INTRODUCTION

The double-lumen endotracheal tube (DLT) is the most frequently used device to achieve one-lung ventilation (OLV) in various thoracic surgeries and other objectives requiring lung separation [1]. Appropriate DLT placement is crucial for patient safety because respiration is interrupted during DLT placement, and DLT malposition is the leading cause of complications such as hypoxemia. This study evaluated the effectiveness of the triple-cuffed DLT (tcDLT) in the supine and lateral positions for correct placement without bronchoscopic guidance.

Effect of patient position on the success rate of placing triple-cuffed double lumen endotracheal tubes: a two-center interventional observational study

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Background: Double-lumen endotracheal tubes (DLT) are essential for one-lung ventilation during thoracic surgery. Bronchoscopy is crucial for correct placement of a DLT to avoid complications such as hypoxemia. This study evaluated the effectiveness of the triple-cuffed DLT (tcDLT) in the supine and lateral positions for correct placement without bronchoscopic guidance.

Methods: This prospective observational study included 167 patients scheduled for elective thoracic surgery requiring one-lung ventilation. The incidence of successful placement of left-sided tcDLTs was compared between the supine and lateral decubitus positions under bronchoscopic surveillance. Successful tcDLT placement was defined as the placement of the proximal end of the bronchial cuff within 5 mm of the carina.

Results: Among 153 patients who completed the study, the successful tcDLT placement rate in the lateral position (70.6%) was significantly higher than that in the supine position (50.3%). The rate of difference was 20.3% (95% confidence interval [CI], 10.6–29.9%). The extended successful placement rate, including slightly deeper placements, showed no significant differences between the positions (88.9%; 95% CI, 83.9–93.9% in supine, 86.3%; 95% CI, 80.8–91.7% in lateral).

Conclusions: tcDLT facilitates correct tube placement in both the supine and lateral positions, with a higher lateral success rate. This finding supports the idea that tcDLTs offer a reliable alternative for lung separation when bronchoscopy is not feasible.

Keywords: Bronchoscopy; Lung separation techniques; One-lung ventilation; Supine position; Thoracic surgery; Tube placement.
acute hypoxemia during one-lung ventilation [2]. Bronchoscopy during DLT placement is the gold standard method for evaluating the appropriateness of DLT positioning [1]. It requires time and skill; sometimes obtaining the correct view in cases of massive secretion or bleeding is difficult.

Various attempts have been made to manage these patients using railroad DLT without bronchoscopy. Chest roentgenography confirms the DLT position with auscultation [1]. Various other methods and techniques have been introduced, such as the retractable carinal hook [3], use of compliance changes [4], bronchial cuff pressure changes [5], height-based assumptions [6], and video-incorporated DLT [7].

Changing from the supine to the lateral position can displace the previously positioned DLT used in thoracic surgery [8]. Bronchoscopic surveillance should be performed before commencing OLV and after any positional change to ensure that the DLT is correctly positioned. Such positional changes can cause DLT displacement and alter the anatomical angulation of the main lung bronchi. These effects were augmented when the patient was positioned laterally and flexed to increase the inter-rib distance in the upper thoracic cavity. A triple-cuffed DLT (tcDLT; Ventibronc, Flexicare, Inc.; ANKOR, Insung Medical Co., Ltd.) was developed to provide a simple method for DLT positioning during thoracic surgery. The specialized carinal cuff of the tcDLT is designed to enhance one-sided endobronchial intubation of the bronchial side tube tip and limit tcDLT advancement over an adequate position [9].

The main objective of this study was to evaluate the successful placement of a tcDLT using a carinal cuff before and after a position change in patients who require lung separation for thoracic surgery. We compared the success rates of tcDLT placement using a carinal cuff in the supine and lateral decubitus positions.

**MATERIALS AND METHODS**

**Study population**

This study was approved by Dongguk Univ. Ilsan Hospital and Konkuk Univ. Medical center Institutional Review Boards (IRB No. DUIH 2022-03-010 and KUMC 2022-03-039) and registered on clinical trials.gov (NCT05462275). Written informed consent was obtained from all study subjects. This was reported in accordance with the Strengthening the Reporting of Observational Studies in Epidemiology guidelines [10].

The reported success rate of left-sided tcDLT placement without bronchoscopic evaluation is 95.4% in the supine position [11]. We assumed that the expected difference in the success rate of tcDLT placement was 10%. A sample size of 150 was required to achieve 80% power to detect a 10% difference in the success rate of tcDLT placement at each position using McNemar’s test, with a significance level of 0.05. Regarding a 10% dropout rate, 167 patients were required.

After obtaining informed consent, 167 patients who underwent thoracic surgery under OLV were included. Patients were recruited from April 28, 2022, to January 17, 2024, at two teaching hospitals. The inclusion criteria were American Society of Anesthesiologists physical classification I or II, age 19–85 years, and elective thoracic surgery in the LLD position under OLV. Patients must undergo preoperative imaging studies to confirm the absence of any anatomical variation in the main bronchus and any history of previous lung resection. The exclusion criteria were pregnancy, anatomical abnormalities of the trachea or bronchi that precluded the use of DLT, ongoing upper respiratory tract infections, hemorrhagic disease, emergency surgery, and cases deemed inappropriate by the investigators (Fig. 1).

Fig. 1. Study flow diagram. *In case of difficult intubation, a single lumen endotracheal tube with an endobronchial blocker was used for lung separation, †Unexpected endobronchial mass in mid left main bronchus - right-sided double-lumen tube was used.
**Anesthetic management and procedures**

The day before the scheduled surgery, the appropriate tcDLT size was determined based on the measured diameter of the left main bronchus, 1 cm below the main carina, in the coronal and transverse views on chest computed tomography. All included patients received general anesthesia and perioperative management according to the department’s standard protocol. After obtaining adequate anesthesia depth and muscle relaxation, the patient’s trachea was intubated with a left-sided tcDLT of an a priori-selected size. The bronchial tube tip of the tcDLT was advanced between the vocal cords using video laryngoscopy (AceScope, Ace Medical). The stylet was then removed, the tcDLT was turned 90°counterclockwise to move the bronchial tube head toward the left, and the tcDLT was railroaded until the tracheal cuff passed through the vocal cords. The carinal cuff of the tcDLT was then inflated with 6–8 ml of air and inserted until resistance was achieved. Once resistance was felt, the carinal cuff was deflated and the tracheal and bronchial cuffs were inflated. The appropriate bronchial cuff position was evaluated using a fiberoptic bronchoscope (LF-DP, Olympus Medical System Corp.). After examination, the bronchial cuff was deflated.

The patient was placed in the supine position for the supine position. The tcDLT was withdrawn by approximately 5 cm to allow the bronchial cuff to fully exit the supra-carina, and the carinal cuff was inflated to 7 ml and advanced until resistance was felt. If resistance was felt, the carinal cuff was again deflated, the bronchial and tracheal cuffs were inflated, and the position of the bronchial cuff was assessed using a fiberoptic bronchoscope. Anesthesia was administered according to the standard anesthesia protocol.

### Assessment of tcDLT placement

After inserting the tcDLT in the supine and LLD positions, the appropriateness of the tube position was confirmed using a fiberoptic bronchoscope. Bronchoscopic examination included serial inspection of the tracheal side tube to verify the appropriateness of the bronchial cuff position and inspection of the bronchial side tube to check for airway obstruction by the tip of the bronchial side tube. In both positions, if the proximal end of the bronchial cuff of the tcDLT was within 5 mm inferior to the carina, it was considered adequate and included in position code 1. If the proximal end of the bronchial cuff of the tcDLT was positioned above the carina or more than 5 mm deeper into the tracheal bifurcation, both were considered inappropriate and were included in position codes 2 and 3, respectively. If the tcDLT entered the right tracheobronchial bifurcation, it was included in position code 4 (Table 1).

We defined successful tcDLT placement using a carinal cuff as position 1, and the other position codes were considered inappropriate. We also defined extended successful tcDLT placement as positions 1 and 3 because the deeply placed left-sided DLT is clinically acceptable, except for an obstructed second bronchus caused by the deeply placed bronchial tube tip. For the primary outcome, we compared successful tcDLT placement in the supine and lateral positions. The effect of position change was assessed for successful placement. Extended successful placement rates were also compared and the factors affecting successful placement were investigated.

### Statistical analysis

All statistical analyses were performed using R software version 4.2.2 (The R Foundation for Statistical Computing). Data are presented as the mean ± standard deviation or number (%). Normality tests were performed for all continuous variables using Shapiro’s test and Q-Q plots. Missing data were identified, and complete case analyses were performed if the missing rate was below 0.05. Outliers were also identified using a box-whisker plot, and any identified outliers were reconciled using case report forms and medical records.

Successful placement rates were compared with estimated 95% confidence intervals (CIs) for each rate. McNemar’s

### Table 1. Assessment of Location of Triple-Cuffed Double-Lumen Tube

<table>
<thead>
<tr>
<th>Assessment</th>
<th>Position code</th>
<th>Explanations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Appropriate</td>
<td>1</td>
<td>The proximal end of the bronchial cuff is within 5 mm from the opening of the left main bronchus.</td>
</tr>
<tr>
<td>Inappropriate</td>
<td>2</td>
<td>The proximal end of the bronchial cuff is located above the opening of the left main trachea.</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>The proximal end of the bronchial tube is more than 5 mm from the opening of the left main carina.</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>The bronchial tube is located in the right main bronchus.</td>
</tr>
</tbody>
</table>
test was used to evaluate the effect of position change on the successful placement rate. Because successful placement rates in the supine and lateral positions were not independent of each other, a generalized estimating equation (GEE) model was used to identify the factors affecting the results. We assumed that all recorded values had the same correlation, and an exchangeable correlation structure was used during the GEE modeling process. Statistical significance was set at P value < 0.05.

RESULTS

A total of 167 patients who underwent thoracic surgery were included in this study. Among them, 14 were excluded because of patient refusal, difficult intubation (use of a single-lumen endotracheal tube with an endobronchial blocker), or unexpected endobronchial mass in the left main bronchus. A total of 153 patients were included in the statistical analyses. No data were missing for any of the included cases.

The patient demographic characteristics are presented in Table 2. The age of the patients was 58.0 ± 17.3 years and body mass index was 24.14 ± 3.55 kg/m². The anteroposterior diameter of the left main bronchus was slightly smaller than the lateral diameter (anteroposterior 12.9 ± 1.8 mm and lateral 13.5 ± 2.1 mm). The most frequently used tcDLT size was 37 Fr, followed by 39 Fr, and 35 Fr catheters.

The results are summarized in Table 3. The successful placement rate (position code 1) was significantly higher in the lateral position than in the supine position (70.6%; 95% CI, 63.4–77.8% in the lateral position and 50.3%; 95% CI, 42.4–58.3% in the supine position). Successful placement rate was significantly increased after position change from supine to lateral position (McNemar’s test, \( \chi^2(1) = 14.286, P < 0.001 \)), and their rate difference was 20.3% (95% CI, 10.6–29.9%, Fig. 2).

Extended successful placement rates (position codes 1 and 3) were similar between supine and lateral positions (88.9%; 95% CI, 83.9–93.9% and 86.3%; 95% CI, 80.8–91.7%, respectively). Extended successful placement rates were not statistically different before and after position changes (McNemar’s test, \( \chi^2(1) = 0.321, P = 0.571 \)), and their rate difference was 2.6% (95% CI, −4.2 to 9.4%). None of the cases were presented with obstructed conducting lobar bronchus at the end of the bronchial tube tip under bronchoscopic examination. The rates of contralateral endobronchial intubation (position code 4) were 4.6% (95% CI, 1.3–7.9%) in the supine position and 0.7% (95% CI, 0.0–1.9%) in the lateral position.

### Table 2. Patients’ Characteristics

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Value (N=153)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (yr)</td>
<td>58.0 ± 17.3</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>163.88 ± 8.83</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>64.76 ± 10.61</td>
</tr>
<tr>
<td>Sex (F)</td>
<td>60 (39.2)</td>
</tr>
<tr>
<td>Left main bronchus diameter (mm)</td>
<td></td>
</tr>
<tr>
<td>Anteroposterior</td>
<td>12.9 ± 1.8</td>
</tr>
<tr>
<td>Lateral</td>
<td>13.5 ± 2.1</td>
</tr>
<tr>
<td>Size of tcDLT</td>
<td></td>
</tr>
<tr>
<td>35 Fr</td>
<td>26 (17.0)</td>
</tr>
<tr>
<td>37 Fr</td>
<td>76 (49.5)</td>
</tr>
<tr>
<td>39 Fr</td>
<td>51 (33.3)</td>
</tr>
</tbody>
</table>

Values are presented as mean ± SD or number (%). tcDLT: triple-cuffed double-lumen endotracheal tube.

### Table 3. Overall Observed Triple-Cuffed Double-Lumen Endotracheal Tube Placement Results in Supine and Lateral Positions

<table>
<thead>
<tr>
<th>Position code</th>
<th>Supine (N = 153)</th>
<th>Lateral (N = 153)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>77 (50.3)</td>
<td>108 (70.6)</td>
</tr>
<tr>
<td>2</td>
<td>10 (6.5)</td>
<td>20 (13.1)</td>
</tr>
<tr>
<td>3</td>
<td>59 (38.6)</td>
<td>24 (15.7)</td>
</tr>
<tr>
<td>4</td>
<td>7 (4.6)</td>
<td>1 (0.7)</td>
</tr>
</tbody>
</table>

Values are presented as number (%).

![Fig. 2. Successful triple-cuffed double-lumen endotracheal tube placement in supine and lateral positions. *P value <0.05 by McNemar’s test.](www.anesth-pain-med.org)
(Table 3). Bronchoscopy confirmed that the left and right directions of the tcDLT and the tracheobronchial tree were aligned in all cases with position code 4.

We evaluated the factors affecting the success of tcDLT placement using the GEE model. None of the included explanatory variables was statistically significant for successful placement in the supine position. Successful placement in the supine position significantly affected successful placement in the lateral position ($P = 0.079$), tcDLT size of 37Fr ($P = 0.037$), and smaller left main bronchus lateral diameter ($P = 0.037$; Table 4).

**DISCUSSION**

Our data indicate that successful tcDLT placement is possible in the supine and lateral positions without fiberoptic bronchoscopy. Numerous methods and techniques have been proposed to adequately place DLT without the aid of bronchoscopy [1]. Ultrasound is an alternative to bronchoscopy with a comparable adjustment time [12] and has better specificity and sensitivity for DLT position correction than clinical evaluations such as bronchoscopy [13]. Video double-lumen endotracheal tubes have the outstanding feature of continuous video surveillance from the tracheal tube tip, providing easy and safe DLT placement [14]. This also reduced the need for bronchoscopic intervention by 85.4%, indicating its universal protective role during the COVID-19 pandemic. Ultrasound confirmation methods and video double-lumen endotracheal tubes are good alternatives to bronchoscopy; however, both have limitations in terms of massive secretions or bleeding [7,12] and cost-related issues. Several attempts have been made to achieve a successful DLT placement without bronchoscopic assistance. The success rate of blind lung isolation techniques, even those performed by specialized thoracic anesthesiologists, is only 63% [15]. Formula-based DLT placement presented favorable performance, with a 70% success rate; however, this success included 0.5-1 cm tube movement required in 30% of patients under bronchoscopic examination [16]. Using the minimum peak inspiratory pressure difference as an indicator of ideal DLT placement achieved clinically successful positioning in 88% of patients, and the result was superior to that of auscultation [4]. Although these techniques have been reported, bronchoscopic examination is still considered the gold standard method for safe lung separation using DLT [15,17].

tcDLT presented excellent performance without bronchoscopy; 95.4% of the cases were within 5 mm of the depth difference between the initial and corrected positions by bronchoscopy in the supine position [11]. Thoracic surgery is often performed in the lateral position, and previous studies have demonstrated that the position of body organs changes with changes in the patient position [18]. In addition to these anatomical changes, the patient’s head and neck positions inevitably change, and DLT displacement is unavoidable during a position change from supine to lateral


<table>
<thead>
<tr>
<th>Variable</th>
<th>Supine position</th>
<th>Lateral position</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>OR (95% CI)</td>
<td>P value</td>
</tr>
<tr>
<td>Successful placement in the supine position</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Age</td>
<td>1.001 (0.981–1.022)</td>
<td>0.913</td>
</tr>
<tr>
<td>Sex</td>
<td>Reference</td>
<td>-</td>
</tr>
<tr>
<td>F</td>
<td>1.095 (0.458–2.617)</td>
<td>0.838</td>
</tr>
<tr>
<td>ASA classification</td>
<td>1.26 (0.593–2.675)</td>
<td>0.548</td>
</tr>
<tr>
<td>Tube size</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>35 Fr</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>37 Fr</td>
<td>1.440 (0.527–3.934)</td>
<td>0.477</td>
</tr>
<tr>
<td>39 Fr</td>
<td>1.397 (0.402–4.850)</td>
<td>0.599</td>
</tr>
<tr>
<td>Left main bronchus anteroposterior diameter</td>
<td>1.093 (0.905–1.320)</td>
<td>0.357</td>
</tr>
<tr>
<td>Left main bronchus lateral diameter</td>
<td>1.000 (0.847–1.180)</td>
<td>0.999</td>
</tr>
</tbody>
</table>

OR: odds ratio, CI: confidence interval. The ORs were estimated using the generalized estimating equation models. *indicates P value < 0.050.
The ability to properly position the tcDLT when inserted blindly without bronchoscopic guidance is crucial for demonstrating the usefulness of the tcDLT in both the supine and lateral positions. In our study, successful placement of the tcDLT, defined as positioning of the proximal end of the bronchial cuff within 5 mm of the opening of the left main bronchus, resulted in a higher success rate in the lateral position (70.6%) than in the supine position (50.3%). This result is consistent with the report by Zhang et al. [21]: blind DLT placement was significantly successful in the lateral position compared to the supine position, and the defined malposition rate requiring corrective tube position movement > 10 mm was 2% vs. 30% under bronchoscopy. Morphological changes in the left main bronchus from the supine to lateral position have been reported in several studies. The proposed mechanisms are gravity-induced conformational changes and the influence of mediastinal organs such as the heart and aorta. When the position changed from supine to lateral, the curvature of the left main bronchus from the trachea increased [22,23]. The influence of this anatomical change on successful placement of the DLT made it easy for the left-sided bronchial tube tip to enter the left main bronchus. In our results, successful tcDLT placement in the lateral position was negatively related to the lateral size of the left main bronchus (odds ratio, 0.78; 95% CI, 0.65–0.94). This means that the larger lateral size of the left main bronchus increases the chance of bronchial tube tip dislocation from the left main bronchus more easily in the lateral position than in the supine position. This is also supported by the correlation analysis results between the lateral size of the left main bronchus and success in supine and lateral positions (Spearman’s correlation coefficients: 0.04 in the supine position for both success and extended success, with P values of 0.601 and 0.593, respectively; −0.14 and −0.26 in the lateral position, with P values of 0.080 and 0.001 for success and extended success, respectively).

The margin of safety for positioning a left-sided tube is 15 mm [1], which is much larger than our criterion of 5 mm. The margin of safety of the right tube was significantly smaller (8 mm). This is also larger than our criteria, which means that right-sided tcDLTs also have the possibility of similar fitting ability without bronchoscopy. However, additional studies and considerations regarding the anatomical differences from left-sided endobronchial intubation are required. For left-sided DLT, some clinicians argue that DLT placement should be deeper than the ideal position at the proximal end of the bronchial cuff just below the carinal ridge [24,25]. Any deeply positioned DLT is considered a malposition, but most patients do not experience any clinical problems [26]. It is clinically essential that the DLT be positioned in the correct bronchus without upper lobe obstruction to facilitate lung isolation and adequate ventilation [27]. However, the risk of dependent lung contamination from blood, pus, or water has been proposed in cases of fine malpositioning [1]. Placing the DLT in an ideal position is crucial in case of an existing contralateral contamination risk. Our results demonstrated a higher lateral positioning success rate, implying that tcDLT is superior in blind positioning in various clinical settings.

When placing a DLT, it is important to consider the possibility of blocking the secondary bronchial orifice if the tube is inserted too deep into the left main bronchus. According to Kim et al. [11], the difference between the target depth and placement depth was greater than 20 mm in 18 patients (21.4%) who underwent conventional DLT, but it did not occur in any of the patients (0%) who underwent tcDLT. This is comparable to our observations; bronchoscopic examination revealed no cases of blocked lobar bronchi near the tip of the bronchial tube. These findings suggest that using a tcDLT with a size appropriately selected for the patient can prevent the tube from being positioned deeper than the safety margin with the help of a carinal cuff.

Our study had several limitations. The rate of successful placement of the tcDLT was considerably lower in our results than in previous research [11]. Our study was conducted by three specialized thoracic anesthesiologists and several residents who were novices in the use of DLT for lung separation. When inserting a tcDLT, the assistant inflated the carinal cuff with a predetermined volume and the performer advanced the tube until they felt sudden resistance, at which point it was stopped. The ability or sensitivity of detecting resistance can vary, which may lead to different outcomes. In this situation, tcDLTs guarantee 70.6% ideal placement or 86.3% acceptable placement, even in emergencies or for nonspecialized clinicians without bronchoscopy. Another limitation of this study was that we did not independently investigate the successful placement rate in the supine and lateral positions. According to the GEE model, success in the lateral position is closely related to success in the supine position. To clarify the genuine ability of blind tcDLT placement in the lateral position, different situations such as tcDLT intubation and railroading in laterally positioned patients must be investigated. Finally, we did not examine cases of intraoperative bronchial cuff displacement and exclud-
ed patients with preoperative tracheobronchial anatomy variations.

In conclusion, the tcDLT is a double-lumen endotracheal tube that incorporates a novel carinal cuff between the tracheal and bronchial tubes. Blind placement with carinal cuff inflation ensured left-side tcDLT placement at an acceptable depth in the supine position and enhanced the success rate in the lateral position with the carinal cuff. The tcDLT will be helpful in blindly placing the DLT and establishing lung separation in the case of unavailable bronchoscopy or difficulty performing bronchoscopy due to massive secretions of bleeding.

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ACKNOWLEDGMENTS

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CONFLICTS OF INTEREST
No potential conflict of interest relevant to this article was reported.

DATA AVAILABILITY STATEMENT
The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

AUTHOR CONTRIBUTIONS

REFERENCES


