Lung Isolation for Surgery: State of the Art

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The techniques and apparatus used for one-lung ventilation (OLV) have changed significantly in recent years. These changes have come largely in response to an increased use of OLV during lung surgery and the advent of newer, minimally invasive surgical procedures. Whereas OLV in the operating room or intensive care unit was once viewed as a complex endeavor largely managed by specialists in academic institutions, the introduction of newer, limited-access thoracic and cardiac procedures has made it necessary for anesthesia staff members who work in community hospitals and outpatient centers to master lung isolation techniques.

Revised approaches to anterior and posterior spinal procedures, cardiac valve replacement, thymectomy, retrosternal thyroid surgery, mediastinal mass biopsy and excision, esophageal surgery, thoracic aneurysm repair, vascular ring release, lung reduction surgery, and various thoracoabdominal trauma interventions now involve lung isolation during some part of the procedure (Table 1). This article discusses the latest techniques for lung isolation and reviews the features, benefits, and drawbacks of the devices available to facilitate OLV (Table 2).

Methods of Lung Isolation

Two basic types of products are used for OLV, endobronchial blockers (EBBs) and endobronchial tubes (EBTs). Both are available as single or divided tubes. Blockers are a bit more difficult and take somewhat longer to position than single- or double-lumen EBTs (DLTs), but they provide equally satisfactory lung isolation for lung surgery. The decision of which technique to use for lung isolation depends on the clinical setting, and no technique is ideal. A long operation on a patient with endobronchial bleeding requiring bronchial or tracheal...
compression and/or drainage of copious secretions may best be managed with DLT. Lung isolation following a very difficult intubation may be best achieved with a smaller, single-lumen EBT (SLT). EBBs are most suitable during a shorter procedure, or when lung isolation is required for a patient with uncomplicated anatomy and a normally compliant chest wall and lungs. In addition, an SLT or a catheter EBB may be the only option for lung isolation in a small child or infant.

**Endobronchial Blockers**

Innovative EBB devices have multiplied since small-diameter plastic tubes and more compliant cuffs evolved and improved through the last decades of the 20th century. Now, in addition to Foley urinary and Fogarty venous catheters, clinicians can use the TCB Univent Tube (Fuji Systems/Vitaid) with an enclosed bronchial blocker, the Arndt Endobronchial Blocker (Cook Critical Care), the Cohen Tip Deflecting Endobronchial Blocker (Cook Critical Care), or the TCB Uniblocker (Fuji Systems/Vitaid) (Figures 1-4). These blockers should be placed under direct visualization with the guidance of a rigid or flexible fiber-optic bronchoscope (FFB).

Unlike DLTs, EBBs can be used to selectively isolate individual lung lobes or segments, when desired, for improved oxygenation and ventilation. Because of their versatility for selective blockade and their ability to manage special situations in which the use of DLTs is limited, interest in blocker design and applications has increased in past years. For example, they are the only option for OLV in infants and small children. In addition, the selective use of EBBs may be the only feasible option in patients with certain tracheobronchial abnormalities, such as an abnormally placed right upper lobe (RUL) bronchus or a severely angulated left main bronchus. Both EBBs and DLTs have an essential role as apparatus used for OLV.

**Fogarty Catheter.** Fogarty vascular and Foley urologic catheters of various sizes have been used for OLV during pediatric thoracic surgery for years. The Fogarty venous catheter has a central lumen with a wire stylet that can be angulated for tip direction and removed during use. It also has a balloon lumen, and the terminal portion of the balloon can be inflated with up to 10 to 12 mL of air to occlude

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**Table 1. Indications for One-Lung Ventilation**

<table>
<thead>
<tr>
<th>Essential for Surgical Procedure</th>
<th>Convenient for Surgical Procedure</th>
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</thead>
<tbody>
<tr>
<td>Airway bleeding</td>
<td>Esophagogastroctomy</td>
</tr>
<tr>
<td>Bronchiectasis/drainage secretions</td>
<td>Chest wall/thoracic spine procedures</td>
</tr>
<tr>
<td>Large bronchopleural fistula</td>
<td>Thoracic vascular procedures</td>
</tr>
<tr>
<td>Lung transplantation</td>
<td>Closed/limited cardiac procedures</td>
</tr>
<tr>
<td>Minimally invasive cardiac surgery</td>
<td>Patent ductus arteriosus ligation</td>
</tr>
<tr>
<td>Thoracic aneurysm procedures</td>
<td>Chamberlain procedure</td>
</tr>
<tr>
<td>Thoracic procedures with coagulopathy</td>
<td>Pleural stripping or biopsy</td>
</tr>
<tr>
<td>Tracheobronchial obstruction</td>
<td>Coarctation of aorta</td>
</tr>
<tr>
<td>Tracheoesophageal fistula</td>
<td>Lung/lobe/segmental resection</td>
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<tr>
<td>Video thoracoscopy</td>
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</tr>
</tbody>
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**Table 2. State-of-the-Art Devices for Lung Isolation**

<table>
<thead>
<tr>
<th>Device Name</th>
<th>Manufacturer</th>
<th>Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arndt Endobronchial Blocker</td>
<td>Cook Critical Care</td>
<td>Coaxial, FFB-guided WEB</td>
</tr>
<tr>
<td>TCB Univent Tube</td>
<td>Fuji Systems, marketed in the United States and Canada by Vitaid</td>
<td>SLT with enclosed EBB</td>
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</tbody>
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Table 2 (continued on next page)
<table>
<thead>
<tr>
<th>Features</th>
<th>Miscellaneous</th>
<th>Dimensions/Specifications/Sizes</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Color changed to yellow to provide endoscopic contrast of EBB catheter with blue blocker balloon.</td>
<td>• For each size of WEB, there is an ETT size for which coaxial placement is limited by diameters of EBB and FFB used for placement. When these limits are exceeded, parallel placement may be required, as with Fogarty catheter. Either WEB is passed outside ETT, with guide loop inoperable, or FFB is also placed in parallel with ETT, whether before or after intubation.</td>
<td>5F, 7F, and 9F; both pediatric (50-65 cm) and adult (65-78 cm) lengths</td>
</tr>
<tr>
<td>• Kits include multiport airway adapter, which allows flexible fiber-optic bronchoscopy via central port, ventilation from right-angled connector that fits standard 15-mm ventilating adapter, angled (~30°) port for the blocker, and 15-mm adapter that fits central lumen so CPAP can be applied during OLV.</td>
<td>• May be good choice if difficult intubation is anticipated and best choice for routine thoracoscopic procedures.</td>
<td>External dimensions: 10 × 11 mm to 13 × 14 mm</td>
</tr>
<tr>
<td>• 9F blocker can be passed via 7.5-mm-ID ETT, 7F via 6-mm-ID ETT, and 5F via 4.5-mm-ID ETT.</td>
<td>• May be more easily passed than DLT.</td>
<td></td>
</tr>
<tr>
<td>• Balloon inflation volumes may be up to 8 mL for the 9F spherical, 12 mL for the 9F elliptical, 6 mL for the 7F spherical, and 2 mL for the 5F spherical EBB.</td>
<td>• Can be used for postoperative ventilation without changing to conventional TT.</td>
<td></td>
</tr>
<tr>
<td>• Spherical balloon is relatively compliant unless overinflated and takes an elliptical form when inflated in a small bronchus. The 9F catheter comes in an “elliptical” balloon version that provides a longer sealing profile for the main bronchus.</td>
<td>• Central lumen can be used for CPAP to improve oxygenation and for intermittently introducing O₂ into blocked lung.</td>
<td></td>
</tr>
<tr>
<td>• Has internal lumen with balloon-tipped bronchial blocker.</td>
<td>• Smaller models can be used in larger children.</td>
<td></td>
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<tr>
<td>• Thick-walled, internal lumen available for ventilation is relatively small (6-9 mm) and divided between ventilating lumen and nonventilating blocker lumen.</td>
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<tr>
<td>• Internal blocker redesigned to be less stiff, enabling 360° rotation and easier passage into left bronchus.</td>
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</table>

CPAP, continuous positive airway pressure; DLT, double-lumen endobronchial tube; EBB, endobronchial blocker; ETT, endotracheal tube; FFB, flexible fiber-optic bronchoscope; ID, internal diameter; SLT, single-lumen tube; TCB, torque control blocker; TT, tracheal tube; WEB, wire-enabled bronchial blocker

Figure 1. TCB Univent Tube.

Figure 2. Arndt Endobronchial Blocker.

Note wire loop protruding from distal tip of blocker below balloon.
a distal bronchus, Fogarty catheters are versatile; they can be used for bronchial and lung isolation, or for segmental blockade. Adult bronchi can be blocked with 7F catheters, whereas 3F to 5F catheters are suitable for segmental and pediatric blockade. When the anatomy is unusual, 2 or more small Fogarty catheters can be used to block individual lung segments.

Fogarty catheter placement techniques require direct guidance, with either a rigid or flexible bronchoscope. Placement with a rigid ventilating bronchoscope is an older variation that has largely been abandoned since both surgical and anesthesia staff have become experienced and comfortable with the use of smaller, flexible fiber-optic instruments. Two techniques have been described: (1) coaxial placement, in which both the Fogarty catheter and the FFB are manipulated through a single-lumen endotracheal tube (ETT), tracheostomy tube, or rigid ventilating bronchoscope, and (2) parallel placement, in which the catheter is placed alongside the airway or ventilating bronchoscope and positioned under
endoscopic guidance. Parallel placement is more useful in pediatric patients and in other circumstances in which the Fogarty catheter cannot be placed through a tube or rigid endoscope without causing significant airway obstruction.3

Univent Tube. Marketed in 1982, the Univent Tube was the first modern tube designed specifically for bronchial blockade. This flexible silastic tube contains a small internal lumen that carries a retractable, cuffed bronchial blocker that is angled to permit external direction into 1 of the bronchi under direct vision. The rigid internal blocker facilitates tracheal intubation because, when retracted within the tube, it acts like a stylet, angling the tip of the tube for laryngeal passage. On the other hand, the coaxial blocker lumen limits the internal area of the tube available for ventilation. Consequently, it is not available in sizes that would fit an infant or small child. Smaller Univent Tubes (outer diameter, 7.5–8 mm) can be used in larger children.5 Several design modifications have improved the flexibility of the Univent blocker (TCB-Univent, in which the acronym TCB stands for torque control blocker): balloon coloration to facilitate recognition during FFB placement, a hexagonal grip to enhance the ability to rotate the blocker from outside the tube, and external depth markings to enable recognition of the blocker position versus the tube. Adult versions of the Univent blocker are hollow and allow removal of gas trapped in pulmonary segments distal to the blocker or insufflation of oxygen during blockade. At the end of procedures requiring blockade, the blocker can be withdrawn into its internal lumen so that the Univent Tube functions like an SLT.

Advocates of the Univent Tube argue that it is more easily passed than a DLT and can be used for postoperative ventilation without changing to a conventional ETT.6 Consequently, the Univent Tube may be a good choice for routine thoracoscopic procedures,7 or for cases in which difficult laryngoscopy and intubation are anticipated.3,8

The speed of lung collapse during blockade with DLTs and EBBs varies. It may take 15 to 20 minutes for gas to be absorbed from the lung after bronchial collapse.

### Features

- Balloon is spherical and catheter is green, with side depth markings and side holes between the soft, hollow tip and the balloon for evacuation of distal lung gas or insufflation of O2 during use.
- Tip can be deflected in one plane to -30°. EBB and FFB do not have to be passed through an ETT at same time for coaxial placement. (Thus, a 9F CB can be passed ahead of 4-mm-ED FFB and positioned under direct vision through a 7.5-mm-ID ETT with less difficulty than WEB.)
- Proximal control wheel adjusts tip deflection on insertion and can be managed between thumb and forefinger.
- Available as a single-use EBB kit that includes the Multiport Ventilating Adapter (Cook).
- Allows coaxial or parallel placement under FFB guidance.
- Large black arrow along one side of catheter just above balloon points at tip to identify direction of tip angulation, allowing endoscopist to line arrow up with desired direction of deflection before advancing and flexing catheter into appropriate bronchus.

- Blue, 9F, stylied and angled tip with elliptical balloon.
- Central lumen can be capped or used for suction/O2 insufflation. Trifurcated airway adapter allows flexible fiber-optic bronchoscopy during EBB placement and use.

### Specifications/Sizes

- 9F (65 cm)

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CB, Cohen Tip Deflecting Endobronchial Blocker; CPAP, continuous positive airway pressure; DLT, double-lumen endobronchial tube; EBB, endobronchial blocker; ED, external diameter; ETT, endotracheal tube; FFB, flexible fiber-optic bronchoscope; ID, internal diameter; SLT, single-lumen tube; TCB, torque control blocker; TT, tracheal tube; WEB, wire-enabled bronchial blocker
occlusion by an EBB. The central lumen of a hollow blocker may be less effective in allowing trapped airway gas to escape passively or with applied suction than the unobstructed endobronchial or tracheal lumen of a DLT. The central lumen of the Univent Tube can be used to intermittently suction gas from or introduce oxygen into the blocked lung for continuous positive airway pressure (CPAP) to improve oxygenation.

The Univent Tube should be placed in the trachea with the cuff just below the larynx because the operator needs adequate clearance between the tip of the tube and the carina for unrestrained manipulation of the blocker (4-6 cm in adults). Depth markings and a locking clamp on the anterior curvature of the tube allow the endoscopist to fix the depth of its placement below the tip of the tube. The tube should be well lubricated before insertion and the internal blocker should be lubricated and withdrawn fully into the blocker lumen. A well-lubricated tube and blocker are less likely to twist or hang up during passage. After intubation and ventilation, a ventilating bronchoscopy adapter will enable flexible fiber-optic bronchoscopy without loss of airway pressure or volume. After preliminary examination of the trachea and bronchi—with therapeutic lavage and suction, if necessary—the FFB is positioned within the tip of the Univent tube so that the EBB can be visualized as it is first passed into the trachea and maneuvered away from the tracheal wall. FFB guidance requires a long view of the trachea and carina so that the EBB can be maneuvered into the appropriate bronchus after it is several centimeters outside the tip of the tube. From there, the EBB should be followed into the appropriate bronchus with the FFB to ensure that it is not too deep and does not injure the bronchial wall.

The Univent EBB should be placed far enough below the carina on the left to prevent dislodgement during surgery but at or above the division of the left upper and lower lobar bronchi. On the right, the EBB cuff should inflate adjacent to and occlude the RUL bronchus. Because the first division of the right main bronchus is often closest to the carina, the blocker cuff may be so close to the carina that surgical movement can displace it. Flexible fiber-optic bronchoscopy should be repeated to check the position after the patient is positioned for surgery. EBB repositioning or secretion clearance may be indicated during and after surgery. When isolation for OLV is achieved, the blocker is locked into place and the carina is occluded. After use of the EBB, the withdrawn blocker lumen should be capped with the cuff deflated: inflation of the cuff while the blocker is within its internal lumen may partially obstruct the ventilating lumen of the Univent. Since an uncapped blocker lumen can provide air “leak” during ventilation and the cuff can be confused with the cuff of the tracheal tube, these should be labeled or disarmed to prevent postoperative confusion in the postanesthesia care unit (PACU) or SICU.

Arndt Endobronchial Blocker. George Arndt, MD, introduced the Arndt wire-enabled bronchial blocker in 1994. He used a novel, coaxial approach for FFB-guided bronchial blockade. Coaxial manipulation through a sufficiently large tracheal tube allows effective ventilation around the wire-enabled bronchial blocker and FFB during placement. The EBB tip is not angled for external manipulation and direction. A tough plastic loop passed through the central channel of the balloon-tipped blocker allows the EBB to be carried over the FFB for placement in the desired bronchus. The unique Cook Multiport Ventilating Adapter facilitates coaxial placement without interruption of ventilation (Figure 5). It is available from Cook as an individual part that may be used with other EBBs. There is a side port with a standard 15-mm ventilating adapter that connects the ET to the breathing system. Both the EBB and FFB are passed coaxially from additional ports of the adapter into an ET. The EBB port can be tightened to fit around most sizes of blocker after placement. The wire in the blocker lumen is used in either of 2 ways: (1) when cinched tightly around the tip of the FFB, FFB passage carries the EBB into its desired location, and (2) when the FFB is passed through the loop, it provides a track for EBB passage after endobronchial FFB placement. With FFB-enabled blocker passage, the operator can slide the wire-enabled blocker down the FFB into the bronchus with one hand, while holding FFB with the other. Continuous observation through the FFB will ensure that tip position is not lost during EBB passage. The wire-enabled blocker should be mounted on the FFB before the multiport adapter is attached to the ET. Thus, the paired FFB-blocker system is advanced into the ET as the adapter is attached to the breathing circuit. It is difficult to manipulate the FFB through the loop if they become separated once they are within an ET.

The EBB should be visualized as it is advanced off the tip of the FFB into the airway regardless of the initial placement technique. Also, flexible fiber-optic bronchoscopy should be used to observe balloon inflation after passage to confirm its position and ensure that it seals properly. If the EBB is misplaced from the bronchus, the operator most often has to withdraw the entire system, remount it, and pass it again into the lumen of the ET. After placement, the central wire may be removed from the EBB so that the central lumen can be used for suction to speed distal lung collapse or for CPAP or oxygen insufflation to improve oxygenation during OLV. Both potential uses are facilitated by side holes in the EBB catheter tip distal to the balloon. Recently, a revised wire was added that makes replacement of the guide loop via the internal blocker channel easier, so that it can be replaced and used again if blocker repositioning is required after initial removal.

Cohen Tip Deflecting Endobronchial Blocker. The 9F, 65-cm Cohen Tip Deflecting Endobronchial Blocker was introduced in 2004. It allows coaxial or parallel
placement under FFB guidance. Because the tip of the Cohen device can be deflected approximately 30 degrees in one plane, the EBB and FFB do not have to be passed through an ETT at the same time for coaxial placement, as they do with the Arndt Endobronchial Blocker. A 9F Cohen blocker can be passed ahead of a 4-mm-external-diameter FFB and positioned under direct vision through a 7.5-mm-internal-diameter ETT. Because the cuff of the blocker can be below the FFB as both are passed, it inserts with less resistance than is encountered with the wire-enabled blocker. This allows the larger blocker to be used for most women and teens who can be intubated with a 7.5-mm-internal-diameter ETT. The balloon is spherical and the catheter is green, with side depth markings and side holes between the soft, hollow tip and the balloon for the evacuation of distal lung gas or insufflation of oxygen during use. A proximal control wheel that can be operated with the thumb and forefinger adjusts tip deflection during insertion. A large black arrow along one side of the catheter just above the balloon identifies the plane of tip angulation. An endoscopist can align the arrow with the desired direction of tip deflection before advancing, rotating, and flexing the catheter into the appropriate bronchus. Either an assistant or video flexible fiber-optic bronchoscopy may be helpful because it may require 2 hands to manipulate the Cohen blocker into position, one to deflect the tip and the other to rotate and advance the catheter.

Uniblocker. The Uniblocker set combines a long, 9F, angled, cuffed blocker with a central lumen and a unique ventilating adapter similar to the Cook multiport adapter (Figure 5). The adapter is keyed to the blocker, and, unlike the multiport Cook adapter, may be difficult to use with another blocker. The Uniblocker is blue and has a spherical cuff. External markings allow the operator to identify the depth of passage below the ventilating adapter. A 15-mm ventilating adapter allows ventilation, while an FFB passed through the central port can guide manipulation and placement of the blocker as it is passed through a small, keyed side port on the adapter.

Endobronchial Tubes

While DLTs are the EBTs most commonly used for lung isolation (Figure 6), SLTs are most often used as EBBs in pediatric patients who are too small for a DLT.22 An SLT can seal the ventilated bronchus, effectively blocking the opposite bronchus. An SLT used for lung isolation must be longer because the carina is well below the larynx, and the SLT seals either by a snug fit or by inflation of an external cuff within the bronchus. An SLT used as an EBB can be positioned blindly with the surgeon’s assistance through the surgical field, or under endoscopic guidance over a small-diameter rigid bronchoscope or FFB. The use of an EBT is most appropriate when the patient’s position or anatomy tends to compress and obstruct the bronchus to the ventilated lung during OLV.
Double-Lumen Endobronchial Tubes. The newer plastic (polyvinyl chloride) DLTs are easier to insert and less likely to damage tracheobronchial structures than were the previous red rubber DLTs. They are more flexible and have more compliant cuffs with an improved internal to external lumen diameter relationship, but they still have important limitations. When upper and lower airway anatomy permit lung isolation with a DLT, the device is unsurpassed for allowing selective lung inflation and deflation, oxygen insufflation or CPAP, and access to either bronchus for intraoperative suction and drainage of secretions. At least 5 manufacturers provide DLTs in different sizes and configurations for both right and left endobronchial intubation. They are also color-coded and marked to facilitate FFB guidance and radiographic localization. The DLT has an angled, cuffed endobronchial lumen with a tracheal lumen and cuff above the angled portion. Thus, the bronchial cuff separates the endobronchial and tracheal lumina when the EBT is pushed into the bronchus. Initial tracheal placement of both right- and left-sided DLTs is the same. Traditionally, the endobronchial lumen is dependent during lung surgery in the lateral position so that the weight of the mediastinum will not block ventilation of the dependent lung.

During direct laryngoscopy, the DLT is advanced through the larynx with the angled tip directed anteriorly. After passage through the larynx, it is rotated 90 degrees toward the side to be intubated, so that the preshaped angle of the endobronchial tip will direct the DLT into the appropriate bronchus. Because the DLT is tapered (the external diameter is smallest at the distal bronchial tip and largest at the tracheal cuff), it is easier to pass the tip of the bulky DLT than the larger full diameter of both lumens together, and it is possible to force an overly large DLT through the larynx. Initially, while the operator is advancing the tip of the DLT into the larynx, the tracheal cuff is normally just passing the upper teeth. Careful technique with direct laryngoscopy allowing a wide intradental separation is required to prevent damage to the tracheal cuff from the upper teeth and subsequent DLT failure during this portion of endobronchial intubation. Approaches used to avoid this problem during direct laryngoscopy in patients with a limited mouth opening include the following: intubating with an SLT as a first stage for a tube changer, followed by later placement of the DLT; using a rubber dam over the upper teeth; placing a shield over the tracheal cuff that can later be removed so it can be passed without causing injury, and abandoning DLT technique entirely for the use of an EBB, Univent, or SLT. The DLT size is chosen based on the patient’s size and sex and on known features of the bronchus. Size can be estimated from a chest radiograph, CT scan, or other diagnostic image.

Major drawbacks of DLTs have not been eliminated with the introduction of plastic DLTs, despite their increased flexibility, greater internal versus external luminal diameter, and more compliant cuffs: DLTs are thicker and harder to pass through the pharynx and larynx than smaller SLTs. Despite increased DLT compliance, the bronchial tip may not be flexible enough to pass into an extremely angulated bronchus. (A recently introduced version, the Silbroncho [Phycon/Vitaid], may overcome this problem with left endobronchial intubation.) It is not possible to design DLTs for small children and infants. With DLTs, an entire lung must be isolated, rather than pulmonary segments. DLTs may not be flexible enough to fit into an abnormally deviated or compressed bronchus or trachea. Compliant plastic cuffs may be overinflated and damage the trachea or bronchi, as can noncompliant rubber DLT cuffs. DLTs consist of 2 long, narrow tubes fused together and, hence, cause greater airway resistance than an ETT of the same external diameter. DLTs are not ideal for the postoperative “weaning” of patients who require a gradual transition from anesthesia and surgery to normal, spontaneous ventilation. Finally, although selective or asymmetric lung ventilation may be useful or even life-saving for a small number of patients with grossly asymmetric pulmonary disease in an intensive care unit (ICU), most recovery and intensive care nursing and respiratory therapy staff have no idea of how DLTs work, and airway management errors are more likely with DLTs than with SLTs.

Left-Sided Double-Lumen Endobronchial Tubes. Because the left main bronchus is longer than the right before the division into lobar bronchi, left-sided tube design is less varied than right-sided. For example, left-sided DLTs have a single endobronchial cuff. As previously noted, the DLT is passed at laryngoscopy with the tip angled anteriorly. As the left-sided DLT is advanced and rotated 90 degrees to the left, the tip most often passes into the left side. Depth of placement may be assessed by clinical examination, with flexible fiber-optic bronchoscopy, or with a size–height algorithm that predicts proper placement based on common anatomic relationships. Some DLT manufacturers have placed radiopaque markers at the tip of the DLT, just above the bronchial cuff and just below the tracheal lumen, so that the DLT position can be checked by x-ray in the ICU or PACU setting.

Flexible fiber-optic bronchoscopy has been shown to increase the success rate and possibly reduce the incidence of complications during the placement of left-sided DLTs and is strongly recommended. The angulation of the left bronchus where it takes off from the trachea is greater than that of the right bronchus, so left-sided EBTs are likely to enter the right bronchus when passed “blindly” toward the left. Extreme angulation of the bronchus may make left endobronchial placement quite difficult. If the tracheal cuff is too high, partial obstruction of the right bronchus may result. If the bronchial tip is too low, it may damage the left lobar carina.

Two FFB techniques are used for left DLT placement. The position of the DLT is verified by passing an FFB alternately through the tracheal and bronchial lumina to observe both the bronchial cuff as it inflates near or
below the carina and the position of the bronchial tip relative to the left upper and lower bronchi before it is used for OLV. Alternatively, during fiber-optic tube placement, the FFB is used as an optical stylet over which the DLT is passed into the left bronchus to a position above the bifurcation of the upper and lower lobar bronchi. Then, the FFB is passed through the tracheal lumen for proximal verification of bronchial cuff placement. Widespread use of the FFB for DLT placement led DLT manufacturers to color-code the bronchial cuffs, pilot balloons, and proximal lumina. The colored bronchial cuff should be visualized below the carina to avoid both cuff herniation above the carina and partial blockade of the other bronchus. In most adult patients, this will place the bronchial cuff 1 to 2 cm below the tracheal carina. Measuring the depth of placement is facilitated by visible depth markings on the side of the DLT.

The Silbroncho, mentioned above, is a left-sided EBT made of silicone rubber with a wire-reinforced tip and small bronchial balloon. The manufacturer asserts that a Silastic tube is less traumatic to the larynx and tracheobronchial structures. The flexible, wire-reinforced tip is intended to allow more reliable placement in the left main bronchus despite angulation or compression. A smaller cuff profile may prevent dislodgement when the trachea or bronchi are manipulated during surgical procedures, although higher inflation pressures will be required to seal the bronchus. This EBT is available in 33F to 39F sizes. Clinical study will demonstrate whether it represents a major improvement in DLT design. Unlike polyvinyl chloride DLTs, silicone rubber tubes may cause anaphylaxis or delayed-sensitivity reactions in latex-sensitive individuals.

**Right-Sided Double-Lumen Endobronchial Tubes.** Right DLT placement begins with initial intubation, as does left DLT placement, but becomes trickier in the lower airway. Initial placement of a right DLT into the right bronchus is easier than left endobronchial intubation because the right bronchus takes off from the trachea at a shallower angle than does the left. In contrast, bronchial cuff placement is more difficult because of the proximity of the RUL bronchus to the tracheal carina. Ventilating the right lung requires access to the RUL bronchus as well as the bronchi of the middle and lower lobe. The orifice of the RUL bronchus is normally just below the division of the right and left main bronchi. Because the takeoff of the RUL bronchus is, most often, within 1.0 to 1.5 cm of the tracheal carina in adults, the design of right-sided DLTs requires an interrupted or divided cuff so that the RUL bronchus can be ventilated without loss of effective lung separation. Two designs taken from the early red rubber tubes have been reproduced in medical-grade plastic by different manufacturers. Direct fiber-optic evaluation confirms the impression that ideal right DLT placement is more difficult to obtain than ideal left EBT placement. For this reason, some recommend that one should never use a rightsided DLT for OLV.

As in left-sided DLT placement, 2 fiber-optic techniques are used in right-sided intubation. The position of a right DLT can be verified by examining the tracheal carina and the bronchial balloons from the tracheal lumen of the DLT and looking for the RUL bronchus from the endobronchial lumen after the DLT has been placed. The cuff of the bronchial lumen is transparent, so that an FFB placed against the bronchial or EBB cuff frequently visualizes the RUL bronchus if the bronchus is occluded by the cuff. Alternatively, the endoscopist can place the right DLT into the bronchus by passing it over an FFB, used as an optical stylet, so that the RUL orifice of the DLT lines up approximately with the RUL bronchus, before examining the position of the bronchial cuff at the carina from the tracheal lumen of the DLT. FFB examination often shows the bronchial cuff to be just at or quite close to the carina. In such cases, the DLT may need to be repositioned when the patient’s position is changed, before or during the procedure, as required.

**Role of Flexible Fiber-Optic Bronchoscopy in OLV**

With the introduction of small-external-diameter FFBs, it became possible to evaluate the tracheobronchial anatomy while performing tracheal intubation and positioning DLTs, EBTs, and EBBs. Despite an ongoing argument that left EBTs can be satisfactorily placed by using clinical criteria alone,34-37 several groups, including those that argue against routine use of the fiberscope, have shown that tube placement can be marginal, at best, in a number of circumstances.30,33,34,38-43 Although it is possible to achieve lung separation by using only left DLTs,28,37 and although the patient’s height, weight, and sex are correlated with the appropriate size of the DLT,44 the routine use of blind lung isolation is not recommended. The use of an FFB for lung isolation offers a number of advantages: 1) more precise DLT, EBT, or EBB placement; 2) a consistently reliable means of EBB placement; 3) improved, guided tracheal toilet; 4) identification of unusual lower airway anatomy; 5) better upper airway management; and 6) earlier recognition of rare surgical complications. A number of airway experts strongly advocate that anesthesiologists develop a facility with the FFB and that they use FFBs routinely when such instruments are available.31,45-47

The argument that lung isolation is best achieved with clinical examination to confirm the placement of left EBTs continues, despite the increasing role of the FFB in airway management and the fact that it is extremely difficult to selectively isolate a specific segmental bronchus without a rigid bronchoscope or an FFB. Catheter EBBs require flexible fiber-optic bronchoscopy for placement.3 Thoracic anesthetists in many centers in the United States and abroad have reported an incidence of poor EBT placement of 16% to 40%, depending on such factors as the type of tube used, the patient population, and the skills of the anesthesia team.
when the physical examination, alone, is used. Unpredictable problems like DLT or EBT displacement during surgical manipulation of the lung,\textsuperscript{48} gradual cuff herniation above the carina with positive-pressure ventilation, and the accumulation of blood or secretions during surgery require therapeutic endoscopy for management or reassessment and repositioning from time to time during surgery.

The most persuasive argument for FFB guidance or verification during routine lung isolation is that although many patients can be managed successfully without it, the goal is to prevent difficulty in all cases, no matter what type of endobronchial apparatus is used.\textsuperscript{31,43,49}

Changing Endobronchial Tubes

Replacing the DLT with a standard ETT at the end of surgery is recommended for delayed extubation or controlled ventilation. DLT lumina are relatively narrow and long. As a result, airway resistance is greater and secretion blockage more likely. Changing to a standard ETT decreases the probability of these events. Standard ETTs are shorter, have a larger, single internal lumen, and are well understood by respiratory therapy and PACU and ICU nursing staff alike.

ETT change is normally performed under direct laryngoscopy. If the initial laryngoscopy and intubation were difficult, tube change is also likely to be difficult. After prolonged surgical procedures that involve significant fluid shifts and dependency, upper airway edema may make an otherwise straightforward direct laryngoscopy more difficult. For these reasons, tracheal tube change after surgery is considered a risky procedure. The Eschman tube changer and similar devices have been used to facilitate DLT change in such circumstances. More recently, airway exchange catheters (AECs) of various sizes that are hollow and allow oxygen insufflation during use have been introduced as an improvement (Figure 7). Only smaller AECs are suitable for passage through adult DLTs. Most AECs have external depth markings that indicate how far they have been placed into the trachea so that the operator can prevent injury to distal airway structures or inadvertent removal of the AEC during tube change.

The technique for tube change is to pass the AEC through the existing tube, remove the tube, and insert a new tube over the AEC, which is used as a guide. Safe passage of the new tracheal tube can be facilitated by using direct laryngoscopy and insufflating oxygen through the AEC. When a large tracheal tube is passed into the larynx over a small-diameter stylet of AEC, it commonly catches on the larynx. For this reason, apneic ETT change may take a long time. Oxygen insufflation via the AEC for apneic oxygenation during tube change reduces the incidence of hypoxemia.

Even when the ETT is guided over an AEC in the trachea after removal of the DLT, it may be difficult to pass. The following maneuvers are suggestions to overcome this problem: 1) withdraw the ETT and rotate it so that the portion of the ETT tip that is catching on the larynx can be moved to a less obstructed position; 2) stage reintubation by placing an AEC of intermediate size over the small AEC so that the larger ETT fits more snugly around the larger, intermediate AEC (Figure 8); 3) pass a small-external-diameter AEC through each lumen of the DLT so that the AECs fill the replacement ETT more completely; and 4) perform direct laryngoscopy so that the tube can be repositioned or angled differently during passage. Some recommend direct laryngoscopy as an adjunct to AEC-guided DLT change in any event because it has been shown to reduce episodes of hypoxia, bradycardia, and airway loss in the ICU setting (personal communication, T. Mort, MD). During all of these maneuvers, the depth of insertion of the AEC should be monitored to prevent distal airway trauma.
Lung Isolation in Pediatric Patients

Pediatric lung isolation has always posed a unique challenge because of problems associated with relatively small airways, a higher requirement for minute ventilation, a higher rate of oxygen consumption, a higher cardiac output requirement, and a higher incidence of congenital malformations. Infants and small children cannot be managed with DLTs or Univent Tubes. Endobronchial intubation with a single-lumen ETT is more easily managed than ventilation through an endobronchially placed rigid bronchoscope. The newer 5F pediatric wire-enabled blocker can be passed coaxially in many toddlers who can be intubated with a 4.5- to 5-mm-internal-diameter ETT. Because of airway size, coaxial placement of EBBs is often impossible in smaller children and infants. Parallel placement of Fogarty or Amplatz EBBs is more frequently reported. Recent advances in FFB design and EBB design have greatly facilitated pediatric OLV by allowing greater access to smaller airways, but there is no ideal solution. Pediatric lung isolation remains a challenge.

Potential Complications of OLV And Endobronchial Intubation

During OLV, patients are at significant risk for tracheobronchial injury due to tube trauma, tube malposition, and cuff hyperinflation with both SLTs and DLTs. Such risk can be minimized by following these rules:

- Avoid blind passage of tubes and blockers. This is more likely to injure abnormal, diseased tissues.
- Avoid stiffening DLTs for blind passage into the left bronchus with an internal stylet. (This evidently increases the success of left endobronchial placement but most likely increases the risk for airway perforation.)
- Avoid overinflating DLT tracheal cuffs and EBBs. (DLTs: Cuff pressures should be controlled so that an overly distended tracheal or bronchial cuff will not damage the particularly vulnerable posterior membranous trachea or small distal airways. EBBs: In an effort to enable ventilation with higher airway pressures for OLV in patients with relatively noncompliant lungs or a relatively noncompliant chest wall, one easily achieves a very high pressure with a noncompliant EBB balloon or by overinflating a low-pressure cuff in a small distal airway.)

The potential for injuring distal lung segments during ETT change with AECs must be appreciated. The AEC can be misplaced and blindly forced into other tracheal devices. Monitor the depth of AEC insertion during exchange procedures to prevent injury from overinsertion.

When OLV is instituted for control of a massive bronchopleural fistula or unilateral endobronchial bleeding, DLTs and EBBs can become malpositioned, with disastrous consequences. Loss of lung isolation at the wrong phase of an open surgical procedure is an annoyance to the surgical team. DLT dislodgement during thoracoscopy can prevent a satisfactory surgical procedure. Malposition following patient movement or surgical manipulation can be prevented or managed by careful FFB-guided placement of the endobronchial apparatus. Careful surgical packing also minimizes the consequences of loss of lung isolation during open thoracic procedures; the lung will not reinflate immediately as EBB or EBT displacement is recognized. In all of these settings, an FFB should be immediately available for reassessment of the endobronchial apparatus. It is not possible to clear blood or secretions from an occluded bronchus before removal of an EBB, as it is with a DLT, which has larger ventilating lumina. If this is done in a lateral position, purulent secretions or blood from the blocked airway may drain into the normal airway and cause severe airway obstruction or soiling and diffuse pneumonia. It also is difficult to provide selective hyperinflation maneuvers after OLV when an EBB is used because the internal lumen of the newer EBBs is so small.

Animal and human data show progressive hypoxemia with an increased shunt fraction during OLV. In fact, unexplained hypoxemia is one of the early indicators of unrecognized endobronchial ETT placement in day-to-day practice. Immediate hypoxemia is due to very poor ventilation-perfusion (V/Q) matching in the ventilated lung or shunt through the nonventilated lung. Delayed hypoxemia, developing after 10 to 20 minutes, is likely a consequence of oxygen absorption from the unventilated lung or progressive failure of ventilation due to secretions, blood, or inadequate volume of the ventilated lung. Hemorrhage and direct surgical manipulation of the lung, such as the retraction of lung units or surgical packing that collapses the lung, can change V/Q matching semiacutely. Various predictors of hypoxemia during OLV have been identified but these are not reliable and careful oxygen monitoring is important. A number of options have been advocated for the management of hypoxemia during OLV (Figure 9).

Simply being certain that the DLT or EBB is in a good position, with no secretions obstructing the ventilated bronchi, prevents many of the problems associated with oxygenation and ventilation during OLV. The relationship between the tidal volumes used for OLV and hypoxemia has been studied repeatedly during the past 50 years. Most studies showed that tidal volumes >10 to 12 mL/kg of body weight were best, whereas large tidal volumes (>15-20 mL/kg) and small tidal volumes (3-8 mL/kg) did not improve oxygenation. Insufflation of 2 to 3 L of oxygen per minute into the nonventilated lung, provided outflow is possible so that the lung does not inflate and sustain barotrauma, will often improve oxygenation when the lung is not completely collapsed. CPAP with oxygen directed to the blocked lung improves oxygenation by restoring lung volume and improving V/Q matching. Partially inflated but immobile lung may not interfere with surgery. Restoration of dual-lung ventilation almost always improves oxygenation and ventilation, but the lung
motion may make the surgery very difficult or impossible. Intermittent periods of dual-lung ventilation alternating with OLV when the oxygen saturation falls to an acceptable lower level is sometimes necessary. Patients with very abnormal V/Q matching in both lungs may require positive end-expiratory pressure (PEEP), dual ventilation with differential PEEP, modified OLV with high-frequency jet ventilation, or combined modes such as high-frequency jet ventilation and low-rate, large-volume ventilation.

Circulatory maneuvers for changing intraoperative V/Q matching have been investigated. A number of authors have looked at the effect of inhaled anesthetics versus I.V. agents on hypoxic pulmonary vasoconstriction in the expectation that the choice of anesthetic will reliably decrease V/Q mismatching during OLV. Although inhaled agents reverse hypoxic pulmonary vasoconstriction more effectively in various models than do some I.V. agents, there appears to be no clinical advantage to any specific agent (Table 3).

Table 3. Ventilatory Strategy For OLV

- Maintain a tidal volume of 10-15 mL/kg (preserves volume in dependent lung).
- Employ rate-adequate exhalation time (prevents air trapping).
- Reduce inspiratory flow rates (less turbulence and lower positive/peak inspiratory/inflation pressures).
- Avoid air trapping (both atelectasis and hyperinflation increase pulmonary vascular resistance).
- Hypercapnea is acceptable, but not with hypoperfusion and acidemia.
- High airway pressures may be required.
- Lung protection strategies are unproven for ventilation in the OR.

Based on reference 73.

Figure 9. Algorithm for treating hypoxemia during OLV.

CPAP, continuous positive airway pressure
volume. A simultaneous display of airway pressure, volume, and flow over time can be a helpful guide to airway malposition, secretion plugging, bronchospasm, and other conditions that arise during both dual-lung ventilation and OLV (Tables 4 and 5).

Monitoring is required for the early identification of adverse trends and for corrective intervention before patient injury ensues. Intervention in the chest may cause gradual adverse trends, such as increasing hypoxemia and falling cardiac output. It is also associated with sudden surgical bleeding; large bronchopleural fistules; deliberate pneumothorax; unphysiologic patient positioning; and recurrent manipulation of major vascular, lung, and mediastinal structures that can dramatically change on short notice. Because several monitors can fail as a consequence of confused clinical settings or measurement error, systems that seemingly duplicate data collection are rational and appropriate. Clinical experience justifies redundant monitoring. With that in mind, several ECG leads, cuff and directly measured arterial pressure, end-tidal CO₂, agent, and O₂ analysis make sense.

Hemodynamic monitors in addition to noninvasive blood pressure (BP) measurement and electrocardiography may include pulse monitors on the dependent side, continuous invasive BP measurement, and CV or PA pressure monitors. CV catheters should be placed in a position that is not likely to allow movement into the right ventricle during surgical positioning and create significant dysrhythmia. High-risk patients may require intraoperative TEE, in addition to PA catheterization. The TEE image allows moment-to-moment assessment of the effect of surgical manipulation and positioning on biventricular function, as well as a clear diagnostic assessment of overall cardiac function. PA catheters that incorporate continuous mixed-venous oximetry permit dual oximetry on line so that oxygen transport variables can be understood on an immediate basis. Continuous cardiac output monitoring via PA catheters can improve the anesthesiologist’s understanding of evolving changes in the circulation during chest procedures. It is important to know which artery the PA catheter has entered, or to withdraw it to a very central location before completing major lobe, segment, or lung resections.

**Conclusion**

OLV is increasingly requested for an expanding range of surgical procedures that require a quiet lung. Fiber-optic bronchoscopy is an important tool for achieving and managing OLV. Special problems, such as hypoxemia during selective ventilation and abnormalities of both the upper and lower airways, are better understood through the use of bronchoscopy. As the American Society of Anesthesiologists Difficult Airway Algorithm has influenced specialized practice, alternative techniques for intubation, extubation, and tube change have made these processes safer and more reliable. Recent advances in the design of endobronchial apparatus make lung isolation easier in special

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**Table 4. Essential Monitoring During OLV**

<table>
<thead>
<tr>
<th>Monitoring Techniques</th>
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<tbody>
<tr>
<td>Pulse oximetry</td>
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<tr>
<td>Breath sounds</td>
</tr>
<tr>
<td>Capnometry</td>
</tr>
<tr>
<td>Airway pressure monitor</td>
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<tr>
<td>Electrocardiogram rate and rhythm</td>
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<tr>
<td>Noninvasive blood pressure measurement or arterial catheter</td>
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Monitor blood gases as needed in cases such as major volume loss, after 15 minutes of one-lung anesthesia, and for SaO₂ changes.

BR, blood pressure; CV, central venous; PA, pulmonary artery; SaO₂, oxygen saturation of arterial blood; TEE, transesophageal echocardiography

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**Table 5. Helpful Adjuncts to Monitoring During OLV**

- Observe an airway pressure trace, which provides dynamic display of changing parameters.
- Exhaled volumes are an early indicator of failed isolation.
- Measure inspiratory/expiratory flow rates to monitor obstruction.
- Employ a capnographic display to detect ventilation and obstruction with air trapping.
- Measure agent concentrations, which are a guide to anesthetic uptake and distribution.
- Use BIS monitoring, etc, for awareness; most helpful for sensitive (hypotensive) or chronically hypertensive patients.
- Continuously monitor ABG—evolving technology, immediate update.
- Continuous noninvasive cardiac output monitoring may be helpful after adjustment to patient position for trending hemodynamics.
- Continuously monitor SvO₂/CCO—allows dual oximetry, autotrending.
- TEE reveals dynamic effect of positioning, filling volumes, and surgical manipulation.

* ABG monitoring provides a clear indication of intrapulmonary and other shunting that pulse oximetry does not reveal; allows “calibration” of the capnogram for various ventilatory patterns and early identification of acidemia associated with failing circulation.

ABG, arterial blood gases; BIS, bispectral index; CCO, continuous cardiac output; SvO₂, oxygen saturation of venous blood; TEE, transesophageal echocardiography
situations, including problematic airways, small adults, and children. Our clinical repertoire includes a wider variety of DLT and EBB options than ever before. The introduction of minimally invasive thoracoscopic surgery, limited access cardiac surgery, and new nonpulmonary thoracic procedures has generated a resurgence of interest in EBBs for OLV. Since the late 1980s, more than 5 manufacturers have marketed various modifications of the DLT, and since 1994, 4 new bronchial blockers have been introduced to thoracic practice. Although some proponents of OLV continue to expound the advantages of left-sided DLTs for almost all adults requiring lung isolation, many practitioners believe that the versatile clinician should have several techniques and solutions available for both common and uncommon problems encountered during lung isolation.

References


