Advancements in Lung Isolation Techniques

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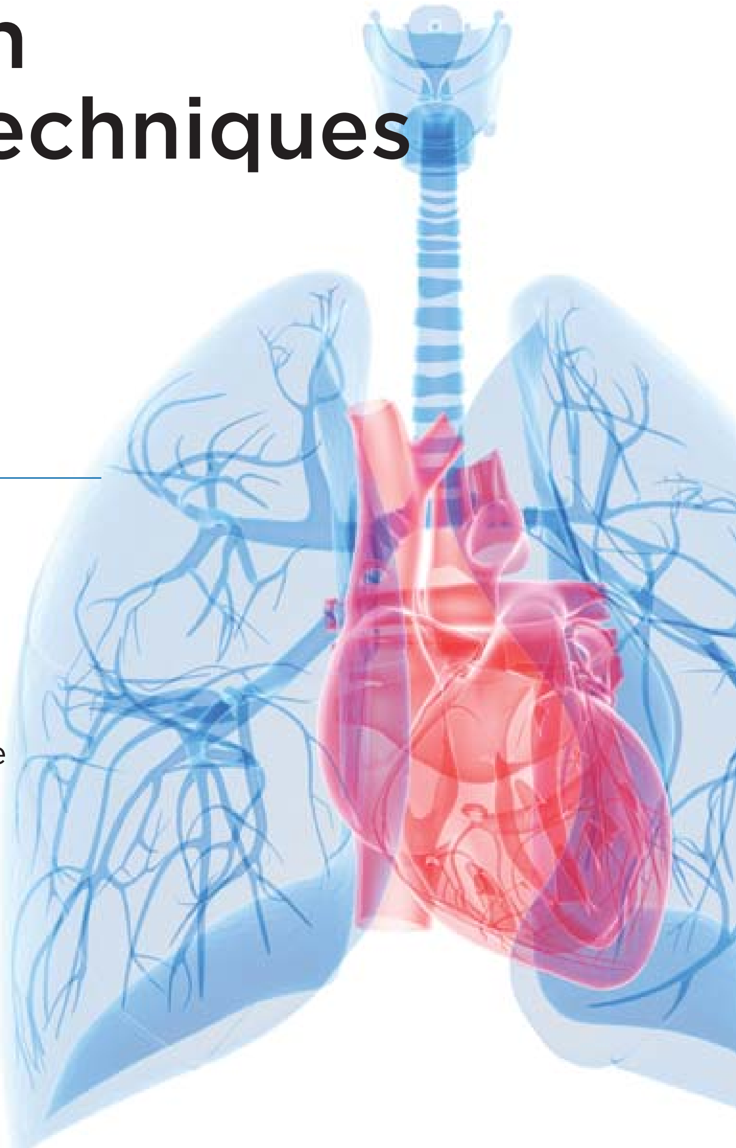

Recent impressive technologic advancements have led to the development of a wide variety of minimally invasive surgical techniques. Cardiothoracic surgery is no exception. In the United States, video-assisted thoracoscopic surgery is being used in 25% to 50% of lung resection surgeries.[1,2] Since its approval by the FDA in 2001, the da Vinci robotic surgery system (Intuitive Surgical) has significantly increased its presence in the cardiothoracic operating room.[3]

Nevertheless, only in the past few years has it been demonstrated that minimally invasive thoracic surgery improves outcomes compared with standard thoracotomy.[4,5] However, one of the key elements for the success of these techniques is excellent lung isolation that allows optimal surgical visualization. A poorly collapsed lung leads to complications, prolongs surgical time, and mitigates the overall advantages of a minimally invasive technique.[3] Therefore, anesthesiologists should feel comfortable when placing and managing all available devices for lung separation. This article describes the currently used lung separation devices, new concepts in ventilatory approaches, and potential strategies to prevent desaturation during one-lung ventilation (OLV).

Double-lumen tubes (DLTs), bronchial blockers (BBs), the Univent (Teleflex) tube, and single-lumen endotracheal tubes (ETTs) represent the currently available devices used for OLV. Indications for OLV are presented in Table 1.

Double-Lumen Tubes

The DLT is the most commonly used device for OLV. It is essentially composed of 2 polyvinyl chloride ETTs sealed together. The longer of the 2 tubes is designed to fit endobronchially. This represents the "bronchial lumen." The other tube, with its end in the trachea, represents the "tracheal lumen." Each tube has its own cuff. To be easily distinguished during flexible bronchoscopy, the bronchial cuff and the pilot balloon serving the cuff are blue. To allow facile insertion in the desired bronchus, the DLT has a fixed, predesigned curvature.[6] The tube also has a stylet placed through the bronchial lumen.

Because the bronchial anatomy of the left side differs from that of the right, separate left- and right-sided DLTs are available. The bronchial lumen of the right DLT is provided with a ventilation slot, which requires proper alignment with the right upper lobe bronchus takeoff. DLTs come in different sizes. A pediatric left DLT is available in 28 F. Adult sizes include a left 32 F and left and right DLTs in 35, 37, 39, and 41 F. Measuring the tracheal or bronchial size on a chest roentgenogram or computed tomography scan can aid in choosing the appropriately sized DLT. However, as a rule of thumb, either a 35 or 37 F DLT is suitable for women, whereas 39 or 41 F is appropriate for men (Figure 1).[7]

Table 1. Indications for One-Lung Ventilation

Absolute indications	
Prevention of contamination of the healthy lung from the contralateral diseased lung	
	Pulmonary hemorrhage
	Lung abscess or infected lung cyst
Differential ventilation	
	Bronchopleural fistula
	Bronchopleural cutaneous fistula
	Large unilateral bullae
	Large bronchial trauma
	Severe unilateral lung contusion
	After unilateral lung transplant when both lungs have significantly different compliances
	Lung lavage
Surgical indications	
	Video-assisted thoracoscopic surgery
	Robotic-assisted thoracoscopic surgery
	Robotic-assisted minimally invasive cardiac surgery
Relative indications	
	High-priority surgical exposure
	Upper lobectomy via thoracotomy
	Pneumonectomy
	Lung volume reduction surgery
	Open thoracic aortic aneurysm repair
	Minimally invasive cardiac surgery
Low-priority surgical exposure	
	Esophageal surgery via thoracotomy
	Middle and lower lobectomies performed via thoracotomy
	Thymectomy
	Sympathectomy
	Thoracic spine surgery

Source: http://www.openanesthesia.org/One_Lung_Ventilation. Accessed July 20, 2014.

Before placement, the DLT and the stylet are well lubricated and the cuffs are tested. The DLT is inserted either using direct or indirect laryngoscopy. If direct laryngoscopy (DL) is chosen, a Macintosh blade ideally should be used as it offers more space for tube manipulation. The DLT is initially inserted with the curvature upward. After the bronchial cuff passes the vocal cords, the DLT is rotated 90 degrees toward the appropriate side and advanced until slight resistance is met. To decrease the risk for tracheobronchial injury, some clinicians prefer to remove the stylet when the tube is advanced endobronchially. Alternatively, the DLT can be placed in the trachea using DL and guided into the desired bronchus using the flexible bronchoscope.

If DL does not offer a good glottic view, other techniques may be employed. When a video laryngoscope is used to place a DLT, a longer stylet, with a curvature similar to the intubating blade, is required. The DLT also can be positioned using a flexible bronchoscope from the start. In this case, the scope should be loaded through the bronchial lumen.

Regardless of the placement method, auscultation for breath sounds and flexible bronchoscopy (FB) are required to verify the position of the DLT. When auscultating, both cuffs should be inflated and breath sounds should be present bilaterally and equally. Following this maneuver, each lumen is clamped sequentially and breath sounds should be present only in the contralateral lung. However, this technique detects only a proper right/left position and has a large margin of error.[8] Therefore, in modern thoracic anesthesiology, FB is highly recommended.

Figure 1. Left double-lumen tube with connector and special suction catheter.

The flexible bronchoscope is initially positioned through the tracheal lumen. This location should offer a good view of the primary carina—the division between the right and left bronchi—with the blue bronchial cuff visible either at carinal level or 1 to 2 mm into the bronchus, depending on the brand of DLT. Subsequently, the flexible bronchoscope is passed through the bronchial lumen. In the case of a left DLT, the secondary carina—the division between the left upper and lower bronchi—should be visualized. However, in the case of a right DLT, the typical trifurcation into the right middle lobe, basilar, and superior segments of the right lower lobe should be observed. When the flexible bronchoscope is withdrawn into the bronchial lumen, the ventilating slot should be identified and it should be confirmed that it is properly aligned with the right upper lobe bronchus takeoff. The DLT position should be checked immediately after intubation and after any change in the patient's position. Desaturation, increased airway pressures, or loss of lung isolation should prompt an immediate bronchoscopic evaluation.

To facilitate observation of the DLT position and to quickly identify and solve placement problems, a special tube has been developed. The VivaSight-DL (ETView Medical Ltd.) has a high-resolution camera at the tip of the tracheal lumen (Figure 2). The camera is connected to a monitor and allows continuous visualization of the tracheal carina. Any dislodgement is easily observed and the correct position is reestablished. Therefore, the need for FB is decreased. However, to confirm correct positioning above the secondary carina, FB through the bronchial lumen should be performed after initial intubation. The additional advantage of this device is that ventilation is unaffected while the airway is observed. The VivaSight-DL is available only in left-sided sizes 37, 39, and 41 F.

DLTs have several advantages over other devices for OLV. Both lumens have large diameters, offering low resistance to gas flow. Suction catheters can be passed through the lumens, allowing the clearing of secretions from both lungs. Similarly, low-flow oxygen insufflation or continuous positive airway pressure (CPAP) can be applied to the nonventilated lung. The FB also can be used on the operative side to inspect the bronchial anastomosis, as required in lung transplant or sleeve pneumonectomy. In comparison with BB, the lung collapse achieved with a DLT is faster. Left DLTs have a lower incidence of dislodgements and malpositionings.[9] However, the right DLT can easily obstruct the takeoff of the right upper lobe bronchus, leading to hypoxemia or inadequate collapse of the right lung. Because the DLT has both a tracheal and bronchial cuff, it is the only device that protects the healthy lung from contamination with either pus or blood from the diseased contralateral lung. The DLT also permits differential ventilation using 2 separate ventilators in situations in which compliance of the right and left lung differ significantly, such as after unilateral lung transplant or severe pulmonary contusion. However, DLTs should not be used in the ICU except in extreme clinical situations because ICU personnel generally are not familiar with the specifics of this particular device. Therefore, for patients who require postoperative ventilation, the DLT should be changed to a regular ETT at the completion of surgery.

The main disadvantage of DLTs is their large size, which may prove problematic during a difficult intubation. For patients with small oral apertures, the teeth can puncture the tracheal cuff during insertion. And for patients with a distorted left bronchial anatomy, such as after a left upper lobectomy, a stiff DLT may be impossible to position.[10,11] Table 2 describes advantages and disadvantages of DLTs compared to BBs and Univent

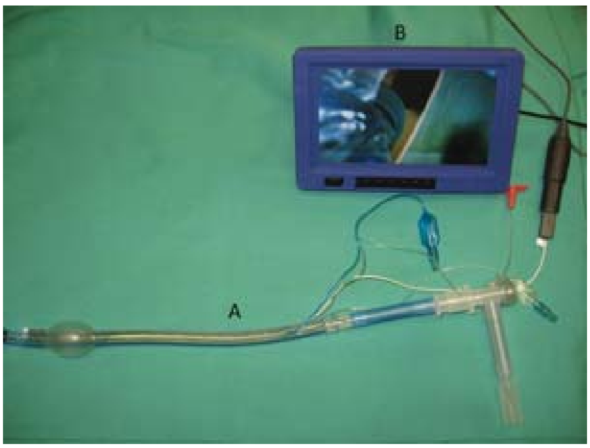

Figure 2. The VivaSight-DL.

A: Double-lumen tube with camera at tracheal lumen tip. B: External monitor allows continuous visualization of the tracheal carina.
Courtesy of Dr. J. Campos.

Table 2. Advantages/Disadvantages of Lung Isolation Devices

	Left DLT	Right DLT	BB	Univent
Ease of positioning	+	-	±	±
Displacement risk	±	++	+	+
Suctioning	+	+	-	-
Separate ventilation	+	+	-	-
Postoperative ventilation	-	-	+	+
Difficult airway	±	-	++	±
Lobar isolation	-	-	+	+

BB, bronchial blocker; **DLT,** double-lumen tube tubes.

Another new device available for clinical practice is the Silbroncho (Fuji Systems), a silicone DLT with a malleable design (Figure 3). The bronchial lumen is reinforced by wire to prevent kinking. This provides flexibility to allow the tube to follow the patient's anatomy and is less likely to damage the tracheobronchial tree during intubation. Moreover, the silicone cuff is more resistant to tearing on the teeth.

The decision to exchange the DLT for an ETT requires the clinician to perform a risk–benefit analysis. As previously mentioned, critical care personnel typically are not familiar with the particularities of these devices. Therefore, any dislodgement can lead to difficulties in ventilation, hypoxia and, if not corrected immediately, even death. However, the potential for loss of the airway during tube exchange should not be dismissed. Clinicians must consider all the safety precautions to avoid loss of the airway. If the surgery was prolonged and the patient required massive fluid resuscitation, it is likely that significant airway edema will be present. In such circumstances, use of an airway exchange catheter (AEC) when performing the tube exchange is advisable.[12] A longer catheter, specially designed for use with DLTs, is optimal. The AEC serves a dual purpose: It acts as a guide to the airway and it permits jet ventilation through its central lumen (Figure 4).

Bronchial Blockers

Bronchial blockers are alternative devices used for lung separation and OLV. Their design derives from vascular Fogarty catheters. The BB is a long, semirigid catheter with a central lumen through its entire length that allows lung deflation and an inflatable balloon at the tip. The BB is positioned within the ETT. A provided multiport adapter connects the ETT with

Figure 3. Silbroncho double-lumen tube.

Figure 4. Airway exchange catheter.

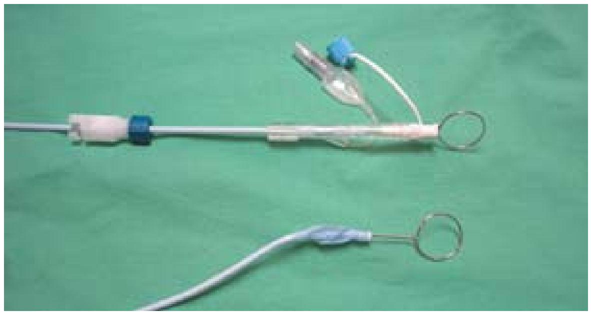

Figure 5. Uniblocker set.

Wire loop protruding from distal tip maintains tip angulation until it is removed just before use. Proximal wire stylet also is removed before use.

Figure 6. Arndt Endobronchial Blocker.

Note wire loop protruding from distal tip of blocker below balloon.

the ventilator circuit and allows for concomitant coaxial placement of the BB and a flexible bronchoscope. Under direct flexible bronchoscopic guidance, the BB is advanced in the desired bronchus and the cuff is inflated to seal the bronchus. At this point, ventilation to the lung with the blocker ceases. Five types of BB currently are available: the Uniblocker (Fuji Systems), the Arndt wire-guided endobronchial blocker (EBB; Cook Medical), the Cohen EBB (Cook Medical), the EZ-Blocker (Teleflex), and the VivaSight EBB (ETView Medical Ltd.). Each of these devices has specific characteristics to allow for a more facile placement of the BB (Table 3).

The Uniblocker shaft is manufactured with a wire mesh coated with polyurethane that confers torque control and allows adequate movement transmission from the top to the tip (Figure 5). To facilitate endobronchial insertion, the shaft is designed with a fixed "hockey stick" curvature and the central lumen has a metallic stylet, which is removed after initial placement.[13] The device's silicone high-volume balloon is impermeable to gas exchange and the cuff, even when inflated to its maximal capacity of 8 mL of air, provides reliably safe endobronchial pressures below 30 mm Hg.

The Arndt EBB has a plastic-coated nylon wire that extends through the entire length of the central lumen and forms a loop at the end (Figure 6). The flexible bronchoscope is passed through the loop and the EBB is inserted using 2 techniques. If the loop is cinched tightly to the flexible bronchoscope, both the EBB and the flexible bronchoscope travel together into the desired bronchus. Alternatively, with the loop loosened, the flexible bronchoscope guides the EBB toward the endobronchial position. Choosing the insertion technique depends on the preference of the operator. The wire loop is removed after initial placement, making the Arndt EBB slightly more cumbersome to reposition. The Arndt EBB is the only blocker with 2 available shapes of high-volume, low-pressure balloons, spherical or elliptical. The spherical balloon is 1 to 2 cm long and is designed particularly for the right mainstem bronchus; the elliptical balloon is for the left mainstem bronchus.[14,15]

The Cohen EBB has a turning wheel at its most proximal part, which allows deployment of the preangled distal tip in the desired bronchus (Figure 7). At the 55 cm mark, the blocker has a torque grip that facilitates rotation. The device has a spherical high-volume, low-pressure balloon at its tip. Above the balloon is an arrow indicating in which direction the tip will deflect. The internal lumen is rather narrow and complete passive lung collapse takes time. Therefore, the Cohen EBB has a cone-shaped device that attaches to the proximal end and, when connected to the suction circuit, speeds deflation of the lung. Its flexible tip and steering mechanism make the Cohen EBB particularly useful for procedures requiring selective lobar blockade.[15,16] However, novice users may find the design cumbersome to manipulate.[17]

The EZ-Blocker has a unique design (Figure 8). The main shaft splits into a Y-shaped end that emulates the tracheobronchial anatomy. The 2 distal ends are 4 cm long and carry a spherical balloon. The 2 cuffs and their pilot balloons are color-coded: One is blue and the other is yellow. As opposed to other blockers, however, the cuffs are high-pressure, low-volume.

As with other blockers, the shaft and the ends of the

Table 3. Bronchial Blocker Specifications

	Uniblocker	Arndt Blocker	Cohen Blocker	EZ-Blocker
Size	5 F, 9 F	5 F, 7 F, 9 F	9 F	7 F
Balloon shape	Spherical	Spherical (S) Elliptical (E)	Spherical	Two spherical (left and right)
Maximum balloon volume	3 cc for 5 F 8 cc for 9 F	2 cc for 5 F 6 cc for 7 F 8 cc for 9 F (S) 12 cc for 9 F (E)	8 cc	6.9 cc for left 9.1 cc for right
Central channel	2.0 mm for 9 F	1.4 mm for 9 F	1.6 mm	4 very small channels
Guidance mechanism	Preshaped tip	Nylon wire loop	Wheel device	None
Smallest ETT required	4.5 ETT for 5 F 8.0 ETT for 9 F	4.5 ETT for 5 F 6.0 ETT for 7 F 7.5 ETT for 9 F	8.0 ETT	7.0 ETT

ETT, endotracheal tube

EZ-Blocker have a central lumen to allow for lung deflation. These lumens are narrow and lung collapse takes a long time even with suction. The split ends of the device have a natural tendency to go into the left and right bronchi. Therefore, it can be introduced blindly or under direct flexible bronchoscopic guidance. When positioned blindly, the EZ-Blocker should be advanced until slight resistance is met, which corresponds to the contact of the bifurcated blocker end with the tracheal carina. After a blind placement, FB is required to verify correct position and to identify which cuff corresponds to which bronchus.[18] The anesthesiologist should label each cuff once the bronchoscopic examination is completed.

In general, the EZ-Blocker is easier to position than the other BBs.[19] Nevertheless, there is a chance that both ends can enter the right mainstem bronchus. To avoid this problem during blind placement, 2 rules must be followed: The distal tip of the ETT must be at least 4 cm above the carina and the blocker should be inserted with the distal ends in a horizontal plane. Because of its construction, this blocker is quite stable and is less prone to dislodgement than other devices[20]—making it particularly useful in situations such as prone esophagectomy in which lung isolation is required but access to the airway is limited. Because it can be successfully and rapidly placed blindly, it is extremely useful for patients with chest trauma and other emergency situations in which the airway is bloody and lung separation is required for surgery.

The newest device on the market is the VivaSight EB, which consists of a steerable balloon catheter with a high-resolution camera at its tip, which is connected to an external monitor that enables real-time video imaging guidance. The blocker is compatible with a standard ETT, in which case FB is still required to observe the position of the blocker and inflation of the cuff. However, if the VivaSight is used with the VivaSight-SL—a single-lumen ETT with high-resolution video camera at the tip—the need for FB is obviated.[21] This blocker functions in a similar manner to other BBs, with the advantage that, unlike the others, it provides real-time visualization below the tip.

One of the advantages of BBs is that their deployment requires no larger than a 7.5-mm ETT or an 8-mm cuffed tracheostomy tube. This feature is particularly

Figure 7. Cohen Tip Deflecting Endobronchial Blocker (shown with Cook Multiport Adapter).

Figure 8. The EZ-Blocker.

Note the bifurcated symmetrical ends with color-coded balloons and corresponding cuffs.

Courtesy of Dr. A. Neyrinck.

useful for patients with difficult airways or for those who arrive in the operating room already intubated.[22] Moreover, selective endolobar blockade can be accomplished with BBs in patients who have undergone previous lung resection surgery or who have significant pulmonary disease and do not tolerate OLV. For patients who require postoperative ventilation, removal of the BB leaves the ETT in place and avoids the need for tube exchange. However, when compared with DLTs, BBs are more prone to intraoperative dislodgements and lung collapse takes longer to complete.[23] They also do not permit the suctioning of secretions or the inspection of the operative-side bronchus.

The clinician can use several strategies to insert a BB and hasten lung collapse. Before placement of the device, the patient should be ventilated with 100% oxygen to promote the development of absorption atelectasis. This technique helps lung collapse at the time OLV is initiated. Placing the ETT higher in the trachea generates more space to manipulate the BB and guide it toward the desired bronchus. If it is difficult to steer the BB towards the desired bronchus, turning the patient's head in the opposite direction may be helpful. Before inflating the balloon, disconnect the patient from the ventilator and allow him or her to exhale passively. The balloon should be inflated with 6 to 8 cc of air under bronchoscopic visualization, making sure that the cuff completely seals the bronchus. Mild suction can be applied to the proximal part of the BB; some blockers allow connection to the suction circuit. Reinstitution of ventilation should be performed after these maneuvers are completed.

Univent

The Univent is a single-lumen silicone ETT with a secondary small lumen along the anterior concave wall containing a BB (Figure 9). The blocker can extend 8 to 10 cm outside the lumen and carries a high-pressure, low-volume balloon. When performing the initial intubation, the clinician should withdraw the Univent into the lumen. The blocker then is extended and guided into the desired bronchus under bronchoscopic visualization. The Univent functions similar to other BBs,[24] but has some distinct disadvantages. When the device is extended or withdrawn into the lumen, the cuff may tear. The outer diameter of the 8.0 Univent tube is similar to that of a 41 F DLT. Therefore, its size does not justify using it in lieu of a DLT when lung separation is required. Finally, the Univent's relatively high cost and the presence of many alternatives make it a rarely used option at this time.

Endobronchial Tubes

As a last resort in clinical emergencies requiring OLV, when exchanging an ETT for a DLT is considered too hazardous and placement of BB is impossible because of blood and secretions in the airway, advancement of the ETT already in place into an endobronchial position can be considered. In certain situations, the ETT may be too short for an endobronchial position. Single-lumen endobronchial tubes are mostly used in the pediatric population because small DLTs are not available. Additionally, in cases of massive pulmonary hemorrhage, such as a ruptured pulmonary artery, the easiest and fastest way to achieve lung isolation is endobronchial intubation. Special endobronchial tubes with an angulated distal tip and 2 cuffs, one in a bronchial and the other in a tracheal position, are available. Endobronchial tubes can be placed under flexible bronchoscopic guidance or blindly. The chance of placing a tube in the left mainstem bronchus is greater if the head of the patient is turned to the right. However, elective use of these tubes for minimally invasive surgical procedures is not recommended, as lung collapse is suboptimal.

Protective Strategies for Lung Ventilation

The most feared complication after thoracic surgery is the development of acute lung injury (ALI), which is associated with extremely high mortality. The pathogenesis of ALI is multifactorial and involves preexisting patient conditions, such as radiation therapy, surgery-induced activation of inflammatory mediators, intraoperative ventilatory strategies, fluid management, and transfusion of blood and blood products. Some of these risk factors are modifiable but others cannot be mitigated. In an attempt to maintain adequate oxygenation and prevent the development of atelectasis and shunt, the traditional OLV strategy required maintenance of similar parameters used during 2-lung ventilation. Lung hyperinflation, hyperoxia resulting in oxidative stress, and the mechanical stress of the opening and closing alveoli may lead to the release of proinflammatory mediators.[25,26] However, more recent studies have demonstrated that protective lung ventilation strategies used during OLV improve postoperative outcomes and reduce the incidence of ALI.[27,28] Therefore, state-of-the-art management of OLV requires protective lung ventilation strategies. These consist of using small tidal volumes—5 to 6 cc/kg—in conjunction with positive end-expiratory pressure (PEEP) at 5 to 10 cm H_2O; a respiratory rate

Figure 9. **Univent tube.**

adequate to maintain normocapnia; and a plateau pressure below 20 cm H_2O. The use of a fraction of inspired oxygen (FiO_2) of 100% has been unquestioned for many years. However, some data suggest that patients ventilated with 100% FiO_2 experience an increase in the inflammatory mediators interleukin-6 and -8 compared with patients receiving lower FiO_2.[27] Before implementing 100% FiO_2 during OLV, a better approach is to evaluate the need for a high level of oxygen in each individual case. Lower FiO_2 has been successfully used during OLV without significant episodes of desaturation.

Management of Hypoxia During OLV

Before determining the optimal management of hypoxia during OLV, the clinician must understand the pathophysiology of hypoxia. Traditionally, anesthesiologists desire maximal oxygen saturation (SaO_2) to create a reserve in case of emergency. A decrease in SaO_2 under 2-lung ventilation implies the possibility of underlying pathology. However, under OLV conditions, the SaO_2 decreases as a result of the induced shunt. In such cases, it may be more prudent to tolerate SaO_2 to 88% for short periods of time rather than perform maneuvers to increase the SaO_2 that could prove more detrimental to the overall long-term outcome.

For persistent desaturations that demand treatment, a predetermined plan is essential. The first step is to assess the position of the lung isolation device. Flexible bronchoscopy allows for immediate detection of malpositioning of the device as well as mucus plugs or blood in the ventilated lung. The next maneuver is to increase PEEP (up to 10 cm H_2O) to the ventilated lung. Values higher than 10 cm H_2O may worsen hypoxia by counteracting the hypoxic pulmonary vasoconstriction effect and diverting blood toward the nonventilated lung. If a lower FiO_2 is used, it should be increased to 100%. CPAP to the nonventilated lung is an acceptable strategy only in open thoracotomies. However, in video- or robotic-assisted cardiothoracic surgery, applying CPAP should be avoided as it reduces surgical visualization and prolongs, or even prevents, the operation.

Applying intermittent recruiting maneuvers to the ventilated lung is an effective strategy in both preventing and treating hypoxemia. If a DLT is used, a suction catheter connected to the auxiliary oxygen port can be inserted in the lumen of the nonventilated lung. This form of "blow by" does not produce lung inflation, as the gas entered has space to exit, but provides some oxygenation to the blood perfusing this lung.[29] If a pneumonectomy is performed, clamping the pulmonary artery will eliminate entirely the shunt. Ultimately, if low saturations, which are potentially deleterious to the patient, persist despite the above maneuvers, returning temporarily to 2-lung ventilation should be considered. This strategy should be discussed with the surgical team.

Conclusion

Minimally invasive techniques are becoming a predominant component of thoracic and cardiac surgery. Now more than ever, therefore, anesthesiologists must be adept at performing lung isolation. A wide variety of devices are currently available for clinical practice, the most widely used of which is the left DLT. Bronchial blockers are particularly advantageous in patients with difficult airways who require postoperative ventilation, who have a tracheostomy in place, or who require selective endolobar blockade. Use of FB is mandatory in identifying correct device position and in repositioning displaced devices. In modern thoracic anesthesia, the use of protective lung ventilation strategies has become standard of care. To best meet the changing clinical scenarios of each individual patient and the various surgical requirements, anesthesiologists should feel comfortable placing and managing a variety of lung isolation devices as well as with performing FB.

References

1. Cooke DT, Wisner DH. Who performs complex noncardiac thoracic surgery in United States academic medical centers? *Ann Thorac Surg*. 2012;94(4):1060-1064.
2. Boffa DJ, Allen MS, Grab JD, et al. Data from the Society of Thoracic Surgeons General Thoracic Surgery database: the surgical management of primary lung tumors. *J Thorac Cardiovasc Surg*. 2008;135(2):247-254.
3. Kim AW, Detterbeck FC. Innovations in thoracic surgery. *Curr Opin Anesthesiol.* 2013;26(1):13-19.
4. Paul S, Altorki NK, Sheng S, et al. Thoracoscopic lobectomy is associated with lower morbidity than open lobectomy: a propensity-matched analysis from the STS database. *J Thorac Cardiovasc Surg*. 2010;139(2):366-378.
5. Swanson SJ, Meyers BF, Gunnarsson CL, et al. Video-assisted thoracoscopic lobectomy is less costly and morbid than open lobectomy: a retrospective multiinstitutional database analysis. *Ann Thorac Surg*. 2012;93(4):1027-1032.
6. Campos JH. Lung isolation techniques. *Anesthesiol Clin North America*. 2001;19(3):455.
7. Pedoto A. How to choose the double-lumen tube size and side: the eternal debate. *Anesthesiol Clin*. 2012;30(4):671-681.
8. Smith BG, Hirsch NP, Ehrenwerth J. Placement of double lumen endobronchial tubes. *Br J Anaesth*. 1986;58(11):1317-1320.
9. Slinger P. Con: the new bronchial blockers are not preferable to double-lumen tubes for lung isolation. *J Cardiothorac Vasc Anesth*. 2008;22(6):925-929.
10. Suriani RJ, Konstadt SN, Camunas J, et al. Transesophageal echocardiographic detection of left atrial involvement in a lung tumor. *J Cardiotorac Vasc Anesth*. 1993;7(1):73.
11. Lohsher J, Brodsky J. Silibroncho double-lumen tube. *J Cardiothorac Vasc Anesth*. 2006;20(1):129.
12. Gatell JA, Barst SM, Desiderio DP, et al. A new technique for replacing an endobronchial double-lumen tube with an endotracheal single-lumen tube. *Anesthesiology*. 1990;73(2):340-341.
13. Campos J. Lung Isolation. In: Slinger P, ed. *Principles and Practice of Anesthesia for Thoracic Surgery*. New York, NY: Springer; 2011:227-246.
14. Neustein, S. The use of bronchial blockers for providing one-lung ventilation. *J Cardiothorac Vasc Anesth*. 2009;23(6):860-868.
15. Dumans-Nizard V, Liu N, Laloë PA, et al. A comparison of the deflecting-tip bronchial blocker with a wire-guided blocker or left-sided double-lumen tube. *J Cardiothorac Vasc Anesth*. 2009;23(4):501-505.
16. Campos JH. Which device should be considered the best for lung isolation: double-lumen endotracheal tube versus bronchial blockers. *Curr Opin Anaesthesiol*. 2007;20(1):27-31.
17. Campos JH, Hallam EA, Van Natta T, et al. Devices for lung isolation used by anesthesiologists with limited thoracic experience: comparison of double-lumen endotracheal tube, Univent torque control blocker, and Arndt wire-guided endobronchial blocker. *Anesthesiology*. 2006;104(2):261-266.
18. Végh T1, Juhász M, Enyedi A, et al. Clinical experience with a new endobrochial blocker: the EZ-blocker. *J Anesth*. 2012;26 (3):375-380.
19. Mourisse J, Liesveld J, Verhagen A, et al. Efficiency, efficacy, and safety of EZ-blocker compared with left-sided double-lumen tube for one-lung ventilation. *Anesthesiology*. 2013;118(3):550-561.
20. Ruetzler K, Grubhofer G, Schmid W, et al. Randomized clinical trial comparing double-lumen tube and EZ-Blocker for single-lung ventilation. *Br J Anaesth*. 2011;106(6):896-902.
21. Giglio M, Oreste D, Oreste N. Usefulness of ETView TVT endotracheal tube for correct positioning of bronchial blockers in left lobectomy: an easy and safe combination. *Minerva Anesthesiologica.* 2009;75(suppl 1):1-4.
22. Campos JH. Lung isolation techniques for patients with difficult airway. *Curr Opin Anesthesiol*. 2010;23(1):12-17.
23. Narayanaswamy, M, McRae K, Slinger P, et al. Choosing a lung isolation device for thoracic surgery: a randomized trial of three bronchial blockers versus double lumen tubes. *Anesth Analg*. 2009;108(4):1097-1101.
24. Campos JH, Kernstine K. A comparison of a left-sided bronchocath with the torque control blocker Univent and the wire-guided blocker. *Anesth Analg*. 2003;96(1):283-289.
25. Licker M, de Perrot M, Spiliopoulos A, et al. Risk factors for acute lung injury after thoracic surgery for lung cancer. *Anesth Analg*. 2003;97(6):1558-1565.
26. Jordan S, Mitchell JA, Quinlan GJ, et al. The pathogenesis of lung injury following pulmonary resection. *Eur Respir J*. 2000;15(4):790–799.
27. Michelet P, D'Journo XB, Roch A, et al. Protective ventilation influences systemic inflammation after esophagectomy: a randomized controlled study. *Anesthesiology*. 2006;105(5):911-919.
28. Licker M, Diaper J, Villiger Y, et al. Impact of intraoperative lung-protective interventions in patients undergoing lung cancer surgery. *Crit Care*. 2009;13(2):R41.
29. Grichnik KP, Shaw A. Update on one-lung ventilation: the use of continuous positive airway pressure ventilation and positive end-expiratory pressure ventilation—clinical application. *Curr Opin Anesthesiol*. 2009;22(1):22-30.