How to achieve successful lung separation

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ABSTRACT
Recent advances in surgical techniques for thoracic, cardiac, and oesophageal surgery have led to an increased use of lung separation techniques. Currently, double-lumen endotracheal tubes (DLT) and bronchial blockers (an Arndt wire-guided endobronchial blocker, a Cohen Flexitip endobronchial blocker, or the Fuji Uniblocker) are used. Achieving successful lung separation relies on knowledge of the anatomical distances of the airway, flexible fibreoptic bronchoscopy techniques, and familiarity with left and right-sided DLTs and bronchial blockers.

In general, lung isolation techniques are designed to: facilitate surgical exposure for cases involving the thoracic cavity, to prevent contamination of the contralateral lung in cases where pus or haemorrhage is present, and to establish airway continuity such as in a patient who presents with bronchopleural fistula and requires mechanical ventilation. Specific indications with bronchial blockers include: patients with difficult airways, patients with tracheostomy that require lung separation, selective lobar blockade, or whenever postoperative mechanical ventilation is contemplated.

This review focuses on the current methods used to achieve lung separation. The objectives include: selecting the proper size device, intubation issues, optimal positioning with the use of a flexible fibreoptic bronchoscope, potential complications, and the management of lung isolation devices and what to do when they do not work.

Introduction
Recent advances in surgical techniques for thoracic, cardiac and oesophageal surgery have led to the increased use of lung separation techniques. Currently, a double-lumen endotracheal tube (DLT) or bronchial blocker (an Arndt wire-guided endobronchial blocker, a Cohen Flexitip endobronchial blocker, or the Fuji Uniblocker) is used.

This review focuses on the current methods used to achieve lung separation in the intraoperative period in a surgical patient undergoing thoracic, oesophageal, vascular or robotic chest surgery. Specific considerations are given to the current use of the disposable polyvinyl chloride DLT, and alternative methods to achieve lung separation with bronchial blocker technology. Also, special emphasis is placed on situations where lung isolation techniques fail and on the alternative methods used to facilitate one-lung ventilation (OLV).

Anatomy of the tracheobronchial tree
In order to successfully place and utilise the lung isolation devices, it is crucial to consider the following basic points: 1) Does the patient have an acceptable airway to place an isolation device? 2) Does the anaesthesiologist have knowledge of the anatomical distances of the airway? 3) Does the anaesthesiologist have knowledge of the complete fibreoptic bronchoscopic exam? And 4) Is the anaesthesiologist familiar with lung isolation devices, including right- and left-sided DLTs and bronchial blockers (Arndt, Cohen, Fuji Uniblocker and Univent tube)?

A common pitfall when placing DLTs is unfamiliarity with the anatomical distances of the airway. Figure 1 shows that the average length from the incisors to the vocal cords is 15 cm, and the distance from the vocal cords to the tracheal carina is 12 cm. In males, the distance from the tracheal carina to the take-off of the right upper bronchus is an average of 2.0 cm, whereas it is approximately 1.5 cm in females. It is also a statistical fact that one in every 250 subjects from the general population may have an abnormal take-off of the right upper bronchus above the tracheal carina. The distance from the tracheal carina to the take-off of the left upper and lower lobe is approximately 5.0 cm in males and 4.5 cm in females. These anatomical distances apply to subjects with a height of 170 cm.

Figure 1: Average length from the incisors to the vocal cords...
Selection of the proper size for lung isolation devices

Regarding the selection of the proper size of DLT, all studies have focused on the left-sided DLT, in part due to the infrequent use of the right-sided DLT. One common problem with the left-sided DLT is the lack of objective guidelines to properly choose the appropriate size. A left-sided DLT that is too small requires a large endobronchial cuff volume, which might increase the incidence of malposition. In addition, a small DLT does not readily allow fibreoptic bronchoscope placement and can make suction difficult.

The most accurate method for selecting a left-sided DLT is to measure the width of the left bronchus. If the width of the left bronchus and the outer diameter of the endobronchial lumen of the DLT are known, then the largest tube that safely fits into that bronchus can be selected. This information is currently unavailable for DLTs.

Since the left bronchus can clearly be seen in approximately 75% of chest radiographs, an alternative and indirect measurement to estimate the width of the left bronchus is the tracheal width taken from the chest radiograph. One study has shown that the best predictor to estimate the size of a DLT is to know the tracheal width from the posterior-anterior chest radiograph.5 This study showed no correlation between sex, height or weight in predicting DLT size. There is no study available that addresses the issue of the optimal size of right-sided DLT for a determined patient. Selecting an undersized or an oversized DLT has led to serious airway complications, including tracheobronchial rupture.6,7,8 Therefore, in women of Asian descent or patients of short stature, predicting the size of the DLT is difficult at best. In contrast, because the independent bronchial blockers rely on the use of a single-lumen endotracheal tube (i.e. 8.0 mm inner diameter for a 9F bronchial blocker), selecting the size of the independent bronchial blocker in a patient with normal stature is not an issue. When the selection of a properly sized device for lung isolation is an issue, placing a single-lumen endotracheal tube followed by a bronchial blocker provides advantages over DLTs.

Intubation and lung isolation devices

Intubation with a DLT can be more difficult than intubation with a single-lumen endotracheal tube. The larger size of the DLT and the special shape of the DLT, with the lack of bevel in the distal tip of the tube, can obscure an otherwise acceptable view of the glottis. There is also a report of arytenoid cartilage dislocation during intubation with a DLT.9 In patients undergoing oesophagectomies requiring rapid sequence induction and cricoid pressure, a single-lumen endotracheal tube followed by an independent bronchial blocker is advantageous. A report on the use of the Arndt wire-guided endobronchial blocker in patients undergoing oesophagectomies with normal or abnormal airways reported no problems during intubation.10,11 In addition, the wire-guided endobronchial blocker has been used in patients requiring nasal, oral or tracheostomy intubation needing lung isolation with acceptable results.12,13

Rupture of the tracheal cuff during intubation is not an uncommon problem when using DLTs, which, on occasion, requires the use of multiple DLT tubes. This problem is not seen with the use of an independent bronchial blocker because the previously placed single-lumen endotracheal tube protects the balloon of the bronchial blocker during insertion while fully deflated.

Optimal depth of insertion for double-lumen tubes versus bronchial blockers

The optimal depth of insertion for a left-sided DLT is strongly correlated with the patient’s height in average sized adults (170 cm).14,15 In adult patients of Asian descent, however, many of whom are individuals of shorter stature (<155 cm), patient height is not a good predictor of depth of insertion for a DLT.16 An inadvertent deep insertion of a DLT can lead to serious complications, including rupture of the left mainstem bronchus.6 The depth of insertion for a DLT should be between 27 and 29 cm at the marking of the incisors for a subject who is 170 cm tall. For every 10 cm in height greater or less than 170 cm, the DLT should be advanced or retreated 1 cm deeper from the incisors.

In contrast, the depth of insertion of a bronchial blocker is not an issue as long as the tip of the single-lumen endotracheal tube is at least 2 cm above the tracheal carina, so that the bronchial blocker can be manipulated into the desired bronchus.

Right-sided double-lumen endotracheal tube versus right-sided bronchial blockers

The anatomical differences between the right and left mainstem bronchi are reflected in the fundamentally different designs of the right-sided and left-sided DLTs. Due to the fact that the right mainstem bronchus is shorter than the left bronchus and the right upper lobe bronchus originates at a distance of 1.5 to 2.0 cm from the carina, techniques using right endobronchial intubation must take into account the location and potential for obstruction of the orifice of the right upper lobe bronchus. The right-sided DLT incorporates a modified cuff or slot on the endobronchial side that allows ventilation for the right upper lobe. In using fiberoptic bronchoscopy guidance, however, Campos and co-workers showed no increased risk of obstruction of the right upper lobe bronchus orifice when using a right-sided DLT.17,18,19 When right-sided DLTs were compared with right-sided bronchial blockers (Univent), both devices were successfully placed with minimal initial malpositions, which were eventually corrected. Therefore, both devices for the right-sided bronchi are efficacious, showing no advantage over one another.

Specific indications for a right-sided DLT include: distorted anatomy of the entrance of the left mainstem bronchus due to external or intrabronchial tumour compression, descending thoracic aortic aneurysm, site of surgery involving the left mainstem bronchus (such as left lung transplantation), left-sided tracheobronchial disruption, and left-sided pneumonectomy or sleeve resection.

Left-sided double-lumen endotracheal tubes versus left-sided bronchial blockers

Benumof et al defined the margin of safety while positioning DLTs as the length of the tracheobronchial tree over which the DLT may be moved or positioned without obstructing a conducting airway.20 In their study, a left-sided DLT was found to have a greater margin of safety compared with right-sided DLTs. Brodsky and Lemmens reported successful lung isolation in 98% of cases in 1166 patients in whom a left-sided DLT was used.21 These tubes were used for a right- or left-sided surgical or sequential lung collapse.

Left-sided DLTs have proven their efficacy and versatility and the evidence suggests that these tubes are safe for a left-sided
mainstem bronchial intubation. Currently, there is no study available on the specific use of bronchial blockers exclusively in the left-sided bronchus.

**Optimal position of double-lumen endotracheal tubes versus bronchial blockers (Arndt, Cohen, Fuji Uniblocker)**

A study by Klein et al involving 200 patients who were intubated first by the blind technique followed by confirmation with a fibreoptic bronchoscope, found that more than 35% of DLTs required repositioning. A different technique has been suggested to improve the positioning of left-sided DLTs, where the radiopaque line encircling the tube is seen above the tracheal carina in order to increase the margin of safety. The line is 4 cm from the distal tip of the endobronchial lumen. This marker reflects white during fibreoptic visualisation and, when positioned slightly above the carina, indicates the necessary margin of safety.

**Figure 2** The blind method technique for placing a left-sided double-lumen endotracheal tube (DLT)

A. The DLT is passed with direct laryngoscopy beyond the vocal cords.
B. The DLT is rotated 90 degrees to the left.
C. The DLT is advanced until moderate resistance is felt, indicating that the endobronchial lumen of the DLT has entered the bronchus (in general 27 cm marks the level of the teeth).

**Figure 3** The fibreoptic bronchoscopy guidance technique for placing a left-sided DLT

A. The DLT is passed with direct laryngoscopy beyond the vocal cords.
B. The fibreoptic bronchoscope is advanced through the endobronchial lumen. The tracheal carina and left mainstem bronchus are visualised.
C. The DLT is rotated 90 degrees to the left and, with the aid of the fibreoptic bronchoscope, the tube is advanced into the left mainstem bronchus.

**Figure 4** The optimal position of a left-sided DLT

A. shows an unobstructed view of the entrance of the right mainstem bronchus when the fibrescope is passed through the tracheal lumen, the white marker line above the tracheal carina and the blue edge of the fully inflated endobronchial cuff below the tracheal carina in the left bronchus.
B. shows an unobstructed view of the left upper and left lower bronchus when the fibrescope is advanced through the endobronchial lumen.
C. shows the take-off of the right upper bronchus with the three segments (apical, anterior and posterior). (With permission from Campos.)

All bronchial blockers require fibreoptic bronchoscopy techniques to achieve an optimal position. The optimal position with any blocker (Arndt, Cohen or Fuji Uniblocker) in either bronchus is achieved when the fully inflated bronchus occludes the lumen of the bronchus on the side where surgery takes place. The outer blue edge of the fully inflated balloon should be positioned at least 10 mm below the tracheal carina in the left mainstem bronchus to facilitate lung isolation for left-sided surgeries. In contrast, the optimal position of the blocker for right-sided surgeries is achieved by taking into account the early take-off of the right upper lobe bronchus. The outer blue edge of the fully inflated balloon should be positioned at least 5 mm below the tracheal carina inside the right mainstem bronchus.

Any lung isolation device requires the use of a fibreoptic bronchoscope to achieve optimal position with the patient in a supine or lateral decubitus position.

**Figure 5** Insertion of an Arndt bronchial blocker in the left mainstem bronchus

Panel A shows the coupling with the nylon guide wire and the fibrescope. Panel B shows the Arndt blocker and the fibrescope inside the left mainstem bronchus. Panel C shows the uncoupling phase of the blocker from the fibrescope.
Figure 6 shows the proper and optimal position of a blocker in the right or left mainstem bronchus. The outer blue edge of the fully inserted cuff is approximately 5 to 10 mm below the tracheal carina into the respective bronchus.

**Figure 6** Proper and optimal position of a blocker in the right or left mainstem bronchus

Panel A shows a bronchial blocker in the right mainstem bronchus and panel B shows a bronchial blocker in the left mainstem bronchus. (With permission from Campos.)

**Effectiveness of lung collapse: double-lumen endotracheal tubes versus bronchial blockers**

A properly placed lung isolation device should allow the lung to be collapsed. In a study comparing a left-sided DLT with the Univent and the Arndt wire-guided blocker, it was shown that the average time for lung collapse is 17 minutes for a DLT (spontaneous lung collapse without suction) versus 19 to 26 minutes for the Univent or Arndt wire-guided blocker (assisted with suction). Once lung collapse is achieved, however, the overall clinical performance appears to be similar for all three devices. This concept applies to a thoracic anaesthesiologist with expertise in DLT and bronchial blocker placement, but may not apply to anaesthesiologists with limited experience in using bronchial blockers or non-thoracic anaesthesiologists.

**Complications with the use of double-lumen endotracheal tube versus bronchial blockers**

In a review of airway ruptures related to DLTs, the authors reported that approximately 50% of the published cases involving airway damage came from Japanese literature. One of the causes contributing to complications is the use of smaller sized DLTs, such as 35F. A near-fatality complication involving the rupture of the tracheal-bronchial membrane has also been reported.

This rupture of the trachea was due to the use of an oversized DLT in a relatively small-sized patient, or keeping the stylet in place while the bronchial lumen of the DLT was positioned into the left mainstem bronchus.

Although serious complications have been reported with the use of current bronchial blockers (Arndt blocker), these complications appear to be more benign than those involving DLTs. There is a case report in which a lack of communication with the surgical team and a lack of attention to detail led to inadvertent resection of the guide wire and part of the tip of the Arndt bronchial blocker during stapler resection of the left lower lobe; this required surgical re-exploration after unsuccessful removal of the bronchial blocker after extubation.

Another near-fatal complication reported with the use of the Arndt bronchial blocker occurred when the fully inflated balloon of the blocker dislodged into the patient's trachea, leading to a complete airway obstruction. Severe air trapping led to pulseless activity in the patient, who was undergoing a ruptured descending thoracic aortic aneurysm. A prompt deflation of the bronchial blocker cuff resolved this problem.

**How to manage lung isolation devices when they do not work**

Optimal positioning of a DLT after placement is crucial for the outcome of the patient requiring lung isolation. Inoue et al have shown that if a DLT is malpositioned in the supine or lateral decubitus position, there is a greater likelihood that the patient will develop multiple episodes or hypoxaemia during one-lung ventilation. In addition, lack of lung collapse due to failed placement of a DLT might contribute to direct damage to the lung during surgery.

A common pitfall in achieving lung collapse is a malpositioned DLT or bronchial blocker. The fully inflated endobronchial cuff of a DLT is often above the tracheal carina, as shown in Figure 7, or the endobronchial cuff protrudes too far out of a mainstem bronchus. Under these circumstances, lung collapse will not be achieved. One method to correct this malposition is to fully deflate all cuffs and reposition the DLT under direct fiberoptic bronchoscopy. If the blue edge of the endobronchial cuff is not seen, every effort should be made to visualise the white radiopaque marker; this marker should be positioned above the tracheal carina in order to increase the margin of safety for a DLT. In addition, to distinguish the right mainstem bronchus anatomy, every effort should be made to advance the bronchoscope inside the take-off of the right upper bronchus and to identify three segments (apical, anterior and posterior). If a DLT is in the most optimal position but lung deflation is not completely achieved, a suction catheter should be passed to the side where lung collapse is supposed to occur; this suction will expedite lung deflation. The suction catheter must be removed to avoid including it in a suture line.

To prevent unnecessary malpositions with bronchial blockers, the cuff should not be inflated when the patient is in a supine position. While the patient is in the supine position, the blocker is advanced to the mainstem bronchus where lung collapse is needed. Once the patient is in a lateral position and in the most optimal surgical position, the blocker is repositioned and the cuff is inflated under direct fiberoptic bronchoscopy. To expedite lung collapse with the use of a bronchial blocker, the centre channel should be connected to low suction.

The effectiveness of lung isolation devices during anaesthesia for one-lung ventilation has been demonstrated by anaesthesiologists with expertise in thoracic anaesthesia. The routine use of fiberoptic bronchoscopy while placing DLTs...
For a patient who requires lung separation and presents with the challenge of a difficult or abnormal airway, bronchial blockers offer greater advantages. Knowledge of tracheobronchial anatomy and familiarity with fiberoptic bronchoscopy techniques may enhance success in lung isolation techniques.

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