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Evaluation of Angles of the Tracheobronchial Tree with the 3-Dimensional Reconstruction Method: A Morphometric and Radiologic Study

Evaluación de los Ángulos del Árbol Traqueobronquial con el Método de Reconstrucción Tridimensional: Un Estudio Morfométrico y Radiológico

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SUMMARY: The objective of the current research is to assess the branching angles of the tracheobronchial tree and the correlation between these angles and the lung volume using the 3-dimensional reconstruction method. Thorax CT (computed tomography) images of 150 individuals, who were over 18 years of age and did not have any pathology on CT, were obtained retrospectively. A 3-dimensional reconstruction of the trachea, bronchi, and lungs was carried out. External and internal angles between the trachea and main bronchi, between the main bronchi and lobar bronchi, and between the lobar bronchi were measured. The volume measurement of the right and left lungs was performed. The individuals included in the study were grouped by sex and age (20-40 years, 41-61 years, and 62-87 years). The left subcarinal angle (LSA), total subcarinal angle (TSA), and left interbronchial angle (LIA) were found to be greater in the 62-87 age group. Both the external angle (LULB-LMBE) and the internal angle (LULB-LMBI) between the left upper lobar bronchus and the left main bronchus were observed to be greater in males. In males, a statistically significant negative moderate correlation was identified between the right lung volume and the right subcarinal angle (RSA). In females, a statistically significant positive moderate correlation was revealed between the external (RULB-IBE) and internal angles (RULB-IBI) between the right upper lobar bronchus and the intermediate bronchus, and the right lung volume. In the literature review we performed, we did not find any studies investigating the correlation between the branching angles of the tracheobronchial tree and the lung volume using the 3-dimensional reconstruction method. Therefore, we are of the opinion that our study will contribute to the literature.

KEY WORDS: Tracheobronchial tree; 3-dimensional reconstruction; Morphometry.

INTRODUCTION

The tracheobronchial tree constitutes an important section of the respiratory system (Hyde *et al*., 2009). The tracheobronchial tree was examined by methods such as chest radiography, computed tomography, multidetector computed tomography (MDCT), 3-dimensional reconstruction of CT images, bronchography, and bronchoscopy (Javidan-Nejad, 2010; Ulusoy *et al*., 2016; Christou *et al*., 2021).

Airway morphology involves significant changes in terms of size and shape. There can be considerable differences among healthy individuals (Choi *et al*., 2009; Poorbahrami & Oakes, 2019; Christou *et al*., 2021). Differences become apparent depending on age, sex, type of disease, and stage of disease. Personal differences are accepted, but interpersonal variability is rarely taken into consideration, while therapeutic approaches and

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pharmaceutical products are designed for drug delivery to the lungs (Shakshuki & Agu, 2017; Christou *et al*., 2021). It is highly important to know the size and branching angles of the airways for the safe and successful use of double lumen tube (DLT) and bronchoscopy applications (Ulusoy *et al*., 2016).

Chronic allergic asthma and emphysema may increase lung volume, while scleroderma and cystic fibrosis may decrease it. In such diseases, lung volume and time are the markers that show the disease activity and progression (Jones & Agusti, 2006; Haas *et al*., 2014).

In this study, the correlation of branching angles of the tracheobronchial tree with age, sex, and same-sided lung volume was evaluated. The objective of the present research is to assess the branching angles of the tracheobronchial tree and the correlation between these angles and the lung volume using the 3-dimensional reconstruction method.

MATERIAL AND METHOD

Study group. One hundred fifty individuals over 18 years of age, who were examined at Lokman Hekim Ankara Hospital between April 2020 and February 2021, who did not have any pathology on CT, and who did not have any chronic diseases, were included in our study. Individuals with

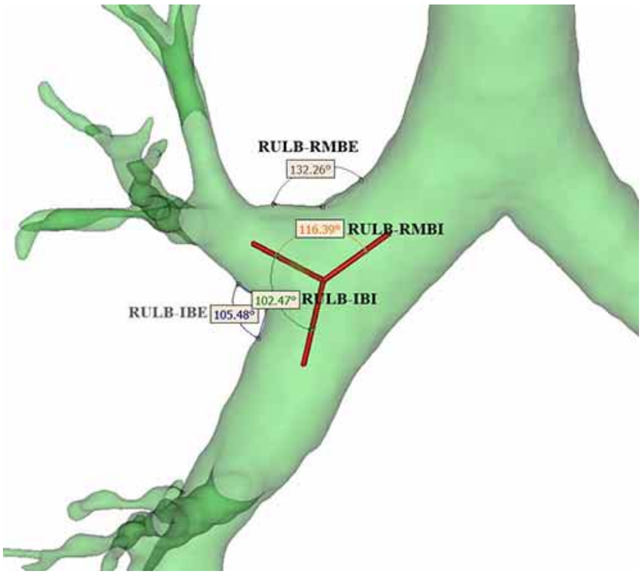

Fig. 1. Measurements of the the external (RULB-RMBE) and internal angles (RULB-RMBI) between the right upper lobar bronchus and the right main bronchus. Measurements of the external (RULB-IBE) and internal angles (RULB-IBI) between the right upper lobar bronchus and the intermediate bronchus.

interstitial lung disease, chronic obstructive pulmonary disease, pulmonary fibrosis, mass lesions pressing on the trachea and bronchi, and with a history of tracheobronchial surgery or tracheal intubation were excluded from the study. CT images of 150 individuals included in the study were obtained retrospectively. All data were anonymized to protect the confidentiality of the individuals who took part in the research. The individuals enrolled in the research were grouped by age and sex. The age groups were determined as 20-40 years, 41-61 years, and 62-87 years.

CT protocol. CT images were taken at Lokman Hekim University Ankara Hospital with Siemens Somatom Emotion 16 Slice Multidetector CT [110 kV, 134 mAs, rotation time 0.5 sec, pitch 1.0, section thickness 4 mm (1.5 mm in reformat images)] while the patient's arms were up and the patient was in the supine position.

3-dimensional reconstruction of CT images. CT images recorded in the DICOM format were transferred to Mimics Innovation Suite 24.0 (Leuven-Belgium) software which is at the Lokman Hekim University Health Innovation and Simulation Education, Application and Research Center (LHUSINERG), and a 3-dimensional reconstruction of the trachea, bronchi, and lungs was carried out.

Measurements on the 3-dimensional model. A vertical line (tracheal axis) parallel to the trachea passing through the middle of the carina was drawn. The right and left subcarinal angles (RSA and LSA) between the lower outer edge of the right and left main bronchi and the tracheal axis were measured. Moreover, the total subcarinal angle (TSA) between the lower outer edges of the right and left main bronchi was measured. The right and left interbronchial angles (RIA and LIA) formed at the intersection of the centerlines of the right and left main bronchi and the tracheal axis were measured. Furthermore, the total interbronchial angle (TIA) between the centerlines of the right and left main bronchi was measured. The external (TR-RMBE) and internal angles (TR-RMBI) between the trachea and the right main bronchus were measured. The external (TR-LMBE) and internal angles (TR-LMBI) between the trachea and the left main bronchus were measured. Formed between the right upper lobar bronchus and the right main bronchus, the external (RULB-RMBE) and internal angles (RULB-RMBI) were measured (Fig. 1). Formed between the right upper lobar bronchus and the intermediate bronchus, the external (RULB-IBE) and internal angles (RULB-IBI) were measured (Fig. 1). Formed between the middle lobar bronchus and the right lower lobar bronchus, the external (MLB-RLLBE) and internal angles (MLB-RLLBI) were measured (Fig. 2). Formed between the left upper lobar bronchus and the left main bronchus, the external (LULB-

LMBE) and internal angles (LULB-LMBI) were measured. Formed between the left upper lobar bronchus and the left lower lobar bronchus, the external (LULB-LLLBE) and internal angles (LULB-LLLBI) were measured. External angle was identified as the angle between outer walls, and internal angle was identified as the angle between centerlines. The volume measurement of the right and left lungs was carried out on the model obtained via 3-dimensional reconstruction. The volume values are the values obtained at the end of inspiration.

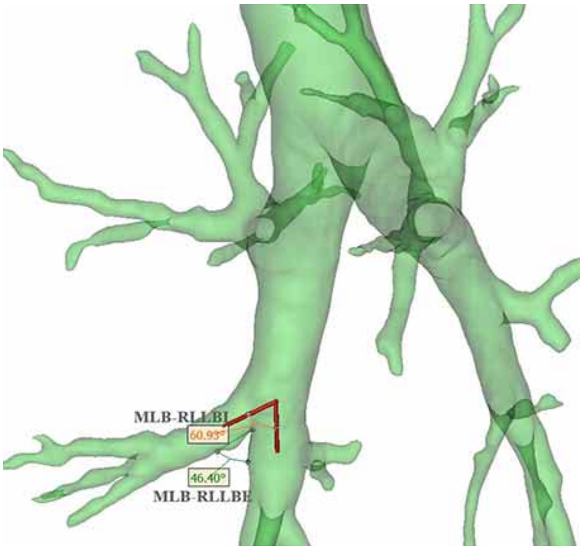

Fig. 2. Measurements of the external (MLB-RLLBE) and internal angles (MLB-RLLBI) between the middle lobar bronchus and the right lower lobar bronchus.

Statistical Analysis. Statistical Package for the Social Sciences v23.0 (SPSS Inc, Chicago, IL) packaged software was utilized to conduct statistical analysis. The Kolmogorov-Smirnov, histogram, and Q-Q plot tests were carried out to evaluate the normality distribution of continuous variables. Student's t-test and one-way ANOVA test were employed to compare the normally distributed continuous variables. Pearson's correlation test was conducted to assess the correlation between the lung volumes and angles. $p<0.05$ was considered statistically significant.

RESULTS

The average values of the angles of the tracheobronchial tree are presented in Table I.

No statistically significant difference was found between the sexes in terms of the measurement of subcarinal angles. The fact that the left subcarinal angle of the 62-87 age group was greater than the left subcarinal angles of the other age groups was revealed to be statistically significant (p:0.021). The total subcarinal angle was also observed to be greater in the 62-87 age group (p:0.017). No statistically significant difference was identified between the sexes in terms of interbronchial angles. However, the 62-87 age group was found to have a greater left interbronchial angle in comparison with the other age groups (p:0.004).

Table I. Mean values of angles of the tracheobronchial tree.

Parameter	Mean±SD (n:150)°
RSA	34.81±6.95
LSA	41.53±7.92
TSA	76.37±13.01
RIA	44.96±14.18
LIA	34.84±6.34
TIA	79.80±16.01
TR-RMBE	145.69±23.22
TR-LMBE	149.85±12.24
TR-RMBI	140.64±18.32
TR-LMBI	139.55±21.21
RULB-IBE	100.56±20.64
RULB-RMBE	127.29±21.17
RULB-IBI	88.77±17.21
RULB-RMBI	104.87±18.96
MLB-RLLBE	52.02±13.02
MLB-RLLBI	65.19±14.02
LULB-LMBE	138.46±21.43
LULB-LLLBE	71.23±18.20
LULB-LMBI	130.69±25.45
LULB-LLLBI	81.69±14.93

RSA: Right subcarinal angle; LSA: Left subcarinal angle; TSA: Total subkarinal angle; RIA: Right interbronchial angle; LIA: Left interbronchial angle; TIA: Total interbronchial angle; TR-RMBE: The external angle between the trachea and the right main bronchus; TR-LMBE: The external angle between the trachea and the left main bronchus; TR-RMBI: The internal angle between the trachea and the right main bronchus; TR-LMBI: The internal angle between the trachea and the left main bronchus; RULB-IBE: The external angle between the right upper lobar bronchus and the intermediate bronchus; RULB-RMBE: The external angle between the right upper lobar bronchus and the right main bronchus; RULB-IBI: The internal angle between the right upper lobar bronchus and the intermediate bronchus; RULB-RMBI: The internal angle between the right upper lobar bronchus and the right main bronchus; MLB-RLLBE: The external angle between the middle lobar bronchus and the right lower lobar bronchus; MLB-RLLBI: The internal angle between the middle lobar bronchus and the right lower lobar bronchus; LULB-LMBE: The external angle between the left upper lobar bronchus and the left main bronchus; LULB-LLLBE: The external angle between the left upper lobar bronchus and the left lower lobar bronchus; LULB-LMBI: The internal angle between the left upper lobar bronchus and the left main bronchus; LULB-LLLBI: The internal angle between the left upper lobar bronchus and the left lower lobar bronchus; SD: Standard Deviation; °: Angle

The LULB-LMBE and LULB-LMBI angles were found to be greater in males (p:0.021, $p<0.001$). The LULB-LLLBI angle was revealed to be greater in females compared to males ($p<0.001$). The TR-RMBE angle was observed to be greater in the 41-61 age group than in the other age groups and in the 20-40 age group in comparison with the 62-87 age group ($p<0.001$). The TR-RMBI angle was determined to be greater in the 41-61 age group than in the other age groups (p:0.001). The TR-LMBI, RULB-IBE, RULB-IBI, MLB-RLLBE, and MLB-RLLBI angles were found to be greater in the 20-40 age group in comparison with the other age groups (p:0.001, p:0.002, p:0.003, p:0.001, $p<0.001$). In the 20-40 age group, the RULB-RMBE angle was identified to be narrower than in the other age groups (p:0.004). The RULB-RMBI angle was seen to be greater in the 62-87 age group in comparison with the other age groups ($p<0.001$).

The correlation of the right lung volume with the angles on the right side of the tracheobronchial tree was reviewed. Likewise, the correlation of the left lung volume with the angles on the left side of the tracheobronchial tree was examined. No statistically significant correlation was detected between the measured parameters and the same-sided lung volumes, regardless of age and sex.

Analysis of the correlation between the right lung volume and the same-sided measured angles within the age groups was performed. In the 20-40 age group, a statistically significant positive moderate correlation was revealed between the right lung volume and RULB-RMBE (r:0.433, p:0.001). In the 41-61 age group, a moderate negative correlation was identified between these two parameters (r:-0.302, p:0.013). In the same age group, a moderate negative correlation was revealed between the right lung volume and RSA (r:-0.355, p:0.003). A moderate positive correlation was determined between TR-RMBE (r:0.469, p:0.018), RULB-RMBE (r:0.489, p:0.013), RSA (r:0.408, p:0.043) and the right lung volume in the 62-87 age group. In the same age group, a strong negative correlation was seen between MLB-RLLBE and the right lung volume (r:-0.662, $p<0.001$). Among the age groups, there was no statistically significant correlation between the left lung volume and the same-sided angles measured.

Analysis of the correlation between the right lung volume and the same-sided measured angles within the sex groups was performed. A statistically significant negative moderate correlation was identified between the right lung volume and RSA in males (r:-0.278, p:0.013). A statistically significant positive moderate correlation was found between RULB-IBE (r:0.357, p:0.002), RULB-IBI (r:0.266, p:0.025), and the right lung volume in females. Among the sex groups, no statistically significant correlation was identified between the left lung volume and the same-sided angles measured.

DISCUSSION

In our study, the branching angles of the tracheobronchial tree were assessed using the 3-dimensional reconstruction method. The 3-dimensional reconstruction method was used to evaluate the trachea and bronchi with 3-dimensional orientations in line with their 3-dimensional structure. Using the 3-dimensional reconstruction method, a 3-dimensional model was created from CT images in the DICOM format, and measurements were performed on this model. In most studies, the angles of the tracheobronchial tree have been measured on 2-dimensional sections (Karabulut, 2005; Kamel *et al*., 2009; Mi *et al*., 2015; Ulusoy *et al*., 2016). Furthermore, there are also studies conducted by creating a 3-dimensional model (Wani *et al*., 2018; Christou *et al*., 2021). However, in the literature review we conducted, we did not find any studies that examined the branching angles of the tracheobronchial tree with a 3-dimensional reconstruction method so extensively prior to our study.

Christou *et al*. (2021) included 185 individuals in the study in which they examined anatomical changes in the tracheobronchial tree. As in our study, a 3-dimensional model of the tracheobronchial tree was obtained via 3-dimensional reconstruction. They only checked three angles: the internal angle between the right upper lobar bronchus and the intermediate bronchus, the internal angle between the right main bronchus and the left main bronchus, and the internal angle between the left upper lobar bronchus and the left lower lobar bronchus. They stated that sex had no direct effect on these angles they measured (Christou *et al*., 2021). All three angles measured in their studies were also measured in our study. In our study, it was elucidated that the internal angle between the left upper lobar bronchus and the left lower lobar bronchus was greater in males than in females. Similar to the study by Christou *et al*. (2021), there is no significant difference between the sexes in the other two angles.

One hundred twenty individuals were involved in the study in which Karabulut (2005) evaluated interbronchial and subcarinal angles. The interbronchial and subcarinal angles discussed in the study are the total interbronchial angle and the total subcarinal angle in our study. The subcarinal angle (73°±16°) and the interbronchial angle (77°±13°) measured in the study were found to be close to the values measured in our study (76.37°±13.01°, 79.80°±16.01°). In the study by Karabulut (2005), interbronchial and subcarinal angles were measured in the coronal sections of CT images. It was reported that the tracheal bifurcation angle, which represents both interbronchial and subcarinal angles, was larger in females (Karabulut, 2005). However, there are also studies suggesting that the tracheal bifurcation angle is independent of sex (Alavi *et al*., 1970; Haskin & Goodman, 1982; Coppola *et al*., 1998). In our research, no significant difference was revealed between the sexes in both interbronchial and subcarinal angles.

Ulusoy *et al*. (2016) who evaluated the diameters, lengths, and branching angles of the trachea and bronchi, included 253 individuals in their study. The mean right subcarinal angle (34.5°±8.1°), left subcarinal angle (38.1°±8.9°), and left interbronchial angle (35.2°±8.1°) were close to the values obtained in our study. The mean right interbronchial angle was found to be 32.4°±7.7°, which is narrower than the value obtained in our study. Both the mean external and internal angle values (86.8°±16.3° and 81°±12.6°) between the intermediate bronchus and the right upper lobar bronchus and the mean external and internal angle values (47.1°±13.9° and 45.1°±13.5°) between the middle lobar bronchus and the right lower lobar bronchus were narrower than the mean values obtained in our study. The mean external and internal angle values between the left upper lobar bronchus and the left main bronchus (142.2°±11.2° and 140.6°±11.4°) and the mean external and internal angle values between the left upper lobar bronchus and the left lower lobar bronchus (58.7°±16.7° and 56.2°±15.4°) were identified to be narrower than the values in our research. The researchers evaluated the trachea and bronchi using MDCT images. They performed the measurements in the 2-dimensional planes of MDCT images (Ulusoy *et al*., 2016). Considering the 3-dimensional structures of the trachea and bronchi, we are of the opinion that the measurements on the 3-dimensional model will be better.

Sixty thorax CT scans and 10 cadavers were included in the research carried out by Kamel *et al*. (2009) to reveal the morphometry of the adult trachea using high-resolution thorax CT images supported by data obtained from cadavers. The subcarinal angle measured in the study is the total subcarinal angle in our study. As in our study, the right and left subcarinal angles were not reported separately. The mean subcarinal angle value measured in the study was 78°±20°, which was close to the value in our study (76.37°±13.01°). In their study, the researchers stated that the subcarinal angle was not correlated with age and sex (Kamel *et al*., 2009). In our study, it was determined that the total subcarinal angle was greater in the 62-87 age group. In our research, however, no significant difference was determined between the sexes in terms of the total subcarinal angle measurement.

The lung volume, airway structure, respiratory muscle strength, lung parenchyma, and elastic forces of the surrounding tissues are determined by alveolar surface tension. Diseases such as pulmonary fibrosis, pleural effusions, sarcoidosis, tuberculosis, and heart failure may lead to a decrease in the lung volume, and diseases such as chronic allergic asthma and emphysema may lead to an increase in the lung volume (Lu & Rouby, 2000; Haas *et al*., 2014; Savas¸ & Öz Özcan, 2021). In the current study, we examined how lung volume was impacted by the change in the tracheobronchial angle in healthy individuals.

In our study, the correlation of the right and left lung volumes with the angles of the same-sided tracheobronchial tree was investigated. In males, a statistically significant negative moderate correlation was identified between the right lung volume and RSA. In females, a statistically significant positive moderate correlation was revealed between RULB-IBE, RULB-IBI, and the right lung volume. In our literature review, no studies evaluating this correlation were encountered. Therefore, we are of the opinion that our study will contribute to the literature.

We think that our research will shed light on future studies on the correlation between tracheobronchial angles and lung volumes and on studies investigating the correlation between diseases, tracheobronchial angles, and lung volumes.

ETHICS STATEMENT. Ethics committee approval was granted for our study by the Scientific Research Ethics Committee of Lokman Hekim University (Decision No. 2022/227).

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RESUMEN: El objetivo de la investigación fue evaluar los ángulos de ramificación del árbol traqueobronquial y la correlación entre estos ángulos y el volumen pulmonar utilizando el método de reconstrucción tridimensional. Se obtuvieron retrospectivamente imágenes de tomografía computarizada de tórax de 150 individuos mayores de 18 años sin patología. Se realizó una reconstrucción tridimensional de la tráquea, los bronquios y los pulmones. Se midieron los ángulos externo e interno entre la tráquea y los bronquios principales, entre los bronquios principales y los bronquios lobares, y entre los bronquios lobares. Se realizó la medición del volumen de los pulmones derecho e izquierdo. Los individuos incluidos en el estudio fueron agrupados por sexo y edad (20-40 años, 41-61 años y 62-87 años). Se encontró que el ángulo subcarinal izquierdo, el ángulo subcarinal total y el ángulo interbronquial izquierdo eran mayores en el grupo de edad de 62 a 87 años. Tanto el ángulo externo (LULB-LMBE) como el ángulo interno (LULB-LMBI) entre el bronquio lobular superior izquierdo y el bronquio principal izquierdo era mayor en los hombres. En los hombres, se identificó una correlación moderada negativa estadísticamente significativa entre el volumen pulmonar derecho y el ángulo subcarinal derecho. En mujeres, se reveló una correlación positiva moderada estadísticamente significativa entre los ángulos externos (RULB-IBE) e internos (RULB-IBI) entre el bronquio lobar superior derecho y el bronquio intermedio, y el volumen pulmonar derecho. En la revisión bibliográfica que realizamos, no encontramos ningún estudio que analizara la correlación entre los ángulos de ramificación del árbol traqueobronquial y el volumen pulmonar utilizando el método de reconstrucción tridimensional. Por lo tanto, consideramos que nuestro estudio contribuirá a la literatura especializada del tema.

PALABRAS CLAVE: Arbol traqueobronquial; Reconstrucción tridimensional; Morfometría.

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