

# Comparison between Computerized Tomography-Guided Bronchial Width Measurement versus Conventional Method for Selection of Adequate Double Lumen Tube Size

## Abstract

**Background:** Selection of adequate size double lumen tube (DLT) is complicated by marked inter-individual variability in morphology and dimensions of tracheobronchial tree. Computerized tomography (CT)-guided left bronchus width measurement has been used to predict adequate size DLT in European and Singapore population; however, no such data exist for Indian population who are racially different. We compared the effect of DLT size selection based on CT-guided bronchial width measurement to the conventional method of DLT selection on the adequacy of both lungs isolation and on the safety margin of right-sided DLT. **Methods:** Fifty-five adults scheduled to undergo thoracotomy were enrolled in this prospective observational study. An appropriate size left- or right-sided DLT with outer diameter 0.5–1 mm smaller than the CT-measured bronchial width was selected for the isolation of lungs. Adequacy of separation was checked using fiberoptic bronchoscope. The safety margin of selected right-sided DLT size was calculated from CT-measured right upper lobe bronchus width and diameter of right upper lobe ventilation slot of the DLT. **Results:** Adequate separation of lungs was achieved in 92.7% of studied population, 90.9% in males, and 95.4% in females. Among these, 54.9% patients required different sized DLT as compared to conventional method. Overall safety of margin of right-sided DLTs was comparable between two methods of DLT selection (median [IQR] 4.8 (3.5–6.8) vs. 6.59 (3.5–7.8),  $P = 0.317$ ). DLT size with adequate isolation of lung correlated with height, tracheal width (TW) on chest X-ray, and age of the patients. A formula to calculate DLT size based on these variable was derived. **Conclusion:** CT-measured bronchial width predicts the appropriate DLT size better than conventional method. In the absence of CT scan facility, patient height, age, and chest X-ray TW may be used to predict DLT size with reasonable accuracy.

**Keywords:** Adequacy of lung isolation, bronchial diameter, double lumen tube size selection, safety margin

## Introduction

Successful one lung ventilation (OLV) requires a reliable method for lung isolation, selection of which is complicated by marked inter individual variability in the morphology and dimensions of tracheobronchial tree.<sup>[1]</sup> Among various available methods of lung isolation, double lumen tube (DLT) is considered to be gold standard. An inappropriately small-sized DLT may cause increased resistance to gas flow, development of high intrinsic auto-positive end expiratory pressure (PEEP), or may require high endobronchial cuff volumes for lung isolation that could cause damage to the bronchus.<sup>[2,3]</sup> In addition, a small-sized DLT may not allow passage of fiberoptic

bronchoscope through its lumen.<sup>[4]</sup> Indeed, an undersized DLT has been implicated for development of tension pneumothorax, pneumomediastinum, and longitudinal laceration of left main stem bronchus.<sup>[5-7]</sup> On the other hand, a too large size DLT may also cause rupture of the trachea or bronchus.<sup>[8]</sup> There is lack of proper objective criteria for selection of adequate size DLT.

Previous studies regarding the selection of adequate size DLT were focused on left-sided DLT, partly because infrequent use of right-sided DLT.<sup>[9-14]</sup> These studies have shown poor correlation of patient age, weight, or height with left bronchial width and size of DLT.<sup>[9,13]</sup> Tracheal width (TW) on chest X-ray has been used as a guide for DLT size selection;<sup>[9,14,15]</sup> however, it

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had shown to have poor correlation with computerized tomography (CT)-measured left bronchial width (LBW), especially in low weight Asian females population.<sup>[11]</sup> Direct measurement of LBW on a chest X-rays is possible in only about 50% of cases.<sup>[14]</sup> Therefore, CT-guided LBW measurement has been suggested for predicting adequate size DLT in European and Singapore population.<sup>[11]</sup> However, no such data exist for Indian population who are racially different from previously studied populations.

Safety margin of a DLT is defined as length of tracheobronchial tree over which it can be moved without obstructing a conductive airway. For right-sided DLT, it is determined by the difference between length of right upper lobe ventilation slot and diameter of right upper lobe of bronchus. The safety margin of right-sided Rush DLT (Duluth, GA) increases from 1 to 4 mm with use of 39 F or 41 F DLT instead of 35 F or 37 F DLT, as the length of the right upper lobe ventilation slot increases with increase in DLT size.<sup>[16]</sup>

We hypothesize that selection of largest possible DLT will increase incidence of adequate lung isolation and the safety margin for right-sided DLT. Hence, we observed the effect of DLT size estimation based on preoperative CT-measured bronchial width, on the adequacy of lung isolation for left and right-sided DLT (primary outcome) and on the safety margin of right-sided DLT. A correlation for adequate size DLT with the TW measured on digital chest X-ray and demographic profile of patients (secondary aim) were accomplished.

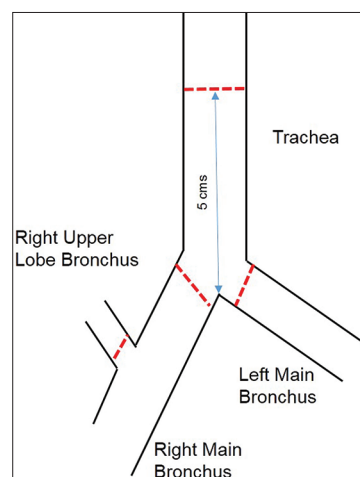
## Materials and Methods

This prospective observational cohort study was conducted between July 2014 and December 2015 at a tertiary care center. After obtaining institutional ethics committee approval and written informed consent from patients, 55 adults with ASA I – III physical status scheduled to undergo thoracotomy, requiring insertion of a right or left DLT were included in the study. Exclusion criteria included ASA grade IV or above, discrete narrowing of trachea or bronchus on chest X-ray or CT scan, abnormal coagulation parameters, and patient refusal for the consent.

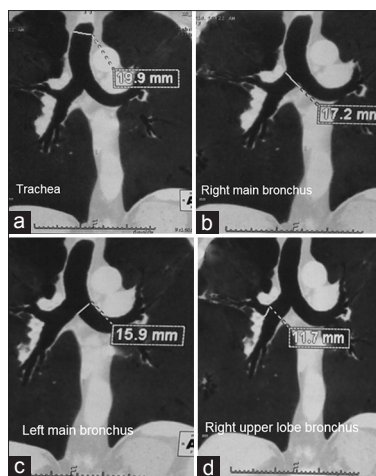
A routine preanesthetic evaluation performed a day prior to surgery included digital chest X-ray PA view and noncontrast CT chest. Patient's demographic profile, associated comorbid illness, preoperative pulmonary functions test, and preoperative medications were noted. Tracheal diameter was measured on the preoperative digital chest X-ray PA view using electronic callipers. The average value of tracheal diameters obtained at mid, upper, and lower border of interclavicular junction was noted. A noncontrast CT volumetric data acquisition was done from apex of lungs to upper border of domes of diaphragm using 64 slice multi-detector CT scans (Toshiba Aquilion, Toshiba medical systems corporation, Japan) in end-inspiratory

breath hold. Axial data set was retro-reconstructed to 0.5-mm slice thickness and subsequently reconstructed in coronal plane on a dedicated workstation. All measurements were taken in true axial plane using electronic calipers by an experienced radiologist. True axial plane refers to measurement of lumen diameter of trachea, bronchi, and right upper lobe bronchus perpendicular to their anatomical plane [Figures 1 and 2]. The diameter of the bronchus was measured within 1 – 2 mm of carina, where left and right bronchi could be distinctly seen as two singular structures. Similarly, diameter of right upper bronchus was measured within 1 – 2 mm of its origin.

Anesthesia management was standardized for all patients. Induction of anesthesia was done using intravenous administration of fentanyl and titrated doses of propofol. Injection vecuronium was used to facilitate endotracheal intubation. Maintenance of anesthesia was accomplished using injection fentanyl and inhalation of isoflurane oxygen mixture titrated to maintain bispectral index between 40 and 60. All patients received Rusch DLT to avoid disparity in outer diameters among various DLT brands and due to increase in safety margin with increasing size of Rusch DLT. Left-sided DLT was used in all except those with narrowing of left main bronchus. For intubation, DLT size was selected on the basis of preoperative CT-measured bronchial diameter. We measured the outer diameters of five each different sizes of Rusch DLTs (32 F, 35 F, 37 F, 39 F, and 41 F) at the widest part of deflated bronchial cuff using vernier callipers. The average value obtained from these measurements was used as the reference for purpose of selecting DLT size. Selected DLT size for both left and right lungs was such that the CT-measured bronchial diameter remains 0.5 – 1.0 mm larger than the upper limit of 95% confidence interval of average outer diameter of the bronchial lumen of the DLT.<sup>[17]</sup> Adequacy of DLT position was checked using a FOB. Adequate lung isolation was defined as presence of complete lung deflation after lung



**Figure 1:** Line diagram shows the technique of measurement of tracheal, bronchial, and right upper lobe diameters on a coronal reconstructed CT image



**Figure 2:** Reconstructed CT coronal images (on 0.5-mm retro-reconstructed axial CT data set) show measurements of trachea (a), bronchi (b and c), and right upper lobe bronchus (d) diameters. Tracheal diameter was measured 5 cm above floor of carina; diameters of bronchi and right upper lobe bronchus were measured within 1-2 mm of their origin

isolation as assessed by an operating surgeon not involved in the study and absence of clinically significant leak (less than 20% of delivered tidal volume) at peak inspiratory pressure of 30 cmH<sub>2</sub>O with 2.5 ml or less air insufflation in the bronchial cuff of a correctly positioned DLT.<sup>[13]</sup> An inability to advance selected DLT into the main bronchus gently was considered as inadequate size DLT, for which one size lower DLT was inserted. If a DLT was found inappropriate for lung isolation, one size larger or smaller DLT based on finding was inserted and adequacy of lung isolation was rechecked. The predicted DLT size based on conventional method of DLT selection based on patients height, gender, and weight<sup>[18]</sup> was noted and correlated with one used for intubation. In case the smallest sized DLT cannot be inserted due to small-sized bronchus, a bronchial blocker of adequate size (1 – 2 mm smaller than bronchial width) was used and adequacy of separation was confirmed using FOB. Safety margin for right DLT was calculated by subtracting diameter of right upper lobe bronchus measured on CT from the diameter of right upper lobe ventilation slot of selected DLT.

During OLV, volume-controlled ventilation with tidal volume 6 – 8 ml/kg to maintain peak inspiratory pressure <35 cmH<sub>2</sub>O and FiO<sub>2</sub> 1 was used. The respiratory rate was adjusted to maintain end tidal CO<sub>2</sub> <45 mmHg. Arterial oxygen desaturation during OLV was managed first by excluding malpositioning or mechanical obstruction of the DLT followed by one or more of the following at the discretion of attending anesthesiologist: application of PEEP to the dependent lung or continuous positive airway pressure to the nondependent lung or intermittent inflation of the dependent lung. Incidence of intraoperative lung isolation failure as defined by occurrence of incomplete lung deflation or partial lung ventilation, clinically significant air leak, systemic oxygen desaturation (<95%

on FiO<sub>2</sub> 1), or CO<sub>2</sub> retention (EtCO<sub>2</sub> ≥ 50 mmHg) were noted. The incidence of right upper lobe collapse in the postoperative chest X-ray was noted. Patients were observed in the postanesthesia care unit for features of airway or vocal cord injuries.

### Statistical analysis

Statistical analysis was done using Statistical Package for Social Sciences (SPSS Inc., Chicago, IL, version 22.0 for Windows). Normality of quantitative data was checked using Kolmogorov – Smirnov tests. For quantitative variables, mean or medians were calculated. Standard deviation or interquartile range as needed was calculated to assess measures of dispersion. Means between two groups were compared using *t*-test or Mann – Whitney *U* test as appropriate. Proportions were compared using Chi-square or Fisher's exact test as applicable. Correlation analysis of patient demographics and TW with the size of DLT used among patients, with adequate lung isolation, was done using Spearman's rank correlation coefficient. Multivariate linear regression analysis of patient demographics and TW with DLT size in patients with adequate lung separation was performed. Two tailed *P* < 0.05 was considered statistical significant.

The sample size was calculated using openEpi, version 3, open source calculator – SSPropor. Based on previous study by Chow *et al.*<sup>[11]</sup> with a positive predictive value of 84%, acceptance error of ±10%, level of significance ( $\alpha$ ) = 0.05, type II error ( $\beta$ ) = 20%, power of study (1-  $\beta$ ) = 80%, and confidence intervals of 95%, the required sample size was 52. Considering possible dropout, we included a total of 55 patients in the study.

### Results

A total of 57 patients were screened for the enrolment in the study, out of which 2 were excluded due to gross tracheal narrowing on the preoperative CT scan contraindicating DLT navigation through trachea. All remaining 55 patients completed the study.

Adequate isolation of lung was achieved in 92.72% (51/55) of patients, of these 54.90% (28/51) patients required different size DLT than that predicted by conventional method. Among patient requiring different size DLT, 33.33% (17/51) required larger, whereas 21.56% (11/51) required smaller sized DLT. Gender-wise, adequate isolation of lung was achieved in 90.9% (30/33) males and 95.45% (21/22) of females [Table 1]. Adequate separation could not be achieved in 7.28% (4/55) cases; of these, 1.82% (1/55) had received same size DLT, whereas 5.46% (3/55) received different size DLT (1 received larger sized DLT, whereas 2 received smaller sized DLT) compared to conventional method [Table 1].

Right-sided DLT was inserted in seven patients. CT-based method of DLT selection resulted in use of same or larger size DLT in six patients and smaller sized DLT in one

**Table 1: Adequacy of lung separation and difference in DLT size prediction between CT-based bronchial width measurement and conventional method of DLT selection**

Adequacy of separation (%)	Study population (n=55)		Male (n=33)		Female (n=22)	
	Adequate	Inadequate	Adequate	Inadequate	Adequate	Inadequate
	51/55 (92.72)	4/55 (7.28)	30/33 (90.9)	3/33 (9.10)	21/22 (95.45)	1/22 (4.54)
<b>Difference in DLT size (%)</b>						
Same	23/51 (45.09)	1/55 (1.82)	15/30 (50)	0	8/21 (38.1)	1/22 (4.54)
Different	28/51 (54.90)	3/55 (5.46)	15/30 (50)	3/33 (9.10)	13/21 (61.9)	0
Larger than conventional	17/51 (33.33)	1/55 (1.82)	8/30 (26.66)	1/33 (3.03)	9/21 (42.8)	0
Smaller than conventional	11/51 (21.56)	2/55 (3.64)	7/30 (23.33)	2/33 (6.07)	4/21 (19.1)	0

DLT=Double lumen tube, CT=Computerized tomography

patient as compared to conventional method. Overall safety margin of right-sided DLTs was comparable between two methods of DLT selection (CT-based method, median (IQR) 4.8 (3.5 – 6.8) vs. 6.59 (3.5 – 7.8) in conventional method,  $P = 0.317$ ). Although safety margin of DLT remains same in six patients with either methods of DLT selection, it reduced by 3 mm in one patient due to smaller size DLT requirement based on CT-based method.

Among those who completed the study, 33 were male and 22 were female. Height and weight were significantly higher in males than females, but age was comparable between two genders in the studied population. The tracheal and bronchial width were significantly larger among males compared to females ( $P < 0.002$ ); however, the ratio of bronchial to TW remains comparable between both sexes ( $P = 0.188$ ) [Table 2].

Selected DLT size showed positive correlation with the height, age, weight of patients, and TW measured on chest X-ray [Figures 3 and 4]. On multivariate regression analysis, DLT size was found correlated with height of patient, TW on chest X-ray, and age of the patients in the descending order of their level of significance [Table 3]. A formula for the prediction of adequate size DLT from variables with significant correlation was derived as  $Y = (A_1X_1 + A_2X_2 + A_3X_3) + B$ , where  $Y =$  DLT size,  $A_1 = \beta$ -coefficient (0.04) of variable 1 (age),  $X_1 =$  age in years,  $A_2 = \beta$ -coefficient (0.09) of variable 2 (height),  $X_2 =$  height in centimeter,  $A_3 = \beta$ -coefficient (0.29) of variable 3 (chest X-ray measured TW),  $X_3 =$  chest X-ray measured TW in mm,  $B =$  constant (13.08) [Table 3].

Among female or male patients, none of the demographics characteristics were found correlated with DLT size on multivariate analysis.

## Discussion

The result of present study showed that DLT size selection based on bronchial width measurement on CT could achieve adequate separation of lungs in 92.7% of studied subjects, 90.9% in males and 95.4% in females. Of these, 54.9% patients required different DLT size when compared to conventional method of DLT selection.

**Table 2: Effect of gender on demographics and airway dimensions**

Patients characteristics	Males (n=33) Median (IQR)	Females (n=22) Median (IQR)	P
Age (years)	40.0 (31.0-56.0)	34.5 (21.0-41.7)	0.087
Height (cm)	167.0 (163.0-170.0)	156.0 (151.0-160.0)	0.0001*
Weight (kg)	53.0 (50.0-65.0)	48.0 (44.5-56.0)	0.013*
BW (mm)	12.0 (10.9-13.4)	10.0 (9.8-10.6)	0.0001*
TW (mm)	19.16±2.81	16.94±1.69	0.002*
Mean±SD			
BW to TW ratio	0.64±0.565	0.606±0.301	0.188
Mean±SD			

CI=Confidence intervals, TW=Tracheal width, BW=Bronchial width. Mann-Whitney test used for age, height, and weight and for bronchial width and Student's independent  $t$ -test used for tracheal width and bronchial width to tracheal width ratio. \*Statistically significant at  $P < 0.05$

**Table 3: Multivariate regression analysis of patient's demographic and tracheal width with DLT size in patients with adequate lung isolation among studied population**

Parameters	Patients characteristics Median (IQR)	DLT size based on CT-measured bronchial width (n=51)	
		$\beta$ -Coefficient	P
Age (years)	36.0 (28.0-50.0)	0.044	0.05*
Weight (kg)	51.0 (48.0-61.0)	0.053	0.077
Height (cm)	163.0 (155.0-169.0)	0.090	0.026*
Tracheal width (mm)	18.0 (16.3-18.9)	0.291	0.029*
Constant		13.082	

C.I=Confidence intervals,  $\beta$ =Bbeta coefficient, DLT=Double lumen tube, CT=computerized tomography. \*Statistically significant at  $P \leq 0.05$

Proper isolation of lung is essential to prevent contamination of contralateral lung during thoracic surgery. An adequate size DLT is the one with largest sizes whose bronchial component fits easily into the bronchus with minimal air leak when the bronchial cuff is deflated.<sup>[13]</sup> Previously bronchial width diameter has been shown to predict appropriate DLT size better than demographic parameters.<sup>[13]</sup> Although bronchial width can be measured directly on chest X-ray, it is seen clearly

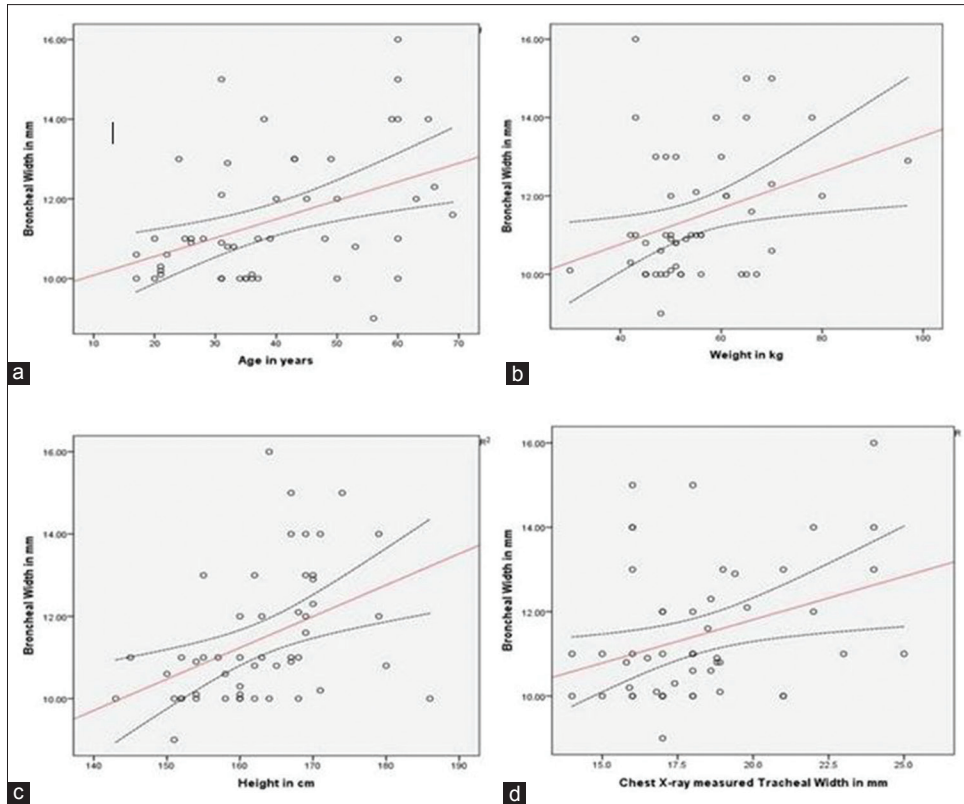


Figure 3: Spearman's correlation analysis of demographics, (a) age,  $P = 0.005$ ; (b) weight,  $P = 0.003$ ; (c) height,  $P = 0.0001$  and tracheal width (d),  $P = 0.038$  with bronchial widths among patients with adequate lung isolation

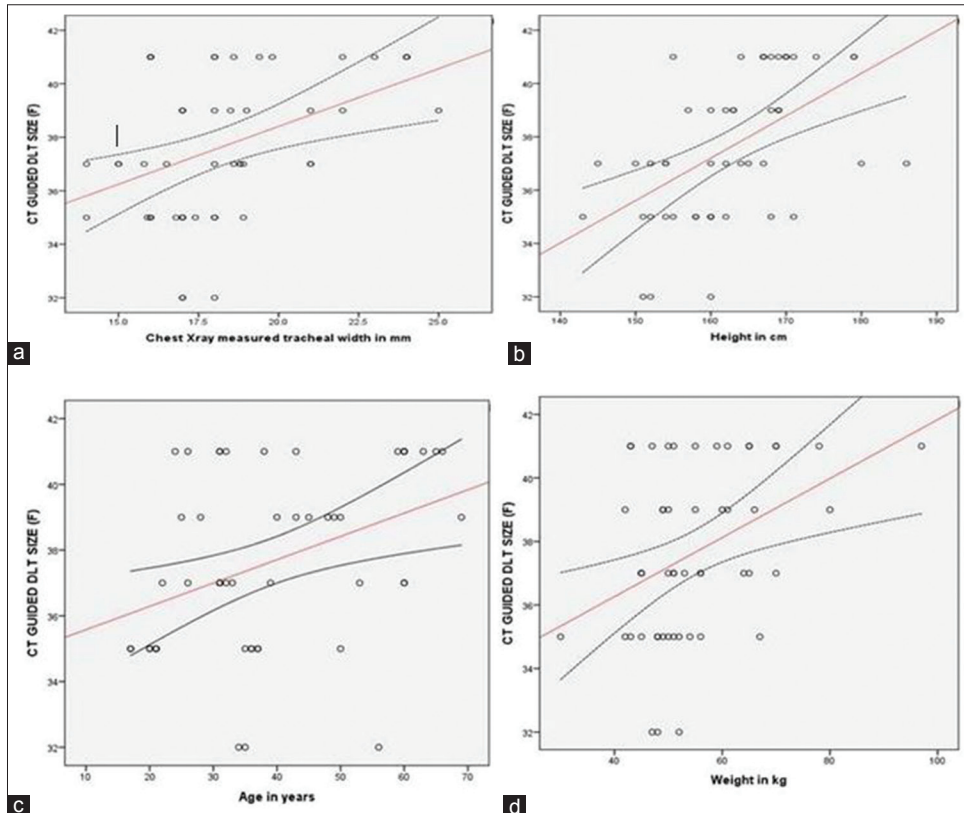


Figure 4: Shows Spearman's correlation analysis of tracheal width (a),  $P = 0.005$ ; demographics (b) height,  $P = 0.0001$ ; (c) age,  $P = 0.005$ ; (d) weight,  $P = 0.01$ , with DLT size among patients with adequate lung isolation

only in about 50% of the cases.<sup>[14]</sup> More accurately, it can be measured from preoperative CT scan. Chow *et al.* achieved overall positive predictive value of 84.4% and 61.1% among males and females, respectively, after selecting DLT sizes 32 F, 35 F, 37 F, 39 F, and 41 F for left main bronchus diameters of <10, 10, 11, 12, and >12 mm, respectively, measured 7 – 10 mm below carina on chest CT scan.<sup>[11]</sup> Hanallah *et al.* achieve adequate isolation of lungs in 85% of patients using left DLT bronchial diameter 1 – 2 mm smaller than the patient's left bronchus diameter measured just beyond the level of carina, where left and right bronchi could be seen as distinct structures.<sup>[13]</sup> Eberle *et al.* achieved adequate separation in 100% cases using preoperative CT scans to perform 3D reconstruction of upper tracheobronchial tree and selecting DLT that best fit reconstructed images on superimposition in at least two planes (frontal and sagittal).<sup>[15]</sup> We achieved satisfactory isolation of lungs in 90.9% males, 95.45% females, and in 92.72% of the studied population. This difference in incidence of isolation from previous study could be related to different criteria used for selecting DLT size and defining adequate isolation of lungs in our study.

Benumof *et al.* showed that the safety margin of Rusch right-sided DLT varies from 1 to 4 mm depending on the size of DLT.<sup>[16]</sup> This was calculated based on his finding of average size of right upper lobe bronchus on autopsy (11 mm) and the size of right upper lobe ventilation slot of 35 F and 37 F Rusch DLT (12 mm) while that of 39 F and 41 F DLT (15 mm). Present study showed higher (3.5 – 7.8 mm) safety of margin for right-sided DLTs. This observed difference may be because we used exact values of right upper bronchus opening measured on CT of each subject to measure their safety margin rather than a single average value (average value of right upper bronchus opening found in autopsy) to calculate safety margin in our patients.<sup>[16]</sup> Present study result showed comparable safety margins with use of either of two methods of DLT selection. This may be because right-sided DLT was used in only few patients. Although three of seven patients received larger size DLT compared to conventional method, their safety margin remained the same. On the contrary, in one patient who received smaller sized DLT (35 F) than conventional method (39 F), its safety margin decreased resulting in net decrease in safety margin in our study.

Bronchial width has been shown to be directly proportional to the TW.<sup>[9,17,19]</sup> TW at mid-clavicular level had good correlation with LBW measured 1 cm below carina on 3D reconstructed CT scans.<sup>[17]</sup> Jesseph *et al.* reported high correlation between LBW and TW in a post-mortem study.<sup>[20]</sup> Brodsky *et al.* showed that LBW can be predicted from TW on chest X-ray by  $LBW = (0.45) (TW \text{ in mm}) + 3.3 \text{ mm}$ .<sup>[10]</sup> The TW and bronchial widths measured in our patients are in consist with previous reports.<sup>[9,17,20]</sup>

Most researchers failed to demonstrate patients demographics such as sex, height, and weight which consistently predict LBW.<sup>[13,19]</sup> Hampton *et al.* suggested that no indirect method of estimating bronchial width is absolutely reliable and that gold standard method for DLT selection would be direct airway measurement.<sup>[19]</sup> Hanallah *et al.* reported a weak but significant correlations ( $r^2 = 0.23$ ) between height and age and LBW in men but no correlation was observed in women.<sup>[14]</sup> Brodsky *et al.* measured TW and LBW from chest radiographs and found weak but significant correlations between age and height and LBW in men and height and LBW in women.<sup>[10]</sup>

Previously sex, height, and weight alone or in combination have been used to select DLT.<sup>[21,22]</sup> In the present study, DLT size was predicted by height of the patient, TW measured on chest X-ray, and age of the patients. Using multivariate regression analysis, we derived a formula to predict suitable DLT size based on the correlated variables as  $DLT \text{ size} = 0.044 (\text{age in years}) + 0.09 (\text{height in cm}) + 0.291 (\text{CXR measured TW in mm}) + 13.082$ .

There were few limitations in this study in addition to small sample size. Study was unblinded and observational in nature; so, possibility of observer bias cannot be ruled out. Sample size was not powered enough to find difference in safety margin of right-sided DLT.

In conclusions, this study confirms that in the studied population, CT-measured bronchial width predicts the appropriate DLT size better than conventional method. In the absence of CT scan facility, patient height, age, and chest X-ray TW may be used to predict DLT size with reasonable accuracy.

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Nil.

### Conflicts of interest

There are no conflicts of interest.

### References

1. Slinger PD. Fiberoptic bronchoscopic positioning of double-lumen tubes. *J Cardiothorac Anesth* 1989;3:486-96.
2. Hannallah MS, Benumof JL, Bachenheimer LC, Mundt DJ. The resting volume and compliance characteristics of the bronchial cuff of left polyvinyl chloride double-lumen endobronchial tubes. *Anesth Analg* 1993;77:1222-6.
3. Burton NA, Fall SM, Lyons T, Graeber GM. Rupture of the left main-stem bronchus with a polyvinylchloride double-lumen tube. *Chest* 1983;83:928-9.
4. Bardoczky G, d'Hollander A, Yernault JC, Van Meulem A, Moures JM, Roemans P. On-line expiratory flow-volume curves during thoracic surgery: Occurrence of auto-PEEP. *Br J Anaesth* 1994;72:25-8.
5. Sakuragi T, Kumano K, Yasumoto M, Dan K. Rupture of the left main-stem bronchus by the tracheal portion of a double-lumen endobronchial tube. *Acta Anaesthesiol Scand* 1997;41:1218-20.
6. Hannallah M, Gomes M. Bronchial rupture associated with the use of a double-lumen tube in a small adult. *Anesthesiology* 1989;71:457-9.

7. Sivalingam P, Tio R. Tension pneumothorax, pneumomediastinum, pneumoperitoneum, and subcutaneous emphysema in a 15-year-old Chinese girl after a double-lumen tube intubation and one-lung ventilation. *J Cardiothorac Vasc Anesth* 1999;13:312-5.
8. Wagner DL, Gammage GW, Wong ML. Tracheal rupture following the insertion of a disposable double-lumen endotracheal tube. *Anesthesiology* 1985;63:698-700.
9. Brodsky JB, Macario A, Mark JB. Tracheal diameter predicts double-lumen tube size: A method for selecting left double-lumen tubes. *Anesth Analg* 1996;82:861-4.
10. Brodsky JB, Lemmens HJ. Tracheal width and left double-lumen tube size: A formula to estimate left-bronchial width. *J Clin Anesth* 2005;17:267-70.
11. Chow MY, Liam BL, Thng CH, Chong BK. Predicting the size of a double-lumen endobronchial tube using computed tomographic scan measurements of the left main bronchus diameter. *Anesth Analg* 1999;88:302-5.
12. Amar D, Desiderio DP, Heerdt PM, Kolker AC, Zhang H, Thaler HT. Practice patterns in choice of left double-lumen tube size for thoracic surgery. *Anesth Analg* 2008;106:379-83.
13. Hannallah M, Benumof JL, Silverman PM, Kelly LC, Lea D. 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* 1997;11:168-71.
14. Hannallah MS, Benumof JL, Ruttimann UE. The relationship between left mainstem bronchial diameter and patient size. *J Cardiothorac Vasc Anesth* 1995;9:119-21.
15. Eberle B, Weiler N, Vogel N, Kauczor HU, Heinrichs W. Computed tomography-based tracheobronchial image reconstruction allows selection of the individually appropriate double-lumen tube size. *J Cardiothorac Vasc Anesth* 1999;13:532-7.
16. Benumof JL, Partridge BL, Salvatierra C, Keating J. Margin of safety in positioning modern double-lumen endotracheal tubes. *Anesthesiology* 1987;67:729-8.
17. Brodsky JB, Malott K, Angst M, Fitzmaurice BG, Kee SP, Logan L. The relationship between tracheal width and left bronchial width: Implications for left-sided double-lumen tube selection. *J Cardiothorac Vasc Anesth* 2001;15:216-7.
18. Miller RD, Eriksson LI, Fleisher LA, Kronish JP, Young WL. Anaesthesia for thoracic surgery. In: Slinger PD, Campos JH, editors. *Text Book of Anaesthesia*. 8<sup>th</sup> ed. Philadelphia: Elsevier; 1956-57.
19. Hampton T, Armstrong S, Russell WJ. Estimating the diameter of the left main bronchus. *Anaesth Intensive Care* 2000;28:540-2.
20. Jesseph JE, Merendino KA. The dimensional interrelationships of the major components of the human tracheobronchial tree. *Surg Gynecol Obstet* 1957;105:210-4.
21. Slinger P. Choosing the appropriate double-lumen tube. a glimmer of science comes to a dark art. *J Cardiothorac Vasc Anesth* 1995;9:117-8.
22. Slinger P. A view of and through double-lumen tubes. *J Cardiothorac Vasc Anesth* 2003;17:287-8.