RESEARCH ARTICLE

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Radiologic Anatomy of the Tracheobronchial Tree: CT Morphometric Analysis of Branching Angle

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Abstract

Objectives: To characterize the radiologic anatomy of tracheobronchial branching using computed tomography (CT)-based morphometric analysis and to evaluate the associations between branching angles and demographic variables, particularly age and sex, in pediatric and adult populations.

Methods: This retrospective cross-sectional study included 712 individuals (310 pediatric and 402 adults) who underwent thoracic CT. Four tracheobronchial angles were measured on coronal 25-mm minimum intensity projection images: the right-left main bronchial angle, right upper lobe bronchus-bronchus intermedius angle, right middle lobe bronchus-right lower lobe bronchus angle, and left upper lobe bronchus-left lower lobe bronchus angle. Angle measurements were compared according to age group and sex, and correlations with age were assessed.

Results: The mean right-left main bronchial angle was 70.1±13.1°. The right middle-lower bronchial angle was significantly greater in adults than in children (44.1±12.8° vs. 38.4±12.7°, $p<0.001$). In children, the right-left main angle was greater in boys than in girls (71.2±12.3° vs. 68.0±13.3°, $p=0.029$), whereas in adults it was greater in women than in men (72.4±14.0° vs. 68.7±12.3°, $p=0.005$). Age showed weak correlations with the right upper-intermedius angle ($r=-0.102$, $p=0.006$) and right middle-lower angle ($r=0.159$, $p<0.001$).

Conclusion: CT-based morphometric evaluation demonstrated that tracheobronchial branching geometry exhibits branch-specific anatomical variation associated with age and sex. Although the main bronchial bifurcation angle remained relatively stable across pediatric and adult populations, distal branching angles showed significant demographic differences. These findings provide radiologic anatomical reference data that may facilitate individualized interpretation of thoracic CT examinations and contribute to the anatomical assessment of patients undergoing bronchoscopic and thoracic procedures.

Keywords: Anatomic variation, morphometry, bronchi, tomography, X-ray computed

Introduction

The tracheobronchial tree is a complex three-dimensional anatomical system whose dimensions, branching angles, and spatial orientation exhibit considerable interindividual variability. Rather than representing a geometrically uniform conduit, central airway anatomy is influenced by demographic and anatomical factors, including age and sex, and may display substantial variation even among otherwise healthy individuals. Accurate characterization of this variability has important implications for diagnostic bronchoscopy, airway stenting, endotracheal and double-lumen tube placement, thoracic surgery, and patient-specific assessment of airflow and inhaled particle deposition. Advances in multidetector computed tomography (CT), multiplanar reconstruction, minimum intensity projection (MinIP), and three-dimensional post-processing now enable non-invasive and reproducible assessment of tracheobronchial morphology beyond the limitations of conventional radiography or cadaveric measurements.[1-3]

Historically, morphometric investigations have focused predominantly on the carinal, subcarinal, and interbronchial angles. However, published findings regarding the effects of age and sex have been inconsistent. Karabulut demonstrated sex-related differences in tracheal carinal geometry on CT, whereas subsequent large-scale CT studies reported population-dependent variation in bronchial dimensions and branching patterns.[2-4] In a multidetector CT study including pediatric and adult participants, Ulusoy et al.[3] showed that several tracheal and bronchial morphometric parameters varied by age and sex, supporting the concept that fixed reference values may inadequately represent the full spectrum of normal airway anatomy. Pediatric three-dimensional CT studies have likewise demonstrated age-related variability in tracheobronchial angulation, further indicating that airway geometry changes across the lifespan.[5] Differences in study populations, measurement definitions, respiratory phase, image reconstruction techniques, and two-dimensional versus three-dimensional assessment may partly explain the heterogeneity of reported results.

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More recent studies have expanded the analysis beyond a single carinal or subcarinal angle. Using three-dimensional CT reconstruction, Erkaya et al.[6] evaluated multiple central and lobar bronchial branching angles and demonstrated complex associations with age, sex, and ipsilateral lung volume. Importantly, in a previous large-scale study by Kahraman et al.[7] —which comprised an independent patient population distinct from the present cohort— 1,511 pediatric and adult patients were evaluated using multislice CT and the MinIP technique. That study measured not only the right-left main bronchial angle but also the angles between the right upper lobe bronchus and the bronchus intermedius, between the right middle lobe bronchus and the right lower lobe bronchus, and between the left upper lobe bronchus and the left lower lobe bronchus. It reported a mean tracheal bifurcation angle of 73.3°±13.7° and demonstrated age- and sex-related differences in selected branching angles, thereby substantially expanding available CT-based reference data across a broad age range. Nevertheless, subsequent three-dimensional evidence suggests that tracheobronchial geometry may reflect a more complex interaction among demographic characteristics, lung morphology, and branch-specific spatial relationships than a single bifurcation measurement can capture.

The clinical relevance of such anatomical variability has become increasingly apparent. A recent randomized controlled trial demonstrated that individualized rotation of a left-sided double-lumen tube based on the left main bronchial angle measured on preoperative CT increased the first-attempt placement success rate from 82.6% to 91.4% and reduced procedure-related morbidity.[8] Similarly, three-dimensional reconstruction studies have shown that demographic characteristics and conventional two-dimensional radiographic estimates may not adequately account for individual variation in bronchial size when selecting double-lumen tubes.[9] These findings emphasize that precise CT-based characterization of airway geometry is not merely descriptive but may contribute directly to personalized procedural planning and to safer airway management.

Despite these advances, substantial heterogeneity persists across studies with respect to angular definitions, reconstruction techniques, age distribution, and anatomical levels assessed, limiting the generalizability of, and direct comparisons between, available reference data. Therefore, the present study aimed to comprehensively characterize tracheobronchial branching geometry using CT-based measurements and to evaluate its associations with demographic variables, particularly age and sex. Although our research group has previously investigated tracheobronchial branching angles across a large-scale pediatric and adult cohort utilizing the MinIP technique, the present study builds upon that foundational work by providing a more refined morphological assessment, exploring detailed age- and sex-stratified reference parameters, and offering a deeper anatomical analysis of tracheobronchial geometry across distinct demographic groups. By providing branch-specific morphometric data, this study seeks to refine normative anatomical reference values and strengthen the basis for individualized radiological, bronchoscopic, anesthetic, and thoracic surgical applications.

Methods

Study Design and Population

This retrospective study was conducted after approval by the Institutional Review Board (approval number: 2026-15/05, date: 06.08.2026). Owing to the retrospective nature of the investigation, the requirement for written informed consent was waived by the ethics committee. Thoracic CT examinations retrieved between January 2023 and January 2026 were evaluated. Thoracic CT examinations were performed for various clinical indications, primarily for trauma evaluation, suspected pulmonary infection, persistent cough, and exclusion of metastasis.

The study cohort comprised 712 patients, including 310 pediatric and 402 adult participants. Participants were classified into a pediatric group (age range: 1-18 years; mean: 13.7±4.5 years) and an adult group (age range: 19-92 years; mean: 55.6±18.1 years).

Of 855 initially screened thoracic CT examinations, patients were excluded due to respiratory motion, artifactual images, inability to comply with breath-hold instructions, insufficient breath-holding resulting in inadequate image quality, or acquisition during the expiratory phase (n=31). Additional exclusion criteria included a history of tracheobronchial or lung surgery (n=23); tracheal intubation; traumatic pneumothorax (n=25) or pneumomediastinum (n=26); and conditions capable of altering mediastinal anatomy, including mediastinal masses, mediastinal lymphadenopathy, and severe cardiomegaly (n=29). Individuals with related musculoskeletal deformities, such as kyphoscoliosis (n=9), were also excluded from the study based on these predefined criteria. As a result, the final analyzed patient group consisted of 712 individuals.

CT Acquisition and Image Analysis

Both contrast-enhanced and non-contrast thoracic CT examinations were included. Both contrast-enhanced and non-contrast CT examinations were evaluated together without a prior separate comparison, because intravenous contrast administration does not substantially alter the geometric or angular relationships of the cartilaginous tracheobronchial tree. Imaging was performed using a dual-source 256-slice CT scanner (Somatom Definition Flash; Siemens Healthcare, Forchheim, Germany). Both pediatric and adult examinations followed standardized institutional scanning protocols, with tube voltage and current parameters adjusted according to patient age and body habitus. All examinations were retrieved from the Picture Archiving and Communication System and reviewed on a Siemens workstation using Syngo.Via software, with particular emphasis on coronal reconstructions and MinIP images.

The CT acquisition protocol included a tube voltage of 120 kV, automatic tube current modulation ranging from 100 to 250 mAs, a section thickness of 1.25 mm, a pitch of 1.4, a gantry rotation time of 0.5-1 s, and a field of view of 455 mm. Examinations were obtained with patients in the supine position and, whenever possible, during adequate inspiration. For contrast-enhanced thoracic CT, 100-120 mL of iodinated contrast material was administered intravenously at an injection rate of 4 mL/s.

Image measurements were subsequently performed on coronal reconstructions generated with a 25-mm MinIP slab using Syngo.via software (Siemens Healthineers, Erlangen, Germany). Two radiologists independently performed the measurements, after which the findings were reviewed by an additional radiologist. Any disagreement between readers was resolved through joint reassessment and consensus. The investigators remained unaware of the patients' ages during the measurement process until the completion of the image analysis. Complete blinding to sex and clinical information was not feasible because anatomical features, including skeletal maturity, could provide indirect visual cues.

Patient age and sex were recorded as demographic variables. All angular measurements were obtained from coronal lung-window MinIP images. The following tracheobronchial branching angles were assessed:

- The angle between the right and left main bronchi;

- The angle between the right upper lobe bronchus and bronchus intermedius;

- The angle between the right middle lobe bronchus and right lower lobe bronchus;

- The angle between the left upper lobe bronchus and left lower lobe bronchus.

For each measurement, reference lines were drawn along the central longitudinal axes of the relevant bronchi, and the angle at their intersection was recorded (Figure 1). The central longitudinal axes were manually defined through the center of the air-filled bronchial lumen on standardized coronal multiplanar reformations, while the MinIP slab orientation was kept fixed at 25 mm.

MinIP is a post-processing technique designed to enhance visualization of low-attenuation structures. Within a predefined volume, the algorithm selects the voxel with the lowest attenuation value along each viewing direction and projects these data onto a two-dimensional image. This approach is particularly suitable for depicting air-filled structures such as the tracheobronchial tree.

For consistency, the measured parameters were designated as follows: the right main bronchus-left main bronchus angle was termed the right-left main coronal angle; the right upper lobe bronchus-bronchus intermedius angle was termed the right upper-intermedius coronal angle; the right middle lobe bronchus-right lower lobe bronchus angle was termed the right middle-lower coronal angle; and the left upper lobe bronchus-left lower lobe bronchus angle was termed the left upper-lower coronal angle.

Statistical Analysis

Statistical analyses were performed using IBM SPSS Statistics for Windows, version 20.0 (IBM Corp., Armonk, NY, USA). The distributions of continuous variables were assessed using the Kolmogorov-Smirnov test. Normally distributed numerical data were summarized as mean ± standard deviation, whereas variables with non-normal distributions were reported as median (minimum-maximum). Categorical variables were presented as frequencies and percentages.

Depending on the data distribution, comparisons of continuous variables between groups were conducted using either the Student's t-test or the Mann-Whitney U test. Categorical variables were compared using the chi-square test or Fisher's exact test, as appropriate. Associations between age and tracheobronchial angular measurements were examined using Spearman correlation analysis. Because multiple subgroup comparisons were performed across age categories and sex, these analyses were considered exploratory, and marginal significance levels (such as $p=0.029$) were interpreted with appropriate caution. A two-sided p value of <0.05 was considered statistically significant.

Results

The study population comprised 712 patients, including 310 pediatric patients (43.5%) and 402 adults (56.5%). The mean age was 13.7±4.5 years in the pediatric group and 55.6±18.1 years in the adult group, with an overall mean age of 37.4±25.0 years. Sex distribution was comparable between the pediatric and adult groups ($p=0.713$).

No significant differences were observed between pediatric and adult patients in the right-left main coronal angle, right upper-intermedius coronal angle, or left upper-lower coronal angle. In contrast, the right middle-lower coronal angle was significantly smaller in the pediatric group than in the adult group (38.4±12.7° vs. 44.1±12.8°, $p<0.001$) (Table 1).

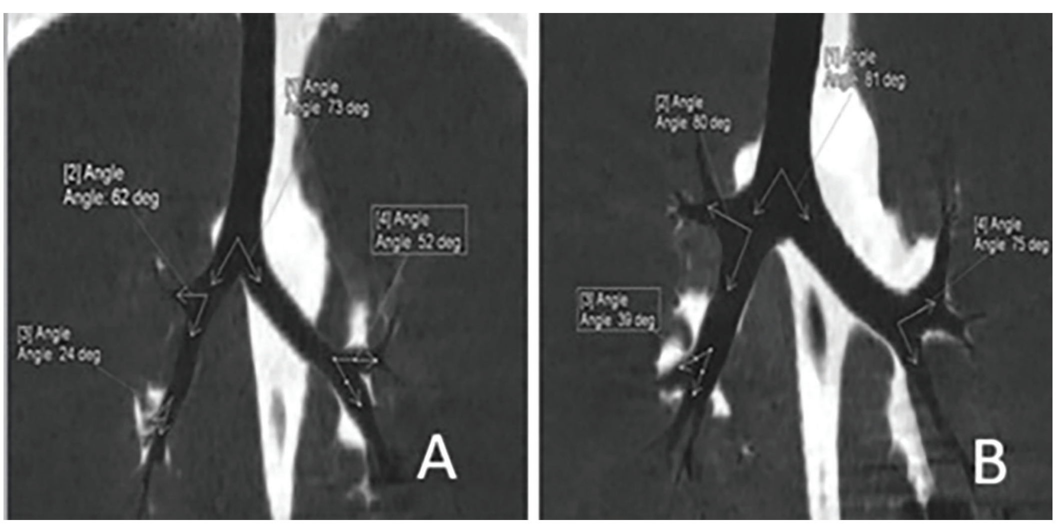

Figure 1. Measurement of tracheobronchial branching angles on coronal thoracic images obtained using the MinIP technique in pediatric and adult patients. A) Measurements in a 9-year-old boy. B) Measurements in a 25-year-old man. The assessed angles were as follows: (1) the angle between the right and left main bronchi in the coronal plane; (2) the right upper-intermedius angle, formed by the right upper lobe bronchus and bronchus intermedius; (3) the right middle-lower angle, formed by the right middle lobe bronchus and right lower lobe bronchus; and (4) the left upper-lower angle, formed by the left upper lobe bronchus and left lower lobe bronchus

MinIP: Minimum intensity projection

Within the pediatric group, the right-left main coronal angle was significantly greater in boys than in girls (71.2±12.3° vs. 68.0±13.3°, p=0.029). No significant sex-related differences were detected in the right upper-intermedius, right middle-lower, or left upper-lower coronal angles. In the adult group, the right-left main coronal angle was significantly smaller in men than in women (68.7±12.3° vs. 72.4±14.0°, p=0.005), whereas the remaining branching angles did not differ significantly according to sex (Table 2).

Correlation analysis demonstrated a significant negative association between age and the right upper-intermedius coronal angle (r=-0.102, p=0.006), and a significant positive association between age and the right middle-lower coronal angle (r=0.159, p<0.001). The correlations between age and the right-left main coronal angle (r=0.067, p=0.074) and between age and the left upper-lower coronal angle (r=-0.073, p=0.052) did not reach statistical significance (Table 3).

Discussion

The principal findings of the present study were as follows: first, the overall right-left main coronal angle was 70.1±13.1°, with no significant difference between pediatric and adult patients. Second, the right middle-lower coronal angle was significantly greater in adults than in pediatric patients (44.1±12.8° vs. 38.4±12.7°, p<0.001). Third, sex-related differences in the right-left main coronal angle showed an age-dependent pattern: in the pediatric group, the angle was greater in boys than in girls, whereas in the adult group it was smaller in men than in women. Finally, increasing age was associated with a modest decrease in the right upper-intermedius coronal angle and an increase in the right middle-lower coronal angle, while correlations with the right-left main coronal and left upper-lower coronal angles did not reach statistical significance. Taken together, these findings indicate that tracheobronchial geometry is not uniform across the airway tree and that demographic effects may vary according to both the anatomical level assessed and the age group under consideration.

Table 3. Relationship between age and angles

Variables (coronal; angles in°)	r	p
Right-left main	0.067	0.074
R upper-intermedius	-0.102	0.006
R middle-lower	0.159	<0.001
L upper-lower	-0.073	0.052

R upper-intermedius: angle between the right upper lobe bronchus and bronchus intermedius in the coronal plane; R middle-lower: angle between the right middle lobe bronchus and right lower lobe bronchus in the coronal plane; L upper-lower: angle between the left upper lobe bronchus and left lower lobe bronchus in the coronal plane

The mean right-left main coronal angle observed in the present cohort was broadly consistent with the range reported in previous CT-based morphometric investigations. Karabulut reported mean interbronchial and subcarinal angles of approximately 77° and 73°, respectively, and demonstrated a strong relationship between the two measurement approaches.[4] Kamel et al.,[10] using both *in vivo* CT and cadaveric assessment, also emphasized the marked interindividual variability of subcarinal geometry, reporting a wide range of values and no consistent association with age or sex. Similarly, large-scale CT analyses have demonstrated considerable variability in central airway dimensions and branching morphology across individuals.[2] Such differences between studies are likely to reflect, at least in part, heterogeneity in patient characteristics, respiratory phase, anatomical landmarks, and image-processing methodology.

A particularly relevant comparison is provided by our previous study, in which 1,511 pediatric and adult patients were evaluated using

Table 1. Demographic and clinical characteristics

Variables (coronal; angles in°)	Whole population, n=712	Pediatric group, n=310	Adult group, n=402	p
Age (year)	37.4±25.0	13.7±4.5	55.6±18.1	<0.001
Sex, n (%)				0.713
Male	357 (50.1)	153 (49.4)	204 (50.7)	
Female	355 (49.9)	157 (50.6)	198 (49.3)	
Right-left main	70.1±13.1	69.6±12.9	70.5±13.3	0.340
R upper-intermedius	72.1±13.4	72.9±12.9	71.6±13.8	0.193
R middle-lower	41.6±13.1	38.4±12.7	44.1±12.8	<0.001
L upper-lower	55.7±12.2	56.2±12.2	55.3±12.2	0.361

Numerical variables are expressed as mean ± standard deviation. A p value of was considered statistically significant. R upper-intermedius: angle between the right upper lobe bronchus and the bronchus intermedius in the coronal plane; R middle-lower: angle between the right middle lobe bronchus and the right lower lobe bronchus in the coronal plane; L upper-lower: angle between the left upper lobe bronchus and the left lower lobe bronchus in the coronal plane

Table 2. Distribution of demographic and clinical findings by sex

Variables (coronal; angles in°)	Pediatric male, n=153	Pediatric female, n=157	p	Adult male, n=204	Adult female, n=198	p
Age (year)	13.4±4.7	14.0±4.3	0.242	54.7±18.0	56.6±18.1	0.292
Right-left main	71.2±12.3	68.0±13.3	0.029	68.7±12.3	72.4±14.0	0.005
R upper-intermedius	72.0±12.4	73.7±13.3	0.245	71.8±13.6	71.3±14.0	0.717
R middle-lower	38.7±12.4	38.1±13.1	0.679	43.8±12.7	44.5±13.0	0.585
L upper-lower	56.1±12.7	56.2±11.8	0.943	55.7±11.3	54.9±13.1	0.513

Numerical variables are expressed as mean ± standard deviation. A p value <0.05 was considered statistically significant multislice CT and the MinIP technique, yielding an overall tracheal bifurcation angle of 73.3±13.7°. The present findings reproduce this general pattern despite a lower absolute mean value, with pediatric and adult patients again showing comparable right-left main coronal measurements and demonstrating that the principal main-bronchial bifurcation angle remains relatively stable when comparing pediatric and adult populations at the group level.[7] At the same time, the modest difference in absolute values between cohorts reinforces the need to interpret reference ranges in relation to population structure and measurement conditions rather than consider a single universal threshold applicable to all individuals. The methodological framework and four branch-specific angular measurements in the previous study are documented in the initially uploaded article.[7]

In contrast to the relatively stable right-left main angle, the right middle-lower coronal angle demonstrated a clear difference among age groups. Adults had significantly larger values than pediatric patients; this parameter also showed the strongest positive correlation with age among all angular measurements. This finding closely parallels our previous study, in which the right middle-lower angle was likewise significantly greater in adults than in children.[7] The consistency of this branch-specific pattern with previous findings is noteworthy because most earlier studies concentrated on the carinal or subcarinal angle and provided limited information on more distal lobar branching geometry. More recent three-dimensional CT analyses have expanded this approach by demonstrating that bronchial branching angles differ according to anatomical level and may be related to demographic characteristics and lung morphology.[6] Therefore, the present data further support the concept that age-related remodeling of the tracheobronchial tree should be evaluated regionally rather than inferred from a single central bifurcation measurement.

The sex-related findings also warrant particular attention. In pediatric patients, boys had a significantly greater right-left main coronal angle than girls; the opposite pattern was observed in adults, with women showing larger angles than men. Although these independent subgroup comparisons revealed opposite descriptive patterns between pediatric and adult populations, formal interaction analysis was not performed. Therefore, these findings should be interpreted as distinct descriptive observations rather than definitive proof of an age-group-by-sex interaction. This finding closely mirrors the age-dependent sex pattern identified in our previous study.[7] Earlier investigations have produced inconsistent results concerning sex-related variation in tracheobronchial angles. Karabulut[4] reported greater interbronchial and subcarinal angles in women, whereas Kamel et al.[10] found substantial variability without a significant sex relationship. Large-population CT studies have nevertheless confirmed that multiple tracheobronchial dimensions differ between men and women.[2,3] These discrepancies suggest that the influence of sex may not be constant throughout life and may depend on the specific airway parameter under investigation. The reversal of the male-female relationship between pediatric and adult groups in the present study may reflect differences in thoracic growth, lung volume development, body habitus, or age-related remodeling of mediastinal geometry; however, these mechanisms cannot be established from the present data and should be regarded as hypotheses requiring dedicated longitudinal investigation.

Previous pediatric studies further support the importance of considering developmental changes in airway geometry. Wani et al.[5] used three-dimensional CT-based measurements and showed that right and left bronchial angles in children vary with age, with particularly relevant developmental differences during early childhood. Herek et al.[11] likewise reported age-related changes in tracheobronchial angles in children, observing wider angles in younger age groups and a tendency for several central airway measurements to decrease with increasing age. In the present study, however, age was not significantly correlated with the right-left main coronal angle, whereas age showed a significant negative correlation with the right upper-intermedius angle and a significant positive correlation with the right middle-lower angle. The discrepancy is not necessarily contradictory; rather, it may indicate that maturation does not affect all bronchial branches in parallel. Differences in age ranges, sample compositions, two- versus three-dimensional assessments, and definitions of angular landmarks may contribute to heterogeneous findings across studies.

An additional observation is that the correlations with age were modest in magnitude. The strongest association was detected for the right middle-lower angle (r=0.159), while the right upper-intermedius angle showed only a weak inverse relationship (r=-0.102). Notably, our previous larger study identified statistically significant correlations between age and all four angular parameters, although the corresponding correlation coefficients were also small.[7] In the present cohort of 712 patients, the right-left main and the left upper-lower correlations did not achieve statistical significance. This difference may partly reflect the smaller sample size compared with that of the previous 1,511-patient cohort because the detection of very weak correlations is particularly sensitive to statistical power. More importantly, the consistently low magnitude of the correlation coefficients suggests that chronological age alone accounts for a limited proportion of interindividual variation in tracheobronchial geometry. This interpretation is compatible with three-dimensional morphometric work indicating that airway angles may be influenced by multiple interacting factors rather than by age alone.[6]

From an imaging perspective, the use of MinIP is an important feature of the present approach. MinIP preferentially displays low-attenuation voxels and therefore facilitates visualization of air-filled tracheobronchial structures. Our previous study demonstrated the feasibility of applying a 25-mm MinIP slab for branch-specific angular assessment in a large cohort of pediatric and adult participants.[7] Earlier MinIP-based investigations predominantly focused on the subcarinal angle,[12] whereas the present approach includes both central and lobar branching levels. Nevertheless, differences between MinIP, conventional multiplanar reconstructions, and three-dimensional airway segmentation should be acknowledged because each method may define the bronchial axis differently. The increasing use of three-dimensional CT reconstruction has demonstrated that airway geometry is inherently spatial and may not always be completely represented by a single coronal measurement.[5,6]

The clinical relevance of individualized tracheobronchial geometry extends beyond descriptive anatomy. Precise knowledge of bronchial orientation may facilitate bronchoscopy, airway reconstruction, lung isolation, and the selection or positioning of endobronchial devices. In particular, a recent randomized controlled trial demonstrated that individualizing left double-lumen tube rotation based on the left main bronchial angle measured on preoperative CT scans improved first-attempt placement success compared with conventional fixed rotation.[8] Likewise, three-dimensional reconstruction studies have shown that conventional demographic or two-dimensional approaches may inadequately predict individual bronchial dimensions for double-lumen tube selection.[9] Earlier investigations demonstrated that direct CT measurement of the left main bronchus can guide individualized double-lumen tube sizing.[13,14] These observations support the broader premise that CT-derived airway morphometry can have procedural implications, although the current study was anatomical in nature and did not directly assess clinical outcomes.

Study Limitations

Several limitations should be acknowledged. First, the retrospective, single-center design may limit the generalizability of the findings. Second, although examinations with inadequate image quality and expiratory acquisition were excluded, subtle variability in inspiratory depth could still have influenced bronchial orientation. Third, measurements were obtained in the coronal plane using MinIP images, therefore, the full three-dimensional orientation of obliquely coursing bronchi may not have been fully represented. Fourth, although age and sex were analyzed, potentially relevant variables such as height, body mass index, thoracic dimensions, total lung volume, and pulmonary function parameters were unavailable for inclusion in multivariable models. Finally, the cross-sectional design does not permit direct evaluation of longitudinal changes in airway geometry within the same individuals. Future multicenter studies combining standardized inspiratory CT, automated airway segmentation, and three-dimensional morphometric analysis may help establish more robust population-specific reference ranges and clarify the independent determinants of branch-specific airway geometry.

Conclusion

The present study demonstrates that tracheobronchial branching geometry varies according to anatomical level and is differentially associated with age and sex. The right-left main coronal angle did not differ significantly between the pediatric and adult groups, whereas the right middle-lower angle was greater in adults and increased with age. Sex-related differences in the main bronchial angle exhibited opposite patterns between pediatric and adult populations, suggesting that demographic effects on airway morphology may be age-dependent. The close agreement of several key patterns with our previous large-scale MinIP study, particularly the greater right middle-lower angle in adults and the contrasting sex distribution of the right-left main angle, supports the consistency of these observations with our previous findings.[7] Further three-dimensional and longitudinal studies are warranted to determine the biological basis and procedural relevance of these branch-specific variations

Ethics

Ethics Committee Approval: This retrospective study was conducted after approval by the Institutional Review Board (approval number: 2026-15/05, date: 06.08.2026).

Informed Consent: This retrospective study.

Footnotes

Authorship Contributions

Concept: K.B., Design: K.B., Data Collection or Processing: K.B., Analysis or Interpretation: K.B., Literature Search: H.Ç., Writing: H.Ç.

Conflict of Interest: No conflict of interest was declared by the authors.

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References

1. Christou S, Chatziathanasiou T, Angeli S, et al. Anatomical variability in the upper tracheobronchial tree: sex-based differences and implications for personalized inhalation therapies. J Appl Physiol (1985). 2021;130:678-707.
2. Mi W, Zhang C, Wang H, et al. Measurement and analysis of the tracheobronchial tree in Chinese population using computed tomography. PLoS One. 2015;10:e0123177.
3. Ulusoy M, Uysal II, Kıvrak AS, et al. Age and gender related changes in bronchial tree: a morphometric study with multidedector CT. Eur Rev Med Pharmacol Sci. 2016;20:3351-7.
4. Karabulut N. CT assessment of tracheal carinal angle and its determinants. Br J Radiol. 2005;78:787-90.
5. Wani TM, Buchh B, AlGhamdi FS, Jan R, Tumin D, Tobias JD. Tracheobronchial angles in children: Three-dimensional computed tomography-based measurements. Paediatr Anaesth. 2018;28:463-7.
6. Erkaya A, Coskun ZK, Akyol S, et al. Evaluation of angles of the tracheobronchial tree with the 3-dimensional reconstruction method: a morphometric and radiologic study. Int J Morphol. 2023;41:512-7.
7. Kahraman Ş, Yazar MF, Aydemir H, Kantarci M, Aydin S. Detection of tracheal branching with computerized tomography: the relationship between the angles and age-gender. World J Radiol. 2023;15:118-26.
8. Zhou H, Fei Y, Zhang Y, Quan X, Yi J. Individualized rotation of left double lumen endobronchial tube to improve placement success rate: a randomized controlled trial. Respir Res. 2024;25:184.
9. 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;24:215.
10. Kamel KS, Lau G, Stringer MD. In vivo and in vitro morphometry of the human trachea. Clin Anat. 2009;22:571-9.
11. Herek D, Herek O, Ufuk F. Tracheobronchial angle measurements in children: an anthropometric retrospective study with multislice computed tomography. Clin Exp Otorhinolaryngol. 2017;10:188-92.
12. Fernandes SF, Pradhan A. Estimation of subcarinal angle using minimum intensity projection in computed tomography. Asian J Pharm Clin Res. 2018;11:383-5.
13. Hannallah M, Benumof JL, Silverman PM, Kelly LC, Lea D. Evaluation of an approach to choosing a left double-lumen tube size based on chest computed tomographic scan measurement of left mainstem bronchial diameter. J Cardiothorac Vasc Anesth. 1997;11:168-71.
14. Chow MY, Liam BL, Lew TW, Chelliah RY, Ong BC. Predicting the size of a double-lumen endobronchial tube based on tracheal diameter. Anesth Analg. 1998;87:158-60.