Ruan et al. Journal of Cardiothoracic Surgery (2025) 20:35
https://doi.org/10.1186/s13019-024-03277-7

Journal of
Cardiothoracic Surgery

RESEARCH

Open Access

Impact of cardiac factors on central airway anatomical parameters in patients undergoing lung mass surgery

Yingding Ruan[1], Hongsheng Xue[2], Wenjun Cao[2], Jianwei Han[1], Aiming Yang[1], Jincheng Xu[1] and Ting Zhang[1,3*]

Abstract

Background The correlation between central airway anatomical parameters and demographic factors, such as sex, age, weight, height, body mass index (BMI), and cardiac factors, remains unclear. This study examined the correlation between these factors and central airway anatomical parameters in adult patients.

Methods All consecutive patients who underwent lung mass surgery at our hospital between December 2020 and December 2023 were included in this study. DeepInsight software was used to analyze high-resolution chest computed tomography (HRCT) images and to measure various central airway anatomical parameters, including tracheal diameter (TD), tracheal length (TL), left main bronchus diameter (LBD), left main bronchus length (LBL), right main bronchus diameter (RBD), right main bronchus length (RBL), and subcarinal angle (SCA). A multivariate linear regression analysis was performed to evaluate the independent effects of sex, age, weight, height, BMI, left atrial diameter, and diastolic left ventricular internal diameter (LVIDd) on these anatomical parameters.

Results Among the 391 patients included in this study, all were over 18 years old, with 192 male and 199 female. The multivariate linear regression analysis indicated that in male patients with lung masses, TD exhibited a negative correlation with age ($\beta = -0.032$, $P = 0.015$) and a positive correlation with height ($\beta = 0.099$, $P < 0.001$). Furthermore, TL exhibited a positive correlation with height ($\beta = 0.311$, $P = 0.004$). LBL was substantially influenced by age ($\beta = -0.098$, $P = 0.011$), height ($\beta = 0.204$, $P = 0.003$), and BMI ($\beta = 0.311$, $P = 0.026$). Conversely, RBD exhibited notable correlations with height ($\beta = 0.062$, $P = 0.02$), BMI ($\beta = -0.113$, $P = 0.039$), and left atrial size ($\beta = 0.111$, $P = 0.007$). In female patients, TD and TL exhibited positive correlations with height ($\beta = 0.065$, $P = 0.01$; $\beta = 0.337$, $P = 0.01$, respectively). LBL was significantly correlated only with height ($\beta = 0.171$, $P = 0.045$), whereas LBD exhibited an inverse correlation with age ($\beta = -0.024$, $P = 0.014$). In addition, changes in SCA were positively associated with left atrial size ($\beta = 0.65$, $P = 0.042$), indicating a potential anatomical correlation.

Conclusion This study innovatively examined the impact of cardiac factors on central airway anatomical parameters in adult patients with lung masses. Notably, age, as an important factor in airway development, was found to have significant associations with tracheal characteristics along with height in males, while tracheal features exhibited a particularly strong relationship with height in females. Furthermore, the study identified associations between right bronchial diameter (RBD) in males and subcarinal angle (SCA) in females with left atrial size, although these findings require further validation in larger and more diverse populations.

†Yingding Ruan and Hongsheng Xue have contributed equally to this work.

*Correspondence:
Ting Zhang
zezht@zju.edu.cn
Full list of author information is available at the end of the article

Keywords Cardiac factors, Central airway parameters, Lung mass surgery, Computed tomography, Multivariate linear regression analysis

Introduction

Lung cancer surgery often involves the use of Double-Lumen Endobronchial Tubes (DLT) to facilitate one-lung ventilation (OLV) [1]. The extensive clinical use of DLTs has not only established a robust anesthetic approach for minimally invasive thoracic surgery but also contributed to swift and stable surgical execution [2, 3]. Nevertheless, significant variations in tracheal and length measurements from radiological assessments have been observed primarily due to the lack of standardized measurement protocols, which makes it challenging to select the appropriate DLT size [4–9]. Rapid advancements in High-Resolution Chest Computed Tomography (HRCT) have enhanced the precision of assessments and quantitative analyses of bronchial tree morphology. The three-dimensional (3D) reconstruction and post-processing techniques of HRCT improve visualization of the bronchial structure, enabling precise measurements of the main bronchus length and internal diameter [10, 11].

Despite available data on tracheal and subcarinal angle (SCA) measurements from domestic and international sources, these values vary considerably, reflecting substantial anatomical differences in the respiratory tract among European, American, and Chinese populations [4, 12–18]. Existing computed tomography studies of Chinese populations often fail to accurately measure bronchial tree parameters, leading to potential deviations from physiological conditions and lack of 3D precision. Consequently, this study aimed to accurately assess the tracheal diameter (TD), tracheal length (TL), and SCA using preoperative HRCT imaging combined with DeepInsight 3D reconstruction. This study also evaluated relationships with demographic factors, including sex, age, weight, height, and body mass index (BMI), and innovatively examined the potential impact of cardiac factors, thereby establishing a foundation for future research.

Methods

This retrospective cohort study mainly examined patients who underwent pulmonary resection at our hospital between December 2020 and December 2023. The inclusion criteria were as follows: (1) patients who had undergone pulmonary resection; (2) patients who had undergone HRCT examination; (3) Age > 18 years. The exclusion criteria were as follows: (1) central lung masses; (2) history of thoracic surgery; (3) thoracic and tracheal malformations; and (4) HRCT scans not extending to the level of the thyroid cartilage.

This study was approved by the Ethics Committee of The First People's Hospital of Jiande (Ethics Committee Approval Number: 20230809011), and the human data were processed in accordance with the Declaration of Helsinki. The First People's Hospital of Jiande waived informed consent.

Data collection

Data on patient demographics and central airway anatomical parameters such as sex, age, height, weight, BMI, left atrial diameter, diastolic left ventricular internal diameter (LVIDd), TD, TL, left main bronchus diameter (LBD), right main bronchus diameter (RBD), left main bronchus length (LBL), right main bronchus length (RBL), and SCA were retrospectively collected.

Image acquisition

Anatomical parameters of the trachea were obtained using a Philips Brilliance 256-slice computed tomography (CT) scanner at end-expiration. The patients were positioned supine with their arms elevated and head first, and they were scanned from the thyroid cartilage to the lung bases. The scanning parameters were 120 kV, 80 mA, a slice thickness and interval of 1.5 mm, and a reconstruction of 1 mm. The window settings were adjusted to − 1500 and 450 HU. Before surgery, two thoracic surgeons independently uploaded CT DICOM images into DeepInsight for 3D airway reconstruction, creating sagittal and coronal views. Cross-sections aligned with the left and right main bronchi axes were generated. To minimize errors, each surgeon measured the parameters twice on a magnified (10–13x) image, and the results were averaged. A third measurement was performed if the measurements differed by more than 5 mm. The final values were determined by averaging the results from both surgeons.

Definition of the measured anatomical parameters for central airways

Tracheal Length (TL): Measured horizontally from the midpoint of the sternum (between the sternal and clavicular ends) to a point 2 cm above the carina.
Tracheal Diameter (TD): Internal diameter measured at sternum midpoint.

Left Main Bronchus Length (LBL): Distance measured from the carina to the proximal wall of the left bronchus opening.
Right Main Bronchus Length (RBL): Distance measured from the carina to the proximal wall of the right bronchus opening.
Left Main Bronchus Diameter (LBD): Internal diameter of the left bronchus measured at the carina level.
Right Main Bronchus Diameter (RBD): Internal diameter of the right bronchus at the carina level.
Subcarinal Angle (SCA): The angle between the left and right main bronchi.

Figure 1 shows the results.

Statistical analysis

The data were expressed as mean and standard deviation or median (Q1, Q3). For normally distributed data, the Student's t-test was applied. For non-normally distributed data, the Wilcoxon rank-sum test was used. Categorical data were presented as frequency (%) and were analyzed using the Chi-square test or Fisher's exact test. A multivariate linear regression model was used to assess the factors influencing the anatomical parameters of the trachea and SCA. Given the anticipated multicollinearity among height, weight, and BMI, weight was excluded as a factor. Based on the adjusted R Square, Durbin-Watson, and *P*-values, relevant linear equations were derived. A *P*-value < 0.05 was considered statistically significant. IBM SPSS Statistics Version 26 software (SPSS, Chicago, IL, USA) was used for data analysis.

Results

Demographic and baseline characteristics

Approximately 512 pulmonary resections were performed at our hospital between December 2020 and December 2023. The analysis included 391 patients after excluding 121 patients (Fig. 2). This study cohort comprised 192 males and 199 females, ranging in age from 20 to 84 years, with mean ages of 64.37 ± 11.06 years for males and 61.65 ± 10.70 years for females. The heights varied from 145 to 180 cm, with mean values of 166.63 ± 6.31 cm for males and 157.23 ± 5.07 cm for females. Body weights ranged from 41.7 to 92.5 kg, with mean weights of 64.55 ± 10.06 kg for males and 55.68 ± 8.04 kg for females. BMI varied from 15.80 to 39.39 kg/m^2, with mean values of 23.24 ± 3.45 kg/m^2 for males and 22.52 ± 3.01 kg/m^2 for females, showing a significant difference favoring males (*P* < 0.001). Left atrial dimensions varied from 20 to 47.1 mm, with average measurements of 34.15 ± 4.59 mm for males and 32.07 ± 4.44 mm for females. LVIDd varied from 32 to 64.1 mm, with mean values of 47.30 ± 4.80 mm for males and 43.98 ± 3.96 mm for females.

Regarding the central airway anatomical parameters, the trachea had an average length of 106.81 ± 10.95 mm and an internal diameter of 15.01 ± 2.66 mm. The left main bronchus had a length of 47.24 ± 6.19 mm and an internal diameter of 12.49 ± 1.96 mm. The right main bronchus had a length of 24.91 ± 5.26 mm and an internal diameter of 13.20 ± 2.26 mm. The average SCA was (83.69 ± 18.67°. Table 1 presents the detailed data.

Analysis of airway and anthropometric parameters in males and females

Statistically significant differences were observed in TD (*P* < 0.001), TL (*P* < 0.001), RBL (*P* < 0.001), RBD (*P* < 0.001), LBL (*P* < 0.001), LBD (*P* < 0.001), SCR (*P* < 0.001), age (*P* = 0.014), height (*P* < 0.001), weight (*P* < 0.001), BMI (*P* = 0.027), left atrial size (*P* < 0.001), and LVIDd (*P* < 0.001) for male and female patients. The detailed data are provided in Table 2.

Multivariate linear regression correlation of airway and anthropometric indices in males and females

Relevant factors followed a normal distribution in male and female patients (Fig. 3). For male patients, a negative relationship was observed between TD and age (β = −0.032, *P* < 0.001), and a positive relationship between TD and height (β = 0.099, *P* < 0.001). TL exhibited a significant positive correlation only with height (β = 0.311, *P* = 0.02). LBL exhibited significant correlations with age, height, and BMI (*P* < 0.001), whereas LBD exhibited a positive correlation only with height (*P* = 0.018). RBD exhibited significant correlations with height, BMI, and left atrial size (all P < 0.001). In female patients, TD and TL showed significant positive correlations only with height (*P* = 0.028 and *P* = 0.018, respectively). LBL was also positively correlated with height (*P* < 0.001), whereas LBD exhibited a negative correlation with age (*P* = 0.019). In addition, SCA exhibited a significant positive correlation with left atrial size (*P* = 0.007). (Tables 3 and 4.)

Results were categorized by gender cohort, and regression analysis was performed to identify correlations that can be expressed as mathematical equations to predict diameters for individual participants. However, the predictive accuracy and the coefficient of determination of these equations did not sufficiently demonstrate a definitive underlying correlation (Tables 5 and 6) despite the statistical significance of the observed correlations.

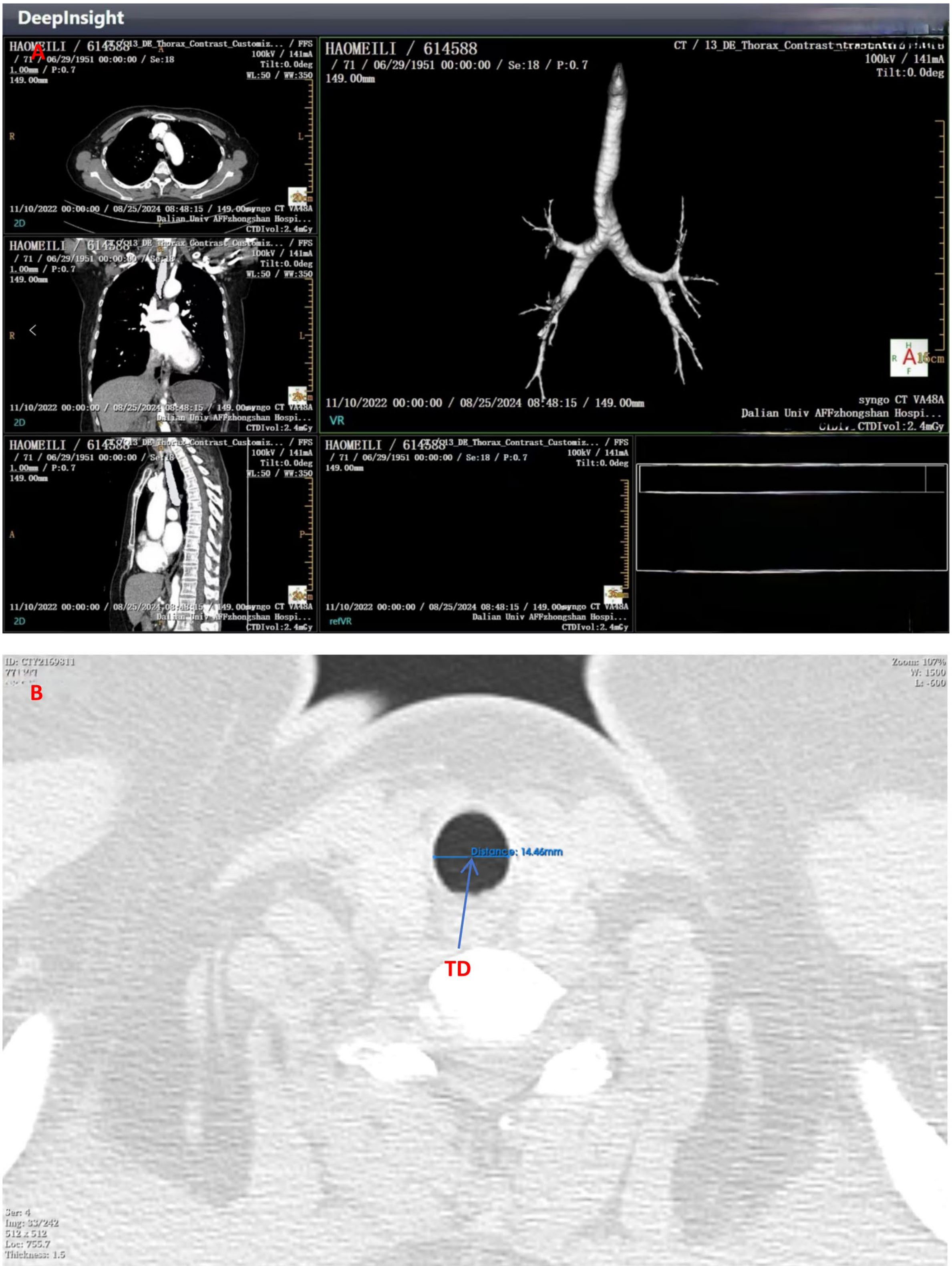


Fig. 1 **A** Bronchial Tree **B** TD: Tracheal Diameter **C** TL: Tracheal Length; **D** RBD: Right main Bronchus Diameter; **E** LBD: Left main Bronchus Diameter; **F** LBL: Left main Bronchus Length; RBL: Right main Bronchus Length; **G** SCA: Subcarinal Angle

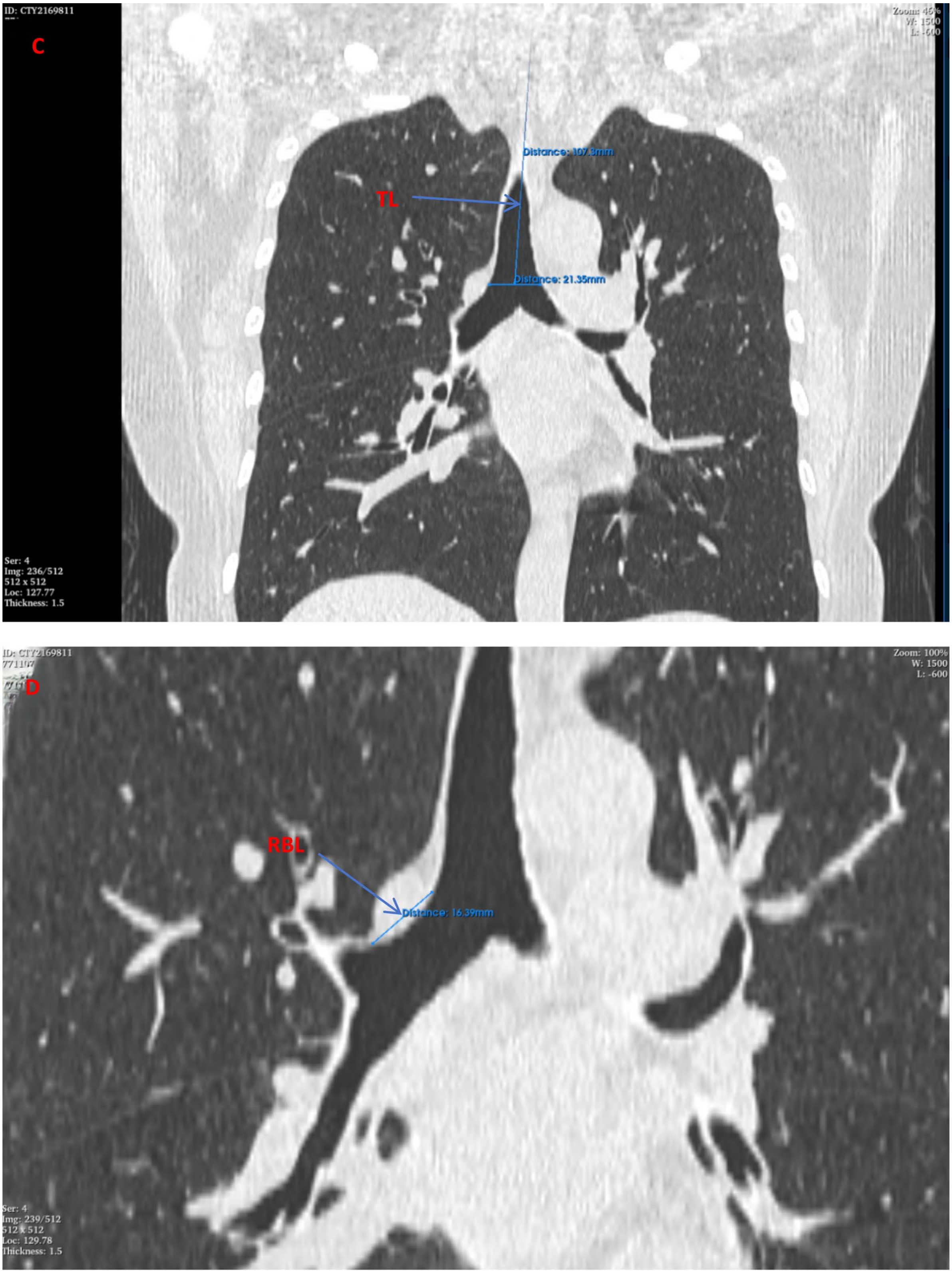


Fig. 1 continued

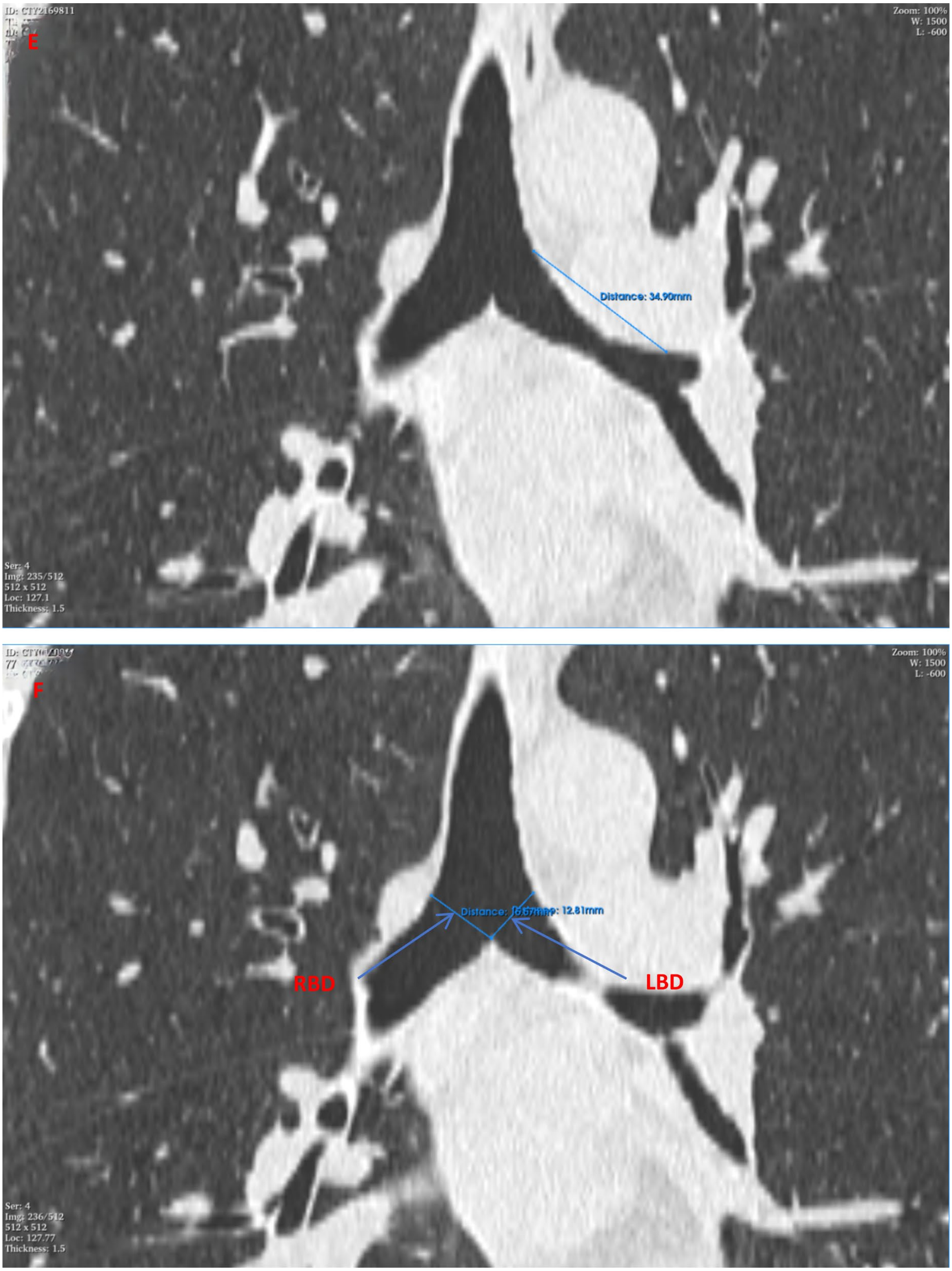


Fig. 1 continued

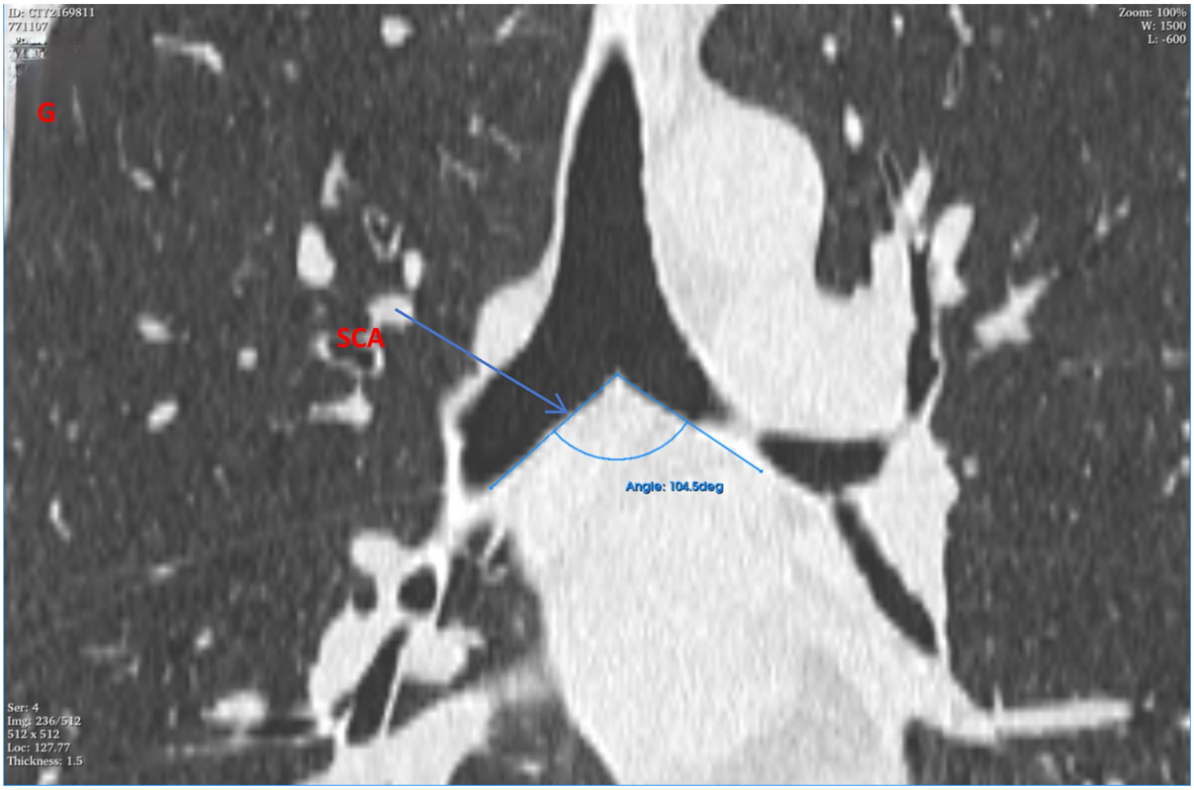


Fig. 1 continued

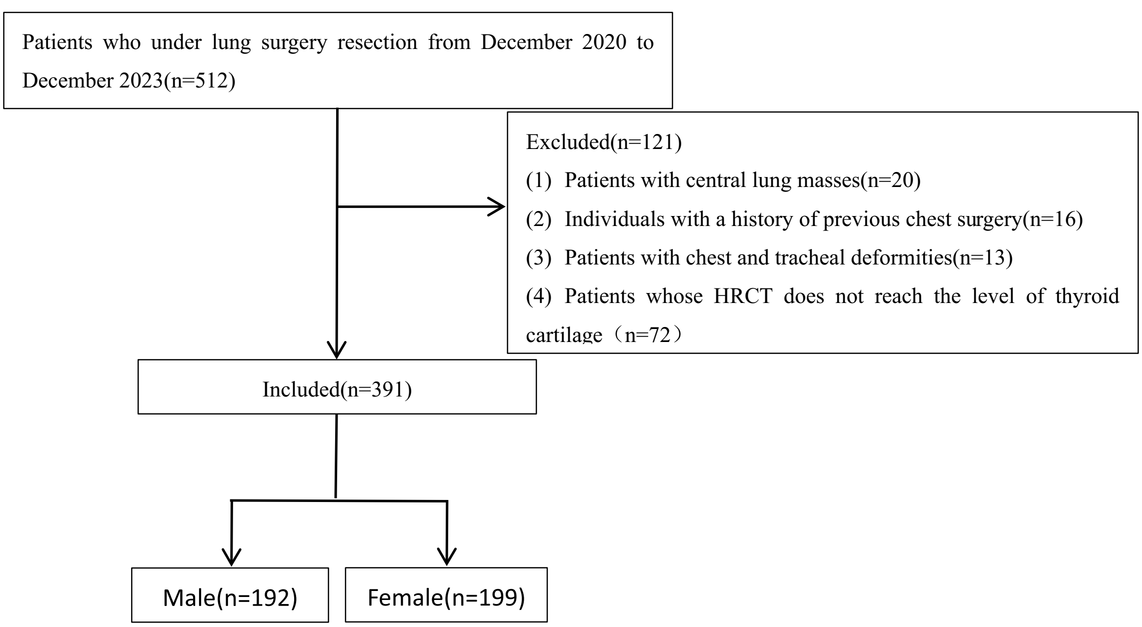


Fig. 2 Flow diagram showing the study selection schema for patients with lung surgery resection (*HRCT* high-resolution chest computed tomography)

Table 1 Patient characteristics and central airway parameters [n(%),mean ± standard deviation]

Characteristics	Data(n = 391)
Age (years)	62.99 ± 10.95
Weight (kg)	60.04 ± 10.10
Height (cm)	161.85 ± 7.39
BMI (kg/m2)	22.87 ± 3.25
LVIDd(mm)	45.61 ± 4.69
Left atrial diameter(mm)	33.09 ± 4.62
Sex, n(%)	
Male	192 (49.1)
Female	199 (50.9)
TL (mm)	106.81 ± 10.95
TD (mm)	15.01 ± 2.66
LBL (mm)	47.24 ± 6.19
RBL (mm)	24.91 ± 5.26
LBD (mm)	12.49 ± 1.96
RBD (mm)	13.20 ± 2.26
SCA (°)	83.69 ± 18.67

BMI Body Mass Index, *LVIDd* Left Ventricular Internal Diameter at end-Diastole, *SCA* Subcarinal Angle, *TD* Tracheal Diameter, *TL* Tracheal Length, *LBD* Left main Bronchus Diameter, *RBD* Right main Bronchus Diameter, *LBL* Left main Bronchus Length, *RBL*, Right main Bronchus Length

Table 2 Patient characteristics and statistical analysis [n(%),mean ± standard deviation]

Variables	Male (*n* = 192)	Female (*n* = 199)	*P*
Age (years)	64.37 ± 11.06	61.65 ± 10.70	0.014
Weight (kg)	64.55 ± 10.06	55.68 ± 8.04	< 0.001
Height (cm)	166.63 ± 6.31	157.23 ± 5.07	< 0.001
BMI (kg/m2)	23.24 ± 3.45	22.52 ± 3.01	0.027
LVIDd(mm)	47.30 ± 4.80	43.98 ± 3.96	< 0.001
Left atrial diameter (mm)	34.15 ± 4.59	32.07 ± 4.44	< 0.001
TL (mm)	112.70 ± 9.54	101.12 ± 9.06	< 0.001
TD (mm)	16.95 ± 1.99	13.14 ± 1.73	< 0.001
LBL (mm)	49.31 ± 5.93	45.24 ± 5.77	< 0.001
RBL (mm)	26.71 ± 5.00	23.17 ± 4.92	< 0.001
LBD (mm)	13.57 ± 1.85	11.44 ± 1.42	< 0.001
RBD (mm)	14.23 ± 2.28	12.20 ± 1.75	< 0.001
SCA (°)	79.62 ± 18.96	87.61 ± 17.57	< 0.001

BMI Body Mass Index, *LVIDd* Left Ventricular Internal Diameter at end-Diastole, *SCA* Subcarinal Angle, *TD* Tracheal Diameter, *TL* Tracheal Length, *LBD* Left main Bronchus Diameter, *RBD*, Right main Bronchus Diameter, *LBL* Left main Bronchus Length, *RBL* Right main Bronchus Length

Discussion

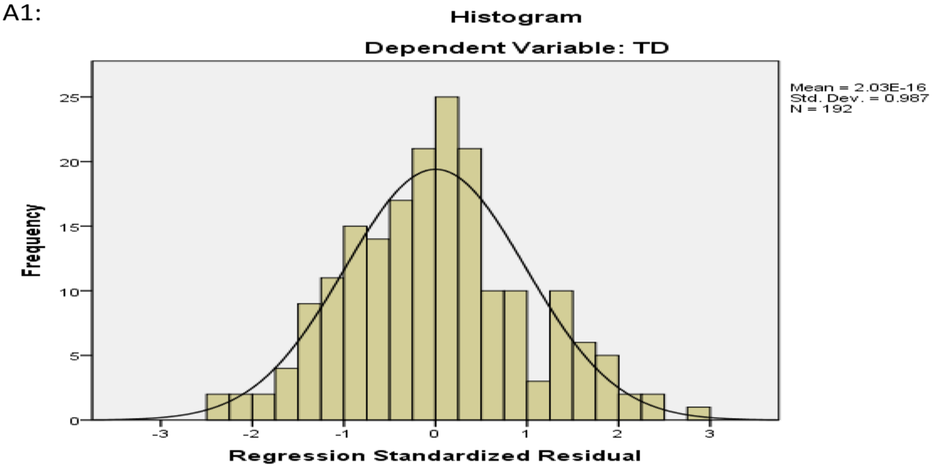
This study employed advanced image post-processing methods to explore alterations in central airway anatomy in adult patients with lung mass, with a particular emphasis on the impact of cardiac factors on central airway parameters. Relationships were analyzed between these parameters and factors such as sex, age, height, weight, BMI, and cardiac factors. This analysis revealed notable clinical correlations between males and females and highlighted significant sex differences. In males, TD exhibited an inverse correlation with age and positively correlated with height, indicating structural adaptations over time. The TL was mainly influenced by height. LBL demonstrated sensitivity to age, height, and BMI. RBD was associated with height, BMI, and left atrial size, indicating a novel relationship between cardiac structure and airway anatomy. In females, the correlations were more nuanced, with TD and TL showing correlations with height but to a lesser extent. Furthermore, the strong relationship between SCA and left atrial size enhances our understanding of the variability in central airway anatomical parameters and provides deeper insights into the heart-airway interaction.

Although direct literature evidence to support our hypothesis was not found, our observations provide valuable insights. In male patients, this study identified a significant association between left atrial size and RBD ($P = 0.007$). Conversely, in female patients, a relationship was observed between left atrial size and SCA ($P = 0.042$). These relationships require further validation and interpretation but highlight the plausibility of our research hypothesis and suggest a need for further investigation in this area.

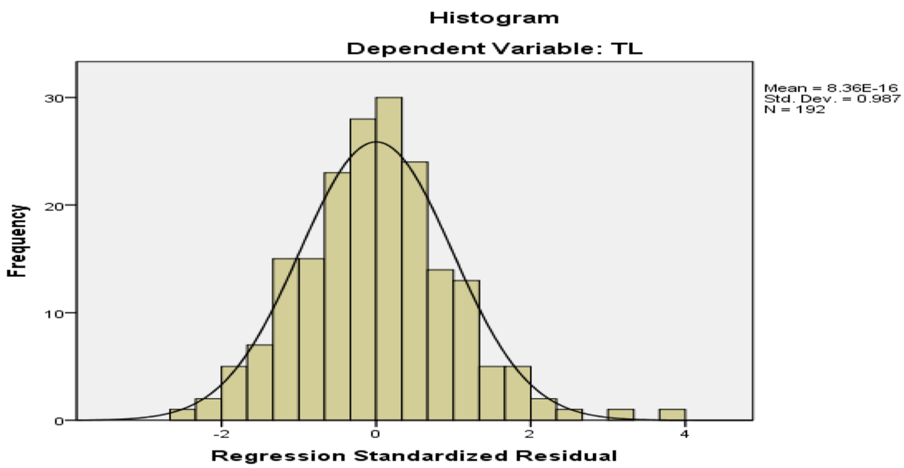
In addition, it is crucial to emphasize the importance of sex differences in this study. In 2024, Yan Liu et al. [7] performed a 3D imaging analysis of the trachea of 888 patients who underwent chest CT and revealed significant sex-based differences in central airway length. Their study found that male patients exhibited significantly longer measurements than female patients ($P < 0.01$). Similarly, Alqaryan et al. [9] observed that the anterior–posterior diameter of the main trachea was significantly longer in male patients than in female patients. Research by MI et al. [4] also revealed that male patients had longer lengths and larger internal diameters for the trachea, left main bronchus, and right main bronchus than female patients. This study used preoperative HRCT scans and DeepInsight software for 3D reconstruction of the bronchial tree to obtain relevant data. The results were consistent with previous findings, indicating that male patients had longer trachea lengths and internal diameters than female patients, with statistically significant differences ($P < 0.05$).

The findings of this study underscore the significant roles that age and BMI play in influencing variations in LBL and RBD among male patients, which is consistent with previous research results [8]. In addition, left atrial size substantially affected RBD, indicating that changes in cardiac structure may have considerable effects on

A1:



B1:



C1

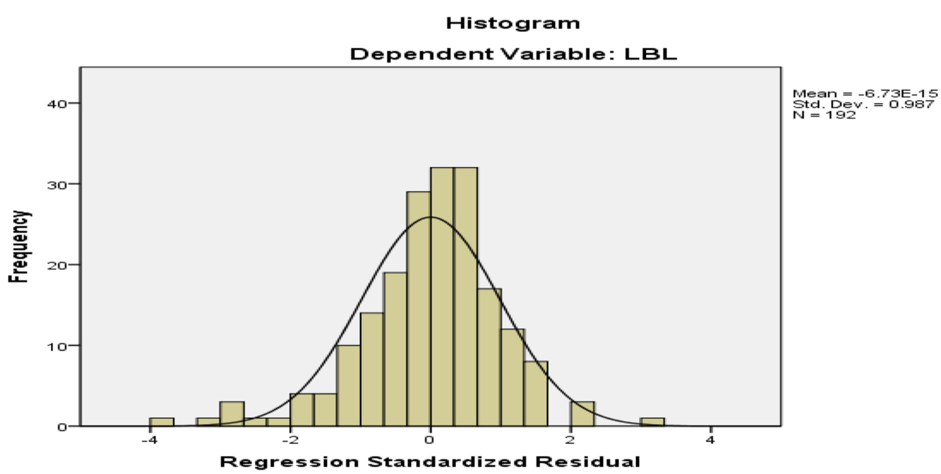


Fig. 3 Figures A1-G1 and A2-G2 depict the normal distribution of Airway Anatomical Parameters for male and female patients, respectively. *A1-2 TD* Tracheal Diameter, *B1-2 TL* Tracheal Length, *C1-2 LBL* Left main Bronchus Length, *D1-2 LBD* Left main Bronchus Diameter, *E1-2 RBL* Right main Bronchus Length, *F1-2 RBD* Right main Bronchus Diameter, *G1-2 SCA* Subcarinal Angle

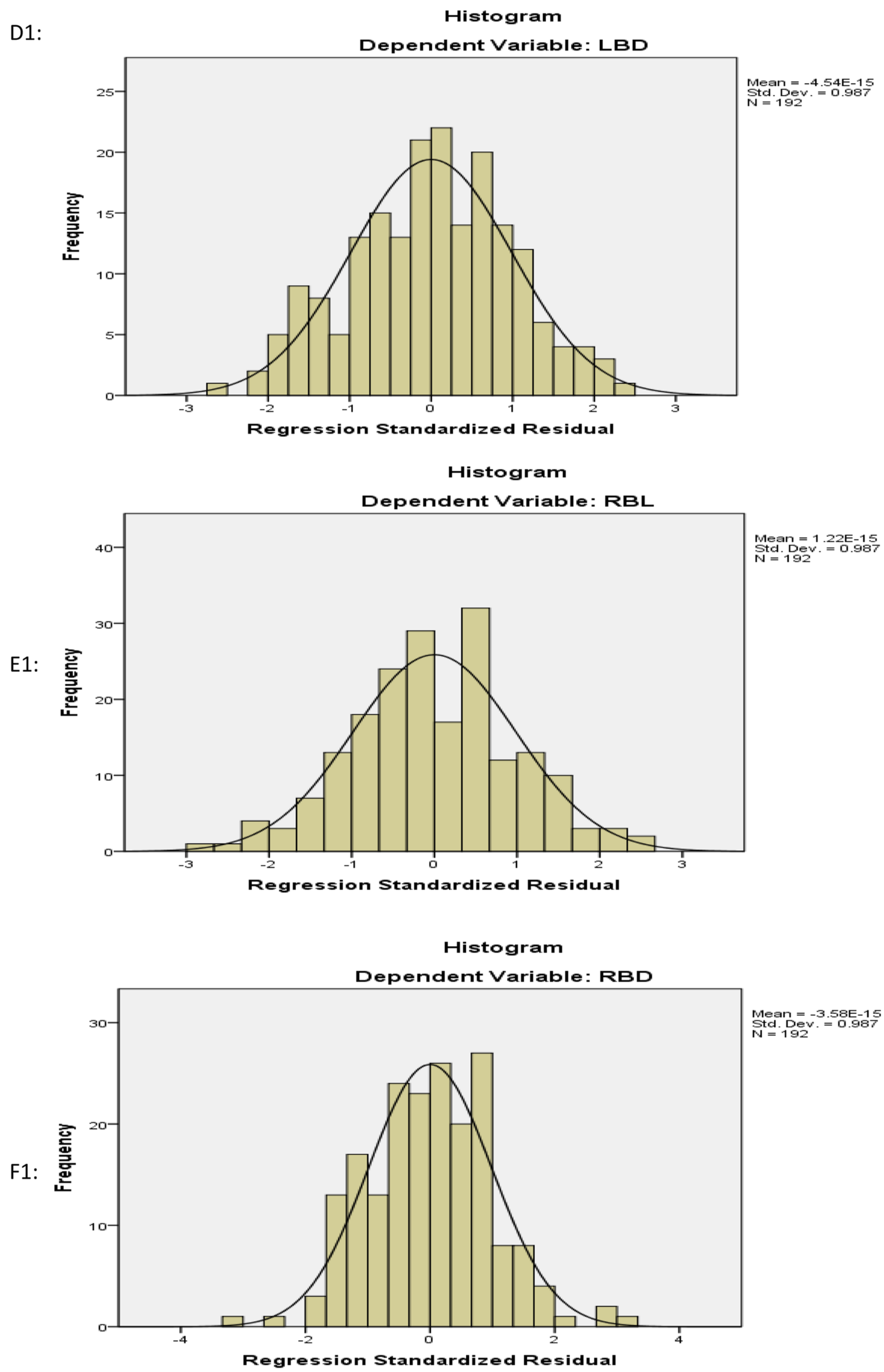


Fig. 3 continued

central airway morphology. Conversely, the results for female patients showed a different pattern in the model outcomes. Although height remained a crucial predictor of tracheal parameters, cardiac factors exhibited a more significant influence on the lateral SCA. This finding challenges the traditional view that heart-respiratory

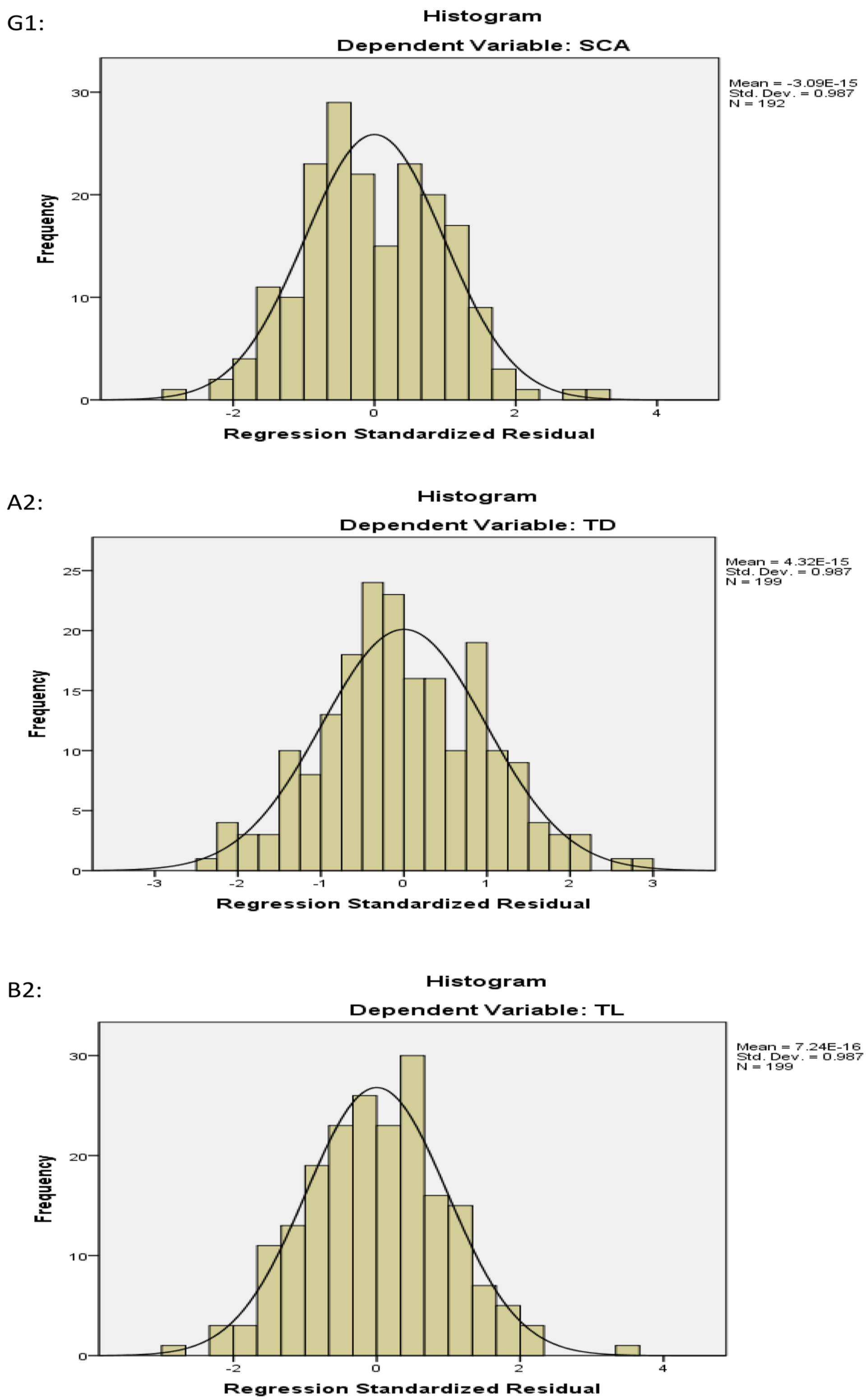
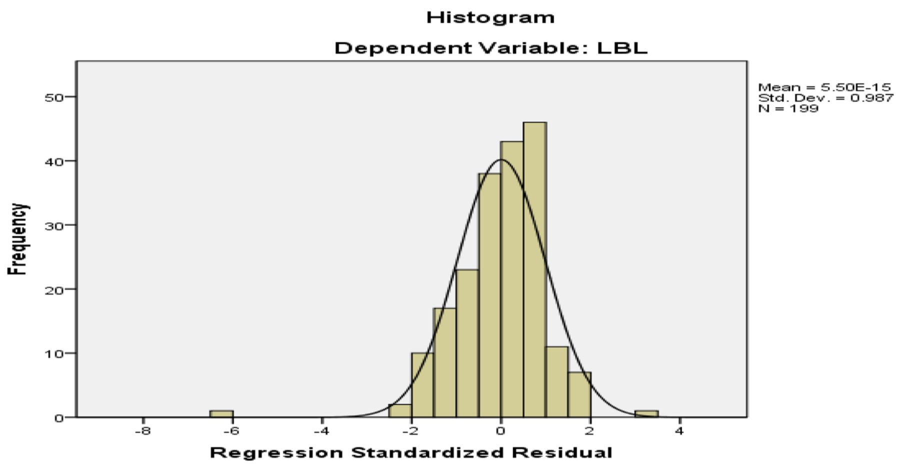
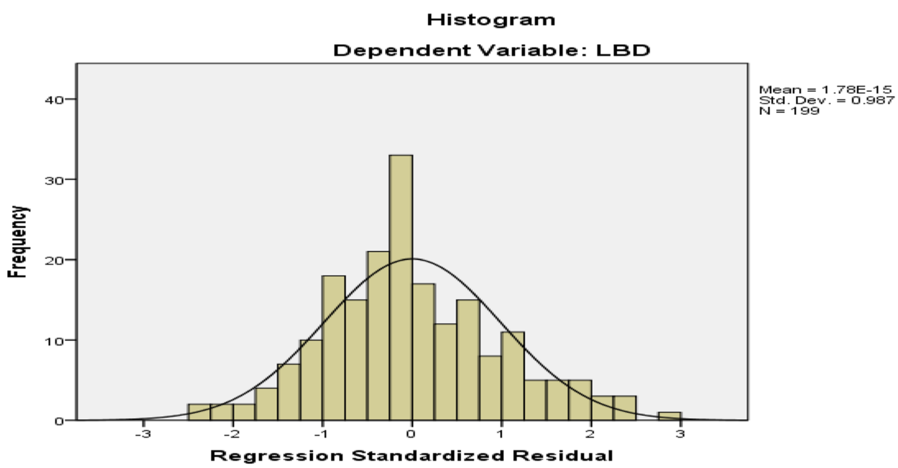


Fig. 3 continued

C2:



D2:



E2:

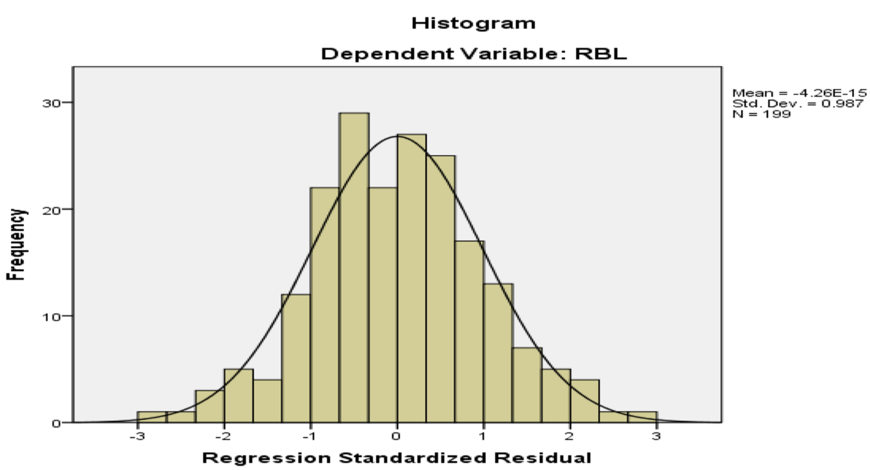


Fig. 3 continued

system interactions predominantly affect male patients and highlights the significant role that sex differences play in this intricate association.

The Durbin-Watson values for all regression models were close to the ideal value of 2, confirming the independence and consistency of the model residuals. This finding highlights the robustness and reliability of the

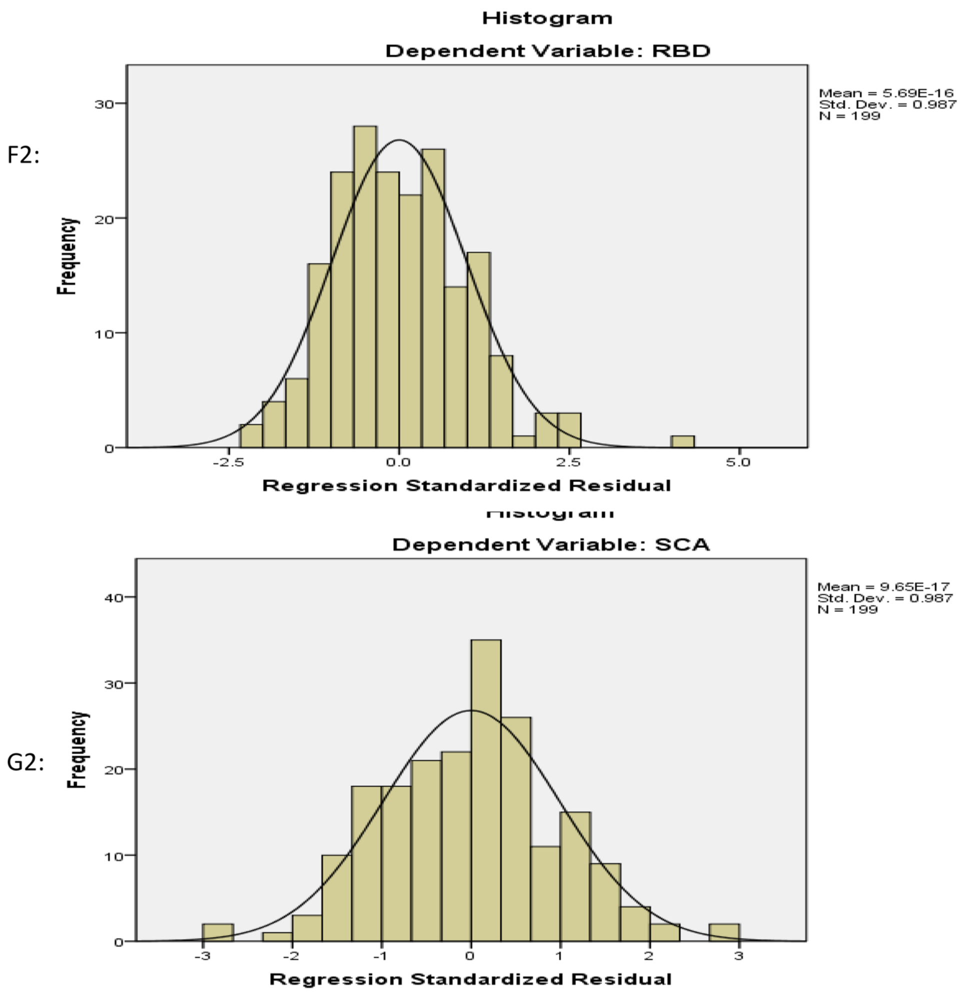


Fig. 3 continued

models in accounting for variations in major airway anatomical parameters. These results not only bolster confidence in the outcomes of the regression model but also offer a strong statistical basis for future clinical applications and further research.

Karmakar A. et al. [15], Olivier et al. [19], and Yan Chen [20] reported in their 3D imaging studies that predicting the internal diameter of bronchial airways in males and females based on height, weight, and sex alone is unreliable. Similarly, Kim et al. [11] found no significant association between the length and internal diameter of the main bronchi and height in either sex. Conversely, the findings of this study indicate that height is a key predictor of TD and TL, which is consistent with previous studies and highlights the essential role of body size in airway morphology [7, 9].

Previous studies have reported varying results regarding the measurement of bronchial length and diameter [4–8]. For example, Weidong Mi et al. [4] conducted a study involving 2107 randomly selected patients who underwent chest CT scan to measure the tracheal and bilateral main bronchial internal diameters and lengths. Their CT-based measurements indicated a TL of 104.9 ± 13.4 mm, LBL of 48.3 ± 6.5 mm, and RBL of 13.6 ± 4.3 mm. Using 3D reconstruction, Matsuoka et al. [8] reported a TL of 11.5 ± 1.0 cm (range, 8.8–14.4 cm). Variations in these measurements may be due to differences in the assessment methods. In this study, the measured lengths of the trachea, left main bronchus, and right main bronchus were (106.81 ± 10.95) mm, (47.24 ± 6.19) mm, and (24.91 ± 5.26) mm, respectively. In addition, the internal diameters of the trachea, left main bronchus, and right main bronchus were (15.01 ± 2.66) mm, (12.49 ± 1.96) mm, and (13.20 ± 2.26) mm, respectively. Mehran et al. [21] previously reported that LBL is generally 2–3 times longer than RBL. Nevertheless, a recent study by Yan Liu et al. [7], which examined airway structures in non-smoking Han Chinese patients,

Table 3 Multivariate linear regression analysis of central airway parameters and SCA in male patients

Variables	**Coefficients**						
	β	**S.E**	**T**	**P**	**Tolerance**	**VIF**	
TD (mm)	Constant	2.034	4.199	0.485	0.629		
	Age	−0.032	0.013	−2.46	0.015	0.889	1.125
	Height	0.099	0.023	4.303	< 0.001	0.868	1.153
	BMI	0.023	0.047	0.498	0.619	0.686	1.457
	LVIDd	−0.022	0.031	−0.695	0.488	0.817	1.225
	Left atrial diameter	0.030	0.035	0.847	0.398	0.695	1.439
TL (mm)	Constant	50.265	21.073	2.385	0.018		
	Age	0.031	0.065	0.478	0.633	0.889	1.125
	Height	0.331	0.115	2.88	0.004	0.868	1.153
	BMI	−0.157	0.236	−0.664	0.507	0.686	1.457
	LVIDd	0.249	0.156	1.6	0.111	0.817	1.225
	Left atrial diameter	−0.083	0.177	−0.471	0.638	0.695	1.439
LBL (mm)	Constant	6.942	12.386	0.56	0.576		
	Age	−0.098	0.038	−2.572	0.011	0.889	1.125
	Height	0.204	0.068	3.018	0.003	0.868	1.153
	BMI	0.311	0.139	2.238	0.026	0.686	1.457
	LVIDd	0.115	0.092	1.261	0.209	0.817	1.225
	Left atrial diameter	0.059	0.104	0.568	0.57	0.695	1.439
LBD (mm)	Constant	2.911	4.074	0.715	0.476		
	Age	−0.009	0.013	−0.691	0.491	0.889	1.125
	Height	0.054	0.022	2.423	0.016	0.868	1.153
	BMI	−0.036	0.046	−0.792	0.429	0.686	1.457
	LVIDd	0.04	0.03	1.326	0.187	0.817	1.225
	Left atrial diameter	0.035	0.034	1.022	0.308	0.695	1.439
RBL (mm)	Constant	2.783	11.269	0.247	0.805		
	Age	0.02	0.035	0.579	0.564	0.889	1.125
	Height	0.142	0.061	2.303	0.022	0.868	1.153
	BMI	−0.016	0.126	−0.127	0.899	0.686	1.457
	LVIDd	−0.023	0.083	−0.275	0.784	0.817	1.225
	Left atrial diameter	0.015	0.094	0.16	0.873	0.695	1.439
RBD (mm)	Constant	1.216	4.838	0.251	0.802		
	Age	−0.027	0.015	−1.798	0.074	0.889	1.125
	Height	0.062	0.026	2.352	0.02	0.868	1.153
	BMI	−0.113	0.054	−2.08	0.039	0.686	1.457
	LVIDd	0.068	0.036	1.904	0.058	0.817	1.225
	Left atrial diameter	0.111	0.041	2.739	0.007	0.695	1.439
SCA (°)	Constant	32.955	42.507	0.775	0.439		
	Age	0.165	0.131	1.262	0.209	0.889	1.125
	Height	0.107	0.232	0.461	0.646	0.868	1.153
	BMI	0.101	0.477	0.211	0.833	0.686	1.457
	LVIDd	−0.158	0.314	−0.503	0.616	0.817	1.225
	Left atrial diameter	0.685	0.356	1.924	0.056	0.695	1.439

BMI Body Mass Index, *LVIDd* Left Ventricular Internal Diameter at end-Diastole, *SCA* Subcarinal Angle, *TD* Tracheal Diameter, *TL* Tracheal Length, *LBD* Left main Bronchus Diameter, *RBD* Right main Bronchus Diameter, *LBL* Left main Bronchus Length, *RBL* Right main Bronchus Length, *VIF* Variance Inflation Factor

consisting of 456 females and 432 males, reported different measurements: RBL was (21.90 ± 5.36) mm for females and (24.01 ± 5.43) mm for males, whereas LBL was (48.35 ± 5.47) mm for females and (51.98 ± 5.80) mm for males. Similarly, our findings revealed a difference in the lengths of the main bronchi, with LBL

Table 4 Multivariate linear regression analysis of central airway parameters and SCA in female patients

Variables	Coefficients						
	β	**S.E**	**T**	**P**	**Tolerance**	**VIF**	
TD (mm)	Constant	4.103	4.329	0.948	0.344		
	Age	−0.016	0.012	−1.382	0.169	0.907	1.103
	Height	0.065	0.025	2.62	0.01	0.906	1.104
	BMI	0.031	0.044	0.705	0.482	0.825	1.212
	LVIDd	0.001	0.033	0.022	0.982	0.832	1.203
	Left atrial diameter	−0.030	0.032	−0.951	0.343	0.742	1.348
TL (mm)	Constant	64.246	22.627	2.839	0.005		
	Age	−0.072	0.062	−1.164	0.246	0.907	1.103
	Height	0.337	0.13	2.586	0.01	0.906	1.104
	BMI	−0.115	0.23	−0.499	0.618	0.825	1.212
	LVIDd	−0.103	0.175	−0.592	0.555	0.832	1.203
	Left atrial diameter	−0.143	0.165	−0.869	0.386	0.742	1.348
LBL (mm)	Constant	18.049	14.718	1.226	0.222		
	Age	−0.02	0.04	−.499	0.619	0.907	1.103
	Height	0.171	0.085	2.015	0.045	0.906	1.104
	BMI	0.025	0.15	0.168	0.867	0.825	1.212
	LVIDd	0.015	0.114	0.133	0.894	0.832	1.203
	Left atrial diameter	0.01	0.107	0.095	0.925	0.742	1.348
LBD (mm)	Constant	10.522	3.555	2.96	0.003		
	Age	− 0.024	0.01	− 2.475	0.014	0.907	1.103
	Height	0.017	0.02	0.811	0.418	0.906	1.104
	BMI	− 0.03	0.036	− 0.842	0.401	0.825	1.212
	LVIDd	0.036	0.027	1.306	0.193	0.832	1.203
	Left atrial diameter	− 0.034	0.026	− 1.321	0.188	0.742	1.348
RBL (mm)	Constant	24.561	12.658	1.94	0.054		
	Age	− 0.03	0.035	− 0.875	0.383	0.907	1.103
	Height	0.009	0.073	0.12	0.905	0.906	1.104
	BMI	−0.106	0.129	− 0.821	0.412	0.825	1.212
	LVIDd	−0.013	0.098	− 0.137	0.891	0.832	1.203
	Left atrial diameter	0.064	0.092	0.699	0.486	0.742	1.348
RBD (mm)	Constant	11.402	4.47	2.551	0.012		
	Age	−0.015	0.012	− 1.187	0.237	0.907	1.103
	Height	0.015	0.026	0.572	0.568	0.906	1.104
	BMI	−0.006	0.045	− 0.143	0.887	0.825	1.212
	LVIDd	0.019	0.034	0.545	0.587	0.832	1.203
	Left atrial diameter	−0.041	0.033	− 1.244	0.215	0.742	1.348
SCA (°)	Constant	28.634	43.593	0.657	0.512		
	Age	0.045	0.119	0.377	0.707	0.907	1.103
	Height	0.036	0.251	0.145	0.885	0.906	1.104
	BMI	0.765	0.443	1.724	0.086	0.825	1.212
	LVIDd	0.283	0.336	0.840	0.402	0.832	1.203
	Left atrial diameter	0.650	0.318	2.046	0.042	0.742	1.348

BMI Body Mass Index, *LVIDd* Left Ventricular Internal Diameter at end-Diastole, *SCA* Subcarinal Angle, *TD* Tracheal Diameter, *TL* Tracheal Length, *LBD* Left main Bronchus Diameter, *RBD* Right main Bronchus Diameter, *LBL* Left main Bronchus Length, *RBL* Right main Bronchus Length, *VIF* Variance Inflation Factor

measuring 1–2 times longer than RBL: (47.24 ± 6.19) mm versus (24.91 ± 5.26) mm, respectively. In our study population, RBL was recorded as (23.17 ± 4.92) mm in females and (26.71 ± 5.00) mm in males, whereas LBL was (45.24 ± 5.77) mm in females and (49.31 ± 5.93) mm in males. The less pronounced difference observed in our

Table 5 Correlation between parameters and the line of best fit in male patients

Dependent variable	Predictive factors	Adjusted R square	Durbin-Watson	*P*	Line of best fit
TD (mm)	Age and height	0.13	1.913	< 0.001	(−0.032) × Age + 0.099 × Height(cm) + 2.034
TL (mm)	Height	0.044	1.925	0.02	0.311 × Height (cm) + 50.265
LBL (mm)	Age, height, and BMI	0.145	1.752	< 0.001	(−0.098) × Age + 0.204 × Height (cm) + 0.311 × BMI (kg/m2) + 6.942
LBD (mm)	Height	0.046	1.984	0.018	0.054 × Height (cm) + 2.911
RBL (mm)	Height	0.006	1.74	0.3	–
RBD (mm)	Height, BMI, and left atrial diameter	0.117	1.786	< 0.001	0.062 × Height(cm) + (−0.113) × BMI (kg/m2) + 0.111 × Left atrial size (mm) + 1.216
SCA (°)	–	0.014	1.687	0.174	–

BMI: Body Mass Index; SCA: Subcarinal Angle; TD: Tracheal Diameter; TL: Tracheal Length; LBD: Left main Bronchus Diameter; RBD: Right main Bronchus Diameter; LBL: Left main Bronchus Length; RBL: Right main Bronchus Length

Table 6 Correlation between parameters and the line of best fit in female patients

Dependent variable	Predictive factors	Adjusted R square	Durbin-Watson	P	Line of best fit
TD (mm)	Height	0.038	1.644	0.028	0.065 × Height(cm) + 4.103
TL (mm)	Height	0.067	1.839	0.018	0.337 × Height(cm) + 64.264
LBL (mm)	Height	0.145	1.752	< 0.001	0.171 × Height(cm) + 18.049
LBD (mm)	Age	0.043	1.962	0.019	(−0.024) × Age + 10.522
RBL (mm)	–	0.017	2.188	0.889	–
RBD (mm)	–	0.001	1.948	0.45	–
SCA (°)	Left atrial diameter	0.055	1.961	0.007	0.65 × Left atrial size + 28.6343

SCA Subcarinal Angle, *TD* Tracheal Diameter, *TL* Tracheal Length, *LBD* Left main Bronchus Diameter, *RBD* Right main Bronchus Diameter, *LBL* Left main Bronchus Length, *RBL* Right main Bronchus Length

results may be due to differences in participant ethnicities or variations in measurement methods, which make direct comparisons with previous studies challenging.

For patients undergoing lung cancer surgery, OLV is used to maintain normal ventilation, protect the affected lung from contamination, and collapse the healthy lung to provide a clear surgical field of view [22]. Although DLTs are frequently used for lung isolation, successful intubation and effective lung isolation may not be achieved in all patients. Some patients face challenges in DLT placement and may experience bronchial rupture due to excessively narrow bronchi, whereas others may experience insufficient OLV due to excessively short bronchi [23]. Proper selection of DLT size and accurate positioning are essential for effective lung isolation. Selecting the catheter size based on the patient's bronchial internal diameter and length is a relatively accurate approach [24]. Consequently, a thorough understanding of tracheal and bronchial anatomical knowledge is crucial for effective endotracheal intubation and perioperative airway management.

Previously, selecting DLT size was mainly based on sex and height [8, 25–28]. However, using only the BMI and sex of patients for DLT selection may not be suitable for all patients. The criteria for selecting an appropriate DLT should include ensuring minimal or no gas leakage after intubation of the main bronchus to achieve effective ventilation. In 2014, Kim et al. [11] assessed the internal diameter of the left main bronchus 2 cm from the carina to guide DLT size selection and comparison. Their findings revealed that some patients, especially females, may require smaller DLT sizes than those typically selected based on sex and height. This underscores the importance of a deeper understanding of the factors affecting large airway anatomical parameters for more accurate DLT selection.

The strength of this study was its thorough multivariate linear regression analysis, which examined large airway anatomical variations in patients with lung masses. By exploring not only sex differences but also the complex influence of height, age, BMI, and cardiac factors, this study enhances our understanding of airway morphology. By incorporating cardiac factors as research variables, this study paves the way for new research directions and provides valuable insights into clinical applications.

The study has several limitations, including a small sample size that may have affected the generalizability of the findings. To enhance applicability, future research should include larger sample sizes. This study also highlighted gaps in variable selection, such as the exclusion of smoking history, as well as chronic lung diseases such as chronic obstructive pulmonary disease and asthma,indicating the need for more comprehensive models. Longitudinal studies are recommended to better understand causality. Validating and optimizing image processing techniques is also crucial for ensuring data accuracy. Enhancing data collection by incorporating important variables, such as DLT size and intubation duration, is vital for maintaining data integrity and conducting a thorough analysis of airway anatomical changes.

DeepInsight software was used to explore the influence of cardiac factors on central airway anatomical parameters in adult patients with lung masses. The findings of this study revealed notable correlations between tracheal characteristics and age and height in males and a more pronounced height relationship in females. Furthermore, this study identified associations between RBL in males and SCA in females with left atrial size, although these associations require further validation. These findings offer important insights into the complex correlations between patient characteristics and central airway anatomy.

Abbreviations

HRCT	High-resolution chest computed tomography
BMI	Body mass index
SCA	Subcarinal angle
LVIDd	Left ventricular internal diameter at end-diastole
VIF	Variance inflation factor
DLT	Double-lumen endobronchial tube
CT	Computed tomography
OLV	One-lung ventilation
3D	Three-dimensional
TD	Tracheal diameter
TL	Tracheal length
LBD	Left main bronchus diameter
RBD	Right main bronchus diameter
LBL	Left main bronchus length
RBL	Right main bronchus length

Author contributions

Yingding Ruan: Conceptualization, Methodology, Investigation, Data curation, Writing– original draft, writing– review and editing. Hongsheng Xue: Investigation, Data curation, Writing–original draft. Wenjun Cao: Methodology, Investigation, Data curation. Jianwei Han: Methodology, Investigation, Data curation. Aiming Yang: Methodology, Investigation, Data curation. Jincheng Xu: Methodology, Investigation, Data curation. Ting Zhang: Conceptualization, Supervision, Writing–review and editing.

Funding

This research was supported by the Hangzhou Science and Technology Bureau (Grant No. B20240282), the Interdisciplinary Project of Dalian University (Grant No. DLUXK-2023-QN-012), and the 2024 Dalian University Teaching Reform Research Project (Grant No. 2024–005).

Availability of data and materials

Any researchers interested in this study could contact Yingding Ruan (E-mail:ruanyingding@sina.com) to request the data.

Declarations

Ethics approval and consent to participate

This study was approved by the Ethics Committee of The First People's Hospital of Jiande (Ethics Committee Approval Number: 20230809011). The human data used in this study was in accordance with the Declaration of Helsinki. Informed consent of patients was waived by The First People's Hospital of Jiande.

Consent for Publication

In the preparation of this study, the authors did not use any AI technology for editing the manuscript. The authors take full responsibility for the content of the publication.

Competing interests

The authors declare no relevant financial or nonfinancial interests.

Author details

[1]Department of Thoracic Surgery, The First People's Hospital of Jiande, Jiande, China. [2]Department of Thoracic Surgery, Affiliated Zhongshan Hospital of Dalian University, Dalian, China. [3]Radiotherapy Department, Second Affiliated Hospital, Zhejiang University School of Medicine, No. 88 Jiefang Road, Hangzhou 310009, Zhejiang, China.

Received: 18 September 2024 Accepted: 25 December 2024
Published online: 06 January 2025

References

1. Falzon D, Alston RP, Coley E, Montgomery K. Lung Isolation for Thoracic Surgery: From Inception to Evidence-Based. J Cardiothorac Vasc Anesth. 2017;31(2):678–93. https://doi.org/10.1053/j.jvca.2016.05.032.
2. Nwajuaku P, Barjaktarevic I, Hoftman N. Research and development of the sOLVe Tube™ dual lumen endobronchial tube: from concept to construct. Front Med Technol. 2023;15(5):1158154. https://doi.org/10.3389/fmedt.2023.1158154.
3. Somma J, Couture ÉJ, Pelletier S, Provencher S, Moreault O, Lohser J, Ugalde PA, Vigneault L, Lemieux J, Somma A, Guay SE, Bussières JS. Non-ventilated lung deflation during one-lung ventilation with a double-lumen endotracheal tube: a randomized-controlled trial of occluding the non-ventilated endobronchial lumen before pleural opening. Can J Anesth. 2021;68:801–11.
4. Mi W, Zhang C, Wang H, Cao J, Li C, Yang L, Guo F, Wang X, Yang T. Measurement and analysis of the tracheobronchial tree in Chinese population using computed tomography. PLoS ONE. 2015;10(4):e0123177. https://doi.org/10.1371/journal.pone.0123177.
5. Liu Z, Liu M, Zhao L, Qi X, Yu Y, Liang S, Yang X, Ma Z. Comparison of the accuracy of three methods measured the length of the right main stem bronchus by chest computed tomography as a guide to the use of right sided double-lumen tube. BMC Anesthesiol. 2022;22(1):264. https://doi.org/10.1186/s12871-022-01744-z.
6. Bussières JS, Gingras M, Perron L, Somma J, Frenette M, Couture EJ, Moreault O, Lacasse Y. Right upper lobe anatomy revisited: a computed tomography scan study. Can J Anaesth. 2019;66(7):813–9. https://doi.org/10.1007/s12630-019-01342-7.
7. Liu Y, Teng J, Mei J, Chen C, Xu QQ, Zhou C, Deng KL, Wang HW. Analysis of airway structural parameters in Han Chinese adults: a prospective cross-sectional study. Ann Med. 2024;56(1):2316258. https://doi.org/10.1080/07853890.2024.2316258.
8. Matsuoka S, Shimizu K, Koike S, Takeda T, Miura K, Eguchi T, Hamanaka K. Significance of the evaluation of tracheal length using a three-dimensional imaging workstation. J Thorac Dis. 2022;14(11):4276–84. https://doi.org/10.21037/jtd-22-595.

9. Alqaryan S, Alrabiah A, Alhussinan K, Alyousef M, Alosamey F, Aljathlany Y, Aljasser A, Bukhari M, Almohizea M, Khan A, Alqahtani K, Alammar A. Measurement of the lengths of different sections of the upper airway and their predictive factors. Surg Radiol Anat. 2024;46(7):1063–71. https://doi.org/10.1007/s00276-024-03345-6.
10. Aljathlany Y, Alamari K, Aljasser A, Alhelali A, Bukhari M, Almohizea M, Khan A, Alammar A. Comparison between mathematical and software calculation methods for the measurement of the cross-sectional area in upper airway imaging. Cureus. 2019;11(11):e6106. https://doi.org/10.7759/cureus.6106.
11. Kim D, Son JS, Ko S, Jeong W, Lim H. Measurements of the length and diameter of main bronchi on three-dimensional images in Asian adult patients in comparison with the height of patients. J Cardiothorac Vasc Anesth. 2014;28(4):890–5. https://doi.org/10.1053/j.jvca.2013.05.029.
12. Sato M, Kayashima K. Difficulty in inserting left double-lumen endobronchial tubes at the cricoid level in small-statured women: a retrospective study. Indian J Anaesth. 2017;61(5):393–7. https://doi.org/10.4103/ija.IJA_13_17.
13. Schiff BA. The relationship between body mass, tracheal diameter, endotracheal tube size, and tracheal stenosis. Int Anesthesiol Clin. 2017;55(1):42–51. https://doi.org/10.1097/AIA.0000000000000127.
14. Li XH, Su ZQ, Li JY, Liu Q, Zeng QS, Li SY. Measurement and analysis of tracheal inner diameter in Chinese adults using multi-slice spiral CT, multiplanar reconstruction and special window technique. J Tuberc Respir Dis. 2017;40(4):284–8. https://doi.org/10.3760/cma.j.issn.1001-0939.2017.04.008.
15. Karmakar A, Pate MB, Solowski NL, Postma GN, Weinberger PM. Tracheal size variability is associated with sex: implications for endotracheal tube selection. Ann Otol Rhinol Laryngol. 2015;124(2):132–6. https://doi.org/10.1177/0003489414549154.
16. Tai A, Corke C, Joynt GM, Griffith J, Lunn D, Tong P. A comparative study of tracheal diameter in Caucasian and Chinese patients. Anaesth Intensive Care. 2016;44(6):719–23. https://doi.org/10.1177/0310057X1604400603.
17. Ge X, Huang H, Bai C, et al. The lengths of trachea and main bronchus in Chinese shanghai population. Sci Rep. 2021;11(1):2168. https://doi.org/10.1038/s41598-021-81744-0.
18. Aljathlany Y, Aljasser A, Alhelali A, Bukhari M, Almohizea M, Khan A, Alammar A. Proposing an endotracheal tube selection tool based on multivariate analysis of airway imaging. Ear Nose Throat J. 2021;100:629S-635S. https://doi.org/10.1177/0145561319900390.
19. Olivier P, Hayon-Sonsino D, Convard JP, Laloë PA, Fischler M. Measurement of left mainstem bronchus using multiplane CT reconstructions and relationship between patient characteristics or tracheal diameters and left bronchial diameters. Chest. 2006;130(1):101–7. https://doi.org/10.1378/chest.130.1.101.
20. Chen Y, Guo Y, Mi W, Zhang C, Wang H, Zhao D, Cao J. Anatomy of the right upper lobe revisited and clinical considerations in Chinese population. PLoS ONE. 2020;15(11):e0242178. https://doi.org/10.1371/journal.pone.0242178.PMID:33237948;PMCID:PMC7688111.
21. Mehran RJ. Fundamental and practical aspects of airway anatomy: from glottis to segmental bronchus. Thorac Surg Clin. 2018;28(2):117–25. https://doi.org/10.1016/j.thorsurg.2018.02.003.
22. Grandjean C, Casso G, Noirez L, Granell Gil M, Savoldelli GL, Schoettker P. Innovations to improve lung isolation training for thoracic anesthesia: a narrative review. J Clin Med. 2024;13(7):1848. https://doi.org/10.3390/jcm13071848.
23. Liu S, Mao Y, Qiu P, Faridovich KA, Dong Y. Airway rupture caused by double-lumen tubes: a review of 187 cases. Anesth Analg. 2020;131(5):1485–90. https://doi.org/10.1213/ANE.0000000000004669.
24. Zhang X, Wang DX, Zhang Q, Shen QB, Tong F, Hu YH, Zhang ZD, Liu FF, Tang YW, Chen JL, Liu H, Zhou F, Hu SP. Effect of intubation in the lateral position under general anesthesia induction on the position of double-lumen tube placement in patients undergoing unilateral video-assisted thoracic surgery: study protocol for a prospective, single-center, parallel group, randomized, controlled trial. Trials. 2023;24(1):67. https://doi.org/10.1186/s13063-023-07075-9.
25. Cui G, Zhao L, Chi C, Liang S, Liu Z. The feasibility and accuracy of the method for selecting the optimal size of double-lumen tube in thoracic surgery: a prospective, randomized controlled trial. Sci Rep. 2024;14(1):17539. https://doi.org/10.1038/s41598-024-68349-z.
26. Mihatsch LL, Weiland S, Helmberger T, Friederich P. Common double-lumen tube selection methods overestimate adequate tube sizes in individual patients–a 3D reconstruction study. BMC Anesthesiol. 2024;24(1):215. https://doi.org/10.1186/s12871-024-02605-7.
27. Li J, Qian Y, Lei Y, Huo W, Xu M, Zhang Y, Ji Q, Yang J, Liu H, Hou Y. Combination of computed tomography measurements and flexible video bronchoscope guidance for accurate placement of the right-sided double-lumen tube: a randomised controlled trial. BMJ Open. 2023;13(11):e066541. https://doi.org/10.1136/bmjopen-2022-066541.PMID:38011975;PMCID:PMC10685955.
28. Cao AC, Rereddy S, Mirza N. Current practices in endotracheal tube size selection for adults. Laryngoscope. 2021;131(9):1967–71. https://doi.org/10.1002/lary.29192.

Publisher's Note