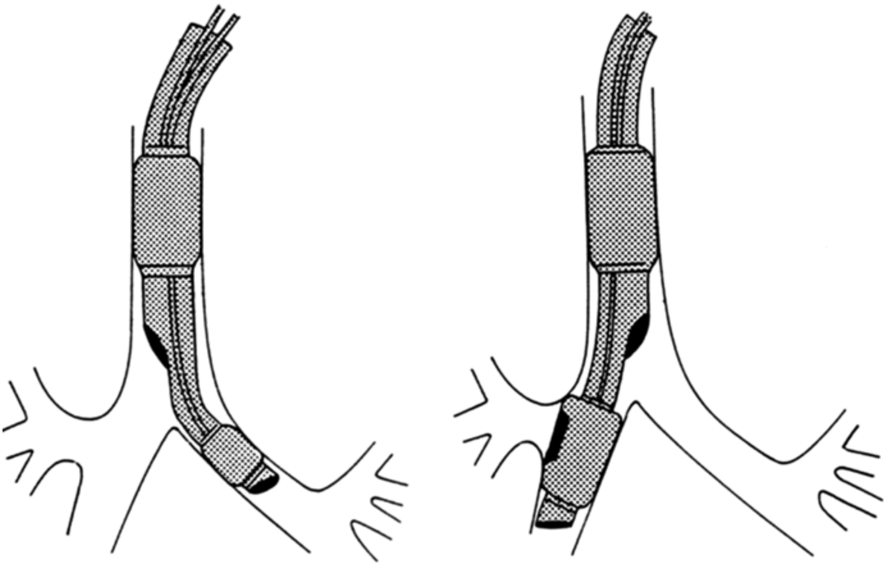

Fig. 13.1 Left and right double-lumen tubes (DLT)

13.2 Methods for One-Lung Separation (OLV)

At first, decades ago, a single-lumen endobronchial tube with a Fogarty catheter used as a bronchial blocker was utilized to achieve OLV. However, it was a difficult technique, as the shape of the balloon is round and not designed for airway blockade and the advancing of the catheter is unguided.

In modern practice, endobronchial double-lumen tubes (DLTs) are most widely employed (Fig. 13.1). These tubes have a fixed curvature and do not have a carinal hook to avoid tracheal laceration and reduce the likelihood of kinking. Numerous manufacturers produce clear disposable Robertshaw design DLTs, which are available in French sizes from 35 to 41 [6]. Essentially, they all have similar features but modify cuff shape and location. A colored bronchial cuff, commonly blue, permits its easy identification by fiber-optic bronchoscopy. The right endobronchial cuff is donut shaped and allows the right upper lobe ventilation slot to ride over the right upper lobe orifice. Most authors refrain from using right-sided DLT simply to avoid potential obstacles. Instead of its extensive use, one of the major challenges for a DLT is the lack of an objective method and guideline for selecting the proper size and its optimal depth. The most accurate method to select a left-sided DLT size is to measure the left bronchus width and the outer diameter of the endobronchial lumen of the DLT, then the largest tube that safely fits that bronchus can be selected [7]. For a right-sided DLT, there is no study available that addresses the issue of optimal size for a determined patient. *In general, a 37 French DLT can be used in most of the adult females, while 39 French can be used in the average adult male.* Keeping in mind that undersized or oversized DLTs could lead to serious airway complications, including tracheobronchial rupture. The optimal depth of insertion for a left-sided DLT is strongly correlated to the patient's height. In general, the depth of insertion for a DLT should be between 27 and 29 cm at the marking of the incisors [8, 9]. An inadvertent deep insertion of a DLT could lead to rupture of the left main stem bronchus. Three other sizes (26 and 28 French for pediatrics and 32 French for small adults) have recently been introduced in the market. When a conventional laryngoscopy reveals a grade III view (only the epiglottis) or a grade IV view (only the soft palate) in the Cormack-Lehane scale, an airway may be termed difficult [10]. When the separation of the lung is strictly indicated, the use of tubes such as DLT or Univent, which are inherently difficult to insert, cannot be recommended [11–14]. If the patient has a recognized difficult airway, awake intubation with fiber-optic bronchoscopy (FOB) can be attempted using a single-lumen tube (SLT) (Table 13.1). The same approach may be used for the patient with an unrecognized difficult airway. However, thoracic anesthesiologist expertise and propensity with a DLT rather than BB and vice versa, and their knowledge in fiber-optic tracheobronchial anatomy, plays an important role in that choice. On the other hand, for the non-thoracic anesthesiologist, DLTs and bronchial blockers are difficult to use, and none of these devices provide any advantage one over the other [15].

In modern clinical practice, this instrument has been replaced by three different types of 9 French BBs with a steering mechanism and a patent 1.6 mm lumen to facilitate the collapse of the lung and/or oxygen insufflations through continuous positive airway pressure (CPAP) to the nondependent lung [16]. Of these three devices, the Arndt blocker is available in 7 and 5 French for small adults and pediatrics; it uses a wire-guided mechanism [17]. The Cohen blocker possesses a rotating wheel that allows it to flex the tip of the blocker [5]. Both blockers use a multiport adapter. The Uniblocker, which has a fixed curve similar to a hockey stick, has been recently introduced in clinical practice. It is essentially the same blocker as the Univent tube which is somewhat bulky, but now available as an independent blocker [18].

Table 13.1 Indication for the use of endobronchial blockers

The upper and lower difficult airway
Patients with a predicted or unpredicted difficult airway
Patients post-laryngeal/pharyngeal surgery
Patients with tracheotomy
Patients with distorted bronchial anatomy from aneurysm compression or intraluminal tumor
Patients who require nasotracheal intubation
Patients with an immobility or kyphoscoliosis

13.3 Double-Lumen Tubes: First Step – The Positioning

Following intubation, the tracheal cuff should be inflated first, and then the tube's correct position should be confirmed. To avoid mucosal damage from excessive pressure applied by the bronchial cuff, the cuff is inflated with incremental volumes until air leaks disappear. Inflation of the bronchial cuff seldom requires more than 2 mL of air. Bilateral breath sounds should be rechecked to confirm that the bronchial cuff is not herniating over the carina and impede the ipsilateral lung ventilation. An important step is to verify that the tip of the bronchial lumen is located in the designated bronchus. One simple way to check this is to first clamp the tracheal lumen, then observe and auscultate. Usually, inspection will reveal unilateral ascent of the ventilated hemithorax. Following proper auscultation, the bronchial lumen is cross-clamped to ventilate the tracheal lumen. Each time a right-sided DLT is used, appropriate ventilation of the right upper lobe should be ensured. This can be accomplished by a careful auscultation over the right upper lung field or more accurately by fiber-optic bronchoscope [19, 20]. When a left-sided DLT is used, the risk of occluding the left upper lobe bronchus by the bronchial tip advanced too far into the left main bronchus should be always kept in mind. If the peak airway pressure is 20 cm H_2O during two-lung ventilation, for the same tidal volume, that pressure should not exceed 40 cm H_2O on OLV.

It has been recently shown that fiber-optic bronchoscopy revealed a malposition in 20–48 % of the DLTs thought to be correctly positioned by inspection and auscultation only [21]. The simplest method to evaluate proper positioning of a left-sided DLT is bronchoscopy via the tracheal lumen. The carina is then visualized, while only the proximal edge of the endobronchial cuff should be identified just below the tracheal carina. Herniation of the bronchial cuff over the carina to occlude partially the ipsilateral main bronchus should be excluded. Bronchoscopy should then be performed via the bronchial lumen to identify the patent left upper lobe orifice [22]. When using a right-sided DLT, the carina is visualized through the tracheal lumen. More importantly, the right upper lobe bronchial orifice must be identified while the bronchoscope is passed through the right upper lobe ventilating slot. This is somewhat complex to accomplish and requires a relatively skilled endoscopist.

Several sizes of bronchoscope are available for clinical use: 5.6, 4.9, and 3.9 mm of external diameter. *The 3.9 mm-diameter bronchoscope can easily pass through a 37 French or larger tube, while it is a tight fit through a 35 French tube* (Fig. 13.2) [19–22].

13.4 Tube Exchanger

The airway guide may be used for inserting an SLT over a DLT and vice versa or simply inserting a difficult tube. Several tube exchangers are available. All of these airway guides are commercially made (depth is marked in cm), are available in a wide range of ODs, and are easily adapted for either oxygen insufflation or jet ventilation. Critical details to keep in mind to maximize benefit and minimize risk of airway injuries are as follows: first, the size of the airway guide and the size of the

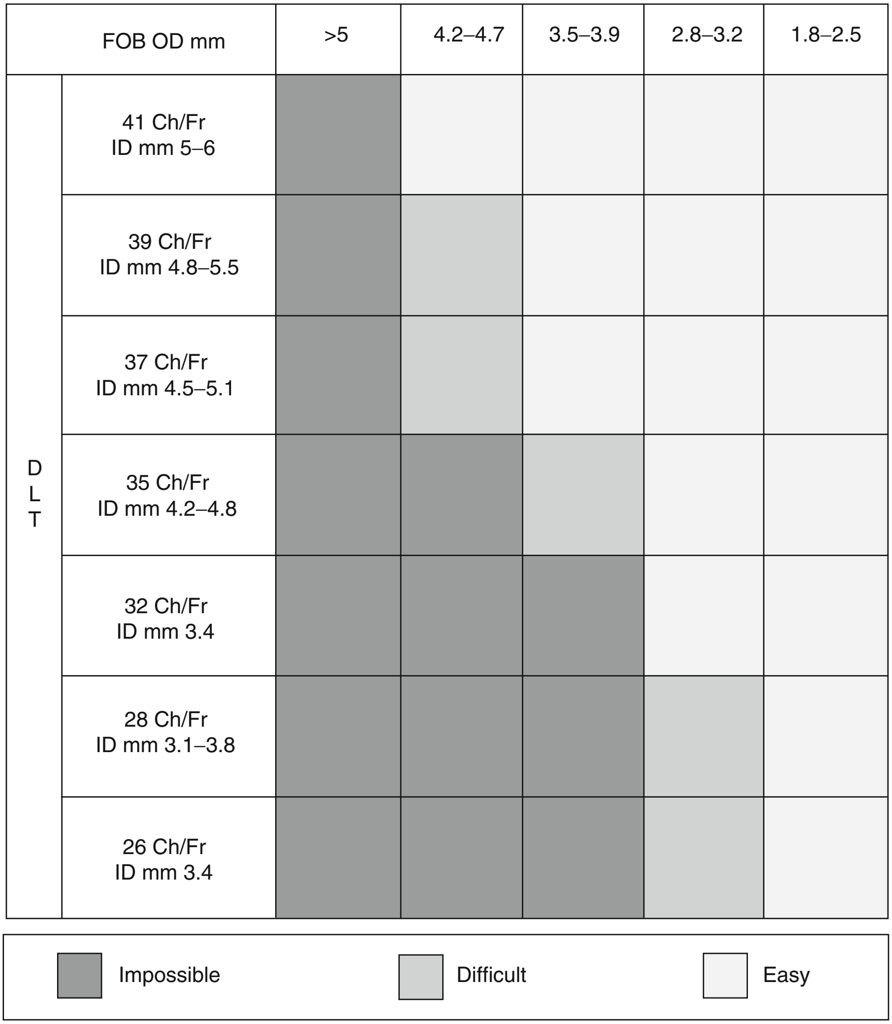

Fig. 13.2 Sizes of bronchoscope reported in mm of external diameter (*OD*) fit differently from 26 to 41 Fr double-lumen tubes (*DLT*) with different internal diameters (*ID*)

difficult tube must be determined and should be tested in vitro before the use of the airway guide. Second, the airway guide should never be inserted against a resistance; the clinician must always be aware of the depth of insertion. Two reported perforations of the tracheobronchial tree have occurred [23, 24]. Third, a jet ventilator should be immediately available in case the new tube does not follow the airway guide into the trachea, and the jet ventilator should be preset at 25 psi by the use of an additional in-line regulator [25]. Finally, when passing any tube over an airway guide, a laryngoscope should be used to facilitate the passage of the tube over the airway guide past the supraglottic tissues. Because of the potential injury to the bronchial tree from the stiff tip of the tube exchanger, a new catheter has been designed with a soft tip to reduce the risk of trauma.

13.5 Mechanical Ventilation

Traditionally, ventilation during OLV has been performed with tidal volumes equal to those used in two-lung ventilation (TLV), high FiO_2, and zero end-expiratory pressure (ZEEP). This practice was recommended to control hypoxemia, because large tidal volumes (10–12 mL/kg) were shown to improve oxygenation and decrease shunt fraction [26–28]. Recently, however, retrospective case series have shown that high ventilating pressures and high tidal volume are significantly associated with lung injury [29, 30]. Studies using both animal models and humans have evaluated the impact of protective lung strategies versus conventional ones during OLV. They report an increase in inflammatory proteins when high volume is used [31, 32]. Patients undergoing esophagectomy and receiving low tidal volumes have been found to present an attenuated systemic proinflammatory response and a lower extravascular lung water index compared with those receiving high tidal volume [31]. Only one prospective study has been performed that analyzes the postoperative period in 100 patients undergoing lung resection. In this case series, patients in the lower tidal volume (6 mL/kg) group were associated with better postoperative gas exchange and lower postoperative complications, with reduced atelectasis and ALI episodes than that in the high tidal volume group (10 mL/kg) [33]. No differences between groups were found for hypoxemia events, whereas in the high tidal volume group, more patients recorded a peak inspiratory pressure exceeding 30 cmH_2O. *These studies provide strong support for the use of a protective lung ventilation strategy in patients undergoing OLV.* Although the causes of perioperative ALI are clearly multifactorial, hyperinflation and repetitive inflation/deflation cycles of lung functional units are now thought to contribute to injury, and excessive tidal volume is associated with insults in susceptible patients. This leads to the primary recommendation for PLV during OLV: the tidal volume should be reduced to a maximum of 6 mL/kg of IBW. *It is interesting to note that the normal mammalian tidal volume is 6.3 mL/kg* [34]; it may thus be that PLV represents physiologic lung ventilation. However, it must be kept in mind that PLV exposes the lung to atelectasis and lung recruiting maneuvers (LRM) are necessary and mandatory to reduce its formation. *LRM consists of an increase of airway pressure up to 40 cm H_2O with a PEEP up to 20 cm H_2O for a short time to recruit the most of the atelectatic alveoli* [35]. Furthermore, low Vt with PEEP may cause dynamic hyperinflation secondary to the increase in respiratory rate to maintain $PaCO_2$. OLV itself may be injurious to both the ventilated and non-ventilated lung, and this injury depends on the duration of OLV. It may be best to avoid OLV whenever possible by applying continuous positive airway pressure to the non-ventilated lung. This is a particularly attractive option in minimally invasive intrathoracic surgery which does not involve the lungs (i.e., cardiac, vascular, or esophageal surgery). Selective lung re-expansion with the use of either a second circuit or transient isolation of the nonoperative lung allows application of targeted pressure to the atelectatic operative lung while avoiding pulmonary tamponade and hypotension. After recruitment of the operative lung, TLV needs to be established with a protective ventilation strategy. The ventilation setting during OLV is also land of debate. Pressure-control ventilation (PCV) versus volume-control ventilation (VCV) during OLV has been studied by Tuğrul et al. in favor of PCV, particularly in patients with poor preoperative lung function [36]. However, other groups have failed to reproduce the oxygenation benefit of PCV during OLV [37, 38]. A recent study by Pardos et al. comparing PCV and VCV with a tidal volume of 8 mL/kg during OLV failed to demonstrate a significant difference in arterial oxygenation between the two ventilatory modes [39]. This study confirms previous work on the comparison of volume-control versus pressure-control ventilation for OLV. No benefit in oxygenation was associated with either ventilatory mode. *The risk of ALI and fluid overload increases proportionally to the extension of the lung parenchyma resection, and historically, thoracic surgery has been the first type of surgery in which anesthesiologists adopted the restricted fluid approach, but recently the emergence of new data shows that the risk of renal insufficiency after lung resection surgery is about 6–24 %* [40]. So it is necessary to specify two major branches: in patients undergoing pneumonectomy, the restrictive fluid approach seems to be up-to-date, but for lesser resection, a goal-direct-therapy approach should be considered. It is still debated whether total intravenous anesthesia could inhibit the protective effect of hypoxic pulmonary vasoconstriction less. Compared with controls under propofol anesthesia, inhaled anesthetics result in attenuation of cytokine elevations in both the ventilated and the operative lung [41]. This approach appears to translate into better outcomes, as patients in the sevoflurane arm experienced less composite adverse events [42]. Pressure-supported ventilation with PEEP is more likely to maintain optimal lung volumes during emergence. Post-extubation oxygenation in high-risk patients can be improved with CPAP or noninvasive ventilation.

13.6 Techniques to Improve Oxygenation

Switching from two-lung to OLV, the non-ventilated lung leads inevitably to transpulmonary shunting and, occasionally, to hypoxemia. Rates as low as 1 % have been reported, but more recent data indicate an incidence around 8 % in patients undergoing minimal invasive mediastinal surgery [43]. In a recent study, hypoxemia during OLV, defined by a decrease in arterial hemoglobin oxygen saturation to less than 90 %, occurred in 4 % of patients whose lungs were ventilated with a fraction of inspired oxygen greater than 0.5. Hypoxemia during OLV may be treated causally. First the position of the double-lumen tube should be checked, then clear the main bronchi of the ventilated lung from any secretions, and finally improve/change the ventilation strategy. A DLT allows easy fiber-optic access to both lungs, which may be crucial if bleeding or secretions are a problem. Both left- and right-sided DLTs are frequently misplaced or dislodged (surgical manipulation) which may lead to impaired oxygenation and inadequate lung separation [19, 20]. If all these efforts are ineffective, several other techniques can be employed to improve oxygenation. In PLV, the lung is exposed to atelectasis and LRM are needed to restore lung aeration.

OLV ventilation has been associated with significant changes in RV dimensions, suggestive of both pressure and volume overload [44–46]. Intraoperative TEE is frequently used during lung transplantation in order to detect and manage acute RV dilation and dysfunction, as may occur after induction of anesthesia, institution of one-lung ventilation, and clamping of the pulmonary artery. In non-transplant thoracic surgery, there is little evidence to support routine use of TEE [47]. *The most effective maneuver for improving PaO_2 is the application of the two-lung ventilation, if the surgical phase is stable.* You could also apply 5 cmH_2O of CPAP to the nondependent lung. It consists of insufflation of oxygen under positive pressure to keep a "quiet" lung, while preventing it from collapsing completely. The beneficial effect of CPAP is not due to the positive pressure effect, potentially causing blood flow diversion to the dependent perfused lung, but from distending the alveoli with oxygen to allow gas exchange. Using an FiO_2 of 1.0 during OLV may increase the risk of atelectasis and would preclude the use of nitrous oxide. Other additional techniques to improve oxygenation are the use of nitric oxide (NO). NO have selective dilating effects on the pulmonary circulation without effect on the systemic circulation. NO 1 to 20 ppm decreased pulmonary vascular resistance [48, 49]. Large clinical trials are required to establish the safety and efficacy profile of inhaled epoprostenol to improve oxygenation during OLV [50].

Conclusion

Thoracic anesthesia includes the world of one-lung ventilation during anesthesia. The indications classified as absolute or relative are more representative of the new concepts in OLV: it includes either the separation or the isolation of the lungs. DLTs are most widely employed to perform OLV including the concept of one-lung separation. Endobronchial blockers are a valid alternative to DLTs, and they are mandatory in the education of lung separation and in case of predicted difficult airways as they are the safest approach (with an awake intubation with an SLT through a FOB). Protective lung ventilation with a TV less than that used for two-lung ventilation (i.e., 4 to 6 mL/kg) and with the lowest feasible peak airway pressure, I:E ratio of 1:2, with a rapid respiratory rate is considered the standard of care for the ventilation strategy. Recruiting maneuvers should be used to reduce the amount of atelectasis in the dependent lung. They should be applied with sustained peak pressure of 40 cmH_2O to be effective. Also CPAP and iNO or inhaled epoprostenol could improve oxygenation in selected cases. Fluid administration should be limited during thoracic surgery procedures to avoid fluid overload. Finally, a balanced anesthetic technique with inhalational agents and opioids to reduce the required concentration of potent inhaled agent appears the best choice during OLV.

References

1. Campos JH (2005) Progress in lung separation. Thorac Surg Clin 15:71–83
2. Campos JH (2007) Which device should be considered the best for lung isolation: double-lumen endotracheal tube versus bronchial blockers. Curr Opin Anesthesiol 20:27–31
3. Cohen E (2008) Pro: the new bronchial blockers are preferable to double-lumen tubes for lung isolation. J Cardiothorac Vasc Anesth 22:920–924
4. Campos JH (2003) An update on bronchial blockers during lung separation techniques in adults. Anesth Analg 97:1266–1274
5. Cohen E (2005) The Cohen flexitip endobronchial blocker: an alternative to a double lumen tube. Anesth Analg 101:1877–1879
6. Seymour AH, Prasad B, McKenzie RJ (2004) Audit of double-lumen endobronchial intubation. Br J Anaesth 93:525–527
7. Brodsky JB, Lemmens HJ (2005) Tracheal width and left double-lumen tube size: a formula to estimate left bronchial width. J Clin Anesth 17:267–270
8. Brodsky JB, Benumof JL, Ehrenwerth J et al (1991) Depth of placement of left double-lumen endobronchial tubes. Anesth Analg 73:570–572
9. Bahk JH, Oh YS (1999) Prediction of double-lumen tracheal tube depth. J Cardiothorac Vasc Anesth 13:370–371
10. Merli G, Guarino A, Della Rocca G et al (2009) Recommendations for airway control and difficult airway management in thoracic anesthesia and lung separation procedures. Minerva Anesthesiol 75:59–96
11. Cohen E, Benumof JL (1999) Lung separation in the patient with a difficult airway. Curr Opin Anesthesiol 12:29–35
12. Arndt GA, Buchika S, Kranner PW et al (1999) Wire-guided endobronchial blockade in a patient with a limited mouth opening. Can J Anaesth 46:87–89
13. Benumof JL (1998) Difficult tubes and difficult airways. J Cardiothorac Vasc Anesth 12:131–132
14. Klafta JM, Ovassapian A (2001) Lung separation and the difficult airway. Probl Anesthesiol 13:69–77
15. Campos JH, Hallam EA, Van Natta T, Kernstine KH (2006) Devices for lung isolation used by anesthesiologists with limited thoracic experience. Anesthesiology 104:261–266
16. Narayanaswamy M, Lacroix M, Kanellakos G et al (2007) A clinical comparison of three designs of bronchial blockers with double-lumen tubes for lung isolation. Anesth Analg 104:123
17. Prabhu MR, Smith JH (2002) Use of the Arndt wire-guided endobronchial blocker. Anesthesiology 97:1325
18. Kamaya H, Krishna PR (1985) New endotracheal tube (Univent tube) for selective blockade of one lung. Anesthesiology 63:342–343
19. Klein U, Karzai W, Bloos F et al (1998) Role of fiberoptic bronchoscopy in conjunction with the use of double-lumen tubes for thoracic anesthesia: a prospective study. Anesthesiology 88:346–350
20. Benumof JL (2001) The position of a double lumen-tube should be routinely determined by fiberoptic bronchoscopy. J Cardiothorac Vasc Anesth 7:513–514
21. Brodsky JB (2004) Fiberoptic bronchoscopy need not to be a routine part of double-lumen tube placement. Curr Opin Anesthesiol 17:7–11
22. Campos JH (2009) Update on tracheobronchial anatomy and flexible fiberoptic bronchoscopy in thoracic surgery. Curr Opin Anesthesiol 22:4–10
23. Benumof JL (1999) Airway exchange catheters: simple concept, potentially great danger. Anesthesiology 91:342–344
24. DeLima L, Bishop M (1991) Lung laceration after tracheal extubation over a plastic tube changer. Anesth Analg 73:350–351
25. Baraka AS (1999) Tension pneumothorax complicating jet ventilation via cook airway exchange catheter. Anesthesiology 91:557–558

26. Cohen E, Eisenkraft JB, Thys DM et al (1988) Oxygenation and hemodynamics changes during one-lung ventilation: effects of CPAP 10/PEEP 10. J Cardiothorac Anesth 2:34–40
27. Capan LM, Turndorf H, Patel C et al (1980) Optimization of arterial oxygenation during one-lung anesthesia. Anesth Analg 59:847
28. Rees DI, Wansbrough SR (1982) One-lung anesthesia and arterial oxygen tension during continuous insufflation of oxygen to the non-ventilated lung. Anesth Analg 61:507–512
29. Gajic O, Dara SI, Mendez JL et al (2004) Ventilator-associated lung injury in patients without acute lung injury at the onset of mechanical ventilation. Crit Care Med 32:1817–1824
30. Gajic O, Frutos-Vivar F, Esteban A et al (2005) Ventilator settings as a risk factor for acute respiratory distress syndrome in mechanically ventilated patients. Intensive Care Med 31:922–926
31. Michelet P, D' Journo X-B, Roch A et al (2006) Protective ventilation influences systemic inflammation after esophagectomy: a randomized controlled study. Anesthesiology 105:911–919
32. de Oliveira RP, Hetzel MP, Silva M et al (2010) Mechanical ventilation with high tidal volume induces inflammation in patients without lung disease. Crit Care 14:R39
33. Yang M, Ahn HJ, Kim K et al (2011) Does a protective ventilation strategy reduce the risk of pulmonary complications after lung cancer surgery? A randomized controlled trail. Chest 139:530–537
34. Tenney SM, Remmers JE (1963) Comparative quantitative morphology of the mammalian lung: diffusing area. Nature 197:54–56
35. Tusman G, Bohm SH, Sipmann FS et al (2004) Lung recruitment improves the efficiency of ventilation and gas exchange during one-lung ventilation anesthesia. Anesth Analg 98:1604–1609
36. Tuğrul M¸ Camci H, Karadeniz M et al (1997) Comparison of volume controlled with pressure controlled ventilation during one-lung anaesthesia. Br J Anaesth 79:306–310
37. Heimberg C, Winterhalter M, Strüber M et al (2006) Pressure-controlled versus volume-controlled one-lung ventilation for MIDCAB. Thoracic Cardiov Surg 54:516–520
38. Unzueta MC, Casas JI, Moral MV (2007) Pressure-controlled versus volume-controlled ventilation during one-lung ventilation for thoracic surgery. Anesth Analg 104:1029–1033
39. Pardos PC, Garutti I, Piñeiro P et al (2009) Effects of ventilatory mode during one lung ventilation on intraoperative and postoperative arterial oxygenation in thoracic surgery. J Cardiothorac Vasc Anesth 23:770–774
40. Della Rocca G, Vetrugno L, Tripi G et al (2014) Liberal or restricted fluid administration: are we ready for a proposal of a restricted intraoperative approach? BMC Anesthesiol 14:62
41. Schilling T, Kozian A, Kretzschmar M et al (2007) Effects of propofol and desflurane anaesthesia on the alveolar inflammatory response to one-lung ventilation. Br J Anaesth 99:368–375
42. Voigtsberger S, Lachmann RA, Leutert AC et al (2009) Sevoflurane ameliorates gas exchange and attenuates lung damage in experimental lipopolysaccharide-induced lung injury. Anesthesiology 111:1238–1248
43. Karzai W, Schwarzkopf K (2009) Hypoxemia during OLV: prediction, prevention and treatment. Anesthesiology 110:1402–1411
44. Wilkinson JN, Scanlan M, Skinner H, Malik M (2009) Right heart function during one lung ventilation: observations using transoesophageal echocardiography. Anaesthesia 64:1387–1388
45. Matyal R, Mahmood F, Hess P et al (2010) Right ventricular echocardiographic predictors of postoperative supraventricular arrhythmias after thoracic surgery: a pilot study. Ann Thorac Surg 90:1080–1086.51
46. Al Shehri AM, El-Tahan MR, Al Metwally R et al (2014) Right ventricular function during one-lung ventilation: effects of pressure-controlled and volume controlled ventilation. J Cardiothorac Vasc Anesth 28:892–896

47. Evans A, Dwarakanath S, Hogue C et al (2014) Intraoperative echocardiography for patients undergoing lung transplantation. Anesth Analg 118:725–730
48. Booth J (1994) Effect of unilateral inhaled NO during selective ventilation in anesthetized human (abstract). Anesthesiology 81:A1457
49. Wilson WC, Kapelanski DP, Benumof JL et al (1997) Inhaled nitric oxide (40 ppm) during one-lung ventilation, in the lateral decubitus position, does not decrease pulmonary vascular resistance or improve oxygenation in normal patients. J Cardiothorac Vasc Anesth 11:172–176
50. Raghunathan K, Connelly NR, Robbins LD et al (2010) Inhaled epoprostenol during one-lung ventilation. Ann Thorac Surg 89:981–983