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Lung separation and the difficult airway

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Selective collapse of a lung and one-lung ventilation (OLV) is now performed for most thoracic surgical procedures. Modern double-lumen endobronchial tubes and bronchial blockers have made lung separation safe and relatively easy to achieve. However, OLV in the patient with a 'difficult airway' can present a challenge to the anaesthesiologist. This review considers the different techniques used to achieve lung separation and their application to the patient with a difficult airway.

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Anaesthesiologists are routinely requested to isolate and selectively ventilate a single lung. For most patients, lung separation is safe, easy to apply, and quickly accomplished. Thoracic surgeons have come to expect a collapsed lung and 'quiet' surgical field, and many of the newer, minimally invasive intrathoracic operations can only be accomplished with selective lung collapse. One-lung ventilation (OLV) is usually achieved with a double-lumen endobronchial tube (DLT) or a bronchial blocker (BB), and on rare occasions by endobronchial placement of a single-lumen tracheal tube (TT). For patients with easy access to their upper airway, the choice between a DLT and a BB is usually one of personal preference. However, for the patient with a 'difficult airway', one technique can be a better choice than another.

Difficult airway

Although the American Society of Anesthesiologists Task Force's general definition of *difficult airway* is the 'clinical situation in which a conventionally trained anaesthesiologist experiences problems with (a) face *mask ventilation* of the upper airway, (b) *tracheal intubation*, or (c) both',[96] they also recognized that a standard, all encompassing definition of what is meant by 'difficult airway' does not exist.

The Task Force noted that the difficult airway represents a complex interaction between many factors, including those specific to the patient and the operation, the clinical situation, and the skills of the practitioner. For example, most anaesthesiologists consider a patient with a Cormack–Lehane grade III (epiglottis only) or grade IV (soft palate only) views during conventional direct laryngoscopy to be 'difficult'. However, when placing a DLT, problems can be encountered in a patient with a grade II (partial glottis) view. For the thoracic surgical patient, direct laryngoscopy, tracheal intubation, or both might not be difficult, but lung separation can still be a problem, especially if the anaesthesiologist is unfamiliar or uncomfortable with what have been termed the 'difficult' tubes used for OLV.[17] What might be simple for an experienced thoracic anaesthesiologist can be challenging and fraught with complications when attempted by an inexperienced one.[36]

Choice of tube

All anaesthesiologists must be familiar with the advantages and disadvantages of the different techniques and tubes used for lung separation (Table 1). As a general principle, if the trachea can be successfully intubated by any route with a sufficiently large TT, then lung separation should be achievable.

Endobronchial tubes

After tracheal intubation, a single-lumen tube can be advanced into a bronchus to isolate that lung. Special double-cuffed, single-lumen endobronchial tubes (EBTs) were previously available for this purpose,[3] but they have been replaced by DLTs and BBs.[45]

EBTs have a narrow bronchial cuff and a relatively short distance from the proximal edge of that cuff to the distal tip of the tube. This design reduces the chance of upper-lobe obstruction. In contrast, TTs are not intended

for bronchial placement. Their *margin of safety*, defined as the length of the tracheobronchial tree over which a tube can be moved or positioned without obstructing a conducting airway, is very small. The distance from the proximal edge of the cuff of a TT to its tip is much longer than an EBT, and advancing a TT until its cuff is entirely within the bronchus will usually cause obstruction of the upper-lobe bronchus,[75] especially in the right main bronchus (Fig. 1A). Withdrawing the tube will result in a cuff in the trachea where it no longer can isolate the healthy lung (Fig. 1B).

In an emergency situation, an uncut conventional TT can be advanced into a bronchus to separate the lungs. Endobronchial placement of a TT should only be considered as a life-saving manoeuvre (airway haemorrhage, acute contralateral tension pneumothorax) when the lung must be isolated immediately;[11] for all situations, a DLT or BB is a better choice.

Double-lumen tubes

Modern plastic, disposable DLTs offer many advantages for lung separation.[43] Their clear material allows observation of moisture during ventilation, the presence of secretions or blood in either lumen, or both.[30] To aid in positioning, the blue bronchial cuff is easily visualized with a flexible fibreoptic bronchoscope (FOB). The bronchial cuff's high volume/low pressure properties reduce the danger of ischaemic pressure damage to airway.[21 61 117] The collapsed lung can be deflated and reinflated at will during the procedure. Material in the operated lung can be suctioned before reinflating the lung, and continuous positive airway pressure is easily applied during OLV.[34] A dislodged cuff of a DLT or BB balloon can obstruct ventilation to both lungs, allow contamination of the healthy lung, or both.[106] DLTs have fewer instances of dislodgement and can be positioned more rapidly than BBs.[88]

Human airway anatomy is asymmetric. The right main bronchus is much shorter (average 2.3 cm males, 2.1 cm females) than the left main bronchus (average 5.4 cm males, 5.0 cm females). For most thoracic procedures (left or right), a left DLT is preferred,[32] since it has a greater margin of safety than a right DLT.[19] A right DLT might be required when there is intrinsic (tumour) or extrinsic (tumour, aortic aneurysm) obstruction to the left main bronchus or when a left DLT will interfere with the procedure (left lung transplant, sleeve resection of left bronchus, and left bronchopleural fistula).[38] Many normal patients have a very short right main bronchus, and in a small percentage of the population, the right upper-lobe bronchus originates in the carina or trachea.[67] Placement of a right DLT can be difficult,[121] and modified right DLTs with larger upper-lobe ventilation slots[31 79] and specially designed right tubes[56] have been described for use in these patients.

In general, the largest DLT that can be atraumatically introduced into the bronchus should be chosen.[63] Larger DLTs cannot be advanced as far as thinner tubes, so there is less chance of upper-lobe obstruction.[28] Their larger lumens allow easier introduction of a suction catheter or an FOB, and offer less resistance to airflow during

Table 1 Advantages of DLTs and BBs

Double lumen tubes
Easier to position
Can be positioned without bronchoscopy; bronchoscopy mandatory with BB
Shorter time required to position than a BB
More rapid lung collapse than with BB
Less likely to be displaced than a BB
Allows either lung to be ventilated, collapsed, and re-expanded
Each lung can be suctioned
Each lung can be inspected with a bronchoscope
Continuous positive airway pressure easily applied to operated lung
Enables split (independent) lung ventilation in ICU
Bronchial blockers
Can be used when a TT is already in place (oral, nasal, tracheostomy)
Not necessary to change TT or Univent tube if postoperative ventilation required
Allows selective lobar blockade
Easier to use in smaller airways; technique of choice in paediatric patients

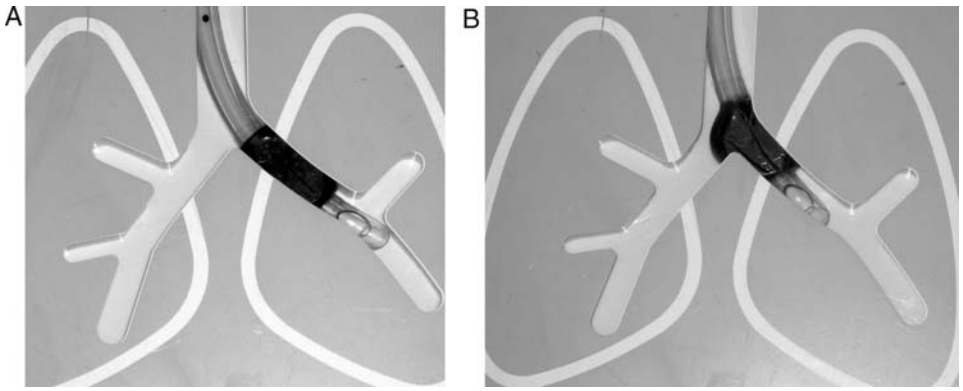

Fig 1 The 'margin of safety', defined as the length of the tracheobronchial tree over which a tube can be moved or positioned without obstructing a conducting airway, is very small when a TT is used to isolate the lungs. (A) Advancing the tube until its cuff is entirely within the bronchus will cause the tip of the tube or the cuff to obstruct the bronchial orifice to the upper lobe. (B) Withdrawing the tube until the upper lobe is no longer obstructed will place the cuff in the trachea where it will no longer isolate the healthy lung.

OLV.[118] There is no absolutely accurate method for selecting the correct size tube. Age,[114] gender, height, or weight[115] are relatively poor predictors of airway size, and choosing a DLT based on these criteria often results in a tube that is either too large or too small. Direct measurement of bronchial width by chest radiography,[26] chest computed tomography,[49] or ultrasound[122] is a better way to select a DLT with appropriate dimensions.[59 91 103] Unfortunately, the left main bronchus is not visible on as many as 50% of chest radiographs.[62] When the bronchus cannot be directly measured, tracheal width can be used to estimate left-bronchial width.[25] The diameter of the left bronchus is directly proportional to the diameter of the trachea.[27] If tracheal width (W_T) is known, left bronchial width (W_{LB}) in millimetres can be calculated as $W_{LB}=(0.4\times W_T)+3.3$.[24]

Plastic DLTs are moulded to conform to the shape of the airway ('memory' of the plastic). A DLT is straight for most of its length (for the trachea) with the distal endobronchial portion curved towards the bronchus. Since the distal end of the tube is inserted into the patient's mouth under direct vision, the bronchial cuff is seldom lacerated. However, if the glottis is anterior, the fragile tracheal cuff is often torn by the patient's upper teeth during intubation attempts. To avoid damage to the tracheal cuff, and as an aid to access the airway, the stylet in the bronchial lumen should be bent, so that the tube assumes a 'hockey stick' shape before laryngoscopy. Direct laryngoscopy for DLT placement is best accomplished using a Macintosh laryngoscope blade,[52] since a curved laryngoscopy blade offers a wider view and more space than a straight blade.

In the patient in whom conventional direct laryngoscopy is anticipated to be problematic, fibreoptic-assisted tracheal intubation has been recommended (Fig. 2). Either a TT or a DLT can be advanced directly over the FOB with the patient awake,[92] or anaesthetized after preoxygenation and induction of anaesthesia.[53 112]

After successful airway intubation, the DLT must be positioned in the appropriate bronchus. Although removal of the stylet in the bronchial lumen once the tip of the tube is past the glottis is recommended, there are no reports of airway trauma resulting from failure to remove

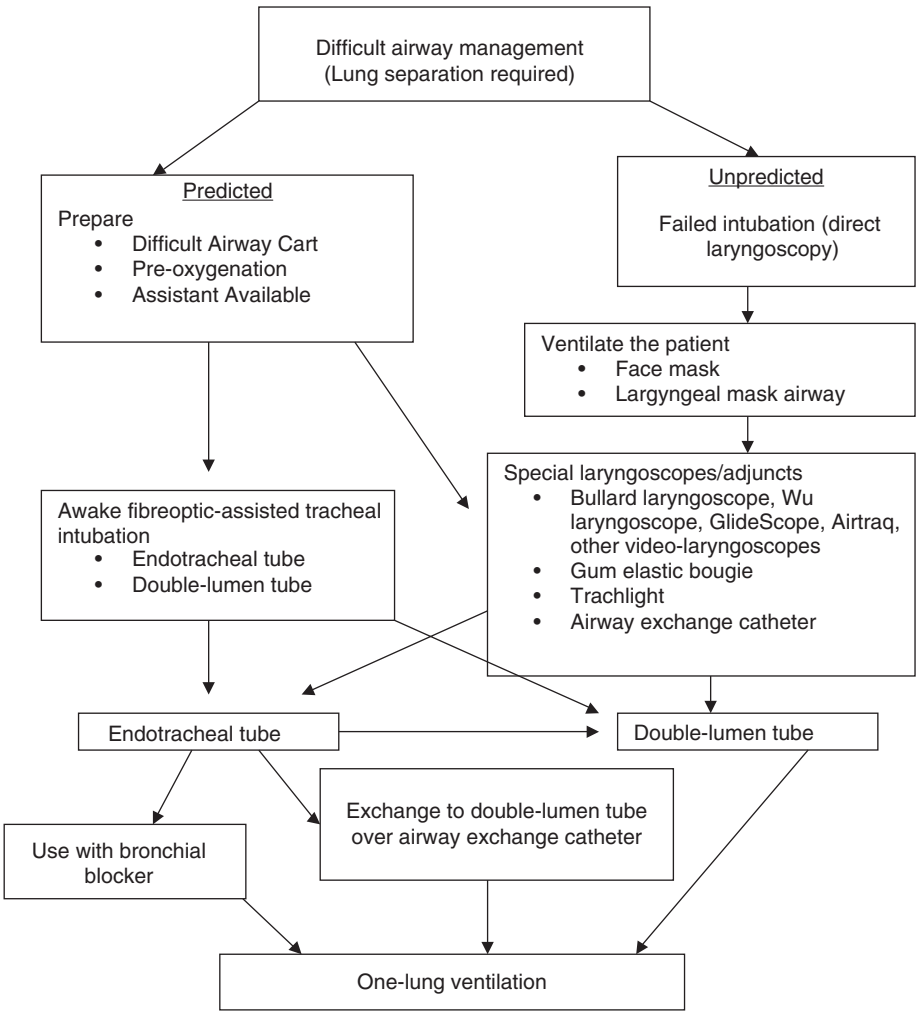

Fig 2 Algorithm for difficult airway management when lung separation is required.

the stylet.[50] Retaining the stylet allowed for more rapid, accurate placement in the bronchus with no increase in the incidence of tracheobronchial mucosa injury in one small study.[78]

Advancing the tube until moderate resistance is encountered will often result in a tube that is too deep in the bronchus, especially when a thin tube is used in a large airway. For both men and women, there is a very significant correlation between height and depth of DLT insertion.[22] Depth for placement of a left DLT (D_{LT}) in centimetres can be calculated as $D_{LT}=12.0+0.1$[height (in cm)].[125]

One advantage of DLTs is that they can be placed without an FOB.[20] This is particularly important in situations when lung separation is required and an appropriate size paediatric FOB is not available.[10] In most instances, DLT position is confirmed by advancing an FOB down the tracheal lumen to identify the blue bronchial cuff just below the carina in the appropriate bronchus.[15 82] The FOB should then be inserted down the bronchial lumen to demonstrate patency of the upper-lobe bronchus.[116] A paediatric FOB with an outside diameter (OD) small enough to fit in the lumen of the DLT must be available (Table 2). Proper fit should be confirmed before intubation.[84] A modification of this placement sequence utilizes the transparency of the plastic to position the tube.[51] The FOB is inserted down the bronchial lumen and position is adjusted, so that the carina lies midway between the black radiopaque line on a Broncho-Cath® (Mallinckrodt Medical, Athlone, Ireland) DLT and the proximal top of the bronchial cuff. Since tube position can change, especially after positioning of the patient, fibreoptic visualization in the supine position only confirms that the bronchial lumen is in the correct bronchus; DLT position must always be verified after the patient is turned to the lateral position.[47]

The bronchial cuff of the left DLT should require <3 ml of air to seal the airway if an appropriately large tube has been chosen.[23] If >3 ml of air is required, the cuff is likely in the trachea. The tension in the pilot balloon to the inflated bronchial cuff should be noted. If the tube subsequently becomes displaced,[12] the pilot balloon will soften because the cuff will then be partially or completely in the larger trachea.[4 5] DLT position can change intraoperatively due to surgical manipulation,[137] changing patient head position,[104] or both, but turning the patient to the lateral position is a very common cause of outward tube movement.[99]

Table 2 Compatibility of FOBs with different size DLTs. FOB, fibreoptic bronchoscope; DLT, double-lumen tube; Fr, French size; OD, outer diameter (mm). Adapted from Merli and colleagues[84]

DLT	FOB
41 Fr	4.2–4.5 OD
39 Fr	3.9–4.2 OD
37 Fr	3.5–3.9 OD
35 Fr	2.8–3.2 OD
32 Fr	2.8–3.2 OD
28 Fr	1.8–2.5 OD
26 Fr	1.8–2.5 OD

Bronchial blockers

Lung tissue distal to an airway obstruction will collapse. With the introduction of modern BBs, there has been renewed interest in this old technique.[33] A BB can be advanced down or alongside a TT. Therefore, if the trachea is intubated orally,[6 90] nasally,[2] or through a tracheostomy[57 74 83 132] with a TT of sufficient internal diameter (ID), a BB can be used to separate the lungs. Bronchial blockade remains the 'technique of choice' in paediatric patients who are too small for the smallest (26–28 Fr) DLTs.[57]

Different balloon-tipped catheters, all intended for other purposes, have been used in adults[55 97] and children[58 101] for bronchial blockade. Catheters like the Fogarty® embolectomy catheter (Edwards Lifesciences, Irvine, CA, USA) are potentially problematic in this role because their inflated balloon exerts very high pressure on the airway. In contrast, newer BBs have low-pressure balloons,[73 100] and should be used except in emergency situations.

The Univent® tube (Fuji Systems, Tokyo, Japan/Vitaid, Toronto, Canada) is a conventional TT with a second lumen that contains a thin coaxial catheter.[70 71] Under FOB guidance, that catheter can be advanced past the TT into either bronchus.[54 68 80] A balloon at its tip, when inflated, functions as a BB. The catheter itself, the TCB Uniblocker® (Fuji Systems/Vitaid), is also sold independently of the Univent tube.[126]

The Arndt Endobronchial Blocker® (Cook Critical Care, Bloomington, IN, USA) is a balloon-tipped catheter with an inner lumen that contains a flexible wire. The wire passes from the proximal end of the catheter and exits past the distal end as a flexible wire-loop.[7–9 69] The wire-loop is coupled with an FOB to guide the blocker into the bronchus. Once the blocker is positioned, the FOB is removed from the TT, the wire loop is withdrawn into the lumen of the catheter, and the balloon is inflated. A special three-part swivel adaptor (Arndt Multi-port Adaptor®, Cook Critical Care) allows introduction of an FOB through one port, the BB through a second port, and a third port connects the TT to the ventilation circuit. This system simplifies simultaneous connection of the anaesthesia circuit and passage of the FOB and a BB through a TT.[76]

The Cohen Endobronchial Blocker® (Cook Critical Care) has a catheter shaft which is bonded at its distal end to a 3 cm soft nylon flexible tip. This tip can be deflected >90° by a counterclockwise rotation of a wheel positioned at the proximal end of the catheter to direct the distal blocker balloon into either bronchus.[42 102]

An FOB is always required to place a BB. Optimally, both the BB and the FOB should fit within a large TT in order to be able to ventilate the patient during blocker placement. If a small ID TT is used, the BB can be advanced alongside the TT whereas the FOB is advanced down the tube.[13 87] When the airway is so small that it cannot accommodate both a TT and an FOB simultaneously, the BB and FOB can be advanced down the airway and the BB positioned. The FOB is then removed and a TT is placed in the airway (Fig. 3).

Lung separation and the difficult airway

It is important to remember that *absolute* indications for lung separation are limited to situations when the healthy lung must be protected from life-threatening contamination, or when positive pressure ventilation of the trachea is impossible due to tracheal or bronchial damage. Although many surgical procedures are more easily performed with the lung collapsed, if placement of a DLT or BB is problematic, one must consider the safety and need for lung separation. Surgical preference alone is an insufficient reason to jeopardize a patient.

Airway intubation

For most patients, a 'difficult airway' is synonymous with *difficult airway intubation*. For a patient with known or predicted difficult airway access, it is usually best to first intubate the airway with a TT. Then if OLV is considered a high priority, the decision can be made to proceed using a BB or to substitute a DLT for the TT (Fig. 2).[37 93] Bronchial blockade is always an option when a DLT cannot be placed, but the airway is accessible to a TT. Examples include patients with very limited mouth opening or in whom only a nasotracheal intubation is possible. For a patient with a tracheostomy, lung separation can be obtained with a BB through a TT or tracheostomy tube,[40 120 131] with a conventional DLT (Fig. 4A),[98 109 113] or with short DLTs intended for tracheostomies (Fig. 4B).[29 127]

An FOB must be available, and the anaesthesiologist must be familiar with both normal and abnormal airway anatomy.[35] When tracheal intubation by conventional laryngoscopy is difficult, awake FOB-assisted TT tracheal intubation has historically been the safest means of securing the airway.[16] However, there have been important recent advances with fibreoptic systems and video technology. New video-laryngoscopes including the GlideScope® (Verathon Medical, Bothell, WA, USA), Pentax Airway laryngoscope® (Pentax, Hoya, Tokyo, Japan), Airtraq® (Prodol/King Systems Corp., Noblesville, IN, USA), LMA CTrach® (LMA North America, Inc., San Diego, CA, USA), McGrath® video laryngoscope (Aircraft Medical/LMA North America), and many others are now available. These devices are proving useful in difficult intubation situations.[105] Protocols are changing and videoscopes are replacing bronchoscopy as the first choice for accessing the difficult airway both for TTs and for DLTs.[81 95 128 130]

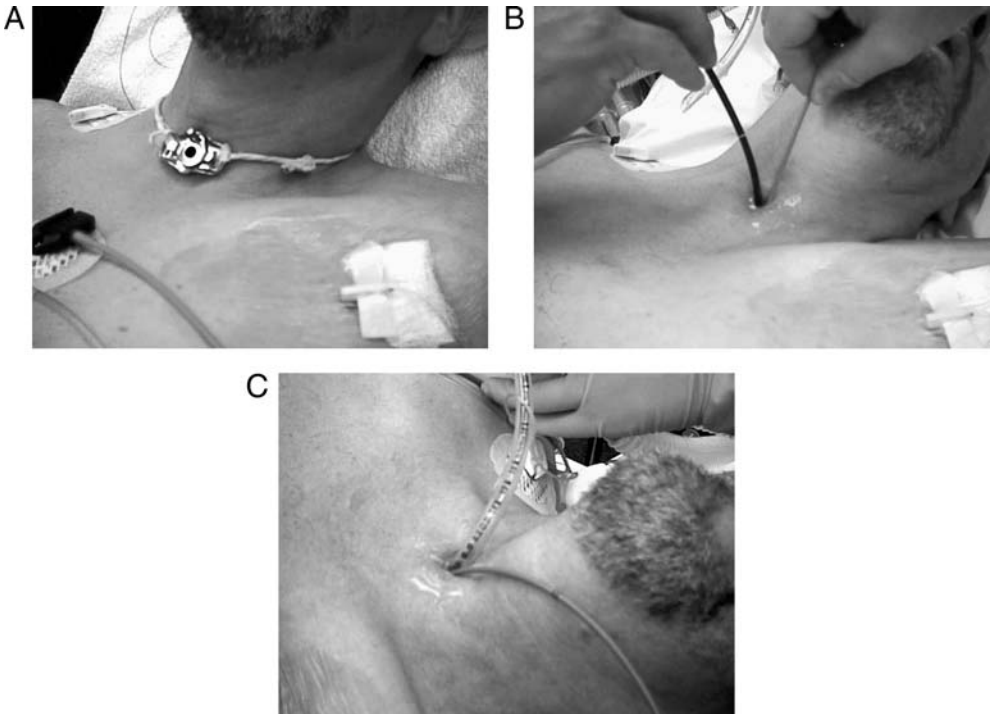

Fig 3 (A) A patient with an extremely small tracheal stoma required lung separation. (B) After preoxygenation and induction of anaesthesia, a paediatric FOB and a BB were placed directly through the stoma and the blocker was positioned in the bronchus. (C) The bronchoscope was then removed, the balloon of the bronchial blocker was inflated, and a small TT was inserted through the tracheostomy stoma to ventilate the patient.

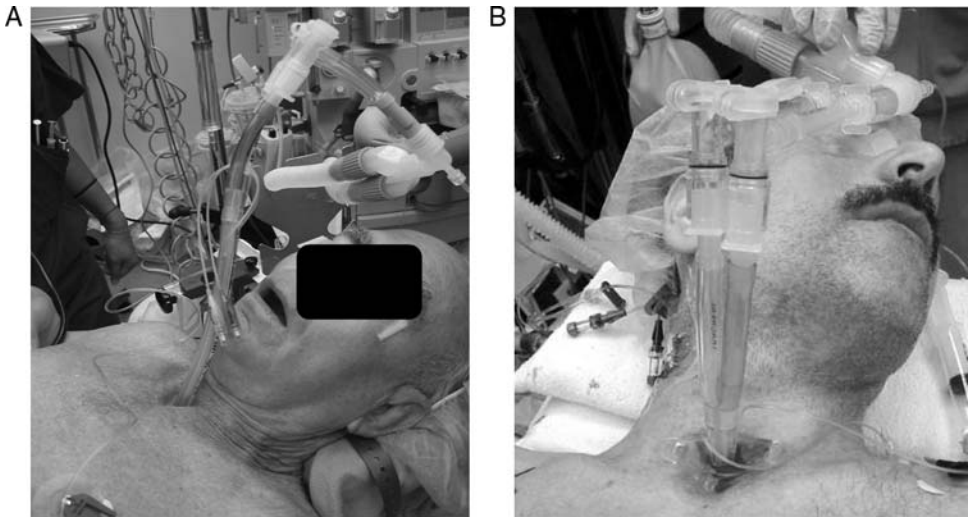

Fig 4 For a patient with a tracheostomy, lung separation can be obtained with a BB through a TT or tracheostomy tube directly in the stoma, with a conventional DLT (A) or with a short DLT intended for tracheostomies (B).

DLT placement in patients with anticipated or proven difficult direct laryngoscopy has been reported with the Bullard® laryngoscope (Gyrus ACMI, Inc., Norwalk, OH, USA),[111] the WuScope® (ACHI Corp, San Jose, CA, USA),[119] the GlideScope,[39 64] the Pentax Airway laryngoscope,[94 123] the Airtraq,[66] and the Bonfils® intubation fiberscope (Karl Storz GmbH, Tuttlingen, Germany).[14] Successful placement has also been achieved using lighted stylets,[41 89 108 136] and other approaches.[1 107 134] Special techniques require practice, especially before attempting them with a DLT in a patient with a difficult airway. The technique most familiar to the anaesthesiologist is usually the best choice.

Table 3 Guidelines for using an AEC. AEC, airway exchange catheter

Select an AEC of at least 70 cm length when using with a DLT
Choose an AEC with a relatively large OD in relationship to a tube with a relatively small ID
Lubricate the AEC
Test the fit between the AEC and the tube before attempting tube exchange
Never advance the AEC against resistance
Use a laryngoscope to lift supraglottic tissue to facilitate tube passage at the glottis
If passage is obstructed, rotate the tube 90° counterclockwise to avoid arytenoid or vocal cord impingement
Note the depth markings on both the AEC and *in situ* tube; never insert the AEC deeper than 25–26 cm into the airway
Have a system for jet ventilation available if the tube cannot be advanced

Airway exchange catheters

An airway guide or airway exchange catheter (AEC) is an essential piece of equipment for thoracic anaesthesia (Table 3). A gum elastic bougie,[77] an Aintree® catheter (Cook Critical Care),[65] or other guides facilitate direct tracheal intubation with a TT, and the Frova® intubating catheter (Cook Critical Care) has been used for DLTs,[133] in patients with Cormack–Lehane grade II or III views during laryngoscopy. The AEC also facilitates changing from a TT to a DLT before surgery and back to a TT at the completion of surgery if postoperative ventilation is necessary.[60] The AEC must be of sufficient length to ensure tracheal introduction of the DLT. Considering the length of the DLT, the distance down the airway to the lower trachea, and additional length needed at its proximal end for control of the tube, the AEC must be >70 cm long. AECs of various lengths and sizes are available. The AEC must have a relatively large OD in relation to a DLT with a relatively small ID for the DLT to successfully follow the guide into the airway. The fit of the AEC in the DLT must be confirmed before attempting tube exchange.

When a thin AEC is used to change to or from a TT, resistance to passage of the tube at the glottis can occur. A laryngoscope should be used to lift supraglottic tissue to help the tube negotiate the angle between the pharynx and the larynx to facilitate passage of the tube over the guide.[48] A counterclockwise rotation of the tube will disengage it, if it is temporarily stuck at the glottis.[72] Two thin AECs, with one inserted in the tracheal lumen and the other in the bronchial lumen, combined with 90° counterclockwise rotation of the DLT reduces the incidence of glottic impingement.[124]

To avoid airway perforation, the AEC should never be advanced against resistance.[46 110] All AEC DLT guides have depth markings on their shaft to monitor the depth of insertion. Although placement of the AEC in a more distal airway decreases the chance of the catheter slipping out of the trachea during tube exchange, it is safer for the guide to remain above the carina in the lower trachea to avoid laceration of the bronchus. The AEC should not be inserted beyond the 25 cm mark at the teeth in adults.[129]

Most AECs have a small lumen that allows oxygen insufflation or jet ventilation. A jet ventilator should be

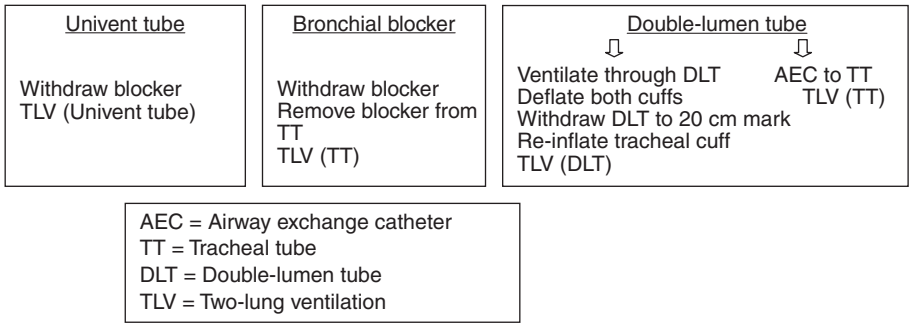

Fig 5 Airway control at completion of surgery for patients requiring postoperative mechanical ventilation.

available if the tube does not follow the guide into the trachea. The ventilator should be set at 25 psi with an in-line regulator. A short (1 s) inspiratory time, low pressure, and sufficiently long expiratory time can be life saving.[44] It is essential the AEC be in the trachea and not the bronchus before instituting jet ventilation to avoid barotrauma.

Completion of surgery

Airway extubation at the completion of surgery is another critical event, especially for patients in whom initial access to the airway was difficult. Depending on the type and length of surgery and the amount of fluid administered, even an airway not considered difficult at the beginning can become one by the end of the procedure. The presence of any mucosal oedema, bleeding, or retained secretions can further complicate an already challenging situation. Continuous access to the airway should be maintained. The TT or DLT can be removed over a thin guide, but with the guide remaining in the trachea to allow immediate access to the airway if reintubation is needed.[86]

For the patient who has a DLT but requires postoperative ventilation, a decision must be made whether to keep the DLT or exchange it for a TT (Fig. 5). A DLT can be used in the critical care setting for selective OLV[85] or for two-lung ventilation (TLV), if exchange to a TT is considered too risky. The bronchial cuff can be deflated to allow TLV, or both cuffs can be deflated and the tip of the DLT withdrawn above the carina. In this position, only the tracheal cuff is reinflated for TLV.

Alternately, the DLT can be exchanged to a TT using the same techniques described for the start of surgery. Tube exchange should be performed under vision with a laryngoscope if possible.[18] Failure to successfully exchange the tubes can result in an extubated airway. In this situation, a laryngeal mask airway can be used to ventilate the patient.[135] Of course, if a Univent tube or BB was used during the procedure, the blocker balloon need only be deflated and the BB catheter withdrawn before instituting TLV through the TT.

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