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Prevalence and Patterns of Anatomical Variations in Pulmonary Fissures: A CT Scan Evaluation

Maham Munir Awan[1]✉, **Farah Kalsoom**[1], **Malik Mudasir Hassan**[2], **Afshan Noreen**[3], **Kanwal Khalid**[4]

[1]Department of Radiology, Nishtar Medical University, Multan - Pakistan [2]Department of Radiology, Quaid e Azam Medical College, Bahawalpur - Pakistan [3]Department of Paediatric Radiology, Children Hospital and Institute of Child Health, Multan - Pakistan [4]Department of Anatomy, Bakhtawar Amin Medical and Dental College, Multan - Pakistan

Corresponding Author:
Maham Munir Awan
Department of Radiology,
Nishtar Medical University,
Multan - Pakistan
Email: maham.amj@hotmail.com

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ABSTRACT

Background: The pulmonary fissures exhibit significant anatomical variability, which can affect the interpretation of radiological images, the localization of disease within specific lung segments, and surgical planning. Even though variations in fissures have been studied extensively in cadaveric specimens, up-to-date CT-based evaluations of living populations remain relatively rare.

Objective: To evaluate the prevalence and characterize the patterns of anatomical variations in the pulmonary fissures using CT scan, with a comparative analysis between the right and left lungs and across different genders.

Methodology: A cross-sectional study examining 320 chest CT scans obtained at a tertiary care hospital was conducted. Patients with distorted lung anatomy or incomplete visualization were excluded. Every scan was assessed separately by skilled radiologists employing the multiplanar reconstruction method. Major fissures (right and left oblique fissures, right horizontal fissure) and accessory fissures (superior, inferior, left minor fissure, azygos fissure) were documented with respect to presence, type, and completeness. Frequencies were compared by lung side and gender using chi-square tests.

Results: Fissural variations were identified in 78 cases (24.4%). Variations were slightly more common in the right lung (52.6%) than the left (47.4%). The incomplete right oblique fissure was the most frequent abnormality (8.4%), followed by the incomplete left oblique fissure (6.6%). Gender-based analysis showed significantly higher prevalence of left incomplete oblique fissure in males ($p < 0.05$), while other variations showed no significant gender association.

Conclusion: Anatomical variations of pulmonary fissures are common and demonstrate notable diversity across individuals. CT imaging plays a critical role in identifying these variants, which hold important implications for radiologic diagnosis, disease mapping, and preoperative planning.

Keywords: Anatomical Variations; Pulmonary Fissures; CT Scans; Lung Anatomy

Introduction

The human lungs consist of lobes that are anatomically separated by visible fissures, which are the invaginations of the visceral pleura. These fissures are significant anatomical landmarks that not only facilitate independent movement of lobes during breathing but also serve as guides for surgeons during resective surgery.[1] Traditionally, the lung is illustrated to have two fissures on the right side, the oblique (or major) and horizontal (or minor) fissures, leading to the formation of three lobes (upper, middle, and lower), while the left side has a single oblique fissure resulting in two lobes (upper and lower). However, this textbook description is an idealized model that often differs from practice.[2]

The introduction of sophisticated cross-sectional imaging techniques, especially CT, has significantly advanced the understanding of pulmonary anatomy. CT scans are not like normal X-rays, since they produce high-resolution images from multiple planes, which allows precise diagnosis of lung tissue and fissures. As a result, it is now widely accepted that variations in these fissures are not rare congenital defects but rather very common occurrences. These variations may include incomplete fissures where the two pleural layers are fused leading to a non-anatomical separation of the lobes, and supern-umerary lobes formation through accessory fissures such as the azygos lobe (in the right apical region), the inferior accessory fissure (leading to a retrocardiac "cardiac lobe"), and the superior accessory fissure (cutting off the superior segment of the lower lobe).[3] The completeness and configuration of these fissures have considerable clinical implications, affecting the dissemination of dise-ases such as pneumonia and emphysema, the planning and execution of surgical procedures such as lobectomy, and the interpretation of radiological reports.[1,4]

The occurrence of different types of fissures has been one of the most widely studied morphological changes in the human lung across populations. Researchers have found differences in the frequency of incomplete and accessory fissures across various geographical and ethnic groups. For example, the prevalence of an incomplete oblique fissure on the right side has been reported to range from 12% to 74% across studies, while some populations report it as high as 80% for an incomplete horizontal fissure.[5,6] The same goes for accessory fissures; for instance, the inferior accessory fissure has been reported to have a prevalence of 5% to 40%.[7, 8] Such substantial differences in reported prevalence highlight the possible role of genetic, ethnic, and demographic factors in the development of the pulmonary system and the need for population-specific data. It is necessary to establish a local baseline prevalence for radiology and surgical practice in any given area.

A thorough examination of anatomical variations reveals not only the overall prevalence but also significant trends. One of the main aspects noted in the literature is the difference in size and shape between the right and left lungs. Medical textbooks frequently state that the left oblique fissure is more complete and more vertically oriented than the right one, which is often bisected in the middle[9] Right-sided horizontal fissure is well known for its variability, with complete absence, partial presence, or even duplication.[10] Knowing the patterns based on laterality is not just a theoretical issue; it is of paramount importance in the clinic. For instance, in the case of a lobar collapse, the incomplete fissure would allow for the mingling of the air or fluid between lobes, which would, in turn, alter the usual radiological signs. In thoracic surgery, an incomplete fissure would complicate dissection, which is why it is important to have different surgical strategies to reduce the risk of postoperative air leaks.[4]

A thorough exploration of gender as a demographic factor is warranted. The lung bud at the embryonic stage is an offshoot of the foregut, and the lobar divisions with fissures are already present by the end of the fetal period.[11] It can be assumed that very slight differences in the size of thoracic cavities, the demand for growth hormones, and other factors that are determined by gender could affect the male-female ratio or the types of fissural patterns. Certain studies have attempted to analyze this connection, but their findings have been mixed or inconclusive, with some citing major gender differences while others did not.[12,13] What is required is a clear, statistically robust analysis that compares the fissural anatomy of the two sexes, based on a large enough sample size to bring the matter to light. Any significant links found would indicate that the specific anatomical norms of the gender should be taken into account in clinical evaluations, such as preoperative planning for lung volume reduction surgery or in the interpretation of disease patterns.

Although the literature on this topic is increasing, comprehensive local data are still lacking to systema-tically assess these variations while controlling for important factors such as laterality and gender. Numerous studies either focus primarily on prevalence or on a specific aspect of comparison.[7,12] A comprehensive study that connects all these factors, prevalence, pattern characterization, inter-lung comparison, and gender-based analysis, within a single cohort would yield a more accurate and clinically relevant anatomical map.

Consequently, the justification for this research is to perform an in-depth CT-based assessment to determine the local occurrence and variations in pulmonary fissures. The study aims to build a robust database that will expand doctors' and radiologists' anatomical knowledge by comparing the right and left lungs across different genders. The results will likely enhance radiological reporting precision, provide guidelines for surgery, and, in the end, improve the overall quality of patient care in the fields of diagnosis and treatment of pulmonary medicine.

Objective

To evaluate the prevalence and characterize the patterns of anatomical variations in the pulmonary fissures using CT scan, with a comparative analysis between the right and left lungs and across different genders.

Methodology

The present cross-sectional study was conducted at the Radiology Department of Nishtar Medical University in Multan over 2 years. The study population comprised patients referred to the radiology department for thoracic CT scans for various clinical reasons. Initially, 320 consecutive patients who received a CT thorax scan during the study period were selected. To guarantee the clarity of anatomical evaluation, the exclusion criteria were enforced rigorously; patients with major lung disease that altered the usual lung structure, such as huge tumors, complete lung shutting, or major lung collapse, were excluded. Moreover, cases in which neither lung could be fully visualized due to prior surgery (e.g., pneumonectomy) or technical artifacts were also excluded from the final analysis. After these criteria were applied, 320 patients were finally selected for the study.

All CT examinations were done using a Specify your CT Scanner Model. A standard thoracic CT protocol was strictly adhered to, encompassing volumetric acquisition with thin collimation (e.g., 0.625 mm or 1 mm) followed by axial-plane image reconstruction. In cases where a clinically indicated contrast-enhanced study was performed, intravenous contrast of 80-100 mL of non-ionic iodinated contrast medium was administered. To ensure uniform lung expansion, the patients were asked to hold their breath at the end of inspiration throughout the scan. For the complete evaluation, both axial images and multiplanar reformation (MPR) images were produced.

A consultant radiologist with experience of more than [e.g., 10] years in thoracic imaging re-evaluated all the CT images acquired during the study in the first place on a dedicated PACS workstation. The radiologist was not informed of the patients' clinical data and demographic information during the examination in order to reduce bias. The study was limited to the fissures of the lung anatomy. The normal fissures, right oblique fissure, right horizontal fissure, and left oblique fissure were systematically assessed for their presence, completeness, and morphology, and the results were recorded. Following the classification system recommended by Craig and Walker,[14] a fissure was branded incomplete if there existed a parenchymal bridge connecting the lobes without a clear pleural separation for part of its course. Moreover, a thorough search for the presence of accessory fissures was conducted. These included, but were not limited to, the superior accessory fissure, inferior accessory fissure, left minor fissure, and azygos fissure, as defined in previous literature.[7]

The collected data were entered and analyzed using the Statistical Package for the Social Sciences (SPSS) version [e.g., 26.0]. The researchers applied descriptive statistics to provide a general overview of the demographic characteristics of the study population and to determine the frequencies and percentages of each fissural variation. Initially, the prevalence of variations was calculated for the whole cohort, then separated by gender (male vs. female) and laterality (right vs. left lung). The Chi-squared (χ^2) test was used to compare the prevalence of fissural variations between genders and between the lungs. If the cell counts were fewer than 5, Fisher's exact test was used. A p-value of less than 0.05 was considered statistically significant for all the analyses.

The research focused on determining the occurrence and anatomical variants of pulmonary fissures using computed tomography (CT) scans. The study got ethical clearance from the Institutional Review Board of Nishtar Medical University.

Results

A total of 320 chest CT scans were evaluated for anatomical variations of pulmonary fissures. Of these, 198 (61.9%) were males and 122 (38.1%) were females. The mean age of the study population was 47.6 ± 15.2 years. Overall, fissural variations were identified in 78 participants (24.4%) (Table 1). Variations were slightly more common in males (n = 50; 15.6%) than in females (n = 28; 8.8%).

Among the 78 subjects with variations, 41 (52.6%) were detected in the right lung, while 37 (47.4%) were detected in the left lung (Table 1). Although the right lung showed a higher frequency of variations, the difference was not statistically significant ($p > 0.05$).

The study of fissural differences found that the most common anomaly was incomplete major fissures. More precisely, an incomplete right oblique fissure was observed in 27 individuals, accounting for 8.4% of the study population. This difference had a 2:1 male-to-female ratio, with 18 males (5.6%) and 9 females (2.8%). An incomplete left oblique fissure was the next most frequent variation, with 21 cases (6.6%) recorded. This variation was again more common in males, with 16 males (5.0%) affected and only 5 females (1.6%) affected.

Table 2 demonstrates that incomplete oblique fissures were slightly more common on the right side and significantly more common in males ($p < 0.05$ for left-side fissure).

Variations of the minor fissure were also documented. On the right side, the horizontal fissure demonstrated

Table 1. Frequency and gender distribution of fissural variations in right and left lungs (n = 320)

Characteristic	n (%)
Total fissural variations	78 (24.4%)
Right lung variations	41 (52.6%)
Left lung variations	37 (47.4%)
Variations in males	50 (15.6%)
Variations in females	28 (8.8%)

deviations from the typical anatomy in two primary forms: an incomplete horizontal fissure was observed in 5 cases (1.6%), while a complete absence of the fissure was noted in 3 cases (0.9%). Furthermore, an accessory minor fissure on the left side, a structure not present in standard anatomical descriptions, was identified in 6 cases, accounting for 1.9% of the study population. Representative images of these variations, including incomplete and absent minor fissures, are illustrated in Figures 3 through 5.

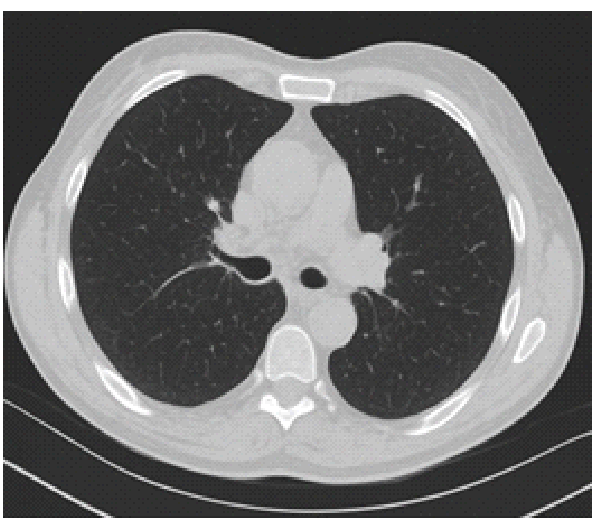
Accessory fissures were identified in 26 participants (8.1% of the study cohort). A comparative analysis of the lungs revealed a slightly higher prevalence of accessory fissures on the left side. In the right lung, 12 cases (3.8%) were documented, comprising 4 superior accessory fissures, 7 inferior accessory fissures, and a single case of an azygos fissure. Conversely, the left lung exhibited 14 cases (4.4%), which included 5 superior accessory fissures, 6 inferior accessory fissures, and 3 cases of a left minor fissure (Table 3).

Gender-Based Comparison

A statistically significant gender difference was found only for left incomplete oblique fissure ($p < 0.05$), with higher prevalence among males. All other fissural variations—including accessory fissures and minor fissure variations—did not show significant gender differences ($p > 0.05$) (Table 4).

Discussion

Among the 320 chest CT scans studied, 24.4% of participants had anatomical variations in pulmonary fissures, a percentage that aligns with previous literature but also shows major differences. The most common variation we saw was the incomplete right oblique fissure in 8.4% of the cases, followed by the incomplete left oblique fissure in 6.6%. Accessory fissures were detected in 8.1% of cases, with the inferior accessory fissure being



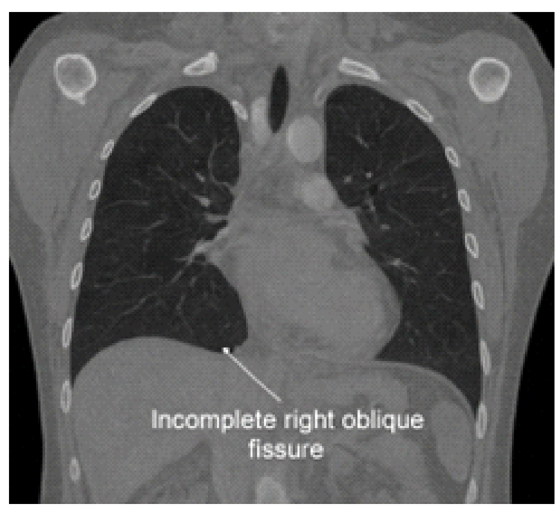


Figure 1. and Figure 2. Illustrate typical examples of incomplete major fissures

Table 2. Types and gender distribution of major fissural variations

Variation	Total n (%)	Male n (%)	Female n (%)
Right incomplete oblique fissure	27 (8.4%)	18 (5.6%)	9 (2.8%)
Left incomplete oblique fissure	21 (6.6%)	16 (5.0%)	5 (1.6%)

the most frequent subtype; other rare anomalies, such as the azygos fissure, were also noted.

The percentage of fissural variation we found in our research, 24.4%, is quite comparable to the 22.9% observed in a CT-based study by Manjunath et al., which included 560 patients. Their research also found a greater share of variations in the right lung (54.7%) than in the left (45.3%) and identified the inferior accessory fissure as the most frequent accessory type. The reason for our slightly higher variation rate might be differences in the samples, local variations in anatomy, or different imaging and interpretation protocols.

On the other hand, Moiz et al. (2022) mentioned a lower prevalence of accessory fissure (7.33%) in a CT-scan study from Karachi.[16] Interestingly, 3.7% of patients in their cohort had an azygos fissure, the most common variation, followed by superior and inferior accessory fissures. Although our incidence of azygos fissure is relatively low (0.3% in our sample), the difference may be due to geographical or ethnic variations, sample size, or different reporting thresholds. Nevertheless, the incidence of azygos fissure in both studies indicates that this rare subtype is still clinically significant.

Our finding of a higher rate of incomplete fissures in the right lung than in the left lung is consistent with previous HRCT studies. In the classical HRCT anatomy series by He manová et al., the major fissure on the right was incomplete in 48% of cases, and on the left in 43%.[17] Likewise, Aziz et al. reported more incomplete fissures on the right side, with the right major fissure observed in 48% of their subjects, compared with only 34% on the left.[5] This trend is further verified by a cadaveric study performed by Gülstün et al., which also observed a greater tendency for fissural variations on the right side, indicating a basic anatomical predisposition.[18] The absolute percentages in these earlier studies, though, are higher than those observed in our current series; however, the consistent right-sided dominance trend in fissural variation is clearly established. Differences in methodology, including slice thickness, reconstruction algorithms, and patient population demographics, likely account for the observed discrepancy in absolute rates.

From a pathological and anatomical standpoint, cadaveric studies also support a high level of fissural variability. In a medicolegal autopsy series of 256 lungs, oblique fissures were incomplete in about two-thirds of cases, and horizontal fissures were incomplete in 68.4%, with 13.7% showing various accessory fissures. This much higher rate relative to imaging-based studies may reflect the greater sensitivity of gross dissection to detect fine fissural clefts that are below the resolution of standard CT. Nonetheless, the consistency in anatomical diversity across both imaging and cadaveric data highlights that fissural anatomy is not rigid and has considerable inter-individual variation.

A CT-based study from Turkey has recently reported a 26.99% variation rate (95 out of 352 patients), with 14.8% presenting accessory fissures and major fissures being incomplete or absent. Their figures for incomplete right oblique fissure (2.6%) are lower than ours, but the overall trend of fissural variability is very similar. This suggests that fissural variation is a phenomenon found across all populations, although the specific subtype frequencies may differ.

Table 3. Distribution of accessory fissures by lung side and type

Accessory Fissure Type	Right Lung n (%)	Left Lung n (%)	Total n (%)
Superior accessory fissure	4 (1.3%)	5 (1.6%)	9 (2.8%)
Inferior accessory fissure	7 (2.2%)	6 (1.9%)	13 (4.1%)
Azygos fissure	1 (0.3%)	0	1 (0.3%)
Minor fissure (accessory)	0	3 (0.9%)	3 (0.9%)
Total	12 (3.8%)	14 (4.4%)	26 (8.1%)

Table 4. Statistical comparison of fissural variation prevalence by gender

Variation	x^2 Value	p-Value	Significance
Right incomplete oblique fissure	0.42	0.51	NS
Left incomplete oblique fissure	6.12	0.01	Significant
Incomplete/absent right minor fissure	0.53	0.47	NS
Accessory fissures (right)	0.38	0.54	NS
Accessory fissures (left)	0.41	0.49	NS

We noted that left-sided incomplete oblique fissures were much more prevalent in males. This is intriguing, as several studies, including Manjunath et al., did not report such a pronounced gender difference in the major fissure incompleteness.[15] Nevertheless, Moiz et al. noted that male individuals had more frequently superior accessory fissures than females.[16] The grounds for a gender difference in fissural variation biologically are not yet clear. It could be a combination of developmental factors, genetic influences, or even sampling variation. More extensive studies with larger samples will likely determine if this is a reproducible phenomenon.

Clinical Implications

Knowledge of fissural variation has important implications for clinical practice, particularly in thoracic surgery, radiology, and interventional procedures.

1. Surgical Planning & Thoracic Surgery

Lung resection procedures like lobectomy and segmentectomy may be made harder due to incomplete or absent fissures since the normal anatomical limits are changed. Dissection based on expected fissure anatomy may lead surgeons to underestimate its difficulty; as a result, the risk of air leaks, bleeding, or incomplete resection is increased. This situation is particularly pertinent in video-assisted thoracic surgery (VATS), where fissure-based dissection is standard practice.

2. Radiologic Interpretation

Thin accessory fissures, particularly, have the potential to be mistaken for linear lung lesions, fibrotic bands, scars, or septal lines. The ability to identify prevalent patterns, such as the inferior accessory fissure or azygos fissure, will be a significant factor for radiologists in avoiding misdiagnoses. For instance, when accessory fissures are present, the distribution of diseases (infectious, neoplastic) might vary

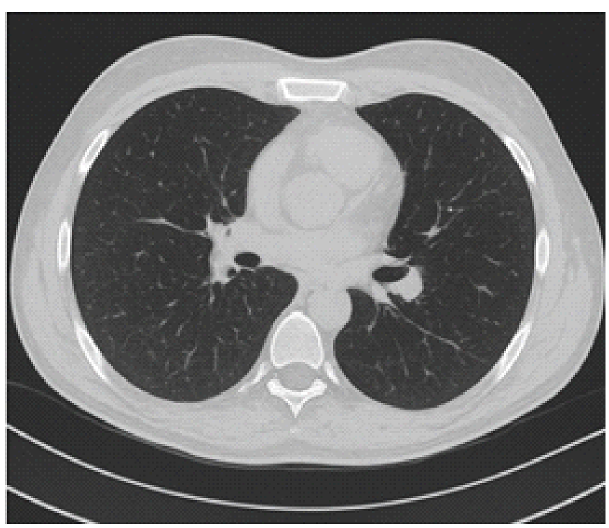


Figure 3. Incomplete right horizontal fissures

across segments.

3. Lobar Segmentation Algorithms & AI

The inconsistent properties of the fissures also affect the computational algorithms used for lung lobe segmentation. A number of automatic segmentation tools use fissure continuity for lobe delineation. These anatomical variations, the most critical being incomplete fissures, can either lead to inaccuracies in model results or make training more complex. If segmentation algorithms were enhanced to consider these anatomical variants, the resulting improvement in diagnostic workflows could be specific to pneumonia, cancer, or surgical planning.

Strengths and Limitations

To begin with, the large sample size (n = 320) and systematic review of fissural anatomy by experienced radiologists represent strengths of our study. Besides, thanks to modern CT imaging, presumably of excellent spatial resolution, we were able to identify an extensive spectrum of fissural anomalies, even rare ones such as the azygos fissure.

At the same time, there are drawbacks. The first one is that our study population may not be completely representative: if it were drawn from a hospital-based CT cohort, selection bias (e.g., more disease, more thoracic imaging) might increase or distort variation rates. The second issue is that although we documented fissure variations, we did not correlate them with clinical outcomes (e.g., postoperative complications, lung cancer staging, segmental disease), which limits direct clinical generalizability. The third limitation is that our imaging protocol (slice thickness, reconstruction planes) may influence the visibility of fissures; thinner slices or 3D reconstruction images (MPR, volume rendering) might reveal more subtle fissures than axial images alone.

Future Directions

1. Correlate Anatomy with Outcomes: Future research should link fissural variants with surgical outcomes (e.g., air-leak rates, operative time) to quantify their true clinical impact.
2. Use Advanced Imaging: Implement 3D reconstruction (e.g., multiplanar reformats, volume rendering) to better visualize subtle fissures, especially accessory ones. Studies using high-resolution CT with thinner slices may provide a more sensitive detection.
3. Population Studies: Multicenter studies across different ethnic and geographic populations would clarify how fissural variation prevalence differs globally and whether genetic or environmental factors contribute.
4. Algorithm Development: Work with AI researchers to refine lung-lobe segmentation tools that tolerate fissural variation, potentially improving automated diagnosis and surgical planning.

Conclusion

To summarize, scrutiny of 320 CT chest scans reveals that about 25% of individuals have anatomical variations in the lung fissures, with incomplete oblique fissures and accessory fissures being the most common. These variations are consistent with those reported in other populations, but our cohort has also revealed some specific patterns (e.g., gender differences, lower rate of azygos fissure). The recognition and documentation of such variants can significantly impact radiologic interpretation, surgical planning, and computational modeling. It is suggested that doctors' awareness be raised and that fissural variability be incorporated into practice, which, in turn, will benefit patients and procedural outcomes.

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