

Title

CT-Guided Measurement Versus Traditional Height-Based Formula for Predicting Double-Lumen Tube Insertion Depth: A Prospective Case-Control Study

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Abstract: Background: Accurate positioning of double-lumen tubes (DLTs) remains challenging in thoracic anesthesia, with malposition rates up to 48% using traditional methods. This study compared a novel CT-guided anatomical measurement method with the traditional height-based formula for predicting optimal DLT insertion depth.

Methods: This prospective case-control study enrolled 90 adults (ASA I-III) scheduled for elective thoracic surgery requiring DLT intubation. Patients were allocated to control (n=45, traditional formula) or experimental groups (n=45, CT-guided method combining external anatomical measurements and CT-derived lung apex-to-carina distance). Primary outcome was first-attempt intubation success rate. Secondary outcomes included intubation time, number of attempts, depth prediction accuracy, and complications. A predictive nomogram was developed using logistic regression analysis.

Results: The experimental group achieved significantly higher first-attempt success rate (88.9% vs. 20.0%, $P<0.001$) with smaller depth prediction error (0.3 ± 0.4 vs. 1.5 ± 1.1 cm, $P<0.001$). The experimental method required fewer attempts (1.1 ± 0.3 vs. 1.8 ± 0.4 , $P<0.001$) and shorter intubation time (125.4 ± 30.0 vs. 156.9 ± 53.3 seconds, $P<0.001$). Complication rates were similar between groups (2.2% vs. 8.9%, $P=0.361$). Multivariate analysis identified the experimental intervention as the strongest predictor of first-attempt success (OR 43.08, 95% CI: 11.07-167.63, $P<0.001$). The predictive model demonstrated excellent discrimination (AUC 0.880, 95% CI: 0.802-0.958).

Conclusions: The CT-guided anatomical measurement method significantly improves DLT placement accuracy and first-attempt success rates compared to traditional height-based formulas. This personalized approach, utilizing routinely available preoperative CT imaging, offers a practical solution for optimizing DLT positioning in thoracic surgery.

Keywords: Double-lumen tube; Thoracic anesthesia; Computed tomography; One-lung ventilation; Airway management

Introduction

Double-lumen tubes (DLTs) are the most commonly used devices for achieving one-lung ventilation (OLV) during thoracic surgery, facilitating optimal surgical exposure while maintaining adequate ventilation of the non-operative lung^[1, 2]. Despite their widespread use, accurate positioning of DLTs remains a significant clinical challenge, with malposition rates ranging from 20% to 48% even when fiberoptic bronchoscopy is employed for confirmation^[3]. Incorrect DLT placement can result in inadequate lung isolation, hypoxemia during OLV, and increased risk of airway complications including tracheal or bronchial injury^[4].

The traditional approach to predicting DLT insertion depth relies on a height-based formula (depth in cm = 12 + height in cm/10), which provides a rough estimation of appropriate positioning^[5, 6]. However, this method demonstrates considerable variability in accuracy, with studies showing that the predicted depth falls within ± 1 cm of the actual required depth in only 62.3% of patients^[5]. The limitations of this approach are particularly evident in patients with anatomical variations, as the formula does not account for individual differences in tracheobronchial anatomy, neck length, or thoracic dimensions^[7].

Recent evidence suggests that imaging-based measurements may offer superior accuracy for DLT placement. Computed tomography (CT) scanning, which is routinely performed preoperatively in most thoracic surgery patients, provides detailed anatomical information about the tracheobronchial tree^[8, 9]. Several studies have demonstrated that CT-based measurement of bronchial diameter can successfully guide DLT size selection, potentially reducing the incidence of oversized tubes and associated complications^[10]. Furthermore, three-dimensional reconstruction techniques and multi-planar CT imaging allow for precise measurement of airway dimensions and the distance from anatomical landmarks to the carina^[11].

The integration of external anatomical measurements with CT-derived internal measurements represents a promising approach to optimize DLT placement. By combining surface landmarks such as the mentum-to-mastoid distance and cricothyroid membrane-to-suprasternal notch distance with CT measurements of the lung apex-to-carina distance, a more accurate prediction of optimal DLT depth may be achieved^[12]. This comprehensive anatomical approach could potentially address the limitations of traditional height-based formulas while maintaining clinical practicality.

Therefore, this study aimed to compare the efficacy of a novel CT-guided anatomical measurement method versus the traditional height-based formula for predicting optimal DLT insertion depth. We hypothesized that the CT-guided method would significantly improve first-attempt success rates and reduce the need for repositioning, thereby minimizing the risk of airway complications and enhancing the efficiency of thoracic anesthesia management.

Methods

Study Design and Setting

This prospective case-control study was conducted at The First People's Hospital of Neijiang City, Sichuan Province From January 2024 to December 2024. The study protocol was approved by the institutional ethics committee . Written informed consent was obtained from all participants..

Participants

Eligible participants were adults aged 18-70 years with American Society of Anesthesiologists (ASA) physical status I-III scheduled for elective thoracic surgery requiring double-lumen tube (DLT) intubation. Exclusion criteria included history of asthma, difficult airway (limited mouth opening, micrognathia, spinal deformity), barrel chest, and tracheal or bronchial tumors. Patients were withdrawn if they or their families requested withdrawal or if the DLT was inadvertently placed in the wrong bronchus during the first attempt.

Study Groups

Participants were allocated to two groups based on the intubation depth calculation method:

Control Group: Traditional height-based formula

Experimental Group: CT-guided anatomical measurement method

Interventions

Control Group (Traditional Method): Predicted insertion depth was calculated using the formula: $\text{Depth (cm)} = 12 + (\text{Height in cm}/10)$.

Experimental Group (CT-Guided Method): Three measurements were obtained: (1) distance from mentum to mastoid process (H1), (2) distance from cricothyroid membrane to suprasternal notch with full neck extension (H2), and (3) distance from lung apex to carina measured on thin-slice chest CT (1-mm slice thickness) (H3). Predicted depth was calculated as: $\text{Depth} = H1 + H2 + H3$.

Anesthetic Management

All patients received standardized general anesthesia without premedication. Anesthesia was induced with etomidate 0.3 mg/kg, rocuronium 0.9 mg/kg, and sufentanil 0.5 µg/kg. Bispectral index was maintained at 40-50. All intubations were performed by experienced anesthesiologists using video laryngoscopy. The anesthesiologist was informed only of the predicted insertion depth before intubation. Anesthesia was maintained with propofol 4-8 mg/kg/h and remifentanyl 0.15-0.2 µg/kg/min infusion.

DLT Positioning Verification

Correct DLT position was verified using fiberoptic bronchoscopy (FOB).

Optimal positioning was defined as: (1) clear visualization of the carina through the tracheal lumen, (2) bronchial cuff upper margin positioned 0-5 mm below the carina, and (3) for left-sided DLT, visualization of upper and lower lobe orifices; for right-sided DLT, $\geq 50\%$ alignment of the side port with the right upper lobe orifice and visualization of middle and lower lobe orifices.

Outcome Measures

The primary outcome was first-attempt intubation success rate. Secondary outcomes included total intubation time (from laryngoscope insertion to correct positioning confirmed by FOB), number of attempts, depth difference between predicted and actual placement, and complications (sore throat, hoarseness, airway injury).

Sample Size Calculation

Based on preliminary data showing first-attempt success rates of 40% (control) and 75% (experimental), with $\alpha=0.05$ and 80% power, a minimum of 37 participants per group were required. To account for potential dropout and ensure adequate power, we enrolled 45 participants per group.

Statistical Analysis

Statistical analyses were performed using SPSS version 25.0 (IBM Corp., Armonk, NY). Continuous variables were expressed as mean $\pm$ standard deviation or median (interquartile range) and compared using independent t-tests or Mann-Whitney U tests as appropriate. Categorical variables were expressed as frequencies (percentages) and compared using chi-square or Fisher's exact tests. Univariate and multivariate logistic regression analyses were performed to identify predictors of first-attempt success. A predictive nomogram was developed using R software version 4.2.0. Model performance was assessed using receiver operating characteristic curves, calibration plots, and decision curve analysis. $P<0.05$ was considered statistically significant.

Results

Baseline Characteristics

A total of 90 patients were enrolled and randomized equally into control ($n=45$) and experimental ($n=45$) groups. The baseline demographics and clinical characteristics were well-balanced between groups (**Table 1**). The mean age was 58.4 ± 10.8 years in the control group and 56.4 ± 11.8 years in the experimental group ($P=0.639$). No significant differences were observed in gender distribution, BMI, ASA grade, or tumor diameter between groups (all $P>0.05$).

Table 1. Patient Demographics and Clinical Characteristics

Characteristics	Control Group (n = 45)	Experimental Group (n = 45)	P-value
Age, years	58.4 ± 10.8	56.4 ± 11.8	0.639
Female, n (%)	28 (62.2%)	25 (55.6%)	0.668
BMI, kg/m ²	24.9 ± 3.0	24.0 ± 3.4	0.204
ASA Grade, n (%)			0.220
Grade 2	37 (82.2%)	41 (91.1%)	
Grade 3	8 (17.8%)	4 (8.9%)	
Tumor diameter, mm	17.8 ± 21.4	16.1 ± 13.3	0.613

Primary Outcome

The experimental group demonstrated a significantly higher first-attempt success rate compared to the control group (88.9% vs. 20.0%, $P<0.001$; **Table 2**, **Figure 1A**). The overall success rate was high in both groups (100% vs. 97.8%, $P=1.000$), with no significant difference in complication rates (2.2% vs. 8.9%, $P=0.361$).

Table 2. Clinical Outcomes

Outcome	Control Group (n = 45)	Experimental Group (n = 45)	P-value
First attempt success, n (%)	9 (20.0%)	40 (88.9%)	<0.001
Overall success rate, n (%)	44 (97.8%)	45 (100.0%)	1.000
Complications, n (%)	4 (8.9%)	1 (2.2%)	0.361

Secondary Outcomes

The experimental group showed superior performance in multiple intubation parameters (**Table 3**). The depth difference between predicted and actual placement was significantly smaller in the experimental group (0.3 ± 0.4 cm vs. 1.5 ± 1.1 cm, $P<0.001$). Additionally, the experimental group required fewer intubation attempts (1.1 ± 0.3 vs. 1.8 ± 0.4 , $P<0.001$) and shorter intubation time (125.4 ± 30.0 vs. 156.9 ± 53.3 seconds, $P<0.001$; **Figure 1B-D**).

Table 3. Intubation Procedure Characteristics

Variable	Control Group (n = 45)	Experimental Group (n = 45)	P-value
Predicted depth, cm	27.9 ± 0.8	27.6 ± 1.9	0.502
Actual depth, cm	27.6 ± 2.3	27.7 ± 1.8	0.811
Depth difference, cm	1.5 ± 1.1	0.3 ± 0.4	<0.001
Intubation time, seconds	156.9 ± 53.3	125.4 ± 30.0	<0.001
Number of attempts	1.8 ± 0.4	1.1 ± 0.3	<0.001

Table 4. Distribution of Surgical Procedures

Surgery Type	Control Group (n = 45)	Experimental Group (n = 45)	P-value
Lobectomy	16 (35.6%)	12 (26.7%)	0.495
Mediastinal lesion excision	3 (6.7%)	3 (6.7%)	1.000
Other	1 (2.2%)	1 (2.2%)	1.000
Radical resection	5 (11.1%)	8 (17.8%)	0.549
Segmentectomy	1 (2.2%)	2 (4.4%)	1.000
Sublobar resection	10 (22.2%)	7 (15.6%)	0.590
Wedge resection	9 (20.0%)	12 (26.7%)	0.618
Total	45 (100.0%)	45 (100.0%)	0.874

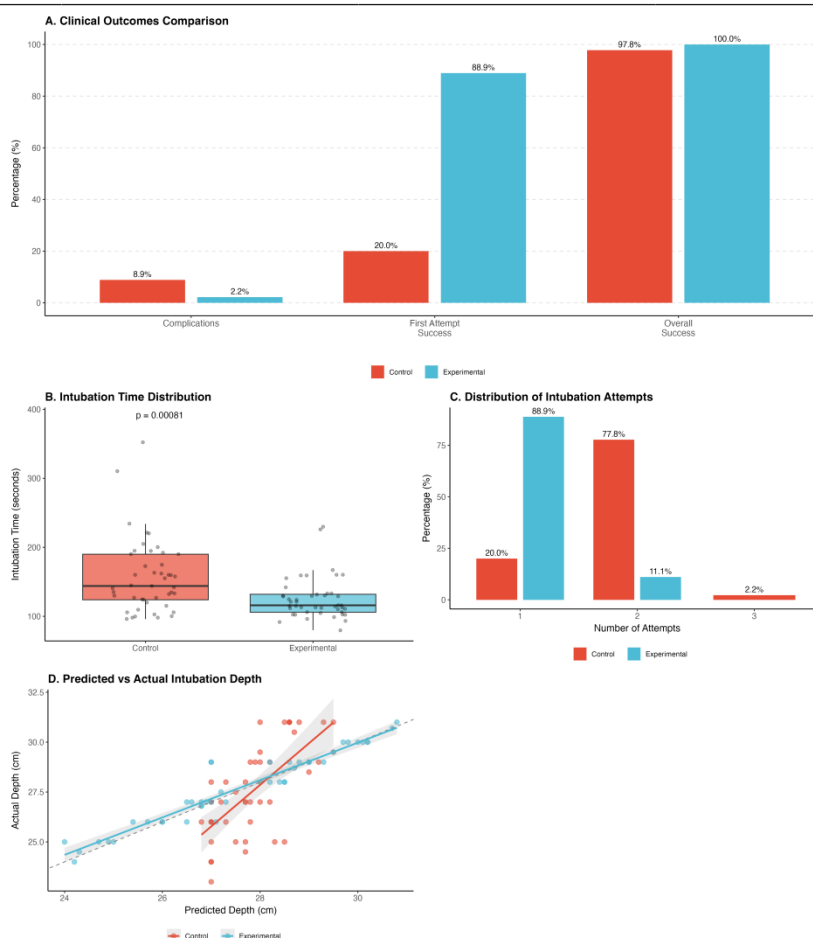


Figure 1. Comprehensive analysis of clinical outcomes and intubation performance metrics. (A) The bar chart shows the percentage of first attempt success, overall success rate, and complications for both groups, (B) Box plot showing the distribution of intubation time between groups. (C) Bar chart displaying the distribution of intubation attempts. (D) Scatter plot comparing predicted versus actual intubation depth with linear regression lines for each group

Predictors of First-Attempt Success

Univariate logistic regression analysis identified the experimental intervention as the strongest predictor of first-attempt success (OR 32.00, 95% CI: 9.81-104.38, $P < 0.001$; **Figure 2A**). The depth difference also showed significant association (OR 0.00, 95% CI: 0.00-0.01, $P < 0.001$). Other variables including

age, gender, BMI, and tumor characteristics showed no significant associations (all $P > 0.05$).

In multivariate analysis, the experimental intervention remained the independent predictor of first-attempt success (OR 43.08, 95% CI: 11.07-167.63, $P < 0.001$; **Figure 2B**), while tumor diameter showed borderline significance (OR 0.95, 95% CI: 0.90-1.00, $P = 0.059$).

Table 5. Patient Characteristics by First Attempt Success

Variable	level	No	Yes	p
n		41	49	
Gender (%)	Female	25 (61.0)	28 (57.1)	0.878
	Male	16 (39.0)	21 (42.9)	
Age (mean (SD))		58.54 (10.29)	56.45 (12.11)	0.386
Height (mean (SD))		159.24 (7.22)	158.69 (7.83)	0.732
Weight (mean (SD))		63.11 (9.37)	60.46 (7.38)	0.137
BMI (median [IQR])		24.44 [22.72, 26.04]	23.66 [21.88, 26.04]	0.345
ASA_Grade (mean (SD))		2.12 (0.33)	0.14 (0.35)	0.774
Max_Diameter (median [IQR])		13.00 [8.00, 18.00]	10.00 [8.00, 17.00]	0.459
DLT_Size_Clean (mean (SD))		42.22 (49.76)	34.92 (1.00)	0.307
Predicted_Depth (mean (SD))		27.76 (0.92)	27.74 (1.74)	0.951
Actual_Depth (mean (SD))		27.63 (2.42)	27.72 (1.72)	0.837

Table 6. Univariate Logistic Regression Analysis

Variable	Univariate Analysis		Multivariate Analysis	
	OR (95% CI)	P Value	OR (95% CI)	P Value
Experimental Group	32.00 (9.81-104.38)	0.000	43.08(11.07-167.63)	0.000
Male Gender	1.17 (0.50-2.73)	0.713		
Age (years)	0.98 (0.95-1.02)	0.383		
Height (cm)	0.99 (0.94-1.05)	0.728		
Weight (kg)	0.96 (0.91-1.01)	0.140	0.98 (0.91-1.05)	0.564
BMI (kg/m ²)	0.93 (0.82-1.06)	0.281		
ASA Grade	1.20 (0.35-4.11)	0.772		
Max Diameter (mm)	0.98 (0.95-1.01)	0.137	0.95 (0.90-1.00)	0.059
DLT Size	0.99 (0.96-1.02)	0.520		
Predicted Depth (cm)	0.99 (0.74-1.33)	0.951		
Actual Depth (cm)	1.02 (0.83-1.25)	0.834		
Depth Difference (cm)	0.00 (0.00-0.01)	0.000		

Table 7. Model Performance Metrics

Variable	OR (95% CI)	P-value
Experimental group (vs Control)	32.00 (9.81-104.38)	<0.001
Male (vs Female)	1.17 (0.50-2.73)	0.713
Age (per year)	0.98 (0.95-1.02)	0.383
BMI (per kg/m ²)	0.93 (0.82-1.06)	0.287
ASA grade (per grade)	1.20 (0.35-4.11)	0.772
Tumor diameter (per mm)	0.98 (0.95-1.01)	0.135
Predicted depth (per cm)	0.99 (0.74-1.33)	0.951
DLT size (per Fr)	0.99 (0.96-1.02)	0.520
Adenocarcinoma (vs Others)	1.78 (0.72-4.42)	0.215
Lobectomy (vs Others)	0.77 (0.32-1.89)	0.570

Model Performance

The predictive model demonstrated excellent discrimination with an AUC of 0.880 (95% CI: 0.802-0.958; **Figure 3B**). The calibration curve showed good agreement between predicted and observed probabilities (**Figure 3C**). Decision curve analysis indicated that the model provided net benefit across a wide range of threshold probabilities compared to treat-all or treat-none strategies (**Figure 3D**). A nomogram was developed to facilitate clinical application of the predictive model (**Figure 3A**).

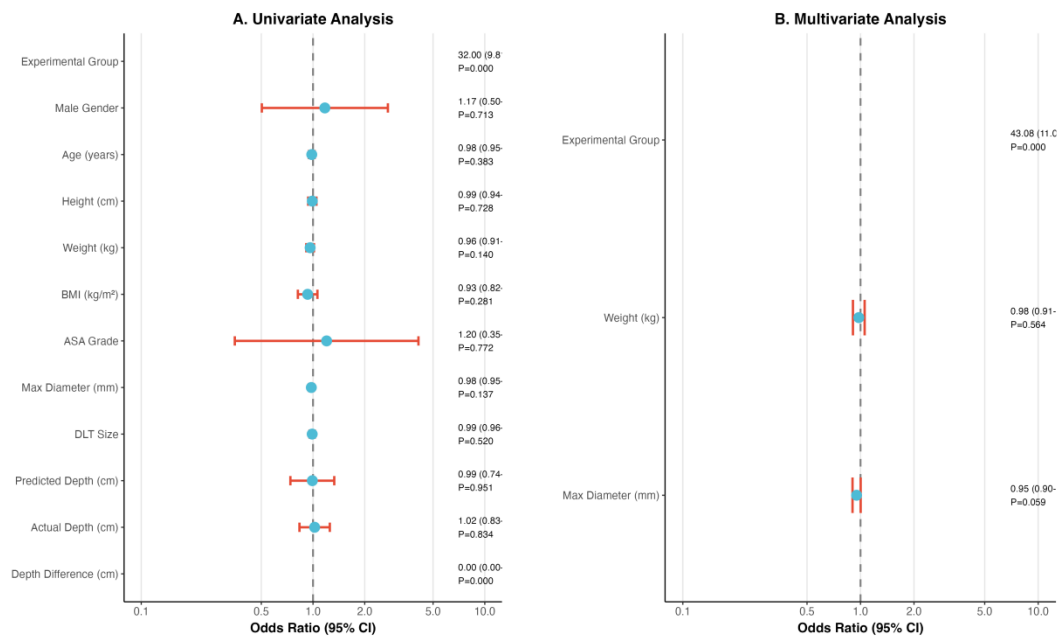


Figure 2. Forest plots showing the results of univariate (A) and multivariate (B) logistic regression analyses for predictors of first attempt success in double-lumen tube placement. OR, odds ratio; CI, confidence interval.

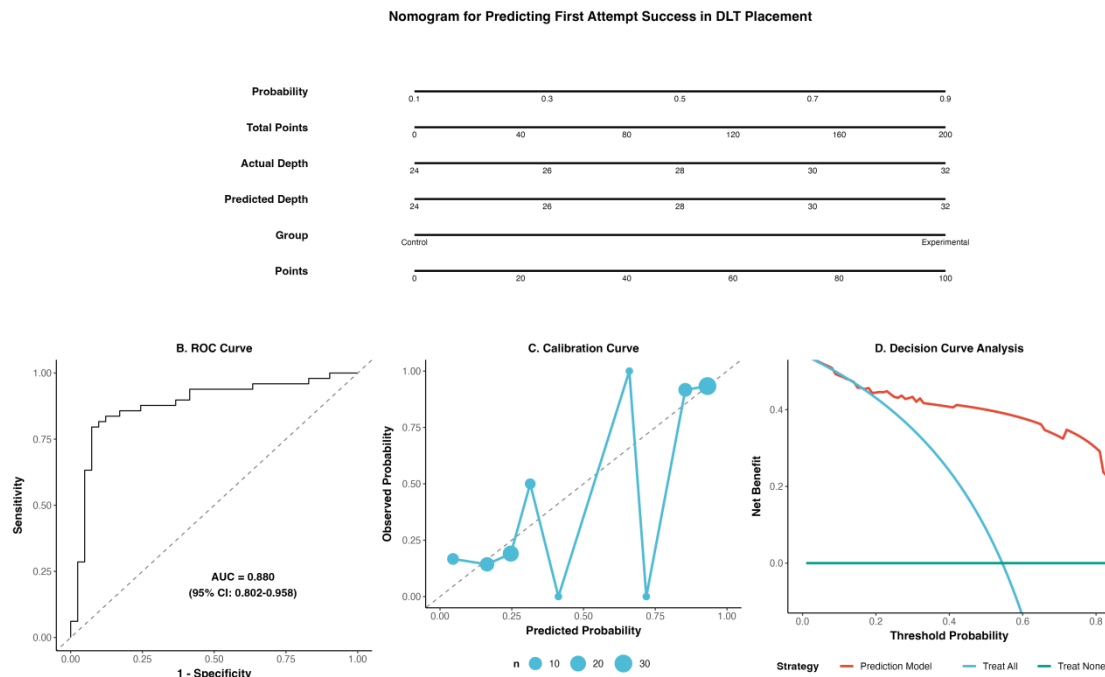


Figure 3. Nomogram for predicting first attempt success (A) and model validation including receiver operating characteristic (ROC) curve (B), calibration curve (C), and decision curve analysis (D). AUC, area under the curve.

Discussion

This prospective case-control study demonstrated that a novel CT-guided anatomical measurement method significantly improved first-attempt success rates for DLT placement compared to the traditional height-based formula (88.9% vs. 20.0%, $P < 0.001$). The experimental approach also resulted in more accurate depth prediction, fewer intubation attempts, and shorter procedural times. These findings represent a substantial advancement in optimizing DLT placement for thoracic anesthesia.

Our first-attempt success rate of 88.9% with the CT-guided method exceeds most previously reported rates in the literature. Kim et al.^[13] in a network meta-analysis of 23 studies reported an overall first attempt success rate of 87.9% with video laryngoscopy compared to 84.5% for direct laryngoscopy, though these studies did not specifically address depth prediction methods. Luiz Maracaja et al.^[14] in a recent study using combined video laryngoscopy and fiberoptic bronchoscopy achieved an 86% first-attempt success rate, like our experimental group. However, our control group's 20.0% success rate was notably lower than most reported rates, possibly reflecting the inherent limitations of the traditional height-based formula when strictly applied without clinical adjustments.

The dramatic improvement observed with our CT-guided method can be attributed to several factors. First, the integration of external anatomical landmarks (mentum-to-mastoid and cricothyroid-to-suprasternal distances) with internal CT

measurements provides a comprehensive, individualized approach that accounts for anatomical variations. Previous studies have shown that the relationship between tracheal and bronchial diameters follows predictable patterns, with Olivier et al.^[15] reporting correlation coefficients of 0.70 for men and 0.65 for women, but our method goes beyond simple diameter measurements to incorporate the actual path length from external landmarks to the carina. This addresses a fundamental limitation of the traditional formula, which assumes a linear relationship between height and airway dimensions without considering individual variations in neck length, thoracic anatomy, or tracheobronchial angles, as demonstrated by Patel et al.^[16] who found the true inclination angle between the left main bronchus and trachea to be 108.4°.

The clinical implications of our findings are substantial. Malposition rates for DLT placement have been reported as high as 48% even with fiberoptic confirmation. Klein et al.^[17] found that after blind DLT intubation and patient positioning, more than one third of DLTs required repositioning, with 79 out of 172 clinically correct placements showing malposition on bronchoscopy. Similarly, de Bellis et al.^[18] reported that 37% of DLTs required repositioning despite positive clinical evaluation. Our method's ability to predict optimal depth within 0.3 ± 0.4 cm compared to 1.5 ± 1.1 cm for the traditional method could significantly reduce the need for repositioning, thereby minimizing airway trauma and procedural delays. The reduction in intubation time from 156.9 to 125.4 seconds, while clinically modest, becomes more significant when multiplied across high-volume thoracic surgery centers.

From a patient safety perspective, our approach offers several advantages. The network meta-analysis by Kim et al.^[13] found that channeled video laryngoscopes showed the highest incidence of oral mucosal damage, highlighting the importance of minimizing manipulation attempts. By improving first-attempt success rates, our method could reduce airway complications. The low complication rate in our experimental group (2.2%) supports this hypothesis, though larger studies would be needed to confirm statistically significant differences in safety outcomes.

The development of a predictive nomogram with an AUC of 0.880 provides a practical tool for clinical implementation. This performance exceeds many existing predictive models for airway management and could be readily integrated into preoperative planning workflows. As CT imaging is routinely obtained for most thoracic surgery patients, our method requires no additional imaging or radiation exposure, making it both practical and cost-effective, as supported by studies showing the utility of CT measurements for DLT sizing[19, 20].

Our study has several limitations. First, the case-control design, while pragmatic, introduces potential selection bias compared to a randomized controlled trial. Second, all intubations were performed by experienced anesthesiologists at a single center, potentially limiting generalizability to less experienced practitioners or different clinical settings. Third, we excluded patients with difficult

airways, yet this population might benefit most from improved DLT placement techniques. Fourth, the study was not powered to detect differences in rare complications such as tracheobronchial injury.

Conclusion

Our CT-guided anatomical measurement method represents a significant advancement in DLT placement technique, offering substantially improved first-attempt success rates and positioning accuracy compared to traditional height-based formulas. The method's reliance on routinely available CT imaging and simple external measurements makes it practical for immediate clinical implementation. Widespread adoption of this approach could improve procedural efficiency, reduce airway complications, and enhance the overall quality of thoracic anesthesia care.

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