Airway dimensions and margin of safety with the left–sided double-lumen tube in patients of a short stature

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Background: The size and depth of the double-lumen tube (DLT) are important for one-lung ventilation (OLV). In patients of a short stature, it is difficult to perform OLV successfully. We designed this study to evaluate the dimensions and margin of safety of the left main bronchi in patients of a short stature for appropriate OLV.

Methods: Chest computed tomography (CT) scans of 241 patients (22 male, 219 female) of a short stature (height below 155 cm) were analyzed retrospectively. The diameters of the trachea (DT), the right and left main bronchi (DR and DL), and the lengths of the right and left main bronchi (LR and LL) were measured at the coronal section of the chest CT scans using a picture archiving communication system program.

Results: There were no significant correlations between the heights and lengths of the right and left main bronchi. In addition, the ages and weights of the patients showed no significant correlations with the airway dimensions. The lengths of the bronchial lumen of the left-sided Mallinckrodt DLT show variations of 3 to 5.5 mm with tubes of identical sizes. The margin of safety is 13.8 \(\pm\) 4.1 mm assuming that appropriately sized DLTs are inserted.

Conclusions: For successful and safe OLV in patients of a short stature, anesthesiologists should consider the length of the main bronchus and the actual length of the bronchial lumen of the DLT.

Key Words: Body height, Bronchi, Computed tomography.

INTRODUCTION

One-lung ventilation (OLV) is essential for lung surgery. There are several methods which can be used to achieve lung separation, and among them the use of a double-lumen tube (DLT) is most common [1]. In most cases of OLV, lung separation is performed successfully. When OLV is not properly achieved, it can affect not only the surgical outcome but also patient safety. The size and depth of the insertion of the DLT are important factors for successful OLV [2-6]. Many previous studies have shown that the patient’s height is correlated with the size and depth of the insertion of the DLT and that the height can be used to determine these values [5,7-9]. In patients of a short stature (below 155 cm), however, the height value is not go good predictor of the size and depth of the insertion of the DLT [2]. It is difficult to achieve successful OLV in these cases, and these patients are more susceptible to airway injuries [10,11]. Several studies have attempted to determine the depth of insertion and the size of the DLT in patients of a short stature [2,12]. Most studies which attempted to determine the optimal position of the DLT focused on the position of the DLT at the tracheal carina level. However, obstruction of the left upper lobe caused by the distal position of the left bronchial lumen is an important cause of hypoxemia during OLV with a left-sided DLT in patients of a short stature [12]. The current authors also experienced several cases of hypoxemia caused by obstruction of left upper lobe in patients of a short stature. In most of these cases, the correct tube position could not be achieved successfully. The authors assumed this stemmed from the narrow margin of safety of the left main bronchus in these patients. Organized data on the airway dimensions of short patients may be helpful in these situations; however, there is no such data as yet.
The present study was designed (1) to establish organized data on airway dimensions in patients of a short stature, and (2) to evaluate the margin of safety of the left main bronchus in these patients. The diameters of the trachea and the main bronchus and the lengths of the right and left main bronchus were measured in chest computed tomography (CT) scans to evaluate the dimensions of the airway and the margin of safety in these patients.

**MATERIALS AND METHODS**

The use of medical records and CT images of the subjects was approved by the Institutional Review Board of our hospital. Among the 20- to 75-year-old patients who had chest CT scans at our hospital from January to December of 2013, patients with a height of less than 155 cm, as measured within a week of their chest CT scans, were selected as the subjects. Patients with tracheal intubation, lung mass lesions, or chronic obstructive pulmonary disease in their medical records were excluded.

Measurements of the diameter and length of the airway were done at the coronal section of the chest CT scans using the picture archiving communication system (PACS) program at our hospital (Maroview; Marotech, Seoul, Korea). To reduce error in the measurements, one anesthesiologist was wholly responsible for them. The diameters of the trachea (DT) and the right and left main bronchi (DR and DL) were defined as the width of the airway at the interclavicular [13] and the 1 mm - subcarinal level [14,15], respectively. The length of the right and left main bronchi (LR and LL) were measured in several steps (Fig. 1). First, the section of the chest CT for which the carina was most clearly visible was selected. Second, the section for which left bronchus bifurcation was most clearly visible (the right upper bronchus branching site in the right main bronchus) was selected. Third, the length from the carinal tip to inflection point of main bronchus was measured (D1) and difference of depth between first and second selected CT scan was checked (D2). Finally, under the assumption that the main bronchus is straight, the length of right or left main bronchus was calculated using the Pythagorean Theorem.

\[
LL^2 \text{ (or } LR^2) = D1^2 + D2^2
\]

The margin of safety can be measured in an intubated state with a left-sided DLT. However, actual intubation could not be done in this case, as the present study was retrospective. The margins of safety were measured on the assumption that DLTs of the appropriate size were intubated. To determine the appropriate tube size, we created a guideline (Table 1). This appropriate tube size guideline was based on DLT dimensions in the present study and on Chow et al. [7] and Brodsky et al. [16] guidelines. The margin of safety was defined as LL minus the length from the upper margin of the bronchial cuff.

| Tube size (Fr) | DT (mm) | DL (mm) |
|---------------|--------|--------|
| 37            | > 15   | > 12   |
| 35            | > 14   | > 11   |
| 32            | > 12.5 | > 9    |
| 28            | > 11   | > 8    |

Fr: French, DT: diameter of the trachea, DL: diameter of the left main bronchus.

**Table 1. Guideline for Selecting the Appropriate Size of the DLT**

Fig. 1. Method used to measure the length of the left main bronchus. In the coronal section of chest computer tomography, a) section 1 (the section for which the carina is visible most clearly) and section 2 (the section that for which of the main bronchus is visible most clearly) were selected. b) The length from the carina tip to the inflection point of the main bronchus (D1) was measured, and the difference in the depth between section 1 and section 2 (D2) was checked. c) Subsequently, under the assumption that the main bronchus is straight, the length of the main bronchus was calculated using the Pythagorean Theorem.
to the bronchial tube tip (Fig. 2). Because the reports noted that the lengths of the bronchial cuff and the bronchial lumen of the DLT have wide variations even with a tube of the same size and from the same manufacturer [17,18], one anesthesiologist directly measured the length and external diameter of the bronchial lumen of a left-sided DLT (Broncho-Cath, Mallinckrodt, USA) sized from 28 to 37 French (Fr). The external diameter of the bronchial lumen of the DLT was measured at a black radiopaque line above the bronchial cuff using vernier calipers.

All measured data are shown as the mean ± standard deviation (SD). To estimate the correlation between the measured parameters and the patient’s height, Pearson’s correlation coefficient and linear regression analysis were used. Differences in the distributions of the body height and the margin of safety according to the tube size were analyzed using ANOVA, and a post-hoc analysis performed by Duncan and Tukey-B analyses. The statistical analysis was conducted using SPSS (ver. 18.0, SPSS Inc., USA), and P values below 0.05 were assumed to be statistically significant.

### RESULTS

Data from 241 patients (22 male, 219 female) were analyzed. The demographic data pertaining to the subjects are shown in Table 2.

#### Dimensions of the airway and DLT

The parameters of the dimensions of the airway (DT, DR, DL, LL and LR) as measured in present study are shown in Table 3. There are no significant correlations between the heights and the measured airway dimensions (Fig. 3). Although there is correlation between the patients’ heights vs LL when using Pearson’s correlation coefficient (P = 0.006), the authors conclude that it is not a significant correlation because R-square is very low in the linear regression analysis (R^2 = 0.031, P = 0.006; Fig. 3F). In addition, age and weight show

### Table 2. Demographic Data of the Subjects

| M/F (person) | 22/219 |
|--------------|--------|
| Height (cm)  |        |
| < 140 cm     | 2      |
| 140-145 cm   | 17     |
| 145-150 cm   | 44     |
| 150-155 cm   | 178    |
| Age (yr)     | 61.3 ± 10.6 |
| Weight (kg)  | 53.6 ± 8.4 |

Values are number of patients or the mean ± SD.

### Table 3. Dimensions of the Airway

| Height (cm) | Diameter (mm) | Length (mm) |
|-------------|---------------|-------------|
|             | DT            | DR          | DL          | LR           | LL           |
| < 140       | 13.0 ± 2.0    | 12.1 ± 2.9  | 12.4 ± 1.4  | 12.1 ± 1.7   | 41.5 ± 3.5   |
| 140-145     | 15.0 ± 1.9    | 12.6 ± 1.5  | 12.5 ± 0.9  | 17.2 ± 3.5   | 40.5 ± 3.9   |
| 145-150     | 15.2 ± 1.3    | 13.1 ± 1.3  | 12.8 ± 1.3  | 18.9 ± 4.0   | 43.4 ± 2.5   |
| 150-155     | 15.4 ± 1.8    | 13.1 ± 1.6  | 13.0 ± 1.6  | 18.1 ± 3.9   | 43.4 ± 3.5   |
| Total       | 15.3 ± 1.8    | 13.0 ± 1.5  | 12.9 ± 1.6  | 18.1 ± 3.9   | 43.2 ± 3.5   |

Values are the mean ± SD. DT: diameter of the trachea, DR: diameter of the right main bronchus, DL: diameter of the left main bronchus, LR: length of the right main bronchus, LL: length of the left main bronchus.
Fig. 3. Scatter plot of the height vs the margin of safety (A), the diameter of the trachea (B), the right and left main bronchus (C, D), and the length of the right and left main bronchi (E, F). There is no significant correlation between the measured airway dimensions and the height ($P > 0.05$).
no significant correlations with the measured airway dimensions. The diameters and the lengths of the left lumens of the DLTs show wide variation (Table 4). There is a length difference of 3 to 5.5 mm within the same size for the left-sided Mallinckrodt DLT.

**Appropriate tube size and margin of safety**

On the assumption that the appropriate size of the left-sided Mallinckrodt DLT, selected by our guideline (Table 1), were inserted, nearly three fourths of the subjects were found to be suitable for a tube which exceeded 35 Fr (Table 5). The margin of safety is $13.8 \pm 4.1$ mm, and a very low R-square was noted in the linear regression analysis with regard to body height ($R^2 = 0.024$, $P = 0.017$; Fig. 3A). Hence, the authors conclude that the margin of safety showed no significant correlation with body height. The minimal and maximal margin of safety values are 2.5 and 29.4 mm, with no negative margin of safety values found among the subjects. When the subjects are divided into four groups according to the selected DLT size, there are no significant differences in heights between the groups (Fig. 4A). However, the margins of safety for the 28 and 32 Fr tube groups are significantly higher than those for the 35 and 37 Fr groups (Fig. 4B).

**DISCUSSION**

The present study investigates the dimensions of the airway in patients of a short stature. The length of the airway is known to be correlated with the height of the patient, and patients’ heights have been used to estimate sizes and depths when inserting DLTs [5,7-9,19]. However, many studies have shown that the lengths of the main bronchi are not significantly correlated with patients’ heights [6,20-22]. Rho et al. [22] measured the lengths of the right and left main bronchi by computed tomography. In their study, patients’ heights were $170 \pm 7.1$ cm for males and $156.2 \pm 5.4$ cm for females, and the lengths of the main bronchi were $21.0 \pm 4.8$ mm (male, right), $49.2 \pm 4.8$ mm (male, left), $18.0 \pm 4.0$ mm (female, right) and $44.6 \pm 3.9$ mm (female, left). They concluded that there were no significant correlations between patients’ heights and the lengths of the main bronchi. Eberle et al. [20] also examined the lengths of the main bronchi, as measured by computed tomography. The lengths of the left main bronchi were $48 \pm 6$ mm in males and $44.5$ mm in females, and there were no significant correlations between heights and lengths of the left main bronchi. The present study also concludes that there are no significant correlations between

| Table 4. Dimensions of the Left-sided Mallinckrodt DLT |
|------------------------------------------------------|
| **Size of tube (Fr)** |
| **N** |
| **Length of Bronchial Lumen (mm)** |
| **Mean ± SD** | **Min-Max** |
| **External diameter of Bronchial Lumen (mm)** |
| **Mean ± SD** | **Min-Max** |
| 28 | 5 | 22.8 ± 1.1 | 21-24 | 7.1 ± 0.2 | 7.1-7.5 |
| 32 | 8 | 25.3 ± 1.6 | 22-27.5 | 8.4 ± 0.2 | 8.2-8.6 |
| 35 | 8 | 30.6 ± 1.5 | 29-33.5 | 10.1 ± 0.2 | 9.8-10.4 |
| 37 | 14 | 31.2 ± 1.1 | 29-33 | 11.0 ± 0.3 | 10.4-11.5 |

Values are the mean ± SD or minimal value (Min) & maximal value (Max). Fr: French, N: number of DLT.

| Table 5. Appropriate DLT Size and Margin of Safety of the Subjects |
|---------------------------------------------------------------|
| **Height (cm)** | **Tube French (person)** | **Margin of safety (mm)** |
| **28** | **32** | **35** | **37** |
| < 140 | 1 | 0 | 1 | 0 | 14.8 ± 8.9 |
| 140-145 | 1 | 3 | 7 | 26 | 11.1 ± 4.5 |
| 145-150 | 1 | 7 | 14 | 22 | 13.6 ± 3.1 |
| 150-155 | 7 | 39 | 52 | 80 | 14.1 ± 4.2 |
| Total | 10 (4.1%) | 49 (20.3%) | 74 (30.7%) | 108 (44.8%) | 13.8 ± 4.1 |

Values are number of patients or the mean ± SD.
the heights and lengths of the main bronchi. Body heights are mainly correlated with the lengths of the trachea, not the main bronchi. The results of previous studies which found that body height was correlated with the depth of the insertion of the DLT [5,7-9] may have been influenced mainly by the length of the trachea, not the main bronchi, as the insertion depth was checked at the tracheal carinal level.

In the present study, the margin of safety is 13.8 ± 4.1 mm in patients of a short stature. Given that the previously reported average margin of safety with a left-sided Mallinckrodt DLT was 19 mm in a person of normal height [23], patients of a short stature show a narrower margin of safety than the general population.

Depending on the depth of the tube, malposition of the left-sided DLT can be categorized as the following three cases: (A) the tracheal tip is located above the carina, (B) the tracheal cuff protrudes over the carina and thus interferes with opposite-side ventilation, and (C) the tracheal lumen is located in the segmental bronchus leading to possible hypoxemia and damage to the airway. The margin of safety is the length between (B) and (C). For successful OLV, the DLT should be located between (B) and (C), and a larger margin of safety means that it is easier to maintain successful OLV. If the margin of safety is narrow, it is difficult not only to locate but also to maintain the DLT in the proper position. The position of the DLT is often checked after intubation by a fiberoptic bronchoscope, but the position of the DLT can deviate due to patient positioning. The position of the endotracheal tube can also deviate by 15 mm with neck flexion and 8.5 mm with neck extension movements [24]. Klein et al. [25] reported deviation that exceeded 0.5 cm in 42.4% of patients with a lateral-side DLT after left lateral positioning, finding also that not only proximal but also distal malposition could occur after patient positioning. In study by Inoue et al. [3], the DLT deviated by more than 1.0 cm in 32% of patients after patient positioning to a lateral position. The margin of safety in the present study is 13.8 ± 4.1 mm, and this result indicates a high probability of DLT malposition when changing the posture or neck position of the patient.

There are two important factors which determine the margin of safety when using a left-sided DLT: the lengths of the left main bronchus and the bronchial lumen of the DLT. If the length of the left main bronchus is short, as in patients of a short stature, it is important to choose a tube with a short bronchial lumen. In terms of extending the margin of safety, it may be beneficial to choose a 28 or 32 Fr DLT than a 35 or 37 Fr DLT, as the length difference between the 35 and the 37 Fr DLT is about 1.5 mm. However, 32 and 35 Fr DLTs show nearly a 5 mm difference (Table 4). Fig. 4B also shows a significantly larger margin of safety with 28 and 32 Fr DLTs than with 35 and 37 Fr DLTs. Although the use of a small DLT increases the margin of safety, it can increase airway resistance as well [26]. While organized data pertaining to airway pressure according to the size of the DLT does not exist, we can estimate it using Poiseuille’s law, as described in the equation below [27].

\[
R = \frac{(8\eta l)}{\pi r^4}
\]
Here, R denotes the resistance, η is the viscosity of the content, l is the cannula length, and r is the internal diameter. The calculated resistance of the bronchial lumen of a left-sided DLT is about 3.0 fold at 28 Fr, 1.7 fold at 32 Fr, 1.3 fold at 35 Fr relative to the value at 37 Fr. In addition, as repositioning the DLT with fiberoptic bronchoscopy is essential in OLV [28], a DLT with a small internal diameter may interfere with the insertion and manipulation of the bronchoscope. It is recommended to use a DP-type (outer diameter: 3.1 mm) bronroscope with a 32 Fr DLT and a LFP-type (outer diameter: 2.2 mm) bronroscope with a 28 Fr DLT [29]. The use of a LFP-type bronroscope, however, is limited on account of its relative fragility and lack of a suction port [30]. Therefore, it would be a better choice to use a 32 Fr DLT and a DP-type bronroscope so as to increase the margin of safety, but anesthesiologists should consider the risks and benefits of a small DLT in every case.

Additionally, the present study shows that the lengths of the left lumen of a DLT have considerable variation of nearly 2 to 5 mm even when the tubes are the same size. Russell and Strong [18] reported that the Fr size of a DLT is a highly limited value when used to determine the appropriate size to be selected, as the lengths and diameters of the bronchial cuff also vary widely. Moreover, in his next study, the length of the bronchial lumen also showed wide variation in the same manner [17]. This manufacturing variance can be critical for the patients with a narrow margin of safety, such as the patients of a short stature studied here. When a DLT is used in such a patient, the physician should consider the actual length of the bronchial lumen of the DLT and measure it before use. The best solution, however, is to improve the quality of manufacturing and create standard guidelines with regard to the length of the bronchial lumen of a DLT.

There are some limitations of the present study. First, we measured the dimensions of patients’ airways from conventional chest CT scans. Hence, there may be some error, specifically from the CT scans. Second, an actual endotracheal intubation with a left-sided DLT was not done in the present study; hence, the clinical relevance is unknown. As previously described, the size of DLT was often determined by the patient’s height. However, height is not a good predictor to determine the size of the DLT in patients of a short stature. The diameter of the trachea and the left main bronchus can also be used to predict the size of the DLT accurately [4,7,13,16]; therefore, the present study uses the diameter of the trachea and the left main bronchus to determine the size of the DLT. Applying this result to short patients has low clinical relevance, further prospective studies are needed. Finally, the number of male patients of a short stature is much lower than that of females, meaning here that any gender difference with reference to airway dimension could not be analyzed. Previous studies reported no significant differences of airway dimensions between genders [6,21]. Although the earlier studies showed larger airway dimensions in male groups, they concluded that this difference was not due to gender but was instead caused by the greater heights of those in the male groups. The small number of male patients in the present study may not be a major problem. In spite of these limitations, the measured dimensions of the left and right main bronchi in the present study may be helpful as a reference for anesthesiologists who perform OLV in patients of a short stature and to companies which manufacture reformed DLTs for patients of a short stature.

In conclusion, the present study investigated the dimensions of the airway and the margin of safety of left-sided DLTs for patients of a short stature (below 155 cm) and the length variation of the bronchial lumen of the DLT. For successful and safe OLV with a left-sided DLT in patients of a short stature, the anesthesiologist should consider the length of the main bronchus and the actual length of the bronchial lumen of the DLT.

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