The Resting Volume of the Bronchial Cuff of the Left-sided Double-lumen Tube and the Diameter of the Left Mainstem Bronchus Indicated for Each Double-lumen Tube Size

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Background: The purposes of this study were to assess the resting volume of the modified bronchial cuff of left-sided double-lumen bronchial tubes (DLT) and to determine the maximum range of the mainstem bronchial diameter indicated for DLT.

Methods: Left-sided DLTs (Broncho-Cath™) of 35-41 Fr (n = 5 each) were used for the study. The cuff was inflated with air in 0.5-ml increments to a volume of 5 ml and the corresponding cuff pressure was recorded. The smallest cuff volume, beyond which a 0.5 ml increase resulted in more than 10 mm Hg increase in cuff pressure, was considered to be the resting volume of that cuff. The resting volume was also calculated by differentiation on the fitted curve. The minimum required bronchial diameter was considered to be the reported OD of the bronchial tube and the maximum diameter was the measured OD of the bronchial cuff at a cuff pressure of 30 mmHg, which was measured with a precision caliper (0.1 mm intervals) at the midcuff level.

Results: The resting volume of the bronchial cuff, measured both traditionally and using the curve fitting analysis, were comparable. A DLT of any size ≥ 35 Fr can be used for a bronchus with a diameter of 10.7-20.6 mm.

Conclusions: There were extensive overlaps in the range of bronchial diameters indicated for each DLT size. Contrary to a common belief, the upper limits of the bronchial diameters indicated for all the DLTs ≥ 35 Fr seemed to be the same regardless of the DLT size. (Korean J Anesthesiol 2005; 48: S 1-4)

Key Words: cuff, double-lumen endobronchial tube, mainstem bronchus, size.

INTRODUCTION

Choice of the size of a double-lumen endobronchial tube (DLT) has so far been based on vague guidelines involving such parameters as the height, weight, and gender. 1,2 Recently, direct measurement of the left mainstem bronchial diameter on plain chest radiographs or computed tomographic scans has been performed with the goal of establishing an objective criterion for the DLT size. 3-7 For this method to be reliable, the bronchial tube diameter of the DLT must be known, 8 and the assessment of the additional space around the deflated bronchial cuff, which is to be filled with a volume of air, is also warranted.

The left-sided DLT (Broncho-Cath™) was modified with the bronchial cuff shortened by 3 mm and moved 3 mm distally. 9 Thus, the resting volume and compliance characteristics should be reevaluated. Adequacy of a DLT size has been determined depending on whether the bronchial cuff volume required for isolation is > zero but ≤ the resting volume. 5,8,10,11 Therefore, the purpose of this study was to determine the maximum range of allowable mainstem bronchial diameter for the left-sided DLTs and to help in the selection of DLT size based on the preoperatively measured mainstem bronchial diameter.

MATERIALS AND METHODS

Measurement of the resting volume of the bronchial cuff (Traditional method)

Five left-sided DLTs (Broncho-Cath™; Mallinckrodt Medical
Ltd., Athlone, Ireland) with sizes of 35, 37, 39 and 41 Fr were tested as previously described.\textsuperscript{10} The one-way valve of the pilot balloon of the bronchial cuff was connected, via a 3-way stopcock, to a pressure transducer through fluid-filled tubing. Prior to performing the measurement, the intracuff pressure was equilibrated at atmospheric pressure by removing the attached syringe, used for complete aspiration of the cuff, and exposing one limb of the 3-way stopcock to the atmosphere. The smallest cuff volume, beyond which a 0.5 ml increase in volume resulted in a more than 10 mmHg increase in cuff pressure, was considered to be the resting volume of that cuff.\textsuperscript{10}

Measurement of the resting volume of the bronchial cuff (Differentiation method)

Some inaccuracy is unavoidable in the traditional method, because the bronchial cuff was inflated in 0.5-ml increments while measuring the cuff pressure. Therefore, exponential curve fitting analysis was performed on the values of each pressure-volume curve using Matlab software (Mathworks Inc., Natick, USA). Three points around the resting volume were used as the reference points for the curve fitting analysis to find the transition point, where the slope of the tangential line on the fitted curve is 10 mmHg / 0.5 ml ($P_0$ cuff pressure / $\Delta$ cuff volume) as obtained by differentiation.

Calculation of the maximum allowable bronchial diameter for each DLT size

To prevent ischemic bronchial injury, the intracuff pressure should be $< 44$ cmH$_2$O, at which pressure the mucosal capillary perfusion was reported to decrease.\textsuperscript{12} Thus, the cuff volume at a cuff pressure of 30 mmHg (a little lower than 44 cmH$_2$O) was calculated on the fitted curve to determine the maximally allowable bronchial cuff volume without mucosal damage for each DLT size.

After inflating the bronchial cuff with the cuff volume calculated at a cuff pressure of 30 mmHg, we measured the outer diameter (OD) of the bronchial tube with a precision caliper (0.1 mm intervals) at the mid-cuff level with caution not to push the soft cuff surface (Fig. 1).

Range of the mainstem bronchial diameter indicated for each DLT size

The allowable bronchial diameter for each DLT size was presumed to range from the OD of the bronchial tube with the cuff completely collapsed\textsuperscript{7} to the largest-available cuff diameter when the resultant intracuff pressure is less than the pressure that decreases mucosal perfusion. Namely, the minimum bronchial diameter indicated for each DLT size was regarded as OD of the bronchial tube with the cuff completely collapsed,\textsuperscript{7} and the maximum bronchial diameter was the measured OD of the bronchial cuff at a cuff pressure of 30 mmHg (Fig. 1).

Statistics

Before beginning the study, a sample-size calculation was performed. Based on the pilot measurements, we calculated a sample size that would permit a type I error rate of two-tailed $\alpha = 0.05$ with a type II error of $\beta = 0.20$, i.e., power equal to 0.80. We considered a 1-mm difference as being significant when we calculated our power analysis. This required five trials in each group.

All the data are expressed as mean $\pm$ SD. Analysis of variance was used to compare the resting volumes of the bronchial cuff depending on the different sizes of DLTs. The Tukey test was used for post hoc comparisons. Paired t-test was used for the comparison between the resting volumes and the bronchial cuff volume at a cuff pressure of 30 mmHg.
Table 1. The Resting Volume and Pressure of the Bronchial Cuff of the Leftsided Double-lumen Tube Measured Traditionally or by Differentiation on the Fitted Curve, and the Cuff Volume at a Cuff Pressure of 30 mmHg

<table>
<thead>
<tr>
<th>Double-lumen tube size (Fr)</th>
<th>Traditional measurement</th>
<th>Measurement by differentiation on the fitted curve</th>
<th>Cuff volume at cuff pressure of 30 mmHg (ml)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Resting volume (ml)</td>
<td>Cuff pressure (mmHg)</td>
<td></td>
</tr>
<tr>
<td>35</td>
<td>2.5 ± 0.0</td>
<td>4.0 ± 2.5</td>
<td>3.3 ± 0.1*</td>
</tr>
<tr>
<td>37</td>
<td>2.4 ± 0.2</td>
<td>6.8 ± 2.9</td>
<td>3.0 ± 0.1*</td>
</tr>
<tr>
<td>39</td>
<td>2.1 ± 0.2</td>
<td>5.8 ± 3.3</td>
<td>2.8 ± 0.1*</td>
</tr>
<tr>
<td>41</td>
<td>2.4 ± 0.2</td>
<td>9.8 ± 3.3</td>
<td>3.0 ± 0.1*</td>
</tr>
</tbody>
</table>

Data are mean SD. N = 5 each. *P < 0.001 versus the resting volumes measured traditionally and by differentiation. Traditional measurement: While the cuff was inflated with air in 0.5-ml increments to a volume of 5 ml, the smallest cuff volume, beyond which a 0.5 ml increase in volume resulted in more than 10 mmHg increase in cuff pressure, was considered to be the resting volume of that cuff. Curve fitting analysis was performed on the mean values by using 3 points around the resting volume and the cuff pressure of 30 mmHg to find the transition point, at which dP/dV (the slope of the fitted curve) was 10 mmHg/0.5 ml as obtained by differentiation, and to determine the maximal cuff diameter without mucosal damage, respectively.

The statistics program, SPSS software version 9.0 (SPSS Inc., Chicago, USA), was used. A P-value < 0.01 was considered to be statistically significant.

RESULTS

The resting volume of the bronchial cuff and the cuff pressure at the resting volume, measured both traditionally and using the curve fitting analysis, were comparable. Cuff volume at a cuff pressure of 30 cmH₂O was higher than the resting volumes measured traditionally and via differentiation (P < 0.001)(Table 1).

When the minimum and maximum bronchial diameters indicated for each DLT size were respectively defined as the reported OD of the bronchial tube with the cuff collapsed and the measured OD of the bronchial cuff at a cuff pressure of 30 mmHg, the range of the mainstem bronchial diameter for 35-41 Fr DLT size was 9.6 ± 0.1-20.8 ± 0.2 mm, 10.0 ± 0.1-20.6 ± 0.1 mm, 10.4 ± 0.1-20.6 ± 0.1 mm and 10.7 ± 0.3-20.7 ± 0.1 mm, respectively. Therefore, a DLT of any size ≥ 35 Fr can be used for a bronchus with a diameter of 10.7-20.6 mm. In the critical bronchial diameter range of 9.6-10.7 mm, the lower limits of the indicated bronchial diameters for each DLT size varied depending on the DLT size.

DISCUSSION

There were extensive overlaps, much greater than generally thought, in the range of bronchial diameters indicated for each DLT size. In the critical bronchial diameter range of 9.6-10.7 mm, extreme caution is needed for the selection of the DLT size. Regardless of the DLT size, the upper limits of the bronchial diameters indicated for all the DLTs ≥ 35 Fr seemed to be the same. Therefore, further studies, which are intended to decide what is the ideal size based on the preoperatively measured bronchial diameter, may be needed to take advantage of a full array of DLT sizes.

In case of the Broncho-Cath® DLTs, a one-sized bronchial cuff is fitted to all the DLT sizes of 35 to 41 Fr (personal communication with the company). Accordingly, the smaller the DLT size, the smaller the cross-sectional area the bronchial tube occupies inside of the cuff. This explains the finding that the resting volume of the bronchial cuff is inversely related to the tube size. In contrast to the method used in other study, however, the intracuff pressure was equilibrated at atmospheric pressure before the injection of air in order to rule out the possible exaggeration of the resting volume by the negative intracuff pressure formed during complete aspiration of the cuff.

Even though differentiation on the fitted curve produced a resting volume similar to that measured with the traditional method, the cuff pressures obtained with both methods were much lower than the clinically allowable maximum values. Through a curve fitting analysis, however, we could obtain the cuff volume at a cuff pressure of 30 mmHg, which was a little lower than the critical value of 44 cmH₂O (reported to
decrease the mucosal capillary perfusion). In this way, the theoretically maximal cuff diameters within the range of safe cuff pressure could be found.

Contrary to a common belief that a larger DLT should be used for patients with a larger bronchus, all of the adult-sized DLTs turned out to have the same upper limits in the allowable bronchial diameters. The rule of a larger DLT for a larger bronchus may be applicable only in the critical range corresponding to the lower limits of the bronchial diameters. In this study, the cuff diameter at a cuff pressure of 30 mmHg and the OD of the bronchial tube with the cuff collapsed were used as reference values for the theoretical upper and lower limits of the mainstem bronchial diameter, respectively. Therefore, when assessing the DLT size at bedside, minimum additional lengths must be reserved as a margin of safety.

In an autopsy study of 57 adult cadavers, the diameters [mean ± SD (range)] of the left main bronchus were reported to be 15 ± 1.9 (10-18) mm in males and 12 ± 1.3 (9-15) mm in females, which are smaller than the maximum safe OD of DLT cuff that was found out in this study. Because this study was performed without outside physical restriction such as a model bronchus, it was possible to calculate the theoretical maximum upper limit on the assumption that the bronchial wall is just in contact with the cuff surface at a cuff pressure of 30 mmHg. Unless, infinite number of model bronchi with serially increasing diameters should have been needed to determine the maximum safe OD of DLT cuff.

The DLT size is determined adequate if the bronchial cuff volume required for isolation was > zero but ≤ the resting volume. Besides, following issues can be considered as guidelines for the selection of DLT size according to the results of this study: The availability of a neonatal fiberoptic bronchoscope for a bronchus of around 10 mm in diameter when the selection is to be made between 32 and 35 Fr DLT; the possible role of the tracheal lumen as a carinal hook to prevent migration of the bronchial tube too far into the lobar bronchus; the presence of any other intraluminal narrowing in the mainstem bronchus; the clinical requirement for watertight isolation (too tight DLT may allow persistent leak through wrinkles on the bronchial cuff); the anesthetist’s personal preference regarding the DLT size and; the necessity for the whole array of DLT sizes to be in stock even though only one size of DLT (35 Fr) generally suffice all adult patients.

In conclusion, the resting volume of the bronchial cuff was comparable even after its modification. There were extensive overlaps in the range of bronchial diameters indicated for each DLT size. Contrary to a common belief, the upper limits of the bronchial diameters indicated for all the DLTs ≥ 35 Fr seemed to be the same regardless of the DLT size.

REFERENCES