The Relationship Between the Diameters of the Adult Cricoid Ring and Main Tracheobronchial Tree: A Cadaver Study to Investigate the Basis for Double-Lumen Tube Selection

Alan H. Seymour, MBChB, FRCA

Objective: **Previous investigation of the adult cadaver larynx has shown that the cricoid diameter never exceeds that of the glottis. This further analysis looks at the anatomic relationships between the diameter of the cricoid ring and those of the main tracheobronchial tree to discover how they relate to double-lumen tube selection.**

Design: **Prospective.**

Setting: **A city mortuary.**

Participants: **Adult cadavers undergoing autopsy.**

Interventions: **The trachea was partially transected above the first ring to expose the cricoid cartilage from below and was then further opened with a progressive longitudinal incision to allow access to the tracheobronchial tree.**

Measurements and Main Results: **In 59 male and 49 female white cadavers, the largest of a graduated series of cylindrical sounds that the cricoid ring would accommodate was noted. They were then used to measure the maximum diameters of the main tracheobronchial tree. In both sexes, the mean diameter of the cricoid was shown to be the same as that of the left main bronchus, the left main bronchus to cricoid ratio almost invariably exceeded 83% (against the maximum double-lumen tube tip-to-body ratio of 80%), and the coefficient of correlation (r) between the cricoid and left main bronchial diameters was 0.6. For the trachea and left main bronchus, *r* was 0.5 in male cadavers and 0.45 in female cadavers.**

Conclusions: **The dimensions of the cricoid ring best define those of the main bronchi. Knowing its diameter should assist anesthesiologists with double-lumen tube selection.**

KEY WORDS: larynx, glottis, cricoid cartilage, tracheobronchial tree, measurement, thoracic, double-lumen tube size

THE CADAVER study by Seymour and Prakash[1] established that the diameter of the adult cricoid cartilage never exceeds that of the vocal cords. Because the cricoid is a nondistensible ring, it would limit the size of double-lumen tube (DLT) that could be passed into the tracheobronchial tree, but there is no published information to show whether this matters. Robertshaw[2] is reputed to have conducted anatomic studies when designing the eponymous tube, but exactly what he measured and how he did it remain uncertain. Jesseph and Merendino[3] produced a detailed analysis of the dimensions of the tracheobronchial tree, but the method is poorly described and they omitted the larynx from consideration. DLT size selection is a field that continues to generate a great deal of interest, and all the current techniques have limitations. The object of this study was to further assess some of the basic anatomic relationships affecting endobronchial intubation, in the hope of throwing fresh light on the process of choosing the right tube.

MATERIALS AND METHODS

This study continues the investigation described in the previous article[1] with measurements taken from the same set of cadavers. As before, a graduated set of cylindrical sounds was used representing 1-mm increments from 9 to 25 mm. The tips were in the form of a blunt cone, and the main bodies were 40-mm long, which is roughly the length of the bronchial portion of some DLTs. After the diameters of the glottis and subglottis had been measured,[1] the first 2 or 3 rings of the trachea were opened and the biggest sound that could be passed down to the carina, without force, was noted. The main surrounding structures were then cleaned away, and the trachea opened fully to a point just above the carina. Again, without force, it was then possible to measure the maximum diameter of the left main bronchus (LMB). After this, the largest sound that would enter the right side up to its shoulder at 40 mm was taken to represent the diameter of the bronchus intermedius. Normally, it was then possible to insert one of larger diameter to a depth of 20 or 30 mm, which was recorded as the size of the right main bronchus (RMB). Lengths were not measured because of the inevitable disturbance in longitudinal relations given the nature of the study. Using Excel 97 (Microsoft Corporation, Redmond, WA) basic descriptive statistics were applied to the results and the correlation among cricoid, tracheal, and bronchial diameters was determined. The results were also analyzed manually to see how the data relate to the dimensions of commonly used DLTs. Numerous studies[1,4,5] have shown poor correlation between patient size and airway dimensions so that exercise was not repeated on this occasion.

RESULTS

A complete set of figures was available for 108 white cadavers (59 men, 49 women); all measurements were taken once by the same individual. Demographic data for males were (mean ± standard deviation in brackets) age 70 (13), height 174 cm (8), weight 75 kg (22). Similarly, for women, the

From the Department of Anaesthetics, Birmingham Heartlands Hospital, Birmingham, United Kingdom.

Address reprint requests to Alan H. Seymour, MB ChB, FRCA, Department of Anaesthetics, Birmingham Heartlands Hospital, Bordesley Green East, Birmingham B9 5SS, United Kingdom. E-mail: alan.seymour@heartsol.wmids.nhs.uk

1053-0770/03/1703-0003$30.00/0

doi:10.1016/S1053-0770(03)00057-0

Table 1. Diameters of Adult Cadaver Tracheobronchial Tree Expressed to the Nearest 0.5 mm

	Male (mm ± SD) (n = 59)	Female (mm ± SD) (n = 49)
Cricoid	17* (1.5)	13 (1)
Trachea	22 (1.5)	19 (1.5)
Left main bronchus	16.5* (1.5)	13 (1)
Right main bronchus	17.5 (2)	14 (2)
Bronchus intermedius	15 (2)	12 (1.5)

Abbreviation: SD, standard deviation.

*The uncorrected difference between these 2 measurements was 0.3 mm.

demographic data were age 78 (9), height 158 cm (8), and weight 59 kg (17). In cross section, the shape of the trachea varied greatly among individuals. The membranous part varied from flaccid and concave to taut and flat or even slightly convex; it was not found to be elastic, and there was little scope for inadvertent stretching beyond its natural maximum. The left main bronchus was nearly always of uniform diameter. On the right, the first subcarina could usually be felt with the tip of the fifth finger but was difficult to visualize given the conditions. No instance of a tracheal origin for the right upper lobe was noted, but in 2 cases it was high and oblique, almost giving the appearance of trifurcation. With these, it was difficult to obtain any meaningful measurements on that side so the 2 sets of results were omitted from analysis. Results are summarized in Table 1. In no individual was the trachea, distal to the third or fourth ring (the point to which it was initially opened), smaller in diameter than the cricoid cartilage. The coefficient of correlation (r) between the diameter of the cricoid and that of the left main bronchus was 0.6 for men ($p < 0.001$), with that of the trachea and left main bronchus being 0.5 ($p < 0.001$). For women, the comparable figures were 0.6 ($p < 0.001$) and 0.45 ($p < 0.01$), respectively. The correlation between cricoid and tracheal diameter was 0.35 ($p < 0.01$) in men and 0.4 ($p < 0.01$) in women. Figs 1 and 2 show the male and female size distributions for left and right main bronchi and the bronchus intermedius.

DISCUSSION

The main points arising from the results are as follows:

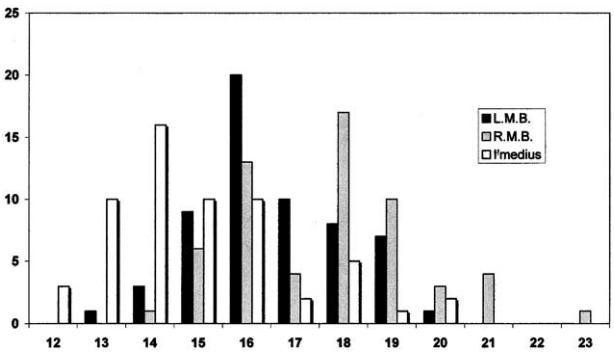

Fig 1. The distribution of adult male diameters for the LMB, RMB, and bronchus intermedius (n = 59). X axis = diameter (mm); y axis = number.

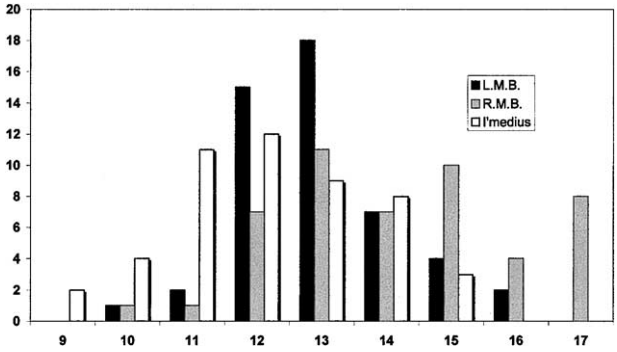

Fig 2. The distribution of adult female diameters for the LMB, RMB, and bronchus intermedius (n = 49). X axis = diameter (mm); y axis = number.

1. The mean diameter of the cricoid in both sexes is practically the same as the mean diameter of the left main bronchus, with a better correlation than that for the trachea.
2. The diameter of the left main bronchus almost invariably equals or exceeds 83% of the diameter of the cricoid ring.
3. The mean diameter of the right main bronchus is about 1 mm greater than the left, but the bronchus intermedius is approximately 1 mm less. The bronchus intermedius-to-cricoid ratio falls below 80% in 8 men (14%) and 2 women (4%)—2 of these men (3%) and 1 woman (2%) lying in the 70% to 75% ratio bracket.

Too few nonwhites were studied to enable their inclusion in the analysis so the possibility of racial differences respecting these 3 points cannot be ruled out. The correlation difference (point 1) is striking but fails to reach statistical significance—double the numbers would be needed to provide an answer either way.

In vivo radiographic techniques[6-8] give diameters that are roughly 12% less than for the cadaver investigation. The reason for this is that the main tracheobronchial tree is essentially a passive structure. Its resting (as opposed to maximum) size is a function of the set of the incomplete cartilaginous rings, pressure from surrounding structures, and the phase of respiration, to name the more obvious factors.

Table 2 gives the dimensions of Bronchcath tubes supplied in the United Kingdom (Mallinckrodt Ltd, Athlone, Ireland), which are in line with those quoted by other authors.[4,5,6,9,10] Because of the flexible nature of the cricoid cartilage and bronchial tree, it is the tube circumference that is important, but this is conveniently expressed as the mean diameter. The figures give a tip-to-body ratio tending toward, but crucially never exceeding, 80%. (Note that the left tip size varies from 9.5 mm for the 35F tube to 11.3 for the 41F. The range of 1.8 mm is less than ± 1 standard deviation on the mean diameter of the left main bronchus *in vivo* or postmortem.)

Predicting the size of the left main bronchus from that of the trachea, an easily accessible parameter, is known to be unsatisfactory.[7] Only time-consuming and expensive 3-dimensional CT reconstruction enables direct measurement of the main

Table 2. Bronchocath Double-Lumen Tube Sizes (Diameters Are Mean)*

Nominal Size (F)	Actual Gauge (F)	Actual Diameter (Rt and Lt Tubes) mm	Diameter of Left Tip (mm)	†Tip Size/Main Body Ratio (%)
35	37	12.3	9.5	78
37	39	12.9	9.9	79
39	42	13.9	10.4	77
41	43	14.5	11.3	76

Abbreviations: Rt, right; Lt, left.
*Author's measurements (2002).
†Left-sided tubes only.

bronchi *in vivo*.[6,8] In view of these difficulties, clinical judgment continues to play a major role in selecting DLT size. However, an undersized tube can suffer instability and cuff overinflation. On the other hand, one that is too large may stick at the cricoid and have to be discarded (at considerable expense) or might, it is suggested, damage the main bronchus as it is forced into position[1,4,6,9]—an assertion that must now be examined. In the cadaver study, force was not used in the measuring process, but the results show that in all but 1 case (whose LMB in any case measured 13 mm) the left main bronchial diameter equalled or exceeded 83% of the cricoid diameter—more, in other words, than the tip-to-body ratio of any current DLT. This strongly suggests that any tube easily negotiating the cricoid ring will not be the primary cause of a ruptured bronchus; faulty technique is far more likely to be to blame. (There is little published information about lesser degrees of trauma.[11]). There is no disagreement that the biggest DLT that can be deployed is the safest; ventilation and suction are easier and tube position more stable.[4,5,6,12] The problem has been to decide what represents this optimum size. The study shows that a tip sealing with little air in the cuff can do so without physically wedging or stretching the bronchus unreasonably; it is, rather, undersized polyvinylchloride types that are most commonly associated with bronchial rupture because the overinflated cuff takes on high-pressure characteristics.[13] The widest cadaver main bronchi encountered were left 21 mm (unsuitable for the main analysis) and right 23 mm—slightly less, on either side, than the size of a fully inflated (but not distended) 41F BronchoCath bronchial cuff. This may help to explain the good safety record of the large tube.

Turning to the right bronchial tree, the profile is usually rather conical, with the main bronchus about 2 mm larger on average than the bronchus intermedius. A tube may have to enter the bronchus intermedius if the upper-lobe slot is to align, and the cadaver cricoid/intermedius ratios suggest that, in some cases, this could be a problem. However, the absolute values for bronchus intermedius diameter meant that, in this series, only 1 woman (and no men) might have caused such a difficulty. In conclusion, the diameter of the cricoid ring is shown to be the ruling dimension of the tracheobronchial tree. Firstly, it controls the maximum size of tube that can be passed into the distal trachea. Secondly, its size correlation with the left main bronchus is at least as good as that of the trachea and probably better. Finally, although the actual choice of tube is a matter for the individual anesthesiologist, the cadaver analysis shows that, in whites, even the biggest DLT that will easily negotiate the subglottis is unlikely to be too large for the main bronchi. (This negates 1 secondary conclusion of the previous cadaver study[1]). With careful alignment and a few extra cuts, the diameter of the cricoid could be established beforehand from the computed tomography scan of the thorax. An alternative would be to measure it directly, after induction, by using specially designed sounds or suitably adapted dilators, echoing the practice of trying the biggest DLT likely to pass the larynx and moving down a size if it fails to do so.

ACKNOWLEDGMENT

The author thanks the city of Birmingham coroner Dr Richard Whittington and the assistance of the staff at the Central Mortuary for their support and encouragement. The author also thanks Karen Stuart-Smith for help with the manuscript.

REFERENCES

1. Seymour AH, Prakash N: A cadaver study to measure the adult glottis and subglottis: Defining a problem associated with the use of double-lumen tubes. J Cardiothorac Vasc Anesth 16:196-198, 2002

2. Robertshaw FL: Low-resistance double-lumen endobronchial tubes. Br J Anaesth 34:576-579, 1962

3. Jesseph JE, Merendino KA: The dimensional interrelationships of the major components of the human tracheobronchial tree. Surg Gynec Obstet 105:210-214, 1957

4. Hannallah MS, Benumof JL, Ruttimann UE: The relationship between left mainstem bronchial diameter and patient size. J Cardiothorac Vasc Anesth 9:119-121, 1995

5. Brodsky JB, Macario A, Mark JBD: Tracheal diameter predicts double-lumen tube size: a method for selecting left double-lumen tubes. Anesth Analg 82:861-864, 1996

6. Brodsky JB, Malott K, Angst M, et al: The relationship between tracheal width and left bronchial width: Implications for left-sided double-lumen tube selection. J Cardiothorac Vasc Anesth 15:216-217, 2001

7. Hampton T, Armstrong S, Russell WJ: Estimating the diameter of the left main bronchus. Anaesth Intensive Care 28:540-542, 2000

8. Eberle B, Weiler N, Vogel N, et al: Computer tomography-based tracheobronchial image reconstruction allows selection of the individually appropriate double-lumen tube size. J Cardiothorac Vasc Anesth 13:532-537, 1999

9. Hannallah MS, Benumof JL, Silverman PM, et al: Evaluation of an approach to choosing a left double-lumen tube size based on chest computed tomographic scan measurement of left mainstem bronchial diameter. J Cardiothorac Vasc Anesth 11:168-171, 1997

10. Chow MY, Liam BL, Thng CH, et al: Predicting the size of a double-lumen endobronchial tube using computed tomographic scan measurements of the left main bronchus diameter. Anesth Analg 88: 302-305, 1999

11. Clapham MCC, Vaughan RS: Bronchial intubation. A comparison between polyvinylchloride and red rubber double-lumen tubes. Anaesthesia 40:1111-1114, 1985

12. Benumof JL, Partridge BL, Savatierra C, et al: Margin of safety in positioning modern double-lumen endotracheal tubes. Anesthesiology 67:729-738, 1987

13. Brett G, Fitzmaurice BG, Brodsky JB: Airway rupture from double-lumen tubes. J Cardiothorac Vasc Anesth 13:322-329, 1999