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Margin of Safety in Positioning Modern Double-lumen Endotracheal Tubes

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The authors have defined the margin of safety in positioning a double-lumen tube as the length of tracheobronchial tree over which it may be moved or positioned without obstructing a conducting airway. The purpose of this study was to measure the margin of safety in positioning three modern double-lumen tubes (Mallinkrodt [Broncho-Cath®], Rusch [Endobronchial tubes], and Sheridan [Broncho-Trach®]). The margin of safety in positioning a: 1) left-sided double-lumen tube (all manufacturers) is the length of the left mainstem bronchus minus the length from the proximal margin of the left cuff to left lumen tip; 2) Mallinkrodt right-sided double-lumen tube is the length of the right mainstem bronchus minus the length of the right cuff; and 3) Rusch right-sided double-lumen tube is the length of the right upper lobe ventilation slot minus the diameter of the right upper lobe. The length of the right and left mainstem bronchi were measured by *in vivo* fiberoptic bronchoscopy (n = 69), in fresh cadavers (n = 42), and in lung casts (n = 55), and the diameter of the right upper lobe bronchus was measured in lung casts (n = 55). The average ± SD male left and right mainstem bronchial lengths were 49 ± 8 and 19 ± 6 mm, respectively, the average ± SD female left and right mainstem bronchial lengths were 44 ± 7 and 15 ± 5 mm, respectively, the average right upper lobe bronchial diameter was 11 mm, the proximal left cuff to left lumen tip distance was 30 mm, the length of the Mallinkrodt right cuff was 10 mm, and the length of the Rusch right upper lobe ventilation slot was 15 mm. The average margin of safety in positioning left-sided double-lumen tubes ranged 16–19 mm for the different manufacturers. The average margin of safety in positioning Mallinkrodt right-sided double-lumen tubes was 8 mm, and the margin of safety in positioning Rusch right-sided double-lumen tubes ranged 1–4 mm, depending on French size. The authors concluded that left-sided double-lumen tubes are much preferable to right-sided double-lumen tubes because they have a much greater positioning margin of safety, and that proper confirmation of proper position of either a left- or right-sided double-lumen tube should be aided by fiberoptic bronchoscopy, because the absolute distances that constitute the margin of safety are extremely small. (Key words: Anatomy: tracheobronchial tree. Anesthetic techniques: fiberoptic bronchoscopy; tracheal intubation. Complications: airway obstruction. Equipment: double-lumen tubes.)

A PROPERLY POSITIONED double-lumen endotracheal tube should not obstruct any conducting airway. We have defined the length of tracheobronchial tree over which a double-lumen tube may be moved or positioned without obstructing a conducting airway as the margin of safety in positioning the tube.

In order to calculate the margin of safety in positioning currently available, clear plastic, double-lumen tubes (Mallinkrodt [Broncho-Cath®], Rusch [Endobronchial Tubes], Sheridan [Broncho-Trach®]), precise measurements of left and right mainstem bronchial lengths, the diameters of the right upper and left lower lobe bronchi, and various lengths and diameters of double-lumen tube segments are required. The purpose of this study was to make these measurements and calculate the margin of safety in positioning double-lumen tubes.

Methods

Left and right mainstem bronchial anatomy and the design of left- and right-sided double-lumen endotracheal tubes are different. Consequently, the definition of the margin of safety in positioning a left-sided tube is much different than for a right-sided tube.

Definition of Margin of Safety in Positioning Left-sided Double-lumen Tubes

The left-sided tubes made by different manufacturers have the same basic structural design and, therefore, can be considered together. The most proximal acceptable position of a left-sided tube is when the left endobronchial cuff is just below the tracheal carina (fig. 1, top left panel). If the endobronchial cuff is placed in a progressively more proximal position, then the endobronchial cuff would progressively fill the space above the carina and obstruct the trachea and contralateral (right) mainstem bronchus. In addition, the positive pressure gas and fluid seal between the two lungs would be lost.

The most distal acceptable position of a left-sided tube is when the tip of the left lumen is at the proximal edge of the left upper lobe bronchial orifice (fig. 1, top right panel). If the tip of the left lumen is placed in a progressively more distal position, then the tip of the left lumen would progressively obstruct the left upper lobe bronchial orifice. This definition of the most distal acceptable position for a left-sided tube is valid, provided that two assumptions inherent in this definition are correct. First, the distance between the right and left lumen tips must be greater than the length of the

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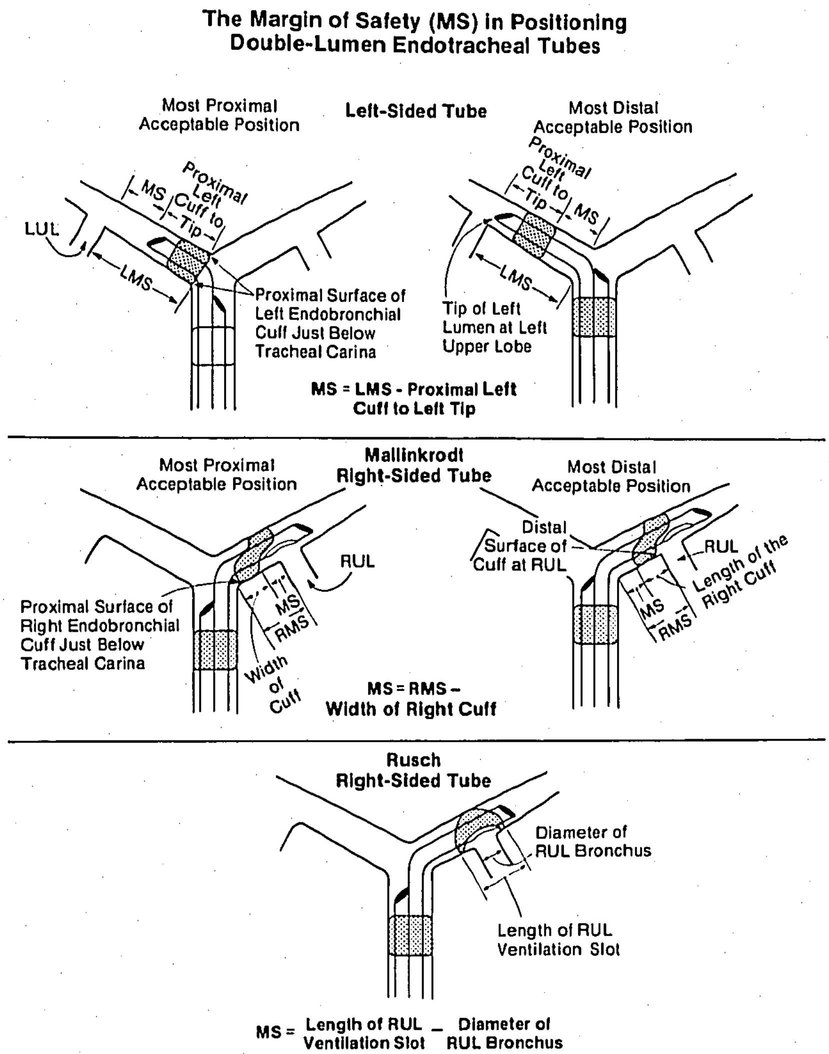

FIG. 1. This schematic shows the definitions of most proximal and most distal acceptable positions of left- and right-sided double-lumen tubes and the margin of safety in positioning these double-lumen tubes. Top panel = all left-sided double-lumen tubes; middle panel = Mallinkrodt right-sided double-lumen tube; bottom panel = Rusch right-sided double-lumen tube; LMS = length left mainstem bronchus; RMS = length right mainstem bronchus; MS = margin of safety in positioning double-lumen tube; LUL = left upper lobe; RUL = right upper lobe.

left mainstem bronchus; this means that the tip of the right lumen will not enter the left mainstem bronchus before the tip of the left lumen bypasses the left upper lobe. Second, the outside diameter of the left lumen tip of a left-sided tube must be nearly equal to the internal diameter of the second generation bronchus to the left lower lobe; this means that there is no, or minimal, space between the tip of the left lumen and the left lower lobe bronchus for retrograde gas exchange between the left lumen and left upper lobe.

The length of tracheobronchial tree between the most distal and most proximal acceptable position is the margin of safety in positioning a left-sided tube. This margin of safety is thus the length of the left mainstem bronchus minus the distance between the proximal margin of the left endobronchial cuff and the tip of the left lumen (fig. 1, top panel).

DEFINITION OF MARGIN OF SAFETY IN POSITIONING RIGHT-SIDED DOUBLE-LUMEN TUBES

The Mallinkrodt and Rusch right-sided double-lumen tubes are designed differently (the shapes of the right endobronchial cuffs are very different) and, therefore, they must be considered separately. At present, Sheridan does not manufacture a right-sided tube. The most proximal acceptable position of a Mallinkrodt right-sided tube is when the endobronchial cuff is just below the tracheal carina (fig. 1, middle left panel). If the endobronchial cuff is placed in a progressively more proximal position, then the right endobronchial cuff would progressively fill the space above the carina and obstruct the trachea and contralateral (left) mainstem bronchus. In addition, the positive pressure gas and fluid seal between the two lungs would be lost.

The most distal acceptable position of the Mallinkrodt right-sided tube is when the distal margin of the right endobronchial cuff is at the proximal margin of the right upper lobe bronchial orifice (fig. 1, middle right panel). If the Mallinkrodt right endobronchial cuff is placed in a progressively more distal position, then the Mallinkrodt right endobronchial cuff would progressively obstruct the right upper lobe bronchial orifice. This definition of the most distal acceptable position for a Mallinkrodt right-sided tube is valid due to the unique shape of the Mallinkrodt right endobronchial cuff (which forces the right upper lobe ventilation slot to ride off of the right mainstem bronchial wall) which allows gas exchange between the right upper lobe ventilation slot, right lumen tip, and the right upper lobe (even though the right upper lobe ventilation slot may not be properly aligned with the right upper lobe bronchial orifice). The margin of safety in positioning the Mallinkrodt right-sided tube is, therefore, the length of the right mainstem bronchus minus the distance between the proximal and distal margins of the right endobronchial cuff (*i.e.*, the length of the right endobronchial cuff) (fig. 1, middle panel).

The most proximal acceptable position of the Rusch right-sided tube is when the distal margin of the right endobronchial cuff is at the distal margin of the right upper lobe bronchial orifice (fig. 1, bottom panel). If the Rusch right-sided tube is placed in a progressively more proximal position, then the distal margin of the endobronchial cuff and the outside lateral wall of the right lumen tip would progressively obstruct the right upper lobe bronchial orifice. The most distal acceptable position of a Rusch right-sided tube is when the proximal margin of the right endobronchial cuff is at the proximal margin of the right upper lobe bronchial orifice. If the Rusch right-sided tube is placed in a progressively more distal position, then the proximal margin of the right endobronchial cuff and outside lateral wall of the right endobronchial lumen would progressively obstruct the right upper lobe bronchial orifice. These definitions of the most proximal and most distal acceptable position for a Rusch right-sided tube are valid because the shape of the Rusch right endobronchial cuff forces the right upper lobe ventilation slot and outside lateral wall of the right endobronchial tube to be in close apposition to the right upper lobe bronchial orifice and lateral bronchial mucosa. The margin of safety in positioning the Rusch right-sided tube is, therefore, the distance between the distal and proximal margins of the right endobronchial cuff (*i.e.*, the length of the right upper lobe ventilation slot) minus the diameter of the right upper lobe bronchial orifice (fig. 1, bottom panel).

Measurement of the Length of the Mainstem Bronchi

The lengths of the right and left mainstem bronchi were measured by three independent methods. First, with human research committee approval, a pulmonologist, experienced in fiberoptic bronchoscopy (CS), measured the length of the left and right mainstem bronchi in 69 intubated patients (36 males, 33 females) under general anesthesia with a flexible fiberoptic bronchoscope. On both the left and right sides, the proximal margin of the upper lobe bronchial orifices was visualized at the very tip of the bronchoscope and a piece of tape was placed on the bronchoscope at the point where it entered the self-sealing diaphragm in the elbow connector. The fiberoptic bronchoscope was then withdrawn until the tracheal carina was at the tip of the bronchoscope and another piece of tape placed on the bronchoscope at the point of entry into the self-sealing diaphragm. The distance between the two pieces of tape, to the nearest ruler millimeter, was the length of the mainstem bronchus.

Second, the lengths of the right and left mainstem bronchi were measured in 42 fresh cadavers. The lungs and trachea were severed from their cardiac and mediastinal connections and removed intact. The lungs were then placed flat and the tracheobronchial tree was incised and opened along the posterior aspect, so that the inner surfaces of the tracheobronchial tree were exposed. Two parallel lines, which were at right angles to the bronchial wall, were visually drawn across the beginning and end of the mainstem bronchi. The proximal line connected the tracheal carina to the opposite wall, and the distal line connected the proximal margin of the upper lobe bronchus to the opposite wall. The distance between the two parallel lines, to the nearest ruler millimeter, was the length of the mainstem bronchus.

Third, the lengths of the left and right mainstem bronchi were measured in 55 resin casts of adult lungs. The resin lung casts were made 30 yr ago by Dr. A. Liebow ("the Liebow Collection").[1] To make the lung casts, Dr. Liebow filled the lower trachea and all the bronchi with resin at a pressure which resulted in full lung inflation. Calipers were used to measure the length of the mainstem bronchi, as defined above for the autopsies, to the nearest ruler millimeter.

Diameter of the Right Upper and Left Upper and Lower Lobe Bronchi

The lung casts were used to measure, by calipers, to the nearest ruler millimeter, the diameter of the right

TABLE 1. Average ± SD Age, Height, and Weight of the Patients in the *In Vivo* Fiberoptic and Autopsy Studies

Type of Study	Sex	N	Average Age Yr ± SD	Average Height Meters ± SD	Average Weight Kg ± SD
In vivo fiberoptic bronchoscopy	Male	36	36 ± 13	1.69 ± 0.07	77 ± 16
	Female	33	44 ± 18	1.52 ± 0.07	62 ± 11
	Combined	69	40 ± 16	1.61 ± 0.11	70 ± 16
Autopsy study	Male	32	57 ± 17	1.56 ± 0.08	73 ± 15
	Female	10	60 ± 16	1.43 ± 0.08	60 ± 10
	Combined	42	58 ± 16	1.54 ± 0.08	69 ± 15

upper and left upper and lower lobe bronchi (just distal to their origins).

Lengths of Various Double-Lumen Tube Segments

The length of the various double-lumen tube segments and the tolerance (variation) in these specifications for all adult-sized double-lumen tubes were provided by the three manufacturers of modern, disposable double-lumen tubes (Mallinkrodt, Rusch, Sheridan). The dimensions provided by the manufacturers were checked on samples received and on inhouse double-lumen tubes, and were found to be acceptable ±1 ruler millimeter.

Statistics

The length of the mainstem bronchi are presented as grouped interval distributions, and as mean ± SD, with the range of values. The diameters of second generation bronchi are presented as mean ± SD and with the range of values. The length of the mainstem bronchi were correlated with height by linear regression, and the length of the mainstem bronchi of males were compared to females by Student's paired t analysis ($P < 0.05$ was considered significant with reference to the r and t values, respectively).

Results

Demographic Data

Table 1 shows the average age, height, and weight of the patients in the *in vivo* fiberoptic bronchoscopy and autopsy studies. The *in vivo* fiberoptic bronchoscopy patients were much younger than the patients in the autopsy study. In both groups of patients, the males were both taller and heavier than the females. No demographic data were available for the patients whose lungs were resin casted.

Distribution of and Average Left and Right Mainstem Bronchial Lengths

Figure 2 shows the distribution of left and right mainstem bronchial lengths for each sex separately for the *in vivo* fiberoptic bronchoscopy and autopsy groups, and for the sexes combined together for the *in vivo* fiberoptic bronchoscopy, autopsy, and cast study groups. The distributions of the left and right mainstem bronchial lengths are, in general, one x-axis interval greater for males than for females in both *in vivo* fiberoptic bronchoscopy and autopsy groups. In all subgroups and combined groups, the mainstem bronchial lengths are approximately normally distributed.

TABLE 2. Mean ± SD and (Range) of Mainstream Bronchial Lengths for Males, Females, and the Sexes Combined in the *In Vivo* Fiberoptic Bronchoscopy, Autopsy, and Cast Study Groups

	Mean ± SD (Range) Mainstem Bronchial Lengths, mm					
	Male		Female		Combined	
Type of Study	RMSB	LMSB	RMSB	LMSB	RMSB	LMSB
In vivo fiberoptic bronchoscopy	19 ± 8 (7–37)	50 ± 8 (29–63)	14 ± 7 (4–33)	45 ± 7 (30–58)	17 ± 8 (4–37)	48 ± 8 (29–63)
Autopsy study	19 ± 6 (8–32)	48 ± 8 (33–60)	16 ± 4 (10–23)	42 ± 7 (32–56)	18 ± 6 (8–32)	47 ± 8 (32–60)
Cast study	—	—	—	—	18 ± 7 (−3–35)*	48 ± 8 (27–68)

* One right upper lobe takeoff was above tracheal carina.
RMSB = right mainstem bronchus; LMSB = left mainstem bronchus; — = sex of the casts were unknown.

Table 2 shows the averages (±SD) and ranges of left and right mainstem bronchial lengths for all the distributions shown in figure 2. From study method to study method, and for the separate sex subgroups and the combined sex groups, the results are strikingly similar. In the combined bronchoscopy and autopsy groups, there was a positive linear correlation between the height of the patients and the length of the left and right mainstem bronchi (r = 0.41 and r = 0.39, respectively; $P < 0.001$ for both studies), and the length of the right and left mainstem bronchi for the taller males was significantly greater than for the females ($P < 0.002$ and $P < 0.001$, respectively). However, these r values are of limited clinical significance.

Average Diameter of the Right and Left Upper Lobe Bronchial Orifices

The average ±SD diameter of the right and left upper lobe bronchial orifices in the lung casts was 10.7 ± 2.1 mm and 10.3 ± 1.9 mm, respectively, with a range of values 6–18 mm. The distribution of values was approximately normal.

Correctness of Definition of Most Distal Acceptable Position of Left-sided Double-lumen Tubes

The most distal acceptable position of a left-sided double-lumen tube was defined as when the left lumen tip is at the proximal margin of the left upper lobe bronchus. This definition is valid provided that the right-to-left lumen tip length is longer than the length of the left mainstem bronchus, and that the space between the outside of the left lumen tip and the inside of the second generation bronchus leading to the left lower lobe is small. The right-to-left lumen tip distance is 70–74 mm for all manufacturers, and is longer than the longest left mainstem bronchus that we measured (68 mm, fig. 2 and table 2). The mean ± SD (range) of the diameter of the left lower lobe bronchus of the lung casts was 10.6 ± 2.0 mm (6–15 mm). Using the average value for the inside diameter of the left lower lobe bronchus, table 3 shows that the difference between the outside diameter of the left lumen tip and the inside diameter of the second generation bronchus leading to the left lower lobe has a maximum of 1.1, 1.2, and 1.3 mm for 35-French Mallinkrodt, Rusch, and Sheridan tubes, respectively; as double-lumen tube size increases from 35 Fr to 41 Fr, the space between the left lumen tip and bronchus to the left lower lobe decreases rapidly from this maximum to 0 mm.

TABLE 3. Relationship Between Outside Diameter of Left Lumen Tip to Inside Diameter of Second Generation Bronchus to Left Lower Lobe

Manufacturer	Size of Double-Lumen Tube, Fr	Outside Diameter of Left Lumen Tip, mm	Average Inside Diameter of Second-generation Bronchus to Left Lower Lobe, mm	Space Between Left Lumen Tip and Bronchus to Left Lower Lobe, mm
Mallinkrodt	41	10.6	10.6	0
	39	10.1	10.6	0.5
	37	10.0	10.6	0.6
	35	9.5	10.6	1.1
Rusch	41	11.5	10.6	−0.9
	39	10.8	10.6	−0.2
	37	10.1	10.6	0.5
	35	9.4	10.6	1.2
Sheridan	41	10.7	10.6	−0.1
	39	9.9	10.6	0.7
	37	9.9	10.6	0.7
	35	9.3	10.6	1.3

Average Margin of Safety in Positioning Left- and Right-sided Double-lumen Tubes

The margin of safety in positioning a left-sided double-lumen tube is the difference between the length of the left mainstem bronchus and the length of tube between the proximal margin of the left endobronchial cuff and the left lumen tip (table 4). This average margin of safety in positioning left-sided double-lumen tubes ranged from 16–19 mm.

The margin of safety in positioning right-sided tubes

TABLE 4. The Average Margin of Safety in Positioning a Left-sided Double-lumen Tube is the Length of the Left Mainstem Bronchus Minus the Proximal Margin of Left Cuff to Lumen Tip Length

Manufacturer	Size 35–41-Fr	Average Length of Left Mainstem Bronchus, mm			Proximal Margin of Left Cuff to Left Lumen Tip, mm	Average Margin of Safety, mm		
		Male	Female	Combined		Male	Female	Combined
Mallinkrodt	All	49	44	48	29*	20	15	19
Rusch	All	49	44	48	32	17	12	16
Sheridan	All	49	44	48	30	19	14	18

* Manufacturer estimates a ±2 mm (variation) tolerance for this value.

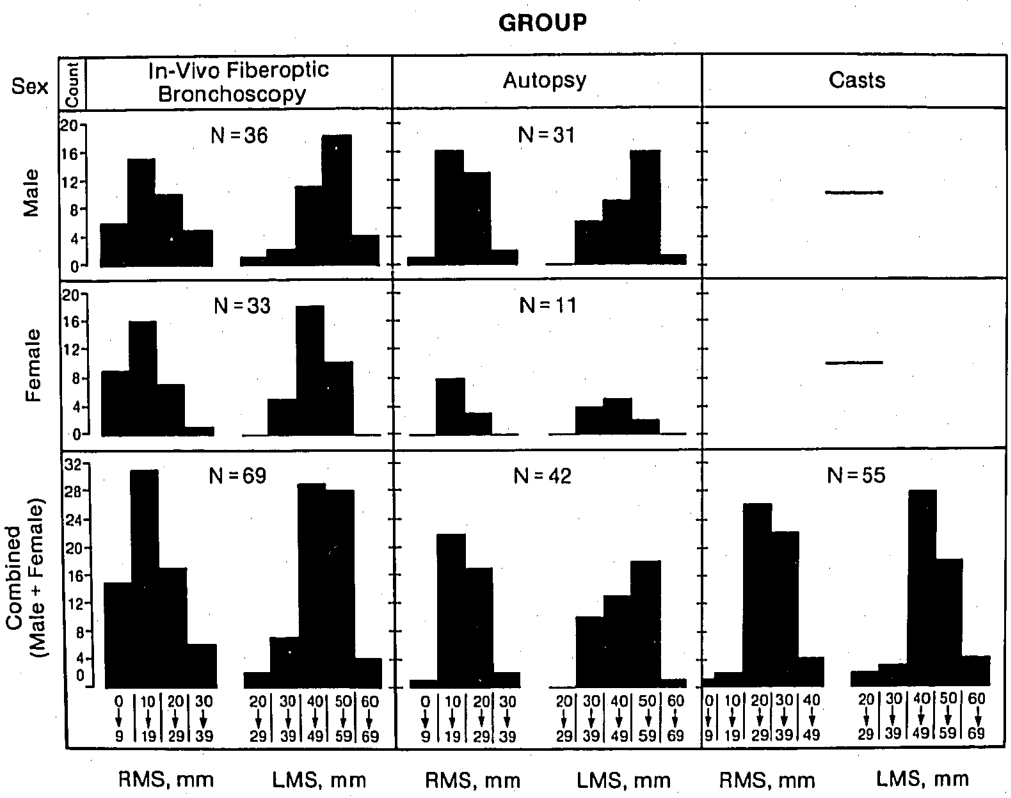

FIG. 2. The distributions of right and left mainstem bronchial lengths for either sex, and the sexes combined, for the *in vivo* fiberoptic bronchoscopy, autopsy, and cast study groups, are normally distributed. RMS = length of right mainstem bronchus; LMS = length left mainstem bronchus.

is shown in table 5. This ranged from 1–9 mm and differed between manufacturers.

The average margin of safety in positioning left-sided tubes is much greater than the average margin of safety in positioning right-sided tubes. As tube size increases, the average margin of safety for positioning left-sided tubes remains constant for all manufacturers, because the proximal margin of left cuff to left lumen tip length remains constant. The average margin of safety for the Mallinkrodt right-sided tubes also does not vary with tube size because the length of the right endobronchial cuff does not vary with tube size. The average margin of safety for the Rusch right-sided tubes decreases with decreasing tube size, because the length of the right upper lobe ventilation slot decreases with decreasing tube size. There is not a substantial difference in the margin of safety between the double-lumen tubes of different manufacturers.

TABLE 5. The Average Margin of Safety in Positioning a Mallinkrodt Right-sided Double-lumen Tube is the Length of the Right Mainstem Bronchus Minus the Width of the Right Endobronchial Cuff, and the Margin of Safety in Positioning a Rusch Right-sided Double-lumen Tube is the Length of the Right Upper Lobe Ventilation Slot Minus the Diameter of the Right Upper Lobe Bronchial Orifice

Manufacturer	Size, Fr	Average Length of Right Mainstem Bronchus, mm			Length of Mallinkrodt Right Cuff, mm	Average Margin of Safety, mm		
		Male	Female	Combined		Male	Female	Combined
Mallinkrodt	All	19	15	18	10	9	5	8

Manufacturer	Size, Fr	Average Diameter of RUL Bronchial Orifice, mm	Length of Rusch RUL Ventilation Slot, mm	Average Margin of Safety, mm
Rusch	41	11	15	4
	39			
	37		12	1
	35			

RUL = right upper lobe.

Largest and Smallest Margin of Safety Situations

Since left and right mainstem bronchial lengths are approximately normally distributed, and since double-lumen tubes are manufactured with a known tolerance (variation) in their specifications, largest and smallest margin of safety situations can be calculated for both right- and left-sided double-lumen tubes. Best margin of safety conditions exist when the length of the mainstem bronchus is long and the tube factor is short. For left-sided tubes, proximal left cuff to left lumen tip distance varies ±2 mm, because the cuffs are put on by hand at the end of the manufacturing process. On the left side, the longest left mainstem bronchus was 68 mm and the shortest proximal left cuff to left lumen tip distance is 28 mm; this results in a best left-sided double-lumen tube margin of safety of 40 mm. On the right side, the longest right mainstem bronchus was 37 mm and all of the Mallinkrodt right cuffs are 10 mm wide; this results in a largest Mallinkrodt right-sided double-lumen tube margin of safety of 27 mm. Calculation of largest Rusch right-sided double-lumen tube margin of safety based on changing right upper lobe bronchial diameter is not appropriate, because, as right upper lobe bronchial diameter decreases (calculated margin of safety increases), the likelihood of satisfactory right upper lobe ventilation does not necessarily increase.

Description of the smallest margin of safety situation is more complex than for the largest margin of safety situation. On the left side, the margin of safety is smallest when the left mainstem bronchial length is short and the length of the proximal margin of left cuff to left lumen tip is 2 mm greater than the company's stated specification (due to placing the left cuff too proximal). With a proximal margin of left cuff to left lumen tip distance of 32 mm, progressive left upper lobe obstruction would occur when the left mainstem bronchial length progressively decreases below 32 mm (*i.e.*, there is no, or a negative, margin of safety, even though the proximal margin of the left cuff is placed just below the tracheal carina). In the *in vivo* fiberoptic bronchoscopy and autopsy study groups together, there were two males (left mainstem bronchial length equal to 29 and 32 mm) and two females (left mainstem bronchial length equal to 30 and 32 mm), and in the cast study group, there were three instances (left mainstem bronchial lengths equal to 27, 28, and 32 mm) where the margin of safety for left-sided tube would have been 0 mm or less than 0 mm (4% incidence for all three study groups together). In other words, in these few patients, it would not be possible to position a left-sided tube without some degree of left upper lobe obstruction. However, the degree of obstruction would have been moderate in two patients (4–6 mm), and minimal in five patients (less than 4 mm). During the time the study was being conducted, we anesthetized (CS) one patient for pulmonary resection (not part of the study) in whom the left upper lobe was partially obstructed (bronchoscopically confirmed) when the proximal margin of the left cuff was just below the tracheal carina (bronchoscopically confirmed).

On the right side, the margin of safety is smallest when the right mainstem bronchial length is shorter than the 10-mm wide Mallinkrodt right endobronchial cuff. In the *in vivo* fiberoptic bronchoscopy and autopsy groups together, there were six males (right mainstem bronchial lengths equal to 7 mm four times, 8 and 9 mm one time) and nine females (right mainstem bronchial lengths equal to 4 mm two times, 6 mm two times, 7 mm three times, and 8 and 9 mm one time), and, in the cast study group, there were three instances (right mainstem bronchial lengths equal to −3 mm, 6 mm, and 8 mm) when the right mainstem bronchial lengths were less than 10 mm (11% incidence for the three groups together). In these patients, even if the Mallinkrodt right endobronchial cuff were placed just below the tracheal carina, the degree of right upper lobe obstruction by the right endobronchial cuff would have been complete in one patient, moderate (4–6 mm) in five patients, and minimal (less than 4 mm) in 12 patients. Figure 3 shows an autopsy example of a patient who had a right mainstem bronchial length of 10 mm; the right endobronchial cuff completely fills the right mainstem bronchus and there is no margin of safety. Calculation of a smallest Rusch right-sided tube margin of safety based on changing right upper lobe bronchial diameter is not appropriate because, as right upper lobe bronchial diameter increases (calculated margin of safety decreases), the likelihood of inadequate right upper lobe ventilation does not necessarily increase.

Discussion

The lengths and diameters of the tracheobronchial tree and double-lumen tube segments involved in the definition and calculation of the margin of safety in positioning double-lumen tubes are very small. Consequently, consideration should be first given to the validity of our definitions and accuracy of our measurements. Next, our measurements should be compared to previous studies. Finally, our findings strongly support several clinical practice and manufacturing recommendations and conclusions.

Validity of Margin of Safety Definitions

The definitions for the most proximal acceptable position for both left- and right-sided tubes and the most

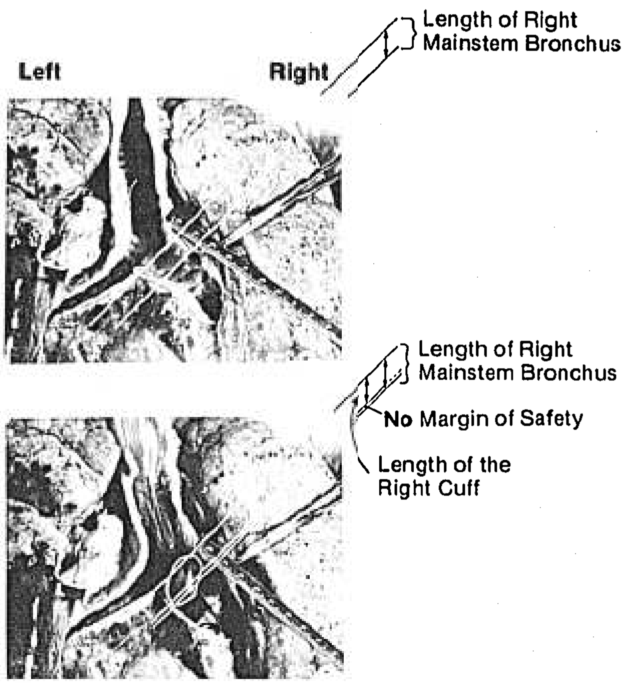

FIG. 3. Placement of a 37-French right-sided double-lumen tube within the tracheobronchial tree of an autopsy patient who had a right mainstem bronchial length of 10 mm. The width of the right endobronchial cuff very nearly fills the right mainstem bronchus and there is no margin of safety.

distal acceptable position for right-sided tubes are straightforward. In each of the above three situations, progressive movement of the tube, in the direction in question, results in progressive obstruction of a major conducting airway by the endobronchial balloon.

The definition of the most distal acceptable position of a left-sided tube requires discussion. Since the distance between the left endobronchial and right tracheal lumen tips (70–74 mm) is greater than the longest measured left mainstem bronchus (68 mm), the first conducting airway that will be obstructed by a too-distal insertion will be the left upper lobe by the left lumen tip (rather than obstruction of the right mainstem bronchus due to the right lumen entering the left mainstem bronchus). Our finding of a maximum available space between the outside of 41–35-French left-sided tubes and the inside of the second generation bronchus of only 0–1.3 mm indicates that, on the average, all sized left-sided tubes can be expected to functionally wedge in the bronchus leading to the left lower lobe if inserted too distally.

Accuracy of Mainstem Bronchial Lengths Measurements

We measured the length of the left mainstem bronchi by three independent methods. The reason for the multiplicity in methods is that we were not confident that we could rely on any given method to be error free. We interpret the fact that all three methods yielded nearly identical means for mainstem bronchial lengths to strongly indicate that all three methods were accurate.

Our *in vivo* fiberoptic bronchoscopy measurements were performed by an experienced pulmonologist (CS). We tried to place the tip of the fiberoptic bronchoscope just proximal to both the tracheal carina and proximal margin of the upper lobe. Although the two very small distances between the tip of the bronchoscope and the tracheal carina, and the tip of the bronchoscope and the proximal margin of the upper lobe, should cancel each other out, minor differences in focusing the structures, our method of sequentially placing tapes on the fiberoptic bronchoscope, translating the distance between the tapes to a piece of paper, and then measuring that distance with a ruler to the nearest millimeter must have created a small, but undefined, error. The error in the autopsy and cast studies are also unknown, but should be very small. In both of these studies, the beginning and end of the mainstem bronchus could be measured with precision. In the autopsy study, we were careful to not distort the anatomy when laying the ruler parallel to the mainstem bronchus.

Comparison of Our Findings with Previous Studies

There have been previous autopsy studies of tracheobronchial tree lengths and diameters.[2-6] However, in these previous studies, the exact beginning and end of the mainstem bronchi were not stipulated.[2-6] This is important in our study because of the small distances involved in the margin of safety in positioning double-lumen tubes. Nevertheless, our average mainstem bronchial lengths, and, in particular, the distribution and ranges of our mainstem bronchial lengths agree well with the largest and one of the most recent of the previous autopsy studies.[6] We found that male left and right mainstem bronchi were 6 mm and 4 mm longer, respectively, than the corresponding female bronchi, which is in good agreement with a previously observed 4 mm and 2 mm male-to-female difference for the left and right mainstem bronchial lengths, respectively.[6] In addition, both studies found good positive correlation between the length of the left and right mainstem bronchi. Our findings also agree well with a large bronchography study of 1,250 patients in which there were 19 instances of very short right mainstem bronchial lengths and five instances (1/250 incidence) of takeoff of the right upper lobe from the trachea.[5] The incidence of anomolous takeoff of the right upper lobe bronchus in patients with congenital heart disease may be as high as 1/50.[1] Our right upper lobe bronchial diameter findings also agree well with previous studies with respect to both average values[6,7] and distribution of values.[6]

Clinical Practice and Manufacturing Recommendations

Obstruction of the upper lobe of the ventilated lung by a double-lumen tube during one-lung ventilation will likely have disastrous effects on gas exchange. The left lower lobe constitutes only 20–25% of the lung, and the right middle lobe and right lower lobe together constitute only 30–35% of the lung, and ventilation of only these small segments will be associated with extremely large shunts. Consequently, the margin of safety in positioning double-lumen tubes is a critical issue.

Our findings strongly support five clinical practice and manufacturing recommendations. First, since the average margin of safety in positioning left-sided tubes is much greater than the average margin of safety in positioning right-sided tubes, left-sided tubes should be used whenever possible. In addition, since the position of the right upper lobe takeoff is so variable, use of a Mallinkrodt right-sided tube will result in right upper lobe obstruction in approximately 11% of patients, even if the right endobronchial cuff is positioned just below the tracheal carina. Since the average margin of safety with Rusch right-sided tubes is so small, some degree of right upper lobe obstruction should be expected in an even higher percentage of cases. The only time a right-sided tube should be used is when there is a lesion involving the left mainstem bronchus that could be injured by a left-sided tube or could prevent the correct positioning of the left-sided tube.

Second, after chest inspection and auscultation maneuvers, the position of both left- (all manufacturers) and right-sided (Mallinkrodt) double-lumen tubes should be confirmed with the aid of a fiberoptic bronchoscope and, if necessary, adjusted so that the endobronchial cuff is just below the tracheal carina. When the endobronchial cuff is just below the tracheal carina (the most proximal acceptable position), the possibility of upper-lobe obstruction is minimized. Indeed, when these double-lumen tubes are inserted in a conventional manner (*i.e.*, "blindly"), 48% may be expected to be malpositioned in some way when their position is directly checked with a fiberoptic bronchoscope.[8] In order to place the endobronchial cuff just below the tracheal carina, a fiberoptic bronchoscope with an outside diameter of less than 4.5 mm must be passed down the tracheal lumen of the tube. The position of the tube should be adjusted so that the blue endobronchial balloon is visualized just below the tracheal carina in the contralateral mainstem bronchus. On the left side, this position will prevent obstruction of the left upper lobe in the large majority of cases. On the right side, although this position will minimize right upper lobe obstruction, it will not be able to prevent at least partial obstruction of the right upper lobe in approximately 11% of cases.

The Rusch right-sided tube requires the fiberoptic bronchoscope to be passed down the right lumen. The exact depth of insertion of this tube should be adjusted so that flexion of the fiberoptic bronchoscope through the right upper lobe ventilation slot brings the right upper lobe bronchial orifice into full view. Unfortunately, in practice, this maneuver requires much more expertise than visualizing a blue endobronchial cuff just below the tracheal carina.

Third, our findings suggest the use of larger, rather than smaller, sized right- and left-sided double-lumen tubes. As tube size increases, proximal margin of left cuff to left lumen tip length (all manufacturers) and length of Mallinkrodt right cuff remain constant, and length of Rusch right upper lobe ventilation slot increases; thus, the margin of safety either remains constant (all left-sided and Mallinkrodt right-sided tubes) or increases (Rusch right-sided tubes) with increasing tube size. While the margin of safety remains constant or increases with increasing double-lumen tube size, airway resistance and difficulty in secretion removal decreases. In view of the positive correlation between patient height and mainstem bronchial length, and with the provision that an intubation can be atraumatically performed, we suggest the use of 39- and 41-French tube in patients who are 5′8″ or taller, and use of 35–39 French tubes in patients who are shorter.

Fourth, since the margin of safety in positioning both left- and right-sided tubes is small, our findings emphasize how dangerous head movement can be (flexion or extension) in displacing a previously well-positioned tube. Both extreme head flexion and extension from the neutral head position can cause a 28-mm distal or proximal movement of the catheter tip, respectively,[9,10] which is a distance greater than the average margin of safety in positioning any double-lumen tube. Thus, a previously well-positioned tube with the endobronchial cuff just below the tracheal carina can either obstruct an upper lobe or become decannulated from the mainstem bronchus by head flexion and extension, respectively. Therefore, during turning of the patient from the supine to the lateral decubitus position, the anesthesiologist should pay strict attention to holding the head in a neutral position and the tube perfectly still while other members of the operating room team are responsible for the rest of the body, catheters emerging from the body, and placing supports about the patient. The position of the tube should be rechecked again with the fiberoptic bronchoscope once the patient has been settled into a lateral decubitus position.

Finally, our findings have two important manufacturing implications. The bevel of the tip of the left lumen of a left-sided tube, which helps to guide the left lumen into the left mainstem bronchus, should be made shorter and closer to the left endobronchial cuff. This would reduce proximal margin of left cuff to left lumen tip distance and increase the margin of safety by 4–6 mm. The left lumen cuff should be narrower by 5–8 mm. The left cuff would still make contact with the left mainstem bronchus over a wide surface area. Thus, with these two changes combined, the margin of safety for left-sided tubes could be increased by 9–14 mm (a 50% increase). We think modern right-sided tubes are designed as well as they can be, and the margin of safety in positioning right-sided tubes cannot be improved.

References

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