SPECIAL ARTICLE

Left Double-Lumen Tubes: Clinical Experience With 1,170 Patients

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MODERN DISPOSABLE plastic double-lumen tubes (DLTs) are generally safe and easy to use.[1,2] However, a misplaced or improperly used DLT can jeopardize any procedure and even injure the patient. This article reviews considerations for the selection and placement of left-sided DLTs based on data collected from a large series of patients undergoing thoracic procedures requiring one-lung ventilation (OLV) at this institution. Although the information presented represents the authors' experience at a single center, others can apply many of the lessons in their own practices.

With the permission of the Human Subjects Committee at Stanford University Medical Center, over an 8-year period from 1993 and 2001, 1,170 consecutive patients undergoing anesthesia for noncardiac, general thoracic surgical procedures were studied. All patients were anesthetized by anesthesia residents under the supervision of one of the authors (JBB).

At the time of operation, patient sex, height, weight, site, and type of surgical procedure were recorded. When the patient's chest radiograph (CXR) was available the width of trachea, and in some patients the width of the left bronchus, were measured. The size of the DLT selected, the depth of placement of the DLT in the bronchus, and the volume of air used to inflate the bronchial cuff were recorded. Data are reported as the mean ± standard deviation unless indicated otherwise. Relationships between parameters were analyzed using regression analysis.

Any difficulties encountered, complications, or changes in tube position during the procedure were also noted. Data for measured parameters were not complete for some patients.

CHOICE OF (RIGHT VERSUS LEFT) DLT

If the bronchus of the operated (left or right) lung is routinely intubated,[3,4] a malpositioned tube should be obvious during the procedure because its bronchial cuff will usually obstruct the upper lobe.[5-7] During thoracotomy the surgeon can manually help reposition the tube.[8] Because the intubated lung is intentionally collapsed, a malpositioned tube should not compromise ventilation to the opposite lung. However, a DLT in the operated lung can interfere with airway management or can be displaced by the surgeons, so others recommend routine intubation of the nonoperated lung.[9,10]

The authors prefer a left DLT for both right- and left-sided procedures. The right bronchus is much shorter than the left bronchus so there is a greater risk of upper-lobe obstruction with a right DLT.[11,12] Because the right upper-lobe bronchus originates at the carina or even the trachea in as many as 3% of the population,[13,14] a right DLT may be difficult to safely position in some patients.[15,16] Before placing a right DLT, the patient's CXR or chest computed tomography (CCT) scan should be closely examined to identify an early takeoff of the right upper-lobe bronchus.

A left DLT was chosen for 1,166 of the 1,170 patients. The DLT was successfully used for lung separation in 1,145 (98.2%). A left DLT was used in 451 left-sided procedures, 534 right-sided procedures, and 99 procedures involving sequential collapse of both lungs (Table 1).

The only DLT used was the BronchoCath DLT (Mallinckrodt Medical, Inc, St. Louis, MO). During the study 3 versions of the BronchoCath left DLT were commercially available. The original BronchoCath tube was modified in 1994. The major change was elimination of the bevel at the tip of the bronchial lumen.[17] This was done to decrease the chance of obstruction to gas flow from adherence of a beveled tip to the bronchial wall, when the patient was in the lateral position and the DLT was in the bronchus of the nonoperated lung.[18] Other modifications at that time included a tighter curve on the bronchial lumen intended to increase the success rate for entering the left bronchus. The bronchial cuff was also shortened and relocated closer to the distal tip to reduce the chance of left upper-lobe obstruction. In 2000 a beveled tip was reintroduced on the bronchial lumen. Analysis of data from patients intubated with each of the 3 versions of BronchoCath tube found no significant differences in any of the parameters reported in this series. The number of patients before 1994 and after 2000 was too small for statistical comparisons with the majority of patients who were intubated with the second version of the BronchoCath tube between 1994 and 2000.

Despite concerns about potential problems, there was just a single instance of intraoperative tube displacement from surgical manipulation of the left lung during a left-sided procedure with a left DLT.[9,10] This was immediately recognized because the left lung suddenly became inflated when the bronchial seal was lost. The situation was easily corrected by advancing the tube back into the bronchus.

A left DLT in the left bronchus did not interfere with airway management in any patient. A left DLT was used for 32 of 33 left pneumonectomies. At the time of bronchial resection, both

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1053-0770/03/1703-0002$30.00/0

doi:10.1016/S1053-0770(03)00046-6

Key words: thoracic surgery, double-lumen tubes, endobronchial tubes, one-lung anesthesia

Table 1. Procedures in 1,170 Patients

Rightsided	N	Leftsided	N	Bilateral and Other	N
Pneumonectomy	19	Pneumonectomy	33	Thoracotomy	4
Thoracotomy	327	Thoracotomy	243	Thoracoscopy	26
Thoracoscopy	179	Thoracoscopy	148	Sternotomy	69
Other	9	Other	27	Other	86

cuffs were deflated, and, under the guidance of the surgeon, the tube was withdrawn into the trachea. This maneuver resulted in a momentary loss of lung isolation. As soon as the left bronchus was stapled, the tracheal cuff was reinflated and ventilation resumed to the remaining right lung.

A right DLT is indicated when there is obstruction of the left bronchus or for a surgical procedure involving the proximal left main bronchus.[19] A right BronchoCath DLT was selected for 4 patients in this series when obstruction of the proximal left bronchus prevented the use of a left DLT.

In 18 patients the authors were unable to initially advance a left DLT into the left bronchus despite fiberoptic bronchoscope assistance. The usual reason was anatomic distortion of the airway, which was first noted during bronchoscopy after attempted DLT placement. These patients would have been candidates for intubation with a right DLT had the problem been recognized preoperatively. For many patients undergoing pulmonary resection for primary lung tumors, the surgeon often performs a diagnostic bronchoscopy through an ETT before placing a DLT. Potential problems because of abnormal left bronchial anatomy should be sought at the time of that bronchoscopy.

Preoperative examination of the CXR or CCT scan did not show any potential difficulty for left DLT placement in these 18 patients. Except for patients with gross deviations of the major airways, the preoperative CXR has not been shown to help predict problems with left bronchial intubation.[20]

In these 18 patients, rather than replace the DLT, the left DLT was intentionally kept in the right bronchus. Elective collapse of the right lung was planned in 15 of these 18 patients. In these patients, for OLV, the bronchial lumen of the left DLT was clamped, and the left lung was ventilated through the tracheal lumen. In 4 of these patients, during right thoracotomy, the tube was withdrawn into the trachea, the surgeon manually compressed the right bronchus, and the tube was advanced into the left main bronchus.[8]

SIZE

It is important to choose an appropriate-size DLT to avoid the complications and expense associated with a tube that is either too large or too small. The authors believe that the largest DLT that will fit the intended bronchus should be used. Smaller tubes are more likely to be advanced too deeply where they can obstruct upper-lobe ventilation or cause even more serious complications.[21] There is less resistance to gas flow and less intrinsic positive end-expiratory pressure developed during OLV through the wider lumens of larger tubes.[22] However, a DLT that is too large can injure the airway.[23]

There are 2 considerations related to tube size when selecting a DLT. The main body of the tube must pass through the glottis and advance down the trachea, and the bronchial component must be able to enter the intended bronchus. Therefore, if left bronchial width (L-BW) is known, a DLT with a bronchial lumen whose outer diameter is slightly smaller can be selected.

L-BW can be directly measured from a CXR[24] or from a CCT scan.[25-27] Spiral CCT scanning is even more accurate but requires time to reconstruct the image and the assistance of a radiologist or technician to do airway measurements.[26,27]

In adults L-BW is directly proportional to tracheal width (TW). This relationship was 0.69 in men and 0.68 in women at autopsy[28]and slightly higher (0.75 men, 0.77 women) using CCT airway reconstructions.[29]

TW is easily measured on any CXR.[30] To estimate L-BW, the authors measure TW at the level of the clavicles and multiply that value by 0.68. This formula was used in 860 patients to help select an appropriate-size left DLT (Fig 1).[31]

A smaller tube than predicted was used in 42 patients. In several the tracheal cuff was torn during intubation and only a

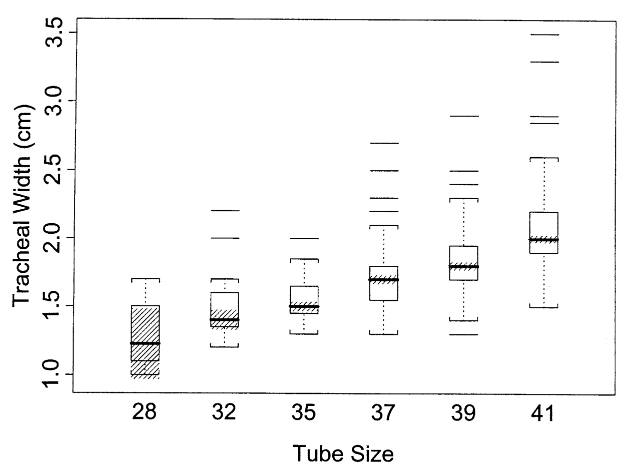

Fig 1. The optimal size left DLT is the largest tube whose bronchial lumen fits the left main bronchus with only a small air leak when its bronchial cuff is not inflated. If LB-W is known, then a left DLT whose bronchial lumen is slightly narrower than the left bronchus can be used. LB-W is directly proportional to tracheal width in adults. Tracheal width was measured from 860 patients' chest radiographs and used as a guide to select a left DLT for each patient. By multiplying measured tracheal width by 0.68, an estimated left bronchial width is obtained. A left BronchoCath DLT was then selected based on estimated LB-W. The horizontal line in the interior of each box is the median tracheal width. The height of the box is the interquartile distance, which is the difference between the third and the first quartile. The whiskers extend to a distance of 1.5 times the interquartile distance. Horizontal lines indicate outliers. Angled hatchings indicate the 95% confidence limits for the median. Nonoverlapping confidence limits indicate a significant difference in tracheal width.

smaller tube was available. In others, a small tube was intentionally chosen because of airway pathology (eg, previous tracheostomy and tracheal web).

Estimating L-BW by measuring TW was unsuccessful in selecting an appropriate-size left DLT in 25 of 843 (3.0%) patients. Almost all (23/25 patients) were women with small airways. In 16 of these patients, the next smaller-size DLT was used; in 6 patients a DLT 2 sizes smaller and in 3 patients a DLT 3 sizes smaller than predicted was successfully used.

The left bronchus is reported to be clearly visible and easily measured on fewer than 50% of CXRs.[24] The authors examined 155 CXRs and were able to measure L-BW at a point 1.0 cm below the carina in 116 (74.8%). The ratio of directly measured L-BW to directly measured TW was 0.69 ± 0.08 in both men and women, a value almost identical to the one used to estimate L-BW.

If L-BW cannot be directly measured from a CXR or CCT scan, estimated L-BW derived from measuring TW can be used to select an appropriate-size left DLT.[32] Like all anatomic relationships, the ratio of L-BW:TW is normally distributed. The authors used the lower 0.68 ratio derived from the autopsy study, rather than the higher value found with 3-dimensional CCT scans because the former will correct for a patient with a smaller-than-average left bronchus.

TRACHEAL INTUBATION

Direct laryngoscopy with a curved laryngoscope blade provides the largest area through which to pass a DLT.[33] Special laryngoscope blades can facilitate tracheal intubation in patients with abnormal anatomy.[34]

Only 1 patient in this series had a tracheostomy in situ; a 37F DLT was placed through the stoma. Despite concerns that DLTs are "difficult tubes,"[35] problems with tracheal intubation were encountered in only 35 (2.6%) of 1,169 patients (Table 2).

Three patients were assessed to have a "difficult" airway preoperatively. After induction of general anesthesia, their tracheas were electively intubated with an FOB in the bronchial lumen of the DLT.[36] In 25 other patients the trachea was successfully intubated with a DLT after several attempts at direct laryngoscopy. Four patients were intubated with an ETT. In 2 a tube exchanger was used to change to a DLT. In one a Fogarty catheter was used as a bronchial blocker, and in the other patient the ETT was advanced into the left bronchus for

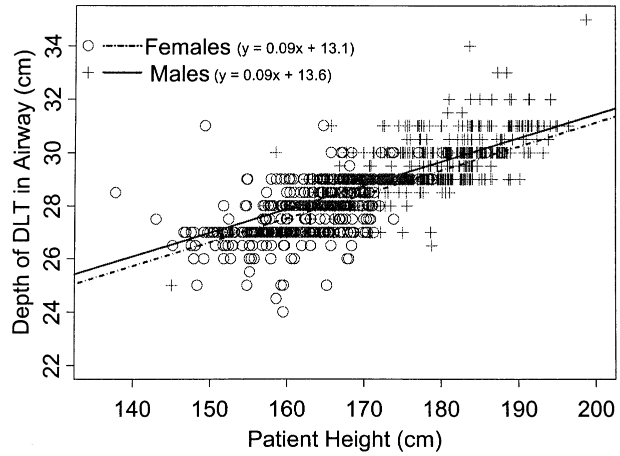

Fig 2. The figure shows the depth of insertion for left DLTs to be in "satisfactory" position in 1,156 patients. In both men and women the depth of insertion of a left DLT is directly proportional to height. The average depth of insertion is 28 to 29 cm for a 170-cm tall patient. For each 10-cm change in height, the tube is advanced or withdrawn approximately 1 cm.

OLV to the left lung. A Univent tube was used in another patient after failure to intubate the airway with a DLT.

The authors were unable to directly intubate 3 patients. In 2 a long bougie was introduced "blindly" through the vocal cords, and a DLT was advanced over it. The airway of only 1 of 1,169 patients could not be intubated. Surgery was considered urgent so a tracheostomy was performed, and a 37F left DLT was placed through the fresh surgical airway.

The cuffs of plastic DLTs are fragile and easily torn by the teeth, usually during a "difficult" laryngoscopy. In 1,169 attempted intubations the bronchial cuff was torn once and the tracheal cuff 11 times (0.9%). If a difficult intubation is anticipated, the tracheal cuff of a DLT can be protected to avoid damage.[37,38]

DEPTH

Once the tip of the DLT is past the vocal cords, the stylet is removed from the bronchial lumen. The tube is then rotated counter-clockwise and advanced down the airway. The height of each patient is always noted before the induction of anesthesia. The DLT is advanced into the airway to a depth based on the patient's height. In both men and women depth of insertion is directly proportional to height.

The common practice of advancing a DLT until moderate resistance to further passage is encountered[39,40] can result in a malpositioned tube, especially when a small tube is used.[21]

The authors' experience confirms several previous reports (Fig 2).[41,42] The average depth of left DLT placement in a 170-cm tall man or woman was 28 to 29 cm, with a change of approximately ± 1.0 cm for each 10-cm change in height.

POSITIONING

DLTs can initially be positioned with one of several techniques using auscultation and clinical signs alone ("blind" placement)[43-47] or with an FOB placed in either the bronchial or

Table 2. Difficult Tracheal Intubation

Difficult airway	No. of Patients
Multiple attempts by direct laryngoscopy (intubation with left DLT successful)	25
Intubation with an ETT	
Tube exchanger changed to DLT	2
ETT advanced into left bronchus	1
Fogarty embolectomy catheter through ETT	1
Bougie through vocal cords, DLT advanced over bougie	2
Intubated with Univent tube	1
Elective DLT intubation with fiberoptic bronchoscope	3
Failure to intubate; tracheostomy performed	1

Abbreviations: DLT, double-lumen tube; ETT, endotracheal tube.

tracheal lumen.[48-50] The authors routinely sequentially clamp each lumen and carefully auscultate each lung to position a DLT.[43]

In 847 of 1,116 (75.9%) patients, the left bronchus was intubated on the first attempt. When the left DLT entered the right bronchus, both cuffs were deflated, and the tube was withdrawn into the trachea. The patient's jaw was turned toward the left shoulder while the right ear was bent to the right shoulder.[51] The tube was then readvanced. This "headturn" maneuver was successful in 208 of the 269 patients (77.4%) in whom it was attempted (Fig 3). The initial attempt to intubate the left bronchus was always with the head and neck in the conventional neutral position. It is possible that by using the "headturn" maneuver from the start the success rate of entrance of the left bronchus might increase.

If the left bronchus could not be intubated after 3 attempts, an FOB was placed down the bronchial lumen and was used to visually guide the DLT into the left bronchus. The authors failed to intubate the left bronchus, even with FOB assistance, in 18 patients.

A recent study claimed 100% success rate (30/30 patients) of left bronchial intubation on the first attempt when the bronchial stylet was retained throughout the entire intubation sequence, compared to a 77% (23/30 patients) success rate when the stylet was removed.[52] The safety of this practice is a concern, and at least 1 anecdotal case of a left bronchial laceration after intubation with the stylet in place has been reported.[53] The authors continue to recommend that the bronchial stylet be removed before advancing a DLT down the trachea.

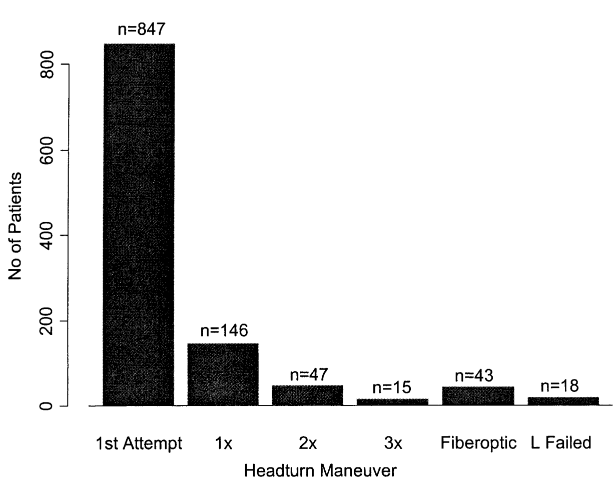

Fig 3. In 847 of 1,116 (75.9%) patients, the left bronchus was intubated directly on the first attempt. When the left DLT inadvertently entered the right bronchus the tube was withdrawn into the trachea. The patient's jaw was turned toward the left shoulder while the right ear was bent to the right shoulder ("headturn" maneuver) and the tube was readvanced. This maneuver enabled successful intubation of the left bronchus in 208 of the 269 patients (77.4%) in whom a right bronchial intubation initially occurred. If the "headturn" maneuver failed after 3 attempts, an FOB was placed down the bronchial lumen and used to visually guide the DLT into the left bronchus. Bronchoscopic assistance was successful in 43 of 61 patients (70.1%) in whom the "headturn" maneuver failed. The authors were unable to intubate the left bronchus in 18 of 1,116 (1.6%) patients.

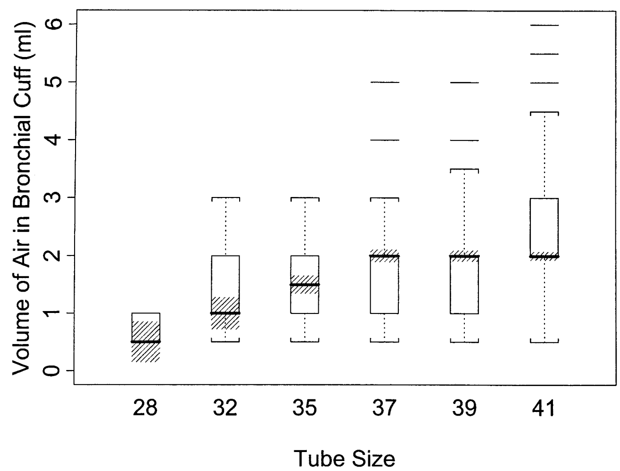

Fig 4. Less than 3 mL of air was needed to inflate the bronchial cuff in 1,037 of 1,145 (90.6%) patients. In 108 patients a larger volume of air was required. Most (88/108 patients) had large airways (average TW = 2.2 cm) and were intubated with a 41F DLT. A larger DLT would have been used had one been available. In only 20 of 643 (3.1%) patients who were intubated with size 28-39F left DLTs (BronchoCath DLT) was more than 3 mL or air necessary in the bronchial cuff to seal the airway. Box plots are coded as described in Fig 1.

Once in the left bronchus, both the bronchial and tracheal cuffs should be slowly inflated with air. The cuffs of plastic DLTs have low-pressure properties[54] but generate dangerously high pressures when overdistended.[55-57] The volume of air used in the bronchial cuff and the tension of its pilot balloon should be noted. Although cuff pressure can be accurately monitored to a "just-seal" volume,[58-61] the "feel" of the pilot balloon is relied on. The practice is to inflate the bronchial cuff until its pilot balloon feels tense.

Less than 3 mL of air was needed for most patients (Fig 4). In 108 of 1145 (9.4%) patients, a larger volume was used. Most (88 patients) had large airways (average TW = 2.2 cm) and were intubated with the largest tube (41F) available. In only 20 of 643 (3.1%) patients with smaller DLTs (sizes 28-39F) was >3 mL or air needed in the bronchial cuff.

The bronchial cuff of an appropriate-size left DLT should require 3 mL of air or less. If more air is needed to seal the airway, the cuff is probably (partially) in the trachea and the tube should be advanced further into the bronchus.

CONFIRMATION OF POSITION

The position of a DLT can change at any time.[62] Correct tube position must always be confirmed before the start of surgery. Auscultation and observation of chest wall movement are used, as well as measure of peak inspiratory pressures during independent ventilation of each lung before turning the patient to the usual lateral position for thoracotomy.

After turning the patient the lungs are again auscultated. Then each lumen is sequentially clamped while ventilating each lung with the same tidal volume. This should produce similar waveforms and peak inspiratory pressures if both lungs have relatively equal volumes and the tube is in satisfactory position.

If there is an unexpected difference in waveform and inspiratory pressures between the 2 lungs, tube position is further evaluated. If the peak inspiratory pressure is significantly higher with the right lumen clamped while ventilating the left lung, the tube is considered too deep. This scenario occurs if the left upper lobe is partially obstructed and only the left lower lobe is being ventilated. The tube is withdrawn in 0.5-cm increments until the pressures are equal. If the peak inspiratory pressure is higher with the left lumen clamped while ventilating through the right lumen, the tube is considered not deep enough. In this situation the bronchial cuff may be partially in the trachea where it will obstruct ventilation to the right lung so the left DLT is advanced in 0.5-cm increments further into the bronchus. An FOB can be useful in these situations to help reposition the DLT.

Immediately after intubation and while the patient is still supine, the volume of air required to inflate the bronchial cuff and the tension of the pilot balloon to the bronchial cuff are noted.[63] Unless immediate and complete isolation of the lungs is required (eg, in the presence of an empyema), the bronchial cuff is sometimes deflated before turning the patient to the lateral position. Then, after turning the initial volume of air is used to reinflate the bronchial cuff. Normal practice is to leave the bronchial cuff inflated even when turning the patient.

The direction of DLT movement during lateral positioning is almost always out of the bronchus,[64] so any subsequent decrease in pilot balloon tension with the same volume of air suggests that the bronchial cuff is no longer completely in the bronchus.[65] Small decreases in tension often occur after turning, and in most instances slight readvancement of the tube results in a return to the initial tension. In 9 patients the degree of tube dislodgement was greater. Both cuffs were deflated, and the tubes were readvanced to their original depth.

Although dual capnography,[66,67] continuous spirometry,[68,69] and a CXR and fluoroscopy are occasionally recommended, bronchoscopy is by far the most widely used adjunct for confirming DLT position.[70,71] An FOB is first advanced down the tracheal lumen. There should be an unobstructed view of the tube entering the appropriate bronchus. The FOB is then passed down the bronchial lumen to ensure lumen patency and to verify that the upper-lobe orifice is not obstructed. The "margin of safety" is greater with intubation of the left bronchus because of its significantly greater length than the right main bronchus.[11]

Many anesthesiologists rely on FOBs to provide visual confirmation of DLT position. Many support[72-75] and others (including the authors) oppose[3,65,76-80] the mandate to always use an FOB to confirm DLT position. The authors find bronchoscopy unnecessary in the majority of patients and do not use it routinely. The decision as to whether to use bronchoscopy, capnography, or another adjunct routinely to confirm left DLT placement is controversial and remains an individual decision. If one technique were universally accepted, there would be no ongoing controversy as to whether to use it.

An FOB was used in 58 patients, often as an aid to cannulate the left bronchus (43 patients) when other attempts failed. However, bronchoscopy is definitely needed to confirm DLT position when absolute lung isolation is essential (eg, lung lavage) and when breath sounds are too distant (eg, lung volume reduction surgery procedures) to hear clearly.

IDEAL VERSUS SATISFACTORY POSITION

Several studies report a high incidence of DLT malposition in the absence of bronchoscopic confirmation.[81-85] These studies generally consider a tube to be malpositioned if it is not in ideal position (ie, if the proximal edge of the bronchial cuff is not immediately below the carina in the appropriate bronchus).[81]

Because a DLT is usually displaced proximally when turning the patient, others believe that the proximal border of the bronchial cuff should not be immediately below the carina but at least 0.5 to 1.0 cm deeper in the bronchus to reduce the risk of displacement into the trachea.[86]

The authors' goal is for a DLT to be in satisfactory position. The DLT should be in the appropriate bronchus, selective lung collapse and effective and safe isolation of the lungs should be easily achieved, and a decrease in oxygenation during OLV should not occur because of tube malposition. A tube in satisfactory position functions without problems but would be considered "malpositioned" if its bronchial cuff was not immediately below the carina.[87]

Using auscultation and clinical signs, there were 71 patients (6.2%) in this series in whom the DLT was not in satisfactory position and required readjustment after initial placement.

In 15 patients the tube needed to be advanced further. In several the problem was recognized by a leak or failure to collapse the right lung during OLV to the left lung. High peak inspiratory pressure because of partial obstruction by the bronchial cuff of ventilation through the tracheal lumen during OLV to the right lung was another presenting sign.

In 56 patients the DLT was too deep in the left bronchus. In 21 of these 56 patients, hypoxemia occurred during OLV to the left lung (see below). In 16 patients peak inspiratory pressure was noted to be high at the initiation of OLV to the left lung suggesting ventilation to just the left lower lobe. In 4 patients the left upper lobe did not collapse when the (left) bronchial lumen was clamped indicating that the bronchial cuff was below the takeoff of the left upper-lobe bronchus.[5] In 2 patients undergoing left thoracotomy the left upper lobe was collapsed prior to initiating OLV because the bronchial cuff was obstructing the left upper-lobe bronchus.[3] The presentation for the remaining patients included unilateral wheezing and marked differences in breath sounds during bilateral auscultation.

In all 56 patients, both cuffs were deflated and the tube was withdrawn in 0.5-cm increments. In 17 patients pulling the tube back only 0.5 cm corrected the problem. The DLT needed to be withdrawn 1.0 cm in 24 patients, 1.5 to 2.0 cm in 9 patients, and 3.0 cm in 7 patients. In 5 others the distance the DLT was withdrawn was not recorded.

Using an FOB might have initially avoided these problems. However, no method of tube placement, including FOB, is foolproof. In a study that compared FOB DLT placement with auscultation and clinical signs, there were almost equal success (and failure) rates.[83] The occurrence of position complications was not correlated with the use of an FOB during intubation. When blind placement alone was used, the overall incidence of complications was 16 of 119 (13%); and when an FOB was used, the incidence of problems was actually slightly higher

Table 3. Hypoxemia During One-lung Ventilation

Procedure	S_pO_2	Corrective Intervention
R thoracotomy-wedge resection	93	Advanced DLT
L thoracoscopy-lung biopsy	75	Increased tidal volume (OLV)
L thoracotomy-wedge resection	90	Increased tidal volume (OLV)
R thoracotomy-wedge resection	88	Withdrew DLT 1 cm
R thoracotomy-wedge resection	91	Withdrew DLT 1 cm
BIL thoracoscopy-LVRS	88	Increased blood pressure
BIL thoracoscopy-LVRS	88	Increased tidal volume (OLV)
Sternotomy-resect mass	88	Patient supine/withdrew DLT 1 cm
Sternotomy-bilateral tumor resections	89	Patient supine
R thoracotomy-lobectomy	80	Withdrew DLT 1 cm
R thoracoscopy-wedge resection	80	Withdrew DLT 1 cm
R thoracotomy-lobectomy	86	Increased tidal volume (OLV)
R thoracotomy-lobectomy	92	Withdrew DLT 0.5 cm
R thoracoscopy-wedge resection	83	Withdrew DLT 2.0 cm
Sternotomy-resect mass	88	Patient Supine
R thoracotomy-wedge resections	90	No correction-poor pulmonary function
R pneumonectomy	88	Withdrew DLT 1.5 cm
R thoracotomy-esophagogastrectomy	92	Increased tidal volume (OLV)
R thoracotomy-wedge resections	83	Withdrew DLT 1 cm
R thoracoscopy-wedge resection	90	Withdrew DLT 1 cm
Sternotomy-resect mass	92	Increased tidal volume (OLV)
R thoracoscopy-wedge resection	90	Withdrew DLT 0.5 cm
R thoracotomy-lung biopsy	91	Withdrew DLT 1 cm
R thoracoscopy-wedge resection	92	Withdrew DLT 1 cm
R thoracoscopy-wedge resections	94	Withdrew DLT 2 cm
R thoracotomy-lobectomy	88	Withdrew DLT 2 cm
R thoracotomy-lobectomy	90	Bronchodilator treatment
R thoracotomy-bilobectomy	93	Withdrew DLT 0.5 cm
R thoracotomy-lobectomy	90	Withdrew DLT 0.5 cm
R thoracotomy-bilobectomy	94	Withdrew DLT 2 cm
R thoracoscopy-biopsy	92	Withdrew DLT 0.5 cm patient supine
Sternotomy-thymectomy	N/A	Increased tidal volume (OLV)
R thoracotomy-biopsy	N/A	Increased tidal volume (OLV)
R thoracotomy-esophagogastrectomy	N/A	Withdrew DLT 0.5 cm
R thoracotomy-lobectomy	N/A	Withdrew DLT 1.5 cm

NOTE. Many patients were initially treated with CPAP to the nonventilated lung while the cause of hypoxemia was sought and corrected. Abbreviations: OLV, one-lung ventilation; S_pO_2, lowest oxyhemoglobin saturation during OLV; N/A, S_pO_2 not noted.

(25/115, 21%). Using auscultation and clinical signs alone, there were only 71 patients (6%) in whom the tube was not in a satisfactory position after initial placement.

HYPOXEMIA DURING OLV

The authors' practice is to ventilate the lungs with 100% oxygen during both two-lung ventilation and OLV. The patient's lungs are initially ventilated with a tidal volume of 12 mL/kg. After conversion to OLV, the tidal volume is left unchanged and the respiratory rate is adjusted to maintain carbon dioxide within the physiologic range. In general, a peak inspiratory pressure of <40 cm H_2O during OLV is usually acceptable. However, each patient must be considered individually. For example, for patients with bullous pulmonary disease, a smaller tidal volume and peak inspiratory pressure may be indicated to avoid intraoperative rupture of a bleb, which could cause a tension pneumothorax in the ventilated lung.

In this experience, with these ventilatory parameters, hypoxemia is uncommon during OLV. Oxygen saturation as measured by pulse oximetry $<90\%$ has been considered a critical minimal level during OLV.[88] Only 14 (1%) patients experienced this degree of desaturation. For the purpose of analysis, an oxygen saturation as measured by pulse oximetry $<94\%$ was defined as hypoxemia. Using this definition, 35 of 1170 (3.0%) patients undergoing OLV during a variety of thoracic surgical procedures experienced hypoxemia (Table 3). The majority (21/35 patients) underwent a right-sided procedure with the right lung collapsed, with OLV through a left DLT. First suctioning the bronchial lumen and then withdrawing the DLT in 0.5-cm increments to relieve obstruction of the left upper lobe corrected hypoxemia occurring during a right-sided procedure with a left DLT.

A malpositioned left DLT in the operated (left) lung was not implicated in any instance of hypoxemia because the left lung was intentionally collapsed. The only 2 cases of hypoxemia during a left-sided procedure each responded to increasing the tidal volume during OLV.

Several patients undergoing sternotomy experienced hypoxemia because of the increased shunt that occurs in the supine position compared with the lateral position during OLV.[89]

POSTOPERATIVE CONSIDERATIONS

If tracheal intubation at the start of the procedure was not difficult and if postoperative ventilation is required, the authors' practice is to change the DLT to an ETT by direct laryngoscopy after the patient is returned to the supine position at the completion of surgery. Less than 1% of patients required mechanical ventilation after surgery.

Replacing the DLT with a single-lumen ETT can be challenging if the initial intubation was difficult or even hazardous if airway edema has developed during the procedure. In only 1 patient, a man who required multiple attempts at tracheal intubation before surgery, the DLT was changed to an ETT using a tube changer.[90,91]

The DLT can also be retained for postoperative ventilation. The effective diameter of each lumen of an adult plastic DLT is comparable to a 6.0- to 7.0-mm outside diameter ETT.[92] In many instances there is no advantage replacing a DLT with an ETT because flow resistance during mechanical ventilation is about the same through either tube.[93]

COMPLICATIONS

Airway trauma from a plastic DLT is uncommon.[94] The most serious injury, tracheobronchial rupture, is usually caused by overinflation of one of the cuffs.[95,96] Airway rupture has also been reported with small volumes of air.[97,98] If nitrous oxide is used, both cuffs must be deflated periodically to avoid excessive pressure buildup. To reduce the chance of injury, many deflate the bronchial cuff before turning the patient[99] and during surgery whenever lung separation is not needed.[100] However, turning the patient with the bronchial cuff inflated has never been implicated in any instance of tracheobronchial rupture.[94] Because a DLT can directly injure the airway during insertion,[101] a warm water bath to soften the DLT has also been used.[102]

The usual site of airway injury is in the membranous wall of the distal trachea or main bronchus. If an injury is suspected, the airway should be immediately examined with an FOB. Early recognition and surgical intervention are essential for a favorable prognosis.[103,104]

There were no serious airway injuries in this series. One patient had blood in her trachea after 3 attempts at laryngoscopy and tracheal intubation. Diagnostic bronchoscopy was essentially negative, and the operation proceeded without sequelae. The only injury possibly attributed to a DLT was in a patient with leukemia. She complained of hoarseness 2 weeks after thoracotomy. A granuloma was noted at the back of her throat, which may have been a result of unrecognized trauma at intubation.

There was 1 intraoperative death from tumor embolism during right pneumonectomy. One patient had significant gastric aspiration during intubation and required postoperative ventilation.

CONCLUSIONS

Based on the data from this large clinical series, the authors propose the following scheme for placement of left DLTs.

A left DLT can be used for most general thoracic procedures, including left pneumonectomy. The "margin of safety" is greater when a left DLT is used.

Each patient's CXR or CCT scan should be examined preoperatively. Direct measurement of L-BW or estimation of L-BW by measuring TW at the level of the clavicles can then be performed to select an appropriate-size DLT.

After tracheal intubation, the DLT should be advanced into the airway to a depth based on the patient's height. The bronchial cuff of an appropriate-size DLT should require <3 mL of air. When more air is needed, especially if a smaller DLT is used, the bronchial cuff is most likely partially in the trachea and should be advanced further into the bronchus.

The position of the DLT must be confirmed while the patient is supine and once again after the patient is turned to the lateral position. FOB is the most common adjunct used to confirm DLT in this country. Every anesthesiologist who uses a DLT should be familiar with bronchoscopy for DLT placement. It is also essential for every anesthesiologist to know how to place a DLT using clinical signs alone.[105] In many settings, an appropriate-size FOB may not be available, particularly for the very small (26F-32F) DLTs used for children. Even when an FOB is being used, the presence of blood and secretions may make visual confirmation of DLT position difficult or impossible.

This article reviews a large clinical experience and, as such, reflects the authors' personal biases. On a busy thoracic surgical service, for the majority of their patients, the authors place left DLTs using auscultation and clinical signs alone. For the many anesthesiologists who occasionally use a DLT in their practice, adjuncts such as FOB are extremely helpful and should be used. However, as more confidence and experience are gained, there are fewer and fewer instances when an FOB is needed.

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