SPECIAL ARTICLE

Airway Rupture From Double-Lumen Tubes

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A DOUBLE-CUFFED double-lumen endobronchial tube (DLT) was used for the first time during thoracic surgery almost 50 years ago to isolate and selectively ventilate the lungs. The benefits of DLTs in terms of improved surgical exposure and their ability to isolate and protect the lungs during thoracic operations are now widely recognized.

Although DLTs are safe and easy to use, complications occur. Table 1 lists the complications associated with DLTs. The most common problems involve tube placement. Rarely, the trachea or bronchus is injured, and even then, trauma to the airway is usually minor, resulting in laryngitis or tracheal irritation.

More serious airway damage was a recognized complication of the original red rubber (RR) DLTs. When the softer plastic polyvinylchloride (PVC) DLTs were introduced in the early 1980s, it was initially believed that these tubes were safer than RR tubes.[1,2] However, reports of airway injury from PVC DLTs soon appeared.

The medical literature on airway disruption with DLTs was reviewed to try to identify factors associated with this potentially devastating complication.

METHODS

After a computer literature search, 33 reports were identified, published between 1972 to 1998, of tracheobronchial rupture from DLTs. There were 20 reports involving 32 patients with RR DLTs[3-22] and 13 reports of 14 patients with PVC DLTs.[23-35] For foreign language publications, whenever possible, the original article was translated into English and one of the investigators was contacted for additional information. Reports were reviewed from the United States, the United Kingdom, Japan, France, Germany, and Switzerland.

Information, recorded for each patient, is listed in Table 2. Data included age and sex, material, type and size of the DLT, comments on problems with positioning the tube, type of surgery, use of nitrous oxide during surgery, volume of air used to inflate the tracheal and bronchial cuffs, and any other pertinent factors. The site, extent and outcome of injury, and the investigators' postulated cause for the injury were also noted. For some patients, several possible causes were suggested, and all were included in this analysis.

Because of incomplete original reports, complete data were not available for every patient. In four reports, two of RR[9,11] and two of PVC[25,33] DLTs, no cause of the airway injury was apparent. Because this is a retrospective review, only presumed associations and risk factors are discussed.

RESULTS

Table 3 lists the data from the individual case reports of airway disruption with RR and PVC DLTs.

Airway trauma during intubation and/or carinal hook injury occurred with about equal frequency for both types of tubes. However, only with RR tubes were tube-tip irregularities cited as a possible cause. Injury from the tip of the RR tube was considered the cause in 6 of 32 patients (18%). A carinal hook, if present, can also injure the upper airway. Hook laceration of the airway occurred in 3 of 32 patients (9%) with RR tubes. The carinal hook was implicated as the cause of injury in both cases in which a PVC DLT with a carinal hook was used.

With four patients with RR tubes (12%), intubation trauma was listed as the cause of injury. One of these patients had invasive cancer of the trachea and another received steroids. In two patients with PVC DLTs (14%), trauma to the bronchus was also noted during intubation. In 2 of the 32 RR cases (6%), movement of the tube, presumably with both cuffs inflated during positioning, was noted as a possible cause.

Asymmetric cuff inflation was considered a factor in 2 of 32 cases (6%) of RR tube injuries. This is not a problem with PVC DLTs.

Initial overinflation of either the bronchial or tracheal cuff at the time of tube placement may have accounted for the greatest number of injuries with RR DLTs. Initial cuff overinflation was probably involved in 16 of 32 patients (50%) with RR DLT injuries. Subsequent cuff distention by nitrous oxide may have occurred in four more patients (12%) with RR DLT injuries. Therefore, almost two thirds of the airway damage from RR tubes was most likely caused by bronchial or tracheal cuff pressure damage to the airway.

For only one patient (7%) in the PVC DLT group was initial overinflation of the cuff suggested as the cause of injury. The most frequently cited factor with PVC DLT injuries (6 of 14 cases; 42%) was believed to be cuff distention because of nitrous oxide. High pressure from either the bronchial or tracheal cuff was the presumptive cause of injury in almost half the PVC group. Four bronchial and two tracheal injuries were believed to be caused by nitrous oxide distention.

The bronchus was the most frequent site of injury with both RR and PVC DLTs (RR tubes, 18 of 32; 56%; PVC tubes, 8 of 14; 57%). The trachea was injured in 10 of 32 RR cases (31%) and 5 of 14 PVC cases (36%). Extensive injury to both the trachea and bronchus occurred in 4 of 32 RR (13%) and 1 of 14 PVC (7%) cases.

Large- and medium-sized tubes were associated with most

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Table 1. Complications of Double-Lumen Tubes

Intubation
Carinal hook unable to pass through glottis (Carlens or White DLTS)
Unable to advance tube into bronchus
Tube too large
Intrinsic or extrinsic airway obstruction
Positioning
Tube not far enough into bronchus
Herniation of bronchial cuff into carina
Unable to ventilate nonintubated lung when both cuffs inflated
Tube down wrong bronchus
Tube too deep in correct bronchus
Upper lobe obstructed
Failure to collapse upper lobe of intubated lung
Contamination of healthy lung, failure of bronchial cuff
Position of tube changes during surgery
Surgical manipulation
Movement of patient to decubitus position
Head flexion or extension
Inadequately taped or secured
Bronchial lumen interferes with procedure
Pneumonectomy
Carinal surgery
Lung transplant
Trauma
Dental injury
Airway injury
Laryngitis
Airway mucosal wall injury
Arytenoid dislocation
Tracheobronchial rupture
Hypoxemia
Malpositioned double-lumen tube
Upper lobe collapse on nonoperated lung
Carinal obstruction
Torsion of lumen against bronchial wall
Carlens tip bent back, obstructing the tracheal opening
Rupture of thoracic aneurysm
Displacement of mediastinal mass
Bronchial lumen sutured to pulmonary vessel
Hemorrhage on attempted extubation

RR DLT injuries. A small RR DLT was involved in 7 of 32 injuries (22%), a medium RR DLT in 9 of 32 injuries (28%), and a large RR tube in 15 of 32 injuries (47%). In one RR case report, the size of the RR DLT was not given. In contrast, the majority of airway injuries with PVC DLTs occurred with smaller size tubes. In 5 of 14 cases (36%), a 35F tube was used, and in 3 of 14 cases (21%), a 37F tube. In 3 of 14 cases (21%), a 39F PVC DLT was used. No 41F PVC DLT was associated with a major airway injury. In two case reports, the size of the PVC tube was not given.

Injuries to men were slightly more common with RR tubes; for PVC tubes, all but one of the patients were women.

Although airway rupture has occurred during all types of pulmonary surgery for both RR and PVC DLTs, the most frequently reported surgery associated with such injury was surgery on the esophagus. In 9 of 32 patients (28%) with RR tubes and 5 of 14 patients (36%) with PVC DLTs, an esophageal procedure was performed.

Five of 32 patients (16%) with RR tube airway rupture and 1 of 14 patients (7%) with a PVC DLT died of their injuries.

DISCUSSION

Types of DLTs

Carlens[36] introduced the first DLT into clinical practice in 1949. That tube was intended for differential bronchospirometry. Bjork and Carlens[37] used the same tube, now known as the Carlens tube, the following year to isolate the lungs during pulmonary surgery for infection.

The Carlens tube was intended for intubation of only the left bronchus. White[38] introduced a similar tube for the right bronchus. Both the Carlens and White tubes have a hook to engage the carina to aid positioning. Bryce-Smith[39] designed a left DLT without a carinal hook. A similar tube for right bronchial intubation was described by Bryce-Smith and Salt.[40] The size and shape of the lumen of the Bryce-Smith tubes facilitated easier passage of a suction catheter than the Carlens and White tubes.

The Robertshaw DLT has no carinal hook and has a gentler curve with thinner walls and larger internal lumens than these other rubber DLTs.[41] Robertshaw DLTs are available in both left and right models.

The reusable Carlens, White, Bryce-Smith, and Robertshaw DLTs are constructed of thick RR material. Modern PVC plastic DLTs resemble the Robertshaw tube in basic design but are intended for single use only.

Four different PVC DLTs are sold in the United States. They are the BronchoCath DLT (Mallinckrodt Medical, Inc, St Louis, MO), the Rusch (Rusch, Duluth, GA), the Sher-I-Bronch (Sheridan, Argyle, NY), and the Portex (Portex, Keene, NH) tubes.[42] Each comes in four adult sizes (35F, 37F, 39F, and 41F) in both right-sided and left-sided models. A 32F BronchoCath DLT is now also available for small adults and larger children.[43] Mallinckrodt and Rusch also offer the option of a Carlens-style plastic DLT with a carinal hook.[44]

All four of the commercially available PVC DLTs are similar in basic design, but differ slightly in the dimensions of their tracheal and bronchial components.[45] The shape and physical properties of their bronchial and tracheal cuffs differ significantly for each of the four tubes.[45-47]

Compared with equivalent-sized RR DLTs, PVC DLTs have thinner walls and thus significantly larger internal lumens relative to their external diameter. Suction catheters and fiberoptic broncoscopes (FOBs) pass more easily down their lumens. During one-lung ventilation, there is less resistance to airflow with plastic DLTs.

Airway Rupture

The actual incidence of airway damage from DLTs is certainly underreported. Assuming that the published reports are representative of the cases that occur, Table 4 lists the factors that appear to be associated with this complication.

Although many of the causes are similar, the cause of injuries can differ depending on whether an RR or a PVC DLT is used.

Tube placement. Although PVC DLTs are used almost exclusively in this country, RR DLTs are still used in many parts of the world. The economic advantage of RR DLTs is that they

Table 2. Airway Rupture From Double-Lumen Tubes

Reference	Age (y)	Sex	Side	Tube	Operation	Site of Injury	Vol	N_2O	Outcome	Comments
Airway rupture with RR DLTS										
Holden[3] (1972)	54	M	LT	L-RS	RUL Lobectomy	L Bronchus	5-7	?	Survived	Asymmetric bronchial cuff distention, overinflation
Bisson[4] (1976)	54	M	LT	L-C	R Pneumonectomy	L Bronchus	?	?	Survived	Overinflated bronchial cuff
Favre[5] (1976)	53	M	LT	L-C	L Thoracotomy	L Bronchus, trachea	?	?	Died	Intubation trauma, invasive cancer in trachea
Borm[6] (1977)	50	F	LT	M-C	RLL Lobectomy	L Bronchus	?	Yes	Survived	Overinflation bronchial cuff and N_2O distention
Borm[6]	68	M	LT	L-C	RML Lobectomy	L Bronchus, trachea	?	Yes	Survived	Overinflation bronchial cuff and N_2O distention
Schapes[7] (1978)	40	M	RT	L-W	LUL Lobectomy	Trachea	10	?	Survived	Carinal hook injury
Bricard[8] (1979)	63	M	LT	M-C	LLL Lobectomy	Trachea	?	?	Survived	Tube tip trauma
Guernelli[9] (1979)	57	M	LT	L-C	Esophagectomy	L Bronchus	?	?	Died	Tube tip trauma
Guernelli[9]	23	F	LT	L-C	RUL Lobectomy	R Bronchus, trachea	?	?	Survived	Tube trauma, intubation wrong bronchus
Guernelli[9]	54	M	LT	L-C	R Pneumonectomy	L Bronchus	?	?	Survived	
Guernelli[9]	63	F	LT	L-C	R Pneumonectomy	Trachea	?	?	Survived	Tracheomalacia
Guernelli[9]	70	F	LT	L-C	R Pneumonectomy	Trachea	?	?	Survived	Tube tip trauma
Heiser[10] (1979)	51	M	LT	L-RS	RUL Lobectomy	L Bronchus	?	No	Survived	Asymmetric bronchial cuff inflation, movement during positioning
Lafont[11] (1981)	65	F	LT	S-C	R Thoractotomy	Trachea	?	?	Survived	
Hentz[12] (1981)	38	M	LT	M-C		L Bronchus	5	?	Survived	Position change with bronchial cuff inflated
Hansen[13] (1983)	68	M	LT	M-C	RML, RUL Bilobectomy	L Bronchus	?	No	Survived	Tube tip trauma or overinflated bronchial cuff
Foster[14] (1983)	78	M	RT	L-W	L Pneumonectomy	R Bronchus	2.5	Yes	Died	N_2O cuff distention
Personne[15] (1987)	52	M	LT	L-C	Esophagectomy	L Bronchus	?	?	Survived	Overinflated bronchial cuff
Personne[15]	64	M	LT	L-C	R Pneumonectomy	L Bronchus	?	?	Survived	Overinflated bronchial cuff
Personne[15]	70	F	LT	S-C	LLL Lobectomy	L Bronchus, trachea	?	?	Survived	Overinflated bronchial cuff, possible intubation trauma
Personne[15]	50	M	LT	M-C	L Pneumonectomy	Trachea	?	?	Survived	Overinflated tracheal cuff
Roxburgh[16] (1987)	67	M	LT	L-RS	Esophagogastrectomy	L Bronchus	?	?	Survived	Overinflated bronchial cuff
Roxburgh[16]	78	F	LT	?-RS	Esophagectomy	L Bronchus	?	?	Survived	Tube tip trauma
Ortolo[17] (1988)	73	M	LT	M-C	RML, RUL Bilobectomy	L Bronchus	?	Yes	Survived	Overinflated bronchial cuff, too rapid inflation, asymmetric
Vieritz[18] (1990)	51	F	LT	S-C	R Thoracotomy	Trachea	?	?	Survived	Carinal Hook injury
Boulanger[19] (1994)	65	F	LT	M-C	Esophageal surgery	L Bronchus	?	Yes	Survived	Intubation trauma, patient on steroids
Massard[20] (1996)	41	M	LT	?-RS	Esophagectomy	L Bronchus	?	?	Survived	Overinflated bronchial cuff or positioning trauma
Brusset[21] (1996)	70	F	LT	M-C	Thoracoscopy	R Bronchus	?	?	Survived	Intubation trauma, overinflated bronchial cuff
Kaloud[22] (1997)	61	F	LT	S-RS	Lobectomy	Trachea	?	Yes	Died	Overinflated bronchial cuff and N_2O cuff distention
Kaloud[22]	43	F	LT	S-RS	Esophagectomy	L Bronchus	?	?	Survived	Overinflated bronchial cuff, esophageal surgery
Kaloud[22]	61	M	LT	M-C	Esophagectomy	Trachea	?	?	Died	Overinflated tracheal cuff, hook trauma, esophageal surgery
Kaloud[22]	45	F	LT	S-C	Esophageal surgery	Trachea	?	?	Survived	Hook trauma, esophageal surgery
Airway rupture with PVC DLTS										
Burton[23] (1983)	72	F	LT		Esophagectomy, RUL lobectomy	L Bronchus	2	Yes	Survived	N_2O Cuff distention tracheal cuff, 5 mL removed
Wagner[24] (1985)	59	F	LT	39	RUL, RML Bilobectomy	R Bronchus, trachea	2	No	Survived	Initial R bronchus, trauma during repositioning
Nomoto[25] (1987)	72	F	LT	35	RLL Lobectomy	Carina, trachea	?	?	Survived	
Nakamura[26] (1989)	58	M	LT	39	Esophagectomy	L Bronchus	?	Yes	Survived	N_2O cuff distention
Hannallah[27] (1989)	79	F	LT	35	RUL Lobectomy	L Bronchus	1	No	Survived	Tube too large; tube readvanced twice (FOB)
Hatta[28] (1991)	68	F	LT	37	RUL Lobectomy	L Bronchus	?	Yes	Survived	Tube too small
Joos[29] (1991)	52	F	LT	37-CS	RLL Lobectomy	L Bronchus	?	No	Survived	Moving patient, carinal hook trauma
Peden[30] (1992)	50	F	LT	35	Esophageal surgery	L Bronchus	5	Yes	Survived	Overinflated bronchial cuff, N_2O distention, 7 mL removed
Hasan[31] (1992)	72	F	RT	37	Esophagogastrectomy	Trachea	?	Yes	Died	N_2O distention tracheal cuff
Hasan[31]	47	F	RT	39	L Pneumonectomy	Trachea	?	Yes	Survived	Trauma during repositioning, N_2O cuff distention
Horie[32] (1994)	58	F	LT	35	RUL Lobectomy	Trachea	?	Yes	Survived	
Kelm[33] (1994)	75	F	LT	39-CS	Thoracotomy	Trachea	?	?	Survived	Cuff overdistention or carinal hook injury
Kinugasa[34] (1996)	59	F	LT		R Pneumonectomy	L Bronchus	?	?	Survived	Intubation trauma
Sakuragi[35] (1997)	76	F	LT	35	Esophagogastrectomy	L Bronchus	2	Yes	Survived	Intubation trauma, too deep; tube too large N_2O cuff distention

Abbreviations: S, small; M, medium; L, large RR DLT; C, Carlens; W, White; RS, Robertshaw; LT, left DLT; RT, right DLT; CS, Carlens style PVC DLT with carinal hook; RR, red rubber; DLT, double-lumen tube; PVC, polyvinylchloride; RUL, right upper lobe; R, right; L, left; RLL, right lower lobe; LUL, left upper lobe; RML, right middle lobe; LLL, left lower lobe; N_2O, nitrous oxide; FOB, fiberoptic bronchoscope; vol, volume of cuff.

Table 3. Airway Rupture From DLTS

	RR DLT	PVC DLT	
No. of patients			
Men	19		1
Women	13		13
Tube			
Carlens/White	25		2
Robertshaw	7		12
Size			
Small	7	35F	5
Medium	9	37F	3
Large	15	39F	4
		41F	0
No size given	1		2
Left side	30		12
Right side	2		2
Site of injury			
Bronchus	18		8
Carina or trachea	10		5
Bronchus and trachea	4		1
Cuff			
Initially overinflated	12		1
Too rapid inflation	1		0
N_2O distention	4		6
Asymmetric inflation	3		0
Intubation			
Intubation trauma	4		2
Tube tip trauma	6		0
Carinal hook trauma	3		2
Other			
Tube movement	3		3
Tracheomalacia	1		0
Invasive cancer	1		0
Steroids	1		0
Tube too large	0		2
Tube too small	0		1
Type of surgery			
Right thoracotomy	14		8
Left thoracotomy	7		1
Esophageal surgery	9		5
No side noted	2		1

are reusable.[48] However, this means that RR DLTs must be resterilized and repackaged between uses. This process can fray the rubber material. Irregularities of the tube tip's leading edge after frequent reuse can damage the airway. This factor is unique to RR DLTs.

The RR material is also more rigid than PVC material. Airway injury is more likely if RR tubes are inserted forcefully during the intubation process, especially when the airway tissue is unhealthy and/or the tip of the tube is damaged.

Stylet. Although PVC DLT manufacturers recommend removal of the bronchial lumen stylet as soon as the tip of the tube passes the vocal cords, a stylet has never been implicated in any case report of major airway trauma from a DLT.

One report actually recommends retaining the stylet throughout the entire DLT placement sequence to facilitate intubation of the appropriate bronchus.[49] Evidence that the stylet is safe is limited to this one relatively small series.

Positioning. Difficulty positioning the DLT is another factor often implicated in airway rupture. Movement while repositioning the tube, especially if both cuffs are inflated, increases the chance of mucosal trauma. Likewise, the cuffs should be deflated when turning the patient to the lateral decubitus position before the start of surgery.

Several adjuncts are helpful for placing or confirming DLT position. These include dual capnography,[50] spirometry,[51] and even obtaining a chest radiograph after tube placement. These methods are usually not practical in the routine clinical setting.

The most popular means of placing or reconfirming the position of a DLT is with an FOB. Many studies have reported that a DLT may not be in ideal position when auscultation and clinical signs alone are used to position the tube.[52-56] Ideal position is usually defined in studies as viewing the blue proximal edge of the inflated bronchial cuff immediately below the carina in the appropriate bronchus.

With care and attention in placing tubes, most DLTs will be in satisfactory position and will function appropriately without bronchoscopy.[57] The authors believe a DLT is best positioned with the proximal edge of the bronchial cuff at least 0.5 cm below the carina in the bronchus. Because changes in tube position often occur during surgery, especially when turning the patient on their side,[58] a DLT that is a little deeper in the bronchus will still be in place after moving the patient.[59] The studies advocating use of an FOB to position a DLT would consider such a tube improperly positioned, when in fact that tube would function quite well.[56]

It is unknown in how many cases of airway rupture an FOB was used to position the DLT. Likewise, there is no evidence from the reported cases as to whether an FOB would have reduced the risk for airway trauma.

Cuff distention. The cuffs of RR DLTs have low volume/high pressure characteristics.[60] The bronchial cuff of an RR DLT will inflate asymmetrically after multiple uses. Asymmetric inflation of the bronchial cuff can force the tip of the tube into the airway and/or will produce dangerously high pressures on that area of the airway wall in contact with the cuff.

Overdistention of either the bronchial or tracheal cuff is the most frequent factor cited as the cause of airway rupture for both RR and PVC DLTs. Both cuffs of PVC DLTs have high

Table 4. Risk Factors for Airway Rupture

- Direct trauma
  - Too forceful insertion
  - Frayed tube tip (RR DLTS only)
  - Tube too large for bronchus
  - Tube advanced with stylet in place?
  - Movement of the tube with cuffs inflated
  - Carinal hook damages upper airway
- Cuff overinflation
  - Too rapid inflation
  - Too large a volume
  - Small tube requires larger volume
  - Nitrous oxide distention
  - Asymmetric cuff distention, pushes tip into airway wall (RR DLTS)
- Preexisting airway pathological disease
  - Congenital airway wall abnormalities
  - Airway wall weakness from tumor infiltration or infection
  - Airway distortion from mediastinal lymph node or intrabronchial and extrabronchial tumors
  - Patients receiving steroids, leukemia, lymphoma
  - Hypotension with hypoperfusion to the airway

volume/low pressure characteristics, but develop dangerously high pressures when overinflated.[61,62]

The single case in which the bronchial cuff of a PVC tube was overinflated at the start of the procedure was the very first case report of airway injury with a PVC DLT.[23] Most anesthesiologists recognize that cuffs of endotracheal and endobronchial tubes require relatively small volumes of air. However, what may be unrecognized is that nitrous oxide can further distend tube cuffs and traumatize the airway.

Either the bronchial or tracheal cuff can damage the airway. Therefore, care must be taken in inflating both cuffs when using a DLT.

Because underinflation of the bronchial cuff can result in failure to collapse the operated lung or contamination of the dependent lung, whereas overinflation can damage the airway, several methods have been described for determining the exact end point for DLT cuff inflation.[61-63] Most are time consuming and unnecessary.

Inflation of both cuffs, but particularly the bronchial cuff, with the appropriate (small) volume of air and periodic attention by digital examination of the pilot balloon to both cuffs is usually all that is needed to maintain cuff pressure. When nitrous oxide is used, both cuffs should periodically be partially deflated during long procedures.

Size. Because the rubber material is so thick, for an equivalent-sized internal tube lumen, a larger size RR tube must be used compared with a thinner walled PVC tube.[1] Smaller airways may not be able to safely accommodate the large RR tube. Almost all injuries from RR DLTs occurred with medium- or large-sized tubes.

Smaller DLTs, even PVC tubes, may have a lumen that is too narrow for safe one-lung ventilation because air flow resistance during one-lung ventilation will be very high. The authors believe that the largest tube that will safely fit the airway should be used.[57] There is less chance that a large tube will be advanced too far into the bronchus; therefore, obstruction of the upper lobe bronchus is less likely with a larger DLT. The bronchial cuff will require less volume to seal the bronchus if a larger tube is chosen.

One investigator postulated that intubation with too large a PVC tube resulted in airway damage.[27] In this case, trauma occurred after the tube was twice advanced too deep into the bronchus. Too much force on insertion may have been the cause, because a large DLT could not have been advanced into the bronchus with normal resistance.

Another investigator stated that the injury occurred from using a PVC DLT that was too small.[28] Smaller DLTs are indicated for small adult patients and for children. In contrast to the RR DLT patients, almost all PVC DLT injuries were associated with smaller tubes. Smaller tubes are used with smaller patients, and all but one of the cases involved women.

Many anesthesiologists use 39F and 41F PVC DLTs for most men.[57] It is therefore surprising that there has never been a report of tracheobronchial rupture with a 41F PVC DLT.

Almost half the published reports of airway damage from PVC DLTs involved Japanese patients.[25,26,28,32,34,35] Although many of these patients are physically smaller than patients in this country, the authors' experience has been that by using guidelines for DLT tube selection, larger DLTs can be used for many Asian patients. It is not known why there are so many reports of airway trauma with PVC DLTs from Japan.

Site of operation. With both RR and PVC tubes, most injuries occurred during left thoracotomy with a left-sided DLT. Left DLTs are usually preferred for both right- or left-sided thoracotomies because the left bronchus is much longer than the right bronchus; the margin of safety is greater with left DLTs.[64]

In the single injury to the right bronchus with a left PVC tube, the right bronchus had been inadvertently intubated at the start of the case. One argument for always intubating the airway on the side of the operation is that any damage to that airway may be obvious at the time of surgery.[65]

With both RR and PVC DLTs, an unexpectedly large number of injuries were associated with esophageal surgery. The injury can be to the trachea when the higher cervical esophagus is dissected near the tracheal cuff that lies next to the thin posterior membranous trachea. Injury can also occur to the bronchus and is likely because of a similar mechanical mechanism of peeling the thinner posterior bronchial wall over a distended bronchial balloon.

Outcome

Airway trauma with DLTs is certainly underreported; therefore, the actual incidence and outcome of such injuries cannot be known. Only 1 of the 14 patients with airway rupture associated with a PVC DLT died. This is in contrast to RR DLTs, from which 5 of 16 patients died.

Airway damage can present with air leak, subcutaneous emphysema, airway hemorrhage, and cardiovascular instability caused by tension pneumothorax. With incomplete laceration, air may dissect into the adventitia, producing an aneurysmal dilation of the membranous wall. If nitrous oxide is used, it will further distend this air collection. The signs of injury may not be evident for many hours after the initial injury, when rupture into the mediastinum or pleural space occurs.[66]

The integrity of the intubated bronchus should be tested with manual ventilation for leaks at the completion of surgery with only the tracheal cuff inflated. Bronchoscopy should be performed before extubation to look for signs of trauma if an airway disruption is suspected because immediate surgical intervention is essential for favorable prognosis.[67]

Bronchoscopy allows early diagnosis of an airway injury. The greater mortality with RR DLTs may reflect the fact that FOBs were not readily available until relatively recently.

Recommendations

Table 5 lists ways to reduce the chance of major airway injury from a DLT. These recommendations are based on information derived from the published individual case reports reviewed and from the experience using DLTs at Stanford University Medical Center (Stanford, CA).

Plastic tubes should be used whenever possible because PVC DLTs have many advantages compared with RR DLTs.[1]

The largest PVC DLT that will safely fit the airway should be chosen. Larger tubes require less air in the bronchial cuff. There is less chance that a larger tube will be advanced too deeply into

Table 5. Recommendations for Safe DLT Placement

1. Choose the largest PVC DLT that will safely fit the patient's airway.
2. Remove the bronchial stylet once the tip of the tube is past the vocal cords.
3. Be extra cautious with patients who have tracheobronchial wall pathological disease, leukemia, steroid therapy, hypoperfusion.
4. Advance the DLT the appropriate distance into the bronchus (based on patient height).
5. Inflate both cuffs slowly.
6. Use a 3-mL syringe to inflate the bronchial cuff.
7. Never overinflate either cuff: usually <3 mL of air is adequate for the bronchial cuff if an appropriate size (large) DLT is selected. If more air is needed, reassess tube position by auscultation or with a fiberoptic bronchoscope.
8. If nitrous oxide is used, inflate both cuffs with saline or an oxygen/nitrous oxide mixture rather than air.
9. If nitrous oxide is used, measure cuff pressures intermittently and periodically relieve pressure (if necessary) by partially deflating the cuff to the original inflation volume. Keep bronchial cuff pressure <30 cm H_2O.
10. Deflate both cuffs before moving the patient.
11. Deflate the bronchial cuff when lung isolation or selective ventilation is not needed.
12. During esophageal procedures, consider partial deflation of the cuff when surgical dissection is near either cuff.
13. Test the integrity of the intubated bronchus at the completion of surgery.
14. Use a fiberoptic bronchoscope to determine site and extent of injury.

Table 6. Guidelines for Choosing a BronchoCath Left DLT

Measured Tracheal Width (mm)	Predicted Left Bronchus Width (mm)	DLT Size (F)	DLT OD (mm)	
			Main Body	Left Lumen
≥18	≥12.2	41	14-15	10.6
≥16	≥10.9	39	13-14	10.1
≥15	≥10.2	37	13-14	10.0
≥14	≥9.5	35	12-13	9.5
≥12.5	≥8.5	32	10-11	8.3
≥11	≥7.5	28	9.4	7.4

NOTE. Tracheal width is measured from each patient's chest radiograph. The predicted size of the left bronchus equals the measured tracheal width (mm) × 0.68.

Abbreviation: OD, outside diameter (mm) for main body and left bronchial lumen of the left BronchoCath DLT (Mallinckrodt Medical, Inc, St Louis, MO). The dimensions of other PVC DLTs differ.

the bronchus, where it could obstruct the upper-lobe bronchus, resulting in hypoxemia during one-lung ventilation.[68] A larger lumen allows easier passage of FOBs and suction catheters and offers less airflow resistance during one-lung ventilation.

Airway size can be measured by either the chest computed tomographic scan or chest radiograph.[69-71] Table 6 shows how measurement of the tracheal width from a chest radiograph can help guide size selection for left-sided BronchoCath DLTs.

A DLT should never be forcibly advanced. Clinicians should be even more cautious with patients who have airway pathological diseases, such as tracheomalacia or tumor infiltration, and with patients who are immunosuppressed or receiving steroids.

Avoid advancing the DLT too deeply into the bronchus. For both men and women, the depth of DLT placement is directly proportional to the patient's height.[72] The DLT should initially be advanced down the appropriate bronchus to a depth based on height, and further passage should be stopped if resistance is encountered. Careful auscultation[73] or an FOB[52] should then be used to determine accurate position of the tube.

Both the bronchial and tracheal cuffs must be inflated with air slowly. It is extremely important not to overinflate the bronchial cuff. A 3-mL syringe can be used for the bronchial cuff as a reminder that 2 to 3 mL of air is usually the volume needed if an appropriate size (large) tube has been selected.

When possible, nitrous oxide should be avoided during the anesthesia.[74] If nitrous oxide is used, then both cuffs should be inflated with either saline or an oxygen/nitrous oxide mixture to prevent cuff distention during the procedure.

Both cuffs should be deflated when moving the patient or changing the position of the DLT. It is safest to keep the bronchial cuff deflated whenever lung isolation or selective ventilation is not required.

An FOB should be available to inspect the airway if mediastinal emphysema or loss of tidal volume occurs at any time during the case. The integrity of the intubated bronchus should always be tested at the completion of the procedure, preferably after the tube has been withdrawn from the bronchus. Early diagnosis of airway rupture is critical because it is associated with the best prognosis.

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