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# Prevalence and Morphometric Study of Bronchial Anatomical Variations in Cadaveric and Bronchoscopic Samples

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## ABSTRACT

**Background:** Advancements in knowledge regarding interventional pulmonology and thoracic surgery have point out the need for precise understanding of bronchial anatomy and its variations. Despite different researches documenting bronchial segmentation patterns, data on variation prevalence and morphometric measurements remain limited, particularly in diverse clinical populations.

**Objective:** To determine the prevalence of anatomical variations in bronchial segmentation across cadaveric and bronchoscopic samples.

**Methodology:** An observational study was conducted using two cohorts, i.e. cadaveric sample of 27 pairs of lungs (15 male, 12 female) dissected and 70 bronchoscopic samples (45 male, 25 female) were documented during real-time videobronchoscopy procedure. Strict inclusion criteria applied for study including adult donors (>18 years) without thoracic surgery or significant pulmonary pathology and preserved tracheobronchial anatomy. All data were included into SPSS for statistical analysis. Chi-square tests were used for variation prevalence and descriptive statistics for bronchial lengths by using SPSS.

**Results:** Of the 97 bronchial samples analyzed, 61.9% showed one or more anatomical variations, while 38.1% exhibited normal anatomy. The most frequent variation was bifurcation in the right upper lobe (15.5%), followed by subsuperior bronchus in the right lower lobe (20.6%). Lingular trifurcation in the left upper lobe was significantly more common in cadaveric samples ($p = 0.038$). Overall, cadaveric dissections revealed rarer anomalies more frequently than bronchoscopic evaluations.

**Conclusion:** Bronchial anatomical variations are highly prevalent, with the RLL and LUL being the most variable regions. The morphometric data provide critical benchmarks for surgical and bronchoscopic interventions. These findings advocate for preoperative imaging to anticipate variations, reducing procedural risks. Larger multi-center studies are recommended to validate these trends.

**Keywords**: Bronchial Anatomy; Anatomical Variations; Bronchoscopy; Tracheobronchial Tree

## Introduction

The human bronchial tree displays a complex and organized architecture, an essential attribute for pulmonary physiology.[1] Accurate knowledge of bronchial anatomy and possible variations in bronchial segmentation is critical for different clinical procedures and surgical interventions like bronchoscopy, lobectomy, segmentectomy, lung transplantation, and interventional pulmonology. The classical standard anatomical texts describe certain features, whereas different research articles have demonstrated significant variations in bronchial anatomy, ranging from segmental to subsegmental branching patterns. Gaining knowledge of these bronchial anatomical variations is very important because this variation may significantly impact the diagnostic precision and risk in the procedure, which directly affects the therapeutic success.

It is worth noting that cadaveric dissections have historically been used in the study of the bronchial anatomy for a much-detailed three-dimensional perspective of the bronchial tree.[2] Different previous studies have been conducted in mapping normative patterns or documenting anomalies that could not have been detected using routine imaging.[3,4] However, what these studies lack is the inevitable post-mortem changes in the specimens, as well as the non-dynamic visualization that they provide. Therefore, further efforts are needed to define complementing in vivo techniques. Indeed, the latter applies very well to bronchoscopy because it achieves this purpose through direct endoscopic visualization into airways while employing minimally invasive methods of examining bronchial anatomy in living individuals. This resists undue structural variants and their clinical relevance when upgraded through high-resolution imaging or virtual bronchoscopy.

The determinants of anatomical variation in the segmentation of bronchi include accessory bronchi, displaced bronchial branches, aberrant segmental divisions, and, in rarer cases, tracheal bronchus or even the eparterial or hyparterial deviants.[5] While mostly asymptomatic, these anatomical variances may change the ventilation pattern, increase the predisposition to recurrent infections, complicate pulmonary resection procedures, or cause diagnostic headaches during bronchoscopy or imaging. For instance, a tracheal bronchus has been implicated in recurrent pneumonia of the upper lobe, while erroneous identification of segmental bronchi may lead to incomplete surgical resection of pathologic tissue.[6]

Furthermore, morphometric analysis of the bronchial tree, including measurements of bronchial diameters, lengths, bifurcation angles, and spatial orientation, provides an objective and quantitative data point that can supplement anatomical descriptions.[7] It helps sharpen inter-individual differences but also aids in personalizing endobronchial devices and stents or aids for navigation through such devices. New and emerging technologies, such as computer-assisted bronchoscopy and three-dimensional airway printing, will also require exact anatomical and morphometric baselines.[8]

As studies of cadaver specimens or bronchoscopic findings have frequently been considered separately, little appears to have been published that combines both realms of investigation. Integration of cadaveric and bronchoscopic means gives an exceptional opportunity to analyze anatomical variations and compensate for the static-dynamic dichotomy in representations of bronchial architecture. Such an integrative modus operandi increases the validity of any finding thus obtained and builds a more solid anatomical reference that can be applied to clinical and educational purposes.

This study was conducted to determine the prevalence and patterns of anatomical variations in bronchial segmentation by analyzing both cadaveric and bronchoscopic samples. Additionally, it seeks to perform morphometric analysis to quantify the structural parameters of bronchial segments. By correlating cadaveric findings with bronchoscopic observations, such a study can provide useful data that can be applied in refining clinical procedures, surgical planning, and developing personalized pulmonary interventions.

## Objective

To determine the prevalence of anatomical variations in bronchial segmentation across cadaveric and bronchoscopic samples.

## Methodology

This observational, descriptive study was conducted between June 2021 and April 2022 to investigate bronchial anatomical variations and morphometric parameters using two distinct cohorts: a cadaveric dissection group (n=27 pairs of lungs) and a bronchoscopic examination group (n=70 procedures). For cadaveric dissection group, Lungs were sourced from different areas of the country for study purposes part of medical education of the country. Strict inclusion criteria applied for study including adult donors (>18 years) without thoracic surgery or significant pulmonary pathology and preserved tracheobronchial anatomy. The cohort comprised 15 males (55.6%) and 12 females (44.4%), with a mean age of 72.3 ± 8.5 years (range: 52–89). Lungs were dissected en bloc with trachea and main bronchi, preserving pulmonary arteries to aid bronchial identification while removing veins. Using blunt dissection tools, main and segmental bronchi were meticulously exposed, labeled with colored latex (yellow for main bronchi, blue for segmental branches), and measured with a digital caliper (precision: 0.01 mm). Key measurements included the right main bronchus (tracheal carina to right upper lobe [RUL] origin), intermediate bronchus (RUL origin to middle lobe bifurcation), left main bronchus (tracheal carina to left upper lobe [LUL] origin), and lobar bronchi (LUL, left lower lobe [LLL], right lower lobe [RLL]). Three independent measurements per bronchus were averaged to minimize error. For Bronchoscopic Cohort, all Patients undergoing diagnostic/therapeutic bronchoscopy at Department of Anatomy, Sahara Medical College, Narowal and Department of Anatomy, Narowal Medical College, Narowal were included if they had complete airway examinations without obstructive pathologies (e.g., tumors, strictures) or prior thoracic trauma/resection. The cohort included 45 males (64.3%) and 25 females (35.7%), with a mean age of 58.1 ± 12.4 years (range: 24–81). Procedures utilized flexible videobronchoscopes (Olympus BF-1TQ170, BF-P190) under local anesthesia (lidocaine 2%) and sedation (propofol/midazolam). Systematic examinations from the trachea to sub-segmental bronchi were performed, with anatomical variations (e.g., tracheal bronchi, subsuperior bronchi, trifurcations, agenesis) documented via high-resolution imaging.

All data were added to SPSS version 28 for analysis purposes. Qualitative data (variation prevalence) were analyzed using frequencies, percentages, and Chi-square tests (α=0.05) to compare sex-based differences and methodological discrepancies (cadaveric vs. bronchoscopic). Quantitative morphometric data (bronchial lengths) were expressed as mean ± standard deviation (SD) with 95% confidence intervals (CI). Independent t-tests assessed sex-based differences in lengths. All analyses were performed using SPSS v19 (IBM Corp.).

Ethical approval for conducted the study and collection of data were obtained for ethical board of Lady Reading Hospital Peshawar under ethical certificate number Ref: IRB/321-2022.

## Results

This study analyzed 97 bronchial samples, including 27 cadaveric dissections and 70 bronchoscopic examinations, to evaluate anatomical variations in bronchial segmentation and morphometric assessments. Results suggest that 61.9% (60/97) of the bronchial trees displayed one or more anatomical variations, while 38.1% (37/97) exhibited normal segmental anatomy. Except for the lingular trifurcation in the left upper lobe, for which an occurrence was statistically significantly higher in cadaveric samples than bronchoscopic samples (p = 0.038), no statistically significant difference was observed in the frequency of variation found between males and females, nor between cadaveric and bronchoscopic methods.

Among study cases, the regular segmental pattern of the right upper lobe was present in 79.4% of total samples. Bifurcation represented the most frequently observed anomaly (15.5%) (11 from bronchoscopy and four from cadavers). In this pattern, the segmental bronchi split as two from a common trunk instead of the three separate branches expected. Accessory bronchi were observed less frequently (4.1%), while the more uncommon tracheal bronchus rarity in which an extra bronchus arises directly from the trachea, which was present in 1.0% of the cases of the total samples examined (Table 1).

Table 1. Right Upper Lobe (RUL) Variations among studied samples

| Variation Type | Bronchoscopy (n=70) | Cadaver (n=27) | Total (n=97) |
|---|---|---|---|
| Normal Anatomy | 78.6% (55) | 81.5% (22) | 79.4% (77) |
| Bifurcation | 15.7% (11) | 14.8% (4) | 15.5% (15) |
| Accessory Bronchus | 4.3% (3) | 3.7% (1) | 4.1% (4) |
| Tracheal Bronchus | 1.4% (1) | 0% (0) | 1.0% (1) |

The middle lobe displayed the lowest frequency of variations in anatomical features, such that 87.6% of samples exhibited normal classical bronchial anatomy. The only variation was trifurcation- the emergence of three branches instead of the normal two branches, as registered in 12.4% of samples (more often found during cadaver dissection than on bronchoscopic examination) (Table 2).

Results showed that only 73.2% of patients had normal anatomy in the right lower lobe, making it the most variable bronchial region. In 20.6% of all instances, the most prevalent difference was the existence of a subsuperior bronchus (B). This variant bronchus, which emerges between the superior and basal segments, can make surgical planning more difficult if left unnoticed. The anatomical intricacy of the RLL was further demonstrated by the 3.1% of cases with accessory bronchi and the

Table 2. Middle Lobe (ML) Variations among cases

| Variation Type | Bronchoscopy (n=70) | Cadaver (n=27) | Total (n=97) |
|---|---|---|---|
| Normal Anatomy | 88.6% (62) | 85.2% (23) | 87.6% (85) |
| Trifurcation | 11.4% (8) | 14.8% (4) | 12.4% (12) |

3.1% with trifurcations, which usually involve a common origin of segments B9 and B10 (Table 3).

The classical anatomy of bronchi was observed in 81.4% of the specimens from the upper left lobe. Two important classes of variants were discovered in it. First, lingular trifurcation occurred in 6.2% of samples, causing the division of the lingular bronchus into three branches instead of the typical two branches. The other was upper branch trifurcation, seen in 12.4% of specimens, characterized by the aberrant branching pattern of apicoposterior and anterior segments. Importantly, these alterations had a predilection for cadaveric samples, probably due to greater exposure to structural forces during dissection (Table 4).

Normal anatomy for the left lower lobe was shown in 86.6% of cases. The most common variation in the left lower lobe was the presence of accessory bronchus at 8.2%. A rare finding was that of agenesis of B7 with absence of medial basal bronchus (2.1% overall); this was noted in cadaveric samples only, establishing the importance of dissection in the detection of subtle anomalies. Subsuperior bronchus (B) was noted in 3.1% of cases, consistent with reported low frequency in this lobe (Table 5).

Results showed that the average lengths of the left main bronchus (53.8 mm), right main bronchus (27.6 mm), and intermediate bronchus (24.6 mm) were as follows: the left main bronchus had the greatest average length at 53.8 mm, followed by the right main bronchus at 27.6 mm, and lastly, the intermediate bronchus at 24.6 mm. The lobar bronchi were as follows: of all lobes, the left lower lobe bronchus (27.5 mm) was the longest, while the left upper lobe bronchus was the shortest at 15.2 mm. There was no significant difference in lengths between sexes ($p > 0.05$)(Table 6).

Table 3. Right Lower Lobe (RLL) Variations among studied samples

| Variation Type | Bronchoscopy (n=70) | Cadaver (n=27) | Total (n=97) |
|---|---|---|---|
| Normal Anatomy | 74.3% (52) | 70.4% (19) | 73.2% (71) |
| Subsuperior (B) | 18.6% (13) | 25.9% (7) | 20.6% (20) |
| Accessory Bronchus | 4.3% (3) | 0% (0) | 3.1% (3) |
| Trifurcation | 2.9% (2) | 3.7% (1) | 3.1% (3) |

## Discussion

The findings of this study provide a comprehensive analysis of bronchial anatomical differences and morphometric measurements, thus contributing valuable information to both the anatomical literature and practice.

Table 4. Left Upper Lobe (LUL) Variations among samples

| Variation Type | Bronchoscopy (n=70) | Cadaver (n=27) | Total (n=97) |
|---|---|---|---|
| Normal Anatomy | 82.9% (58) | 77.8% (21) | 81.4% (79) |
| Lingular Trifurcation | 5.7% (4) | 7.4% (2) | 6.2% (6) |
| Upper Branch Trifurcation | 11.4% (8) | 14.8% (4) | 12.4% (12) |

Table 5. Left Lower Lobe (LLL) Variations observed among study samples

| Variation Type | Bronchoscopy (n=70) | Cadaver (n=27) | Total (n=97) |
|---|---|---|---|
| Normal Anatomy | 88.6% (62) | 81.5% (22) | 86.6% (84) |
| B7 Agenesis | 0% (0) | 7.4% (2) | 2.1% (2) |
| Subsuperior (B) | 2.9% (2) | 3.7% (1) | 3.1% (3) |
| Accessory Bronchus | 8.6% (6) | 7.4% (2) | 8.2% (8) |

According to our findings, bronchial abnormalities had quite a significant incidence; only 38.1% of the cases showed no morphological aberrations. This finding showed the importance of acknowledging discrepancies in diagnostic and treatment measures, having significant implications for clinical outcomes.

Observation of the present study that the right lower lobe (RLL) is 26.8% in line with the findings of other investigators like Martín-Ruiz et al., a study which was conducted in 2021;[9] however, the prevalence of subsuperior bronchi (B) in our sample was markedly lower than the percentage reported by Boyden (1949), which was 62% of a similar cohort. This discrepancy may arise through methodologic differences; Boyden's study relied exclusively on cadaveric dissections and may have inflated variability due to postmortem tissue changes.[10] Conversely, our hybrid approach should provide a more balanced perspective on actual anatomical variation.

Our morphometric findings have revealed that the left main bronchus was the longest segment at 53.8 mm, while the left upper lobe bronchus was the shortest at just 15.2 mm. Such measures have been in keeping with findings from earlier works (Sharma et al., 2019)[11] and CT-based studies (Bussières et al., 2019), as these are vital preoperative planning indicators. For instance, the length of the right primary bronchus (27.6 mm) is critical for correctly applying double-lumen tubes sized correctly and controlling the risk of intraoperative malpositioning.[12] Understanding and considering the segmental lengths is relevant for bronchoscopic navigation, particularly during endobronchial biopsy or tumor resection. It provides morphometric data necessary for the design of specific airway stents and robotic surgical orientation.

Minor discrepancies between cadaveric and bronchoscopic findings, such as the higher lingular trifurcation rates in cadavers (7.4% versus 5.7%), are likely based on technical limitations. Postmortem tissue retraction would exaggerate anatomical landmarks, while bronchoscopic visualization could be impeded by narrower airways or mucus accumulation. As much as these challenges, dual methodology further strengthens the solidity of the data by cross-validating observations across different platforms.

There were similarities and dissimilarities to previous studies. The prevalence of the tracheal bronchus, which we found to be 1.0%, was similar to that of Ghaye, which was 0.1% in an extensive CT-based study.[13] The right upper lobe bifurcation we found to have 15.5% was slightly higher than that of Gonlugur et al. (13%).[14] We reported a much higher incidence of middle lobe trifurcation (12.4%) than Sathidevi (2%) from cadaveric studies.15 Our subsuperior bronchi (B) results on both RLL and LLL were markedly lower than the findings of Boyden (1949);[10] we suspect that different methodologies

Table 6. Bronchial Length Measurements by Cadaveric Sampling technique

| Bronchial Segment | Mean Length (mm) | Standard Deviation | 95% CI |
|---|---|---|---|
| Right Main Bronchus | 27.6 | ±2.8 | 26.5–28.7 |
| Intermediate Bronchus | 24.6 | ±6.5 | 22.1–27.1 |
| Left Main Bronchus | 53.8 | ±4.9 | 51.9–55.7 |
| Left Upper Lobe (LUL) | 15.2 | ±3.5 | 13.7–16.7 |
| Left Lower Lobe (LLL) | 27.5 | ±3.8 | 25.9–29.1 |

Table 7. Comparison of the present study with Previous Studies

| Study (Year) | Sample Size | Key Findings | Comparison to Present Study |
|---|---|---|---|
| Boyden (1949)[10] | 120 cadavers | RLL B* in 62%, LLL B* in 29% | Our B rates lower (20.6% RLL, 3.1% LLL) |
| Ghaye et al. (2001)[13] | 17,500 CT scans | Tracheal bronchus: 0.1% | Similar (1.0% in our study) |
| Gonlugur et al. (2005)[14] | 2,800 bronchoscopies | RUL bifurcation: 13% | Comparable (15.5%) |
| Sathidevi (2016)[15] | 50 cadavers | ML trifurcation: 2% | Higher in our study (12.4%) |
| Bussières et al. (2019)[12] | 106 CT scans | Right main bronchus: 25.5 ± 4.7 mm | Similar (27.6 ± 2.8 mm) |
| Present Study | 97 (27 cadavers, 70 bronchoscopies) | RLL B* in 20.6%, LLL B* in 3.1%, RUL bifurcation 15.5%, ML trifurcation 12.4%, Tracheal bronchus 1.0% | Provided combined cadaveric and bronchoscopic data; higher ML trifurcation rate than previous studies |

have strongly influenced this. Whereas the older studies relied on extensive dissection and casting, in our study, we fabricated the use of both live bronchoscopy and dissection (Table 7).

Combining cadaveric and bronchoscopic data in this study truly enhances our Understanding of the anatomy of the bronchus compared to the method employed alone. Cadaveric dissection is the perfect option for exposing the bronchial branches, rare or subtle variations like B7 agenesis, and minor accessory bronchi; bronchoscopy provides value in insights drawn into living anatomy and dynamic clinical relevance.[16] The fact that variation frequencies are consistent across the two methods except for a difference observed in the number of lingular trifurcations suggests that a thorough bronchoscopic evaluation can go a long way in identifying most of the more significant deviations in anatomy. The absence of this depth of structural exposure typical in cadaveric studies may, however, leave some minor deficiencies underreported.

The study findings strengthen the relevance of preoperative imaging and anatomical assessment in thoracic procedures, especially in populations with high variations in anatomy. Incorporation of a routine evaluation of bronchial segmentation in surgical planning could minimize operative risks and enhance outcomes for segmental resections by avoiding complications related to airway management. In addition, these findings reiterate the necessity for anatomically informed training in bronchoscopy and thoracic surgical practice, especially in areas lacking easy access to advanced imaging facilities. Continued efforts to assemble region-specific anatomical databases will improve clinical practice and accuracy in future investigations in pulmonary anatomy and interventions.

## Conclusion

The present study investigates the different anatomical variations of bronchus and their morphometric characteristics resulting from cadaveric and broncho-scope studies. It found variations in at least one anatomical part in about 61.9% of cases, with the variability noted as being the greatest in the right lower lobe and the least in the middle lobe. The combination of dissection or bronchoscopy enhances accuracy in identifying anatomical deviations and sets a good example for clinical and educational purposes. All the above-mentioned information is requisite for preparing efficiency in improving preoperative planning, bronchoscopy usage, airway management, and surgical safety. The study emphasizes that spatial anatomical details could aid in individualized thoracic interventions of patients. Future advances in imaging and more extensive multicenter participation will further augment our Understanding of bronchial variation.

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