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# Morphological Variations in the Tracheobronchial Tree, Pulmonary Venous Pattern and Fissural Anatomy: A Cadaveric Study.

**Dr Anant Kumar[1*], Dr Roli Joshi[2], Dr Sonali kataria[3]**

*[1]Assistant Professor, G S Medical College & Hospital, Hapur*
*[2]Professor, G S Medical College & Hospital, Hapur*
*[3]Assistant Professor, G S Medical College & Hospital, Hapur*

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**Corresponding Author:**

**Dr Anant Kumar**
Assistant Professor, Anatomy, GS Medical College & Hospital, Hapur
**Email**:kr.infinite@gmail.com

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## ABSTRACT

**Background**: Variations in the tracheobronchial tree are of considerable clinical importance because of their implications in radiological interpretation, bronchoscopy, thoracic surgery and anesthetic management. Detailed anatomical knowledge helps prevent diagnostic errors and intraoperative complications.
Aim: To document variations in the trachea bronchial tree, pulmonary veins, and fissural anatomy observed during routine cadaveric dissection and to assess their embryological and clinical significance.
**Materials and Methods**: The present study was conducted during routine cadaveric dissection for undergraduate (MBBS) teaching. A total of 68 lungs were examined for variations in bronchial branching pattern, pulmonary venous drainage and fissural morphology.
**Results**: Variations in bronchial pattern were observed in 24 of 68 lungs (35.3%). An additional bronchial branch arising directly from the right main bronchus and supplying part of the upper lobe (tracheal/eparterial bronchus) was identified in11 lungs (16.2%). An accessory lobar bronchus causing atypical segmentation in the left lung was noted in 13 lungs (19.1%). Variations in pulmonary venous drainage were observed in 4 lungs (5.9%), involving altered superior or inferior pulmonary vein branches (two right and two left lungs). Absence of fissures was noted in 2 lungs (2.9%).
**Conclusion**: These findings emphasize the need for awareness so bronchial, vascular, and fissural variations for accurate radiological evaluation, safe bronchoscopic procedures, and effective surgical planning. Understanding their developmental basis enhances clinical preparedness and reduces the risk of procedural complications.

***Keywords****: Bronchial variation, tracheobronchial tree, Lungs, Cadaveric dissection, MBBS teaching.*

## INTRODUCTION

The tracheobronchial tree typically divides into eparterial and hyparterial bronchi in the right lung, while the left lung has one principal bronchus.

Anatomical variations in the bronchial tree are frequently observed during routine cadaveric dissections, with some studies finding that a majority of individuals may have at least one variation. These variations, which differ from the standard anatomical pattern, are important for clinicians, radiologists, and surgeons to be aware of for accurate diagnosis and safe intervention. The tracheobronchial tree demonstrates a highly ordered branching pattern that forms the anatomical basis for segmental lung organization and surgical resection. Classical studies by Brock and Boyden established the concept of bronchopulmonary segments and highlighted the close relationship between bronchial and vascular structures [1, 2].

Despite this structured arrangement, anatomical variations in bronchial branching are frequently encountered. Modern radiological evaluations using multidetector computed tomography (CT) have shown that variations such as tracheal bronchi, accessory segmental bronchi, and atypical lobar branching patterns are not uncommon and are clinically significant [3, 4].

Pulmonary venous anatomy also exhibits considerable variability. Although typically two pulmonary veins from each lung drain into the left atrium, studies have reported accessory veins, common trunks, and anomalous drainage patterns that may complicate thoracic surgical and interventional procedures [5, 6]. Similarly, fissural variations, including incomplete or absent fissures, have been documented in both cadaveric and imaging studies, with implications for radiological interpretation and lobar resections [7, 8]. These variations originate from disturbances in branching morphogenesis and mesenchymal remodeling during embryonic lung development.

Therefore, detailed anatomical documentation through cadaveric studies remains essential for enhancing clinical preparedness and minimizing procedural complications. Anatomical variations in bronchial branching may influence surgical approaches, lung resections, bronchoscopy, and interpretation of imaging studies. This article reports a bronchial variation identified during routine dissection of MBBS students' cadavers.

## MATERIALS AND METHODS

During routine dissection of the thoracic cavity for undergraduate teaching, the lungs were removed following standard anatomical procedures. A few old specimens (total 68) from the Department of Anatomy, G. S. Medical College & Hospital, were procured for the study.

Cadaveric dissection remains a cornerstone of anatomical education and continues to provide invaluable insights into rare anatomical variations.

### Cadavers Details

- **Sex:** Adult Males and Females
- **Age:**50-65yr
- **Preservation:** Formalin-embalmed cadaver
- **Institution:** GS MEDICAL COLLEGE &HOSPITAL, HAPUR.

### Observation

During routine dissection of the thoracic cavity for undergraduate teaching, the lungs were removed following standard anatomical procedures. On careful examination of the bronchial tree, an anatomical variation in the bronchial branching pattern was observed.

### Description of Variation

The right main bronchus showed an additional bronchial branch arising directly from it, supplying part of the upper lobe (tracheal or eparterial bronchus) in11 lungs.

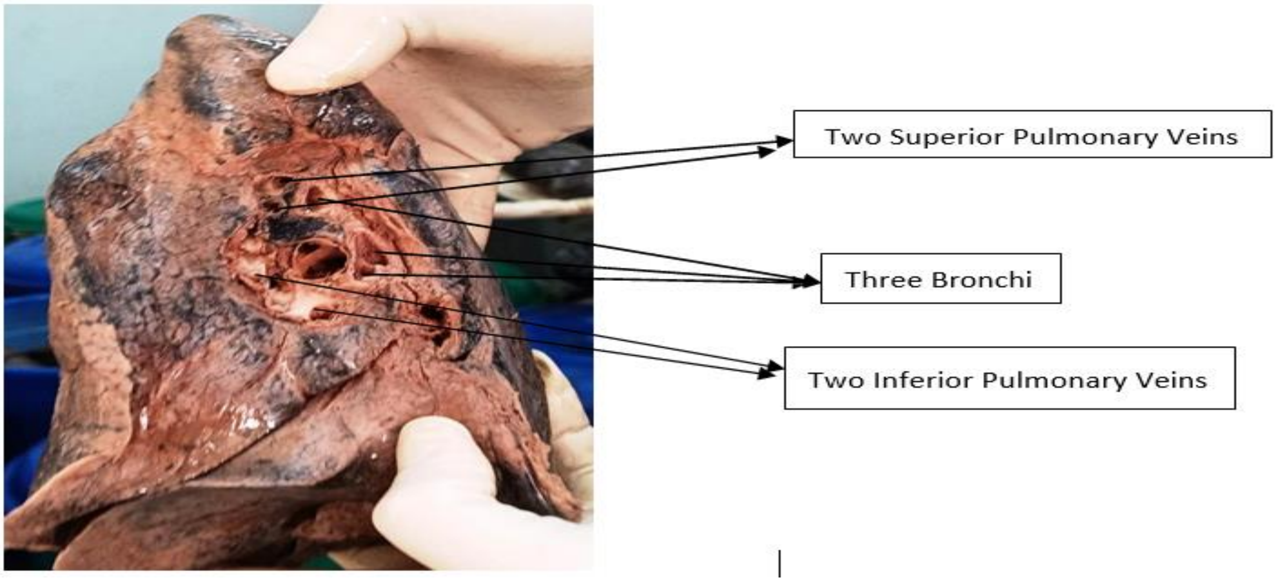


**Fig.–1Hilum Structures of Right Lung showing variation in Superior and Inferior Pulmonary veins and three bronchi**

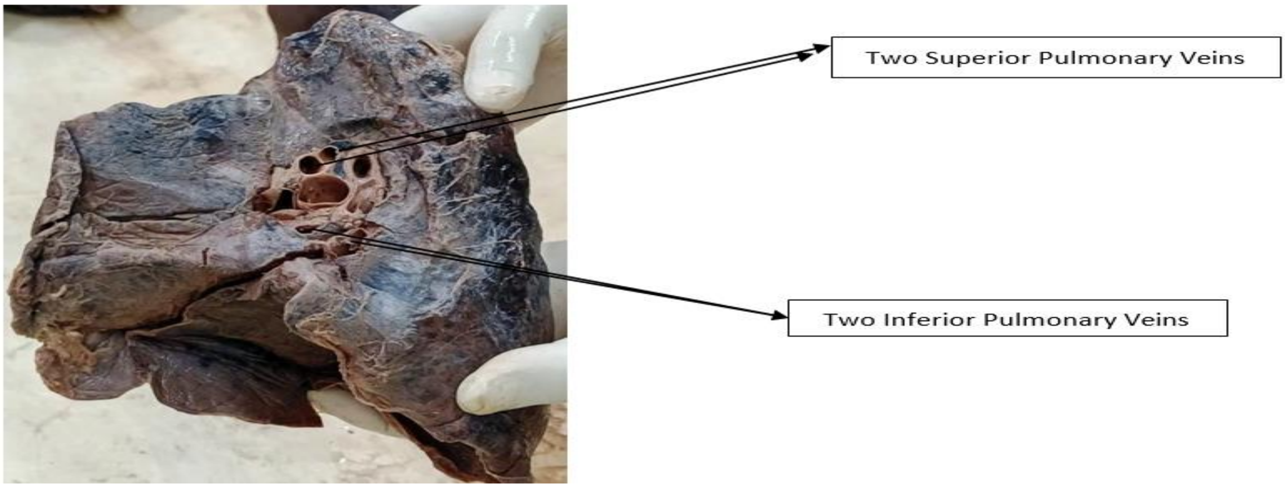


**Fig.–2 Hilum Structures of Right Lung showing variation in Superior and Inferior Pulmonary veins**

The left lung demonstrated an accessory lobar bronchus, resulting in an atypical segmentation in 13 lungs.

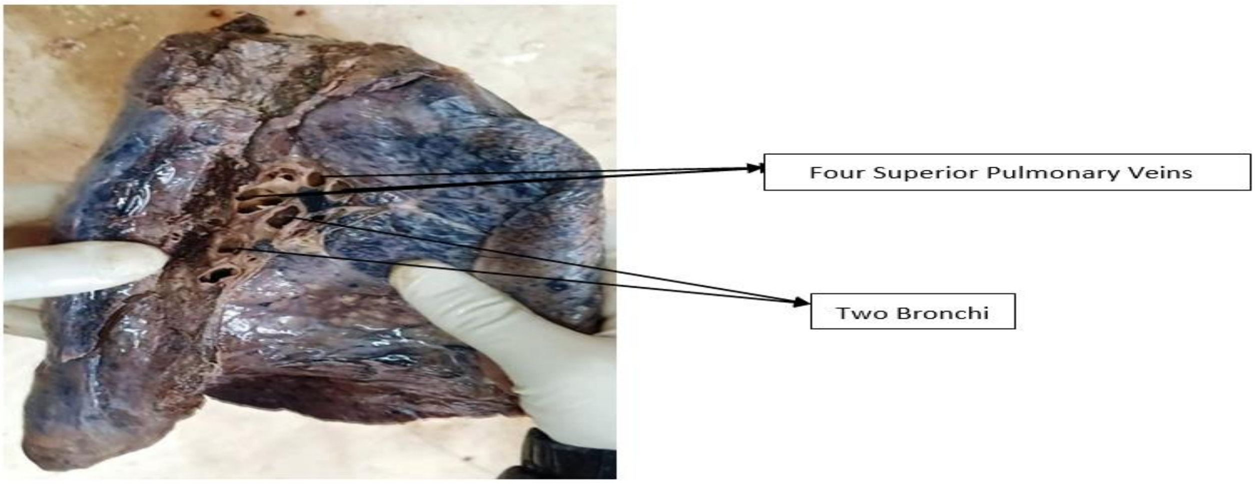


**Fig.–3 Hilum Structures of Left Lung showing variation in Superior Pulmonary veins and two bronchi**

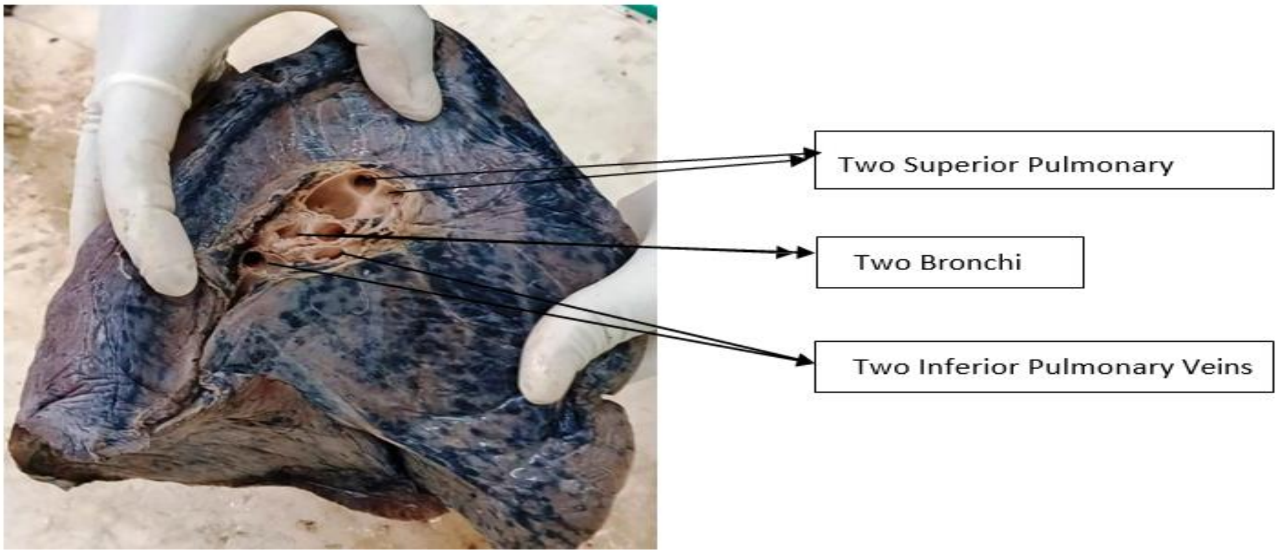


**Fig.–4 Hilum Structures of Left Lung showing variation in Superior and Inferior Pulmonary veins and two bronchi**

The two right and two left lungs also have variation in superior or inferior pulmonary vein branches and two lungs without fissures.

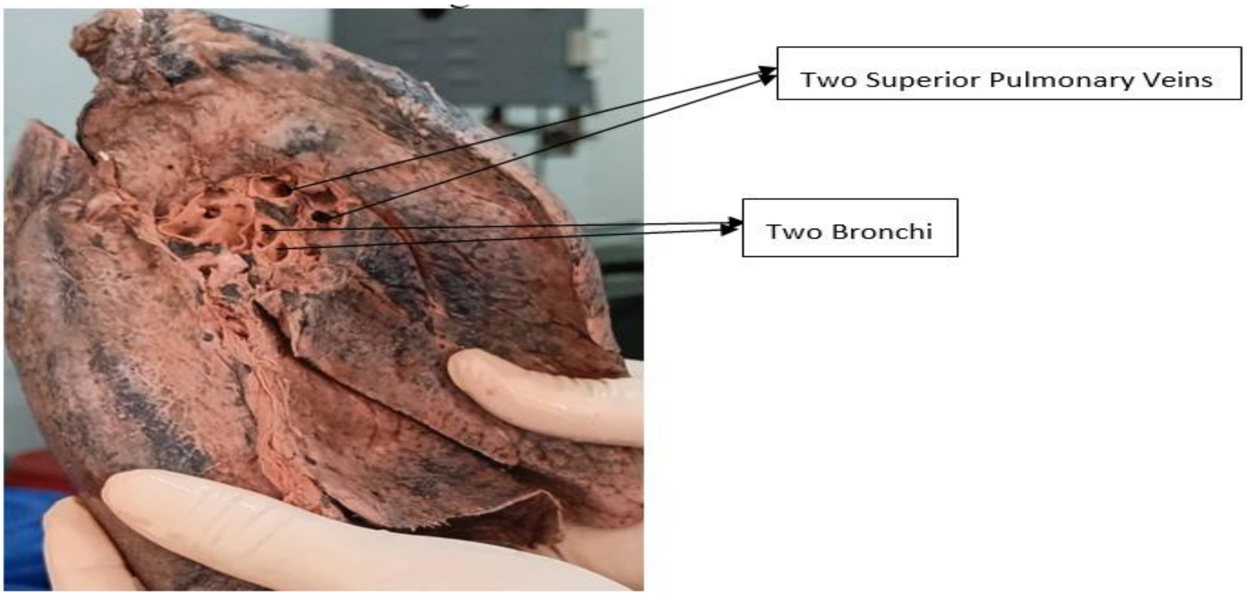

**Fig. --5 Hilum Structures of Left Lung showing variation in Superior and Inferior Pulmonary veins and two bronchi**.


**Fig. –6 Right Lung showing no fissure**

This variation deviated from the classical anatomical description found in standard textbooks. The remaining bronchial branches and lung parenchyma appeared normal.

**DISCUSSION**

Bronchial variations occur due to altered branching patterns during embryological development of the respiratory diverticulum from the foregut. Abnormal persistence or regression of bronchial bud scan result in accessory bronchi or altered lobar distribution.

Reported bronchial variations include:

- Tracheal bronchus.
- Accessory lobar bronchi.
- Absence or fusion of segmental bronchi.

Such variations are clinically significant because:

- They may cause misinterpretation on CT scans or bronchoscopy.

- They increase the risk of incomplete lung resection during surgery.
- They can complicate endotracheal intubation and anesthesia.

**.Table1. Comparison Table of Bronchial and Pulmonary vessels with fissure variation with Previous Studies**

| Study | Sample& Method | Bronchial Variations(e.g., tracheal/eparterial) | Accessory Bronchial Branches/ Atypical Segmentation | Pulmonary Venous Drainage Variations | Fissure Variations/ Absence |
|---|---|---|---|---|---|
| **Ganapathy etal. (Cadaveric lung anatomy) (2018)** | 75 adult lungs | Multiple bronchi at Hilum in 15.38% left, 5.55%right Lungs. | Multiple Bronchi at Hilum noted; Extra lobar bronchi Implied. | Pulmonary vein number variation (more than two)seen in~33% Right,39% Left. | Incomplete/variant Fissures observed. |
| **Regina et al. (2024)** | 75 lungs (cadaveric) | Not specifically tracheal bronchus | N/A | Pulmonary venous drainage pattern variations in 52%. | Incomplete/absent oblique and horizontal fissures Common. |
| **Jabeen et al.(2024)** | 97 bronchial samples (cadaveric+ bronchoscopy) | ~61.9%oflungs had bronchial segmentation variations (Bifurcation patterns). | Subsidiary or accessory bronchi identified among Variations. | N/A | N/A |
| **Vijay K. S etal (2025)** | 70 lungs (35 pairs). | Not primary focus | Not primary focus | Not primary focus | Accessory fissures variation and complete noted |
| **Vidulatha etal (2025)** | 88 lungs (44 pairs). | N /A | N/A | N/A | Incomplete, absent and accessory fissure. |
| **Ryan Winters etal., (tracheal bronchus Review) (2025)** | Clinical + Imaging data | Tracheal bronchus (accessory) described in 0.1–5% generally; more on right | Defines embryological and clinical types. | N/A | N/A |
| **Present Study** | 68 lungs (Anatomical; presumably cadaveric). | 16.2% had tracheal/eparterial bronchus. | 19.1% accessory lobar Bronchus. | 5.9% altered PV Branches. | 2.9% absence of Fissures. |

Anatomical variations in the tracheobronchial tree are well documented in the literature and have substantial clinical implications in radiological interpretation, bronchoscopy, thoracic surgery, and anaesthetic practice. Anatomical variations of the tracheobronchial tree have been recognized since the classical works of Brock R. C. [1], which provided one of the earliest comprehensive descriptions of bronchial branching patterns. This was further elaborated by Boyden E.

A. [2], who detailed the segmental anatomy of the lungs and emphasized the developmental basis of bronchopulmonary segmentation.
Subsequent radiological reassessment by Ghaye B. et al. [3] revisited congenital bronchial abnormalities using imaging correlation, highlighting their clinical importance. Early morphologic analysis by Foster-Carter A. F. [4] described bronchopulmonary abnormalities and accessory bronchi, reinforcing the concept that variations are not uncommon. Radiologic evaluation of pulmonary venous drainage by Marom E. M. et al. [5] demonstrated that venous variations may significantly influence interventional cardiology and thoracic procedures. Similarly, fissural morphology was examined in cadaveric detail by Meenakshi S. et al. [6], who reported frequent incomplete and absent fissures resulting from developmental factors.

More recent cadaveric research by Regina C. et al. [7] documented variations in lung fissures and pulmonary venous drainage, reporting a high frequency of venous pattern variability. Advanced three-dimensional CT reconstruction studies by Zhao B. et al. [8] further refined understanding of bronchial anatomy, particularly in relation to the middle lobe. Expanded radiologic evaluation of pulmonary venous variations by Marom T. et al. [9] reinforced the importance of pre-procedural vascular mapping. CT-based observational work by Singh S. et al. [10] demonstrated that fissural variations are frequently encountered in clinical imaging, often influencing radiologic interpretation.

Comprehensive anatomical documentation of human structural variations by Bergman R. A. et al. [11] provided an extensive reference framework for understanding bronchovascular deviations. Cadaveric studies across various populations have consistently reported morphological variability. George B. M. et al. [12] observed notable fissural and lobar variations in Indian cadavers. Ajeevan G. et al. [13] reported similar findings in Nepalese specimens. Kumari M. T. et al. [14] documented fissural and lobar anomalies in a South Indian population.

A detailed review of pulmonary vascular anatomy by Asha K. et al. [15] emphasized the surgical importance of recognizing vascular variants. Three-dimensional CT-based vascular and bronchial mapping by Deng Y. et al. [16] further illustrated the precision achievable in preoperative planning. Bronchoscopic anatomic correlation by Silvia M. R. et al. [17] highlighted segmentation variability relevant to endobronchial procedures.

Rare bronchial segmentation patterns were described in a case report by Sharma P. et al. [18], demonstrating unusual right upper lobe bronchial division. Similarly, Zhu S. et al. [19] analyzed branching patterns of bronchi and associated vessels in the superior segment of the right lower lobe using CT bronchography and angiography. Variations in lobar bronchi and bronchopulmonary segments were also documented by Sathidevi V. K. [20].

Further cadaveric hilar studies by Jethva N. K. et al. [21] and Neil J. et al. [22] reported considerable diversity in hilar arrangement and lobar anatomy. A South African morphological investigation by Refilwe S. et al. [23] reinforced the influence of demographic and population factors on bronchovascular patterns.

A cadaveric analysis published in the Bratislava Medical Journal further described accessory fissures and variations in fissural completeness. A recent bronchoscopic and cadaveric investigation reported bronchial segmentation variations in approximately 61.9% of lungs, indicating that airway branching diversity may be more frequent than traditionally assumed. Finally, a surgical-oriented cadaveric overview by Arthi G. et al. [24] documented multiple bronchi at the hilum and highlighted the implications for thoracic surgery.

In comparison with these studies, the present investigation observed bronchial variations in 35.3% of lungs, including tracheal/eparterial bronchi (16.2%) and accessory lobar bronchi (19.1%). Pulmonary venous drainage variations were noted in 5.9%, and fissural absence in 2.9% of specimens. These findings fall within the spectrum reported in both classical anatomical literature and contemporary cadaveric and radiologic studies.

The embryological basis of these variations stems from abnormalities in lung bud formation and bronchial branching morphogenesis during early intrauterine development. Disturbances in programmed branching, mesenchymal apoptosis, and vascular differentiation can lead to accessory bronchi, anomalous veins, and atypical fissures.

Awareness of such developmental mechanisms assists clinicians in anticipating associated anatomical deviations.
These collective findings underscore the importance of thorough anatomical knowledge for clinicians. Radiologists must recognize variant bronchial and fissural anatomy to prevent misdiagnosis on imaging studies. Pulmonologists and bronchoscopists should be alert to bronchial segmentation variants that might complicate airway navigation or sampling. Thoracic surgeons require precise anatomic detail for surgical planning, especially in segmental resections and minimally invasive procedures. Preoperative high- resolution imaging with three-dimensional reconstruction plays an increasingly crucial role in identifying these variants and guiding safe clinical decision-making. Cadaveric findings such as this contribute valuable data to anatomical literature and help improve awareness among clinicians and surgeons.

## CONCLUSION

The present cadaveric study demonstrates a significant prevalence of variations in the bronchial tree, pulmonary venous drainage, and fissural morphology. Bronchial variations were the most frequently observed, followed by venous and fissural anomalies. These findings are consistent with both foundational anatomical literature and recent imaging and dissection-based research.

Recognition of such anatomical variants is essential for accurate radiological assessment, safe bronchoscopic procedures, effective anesthetic management, and careful surgical planning. A combination of thorough anatomical understanding and detailed preoperative imaging can reduce the risk of diagnostic errors and procedural complications. These insights support continued emphasis on detailed anatomical training and routine evaluation of broncho vascular and fissural variants in clinical practice. Cadaver-based studies continue to play a vital role in identifying and documenting these variations for educational and clinical purposes.

**Clinical Significance**

- Important for thoracic surgeries and lung resections.
- Helps avoid diagnostic errors in radiology.
- Essential for safe bronchoscopy and airway management.

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