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CASE REPORT

Anatomical Variations of Human Pulmonary Fissures: A Cadaveric Study Conducted in Western Kenya

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Abstract

Aim and Objective: This cadaveric study was performed to describe the variations in the pattern of pulmonary fissures in the Western Kenyan population. Data were sourced from 68 lungs fixed in formalin in the gross anatomy laboratory of the Department of Human Anatomy, Uzima University. The fissures were studied, and the results were compared with the previous studies.

Results: In this study, 83.82% of lungs had a classical appearance: three major fissures (horizontal and two oblique fissures) that were complete without any accessory fissures. Out of the 31 right lungs examined, the horizontal fissure was absent in none of the lungs, incomplete in six lungs (16.13%), and complete in 25 lungs (80.64%). Out of the 37 left lungs, the oblique fissure was incomplete in four lungs (10.70%) and complete in 29 lungs (86.30%). The fissure was absent in one left lung (2.70%). Four right lung accessory fissures were observed (12.90%). Six left lungs (16.67%) had accessory fissures.

Conclusion: The incidence of the complete oblique fissures was more significant in our present work when compared with other authors' work. Our study's incomplete oblique fissure and horizontal fissure varied compared with other studies. Our study recorded a prevalence of absent oblique fissures in the left lung that was greater in relation to absent horizontal fissures. The superior accessory fissure was significant in our study compared to other studies, as well as when other studies were compared to the inferior accessory fissure prevalence in our study. The left minor fissure was our study's most frequently appearing accessory fissure. Anatomists should note that lung fissure anatomy is more variable than traditionally presented, and clinicians must be aware of the prevalence these variations. Considering these variants, we recommend that more explorative research be done on this topic to increase awareness.

Key Words: *Fissures; Bronchopulmonary; Accessory; Pulmonary; Lung variations*

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Introduction

A pulmonary fissure is a distinct space on the surface of each lung occupied by the enfolded cellular membrane of the visceral pleura. This membrane is double layered. The pulmonary fissures serve to separate the lung lobes from each other. The right lung comprises three lobes, while two lobes make up the smaller left lung [1-2]. The formation of lobes during development results from the obliteration of existing spaces between bronchopulmonary segments, except where the three main fissures are located [3]. The fissures are categorized into two types: major fissure (lobar fissure) and accessory fissure. Traditionally, the major fissure types are oblique and horizontal fissures. They cut into the whole thickness of the lung, excluding the hilum located on the medial surface. Accessory fissure is described as a cleft of varying locations. They are the superior accessory fissure, inferior accessory fissure, left minor fissure, and azygos fissure [4].

An oblique fissure separates the two lobes that constitute the left lung into the left superior lobe and the left inferior lobe. Three lobes form the larger right lung: the superior lobe of the right lung is separated from the middle lobe by a horizontal fissure, and the inferior lobe of the right lung is separated from the middle lobe by the oblique fissure. It has been established that the right oblique fissure corresponds closely to the left oblique fissure. However, the right is less vertical. During respiration, pulmonary fissures greatly accommodate distension by allowing relative motion of the lobes about one another, thus allowing the entire lung to expand uniformly [5-6].

The fissures extend from the surface of the lung to its hilum. After rising above the hilum on the medial surface of the lung, the oblique fissure cuts the vertebral spine's border at the level of the fourth or fifth thoracic vertebra. Traced downwards, it courses along the costal surface and then continues across the diaphragmatic surface after cutting the inferior border. It ends on the medial surface by turning upwards towards the hilum. Laterally, the horizontal fissure begins near the midaxillary line from the oblique fissure. It transversely courses across the costal surface, around the anterior margin, and back to the hilum [7].

Partial or total obliteration of fissures along the division of the principal bronchus could lead to an incomplete or absent fissure, respectively. Major fissures are considered complete when lobes remain intact only at the hilum by bronchi and pulmonary vessels. They may be insufficient in some cases when the fusion of the parenchymatous lobes fails to reach the hilum, or even they may completely be absent. Most importantly, the incompleteness or lack thereof causes a change in the number of lung lobes [8-9]. Accessory fissure is a genetic variation that results when the fissure separating individual bronchopulmonary segments fails to obliterate during development [10]. The cleft can be complete or incomplete. This fissure occurs at the boundaries of the bronchopulmonary segments and is most often seen in unusual lung locations, especially for infants [7,11]. The superior accessory fissure can be spotted in the lower lobe. It divides the apical segment of the lower lobe, also referred to as the posterior or dorsal lobe, from the basal segments. The inferior accessory fissure separates the medial basal segment and the remainder of the lower lobe. The left minor fissure or the left horizontal fissure may form in 10% of patients and is considered a normal variant. The lingula is separated from the rest of the left upper lobe by the left minor fissure. The azygos fissure, containing the azygos vein, separates the apicomedial segment of the upper lobe from the rest of the right upper lobe [7,11,12].

According to Akhtar et al. (2018) [13], the azygos vein's abnormal embryological development is thought to have led to the formation of this accessory fissure. Since fissures delimit the lobes of the lungs, it is essential to establish their position for academic interest, clinical practice of lobectomies, and the interpretation of radiological images.

Several cadaveric studies have been conducted on significant anatomic variations in the number and pattern of accessory fissure and major fissure and lobes [7-13]. In Kenya, to the best of our knowledge, only one study has been conducted [14]. The current research on the Kenyan population aimed at adding a database for pulmonary fissure pattern by describing the possible variations seen during routine cadaveric dissection. It will also enlighten clinicians on various incidences of fissure normality and laterality between these populations and whether the possible variation could be attributed to ethnicity, genetics, ecological factors, or congenital factors. This information is necessary when making a diagnosis or during surgical intervention.

Materials and Methods

With permission from the Department of Human Anatomy, 72 African cadaveric lungs fixed in formalin were collected during routine undergraduate dissection classes and those preserved in departmental museums of Uzima University, Kisumu, Kenya. The organs were examined, the sex of the deceased notwithstanding. Dissection guidelines of the thorax followed Cunningham's Manual of Practical Anatomy. Lungs with intact visceral membranes covering the entire surface, but the hilum were included. The lung fissures damaged through rib-cutting, extraction, and preservation were excluded. Lungs that did not show the typical pyramidal shape and had extensive lacerations and lesions were also excluded from the study.

The lungs were observed and digitally photographed for their anatomical morphology in terms of (1) whether or not they had main fissures; 2) variations in the main fissures (complete or incomplete); and, if any, 3) accessory fissures.

Because the human subjects used in the study are already covered by the National Health Act Cap 249, Republic of Kenya, the study did not require ethical approval.

Tables and digitally shot images were used to interpret descriptive observations. Microsoft Excel was used to enter the data and calculate the percentage.

Results

The study included 68 lungs, 37 left-side and 31 right-side. These lungs met the inclusion criteria. The horizontal fissure was incomplete in six of the 31 right lungs examined (16.13%), complete in 25 of the lungs (80.64%), and absent in none of the lungs (0%). The oblique fissure was absent in none of the lungs (0%), incomplete in two lungs (6.45%), and complete in 29 lungs (93.55%).

Out of the 37 left lungs, a complete oblique fissure was noted in 32 lungs (86.30%). An incomplete oblique fissure was indicated in four lungs (10.70%). The fissure was absent in one of the lungs (2.70%). Table 1 summarizes the variation of fissures prevalent in the study.

Four right lung accessory fissures were observed (12.90%); the superior accessory fissure was found in three, and the inferior accessory fissure was found in one. An azygos fissure was also seen in one right lung. Six left lungs (16.67%) had accessory fissures: one superior, two inferior, and three left minor fissure. Observed accessory fissures are summarized in Table 2.

TABLE 1
A summary of variations in major fissures in both the left and right lungs

Lung Specimen	Fissures	Results		
		Complete	Incomplete	Absent
Right Lung N= 31	Oblique	93.55%	6.45%	0%
	Horizontal	80.65%	19.35%	0%
Left Lung N= 37	Oblique	86.49%	10.81%	2.70%

TABLE 2
Summarizes variations in accessory fissures in both the left and right lungs.

Accessory fissures	Right Lung n= 31	Left lung n= 37
Superior accessory fissure	9.68 (3/31)	2.70 (1/37)
Inferior accessory fissure	3.22 (1/31)	5.41 (2/37)
Left minor fissure	-	8.11 (3/37)
Azygos fissure	3.22 (1/31)	-

Figures (1-3) show some of the variations in both the left and right lungs observed in the study. An accessory lobe was seen on the inferior surface of the right lobe (Figure 2A). An anomalous appearance of an accessory azygos fissure (3.22%) was seen on the mediastinal surface with the absence of azygos lobe on the right lung. Azygos fissure separates the azygos lobe from the rest of the right upper lobe of the right lung. Like any other accessory fissure, azygos fissure varies from notch to prominent fissure, often separating the azygos lobe (Figure 2B and 2C).

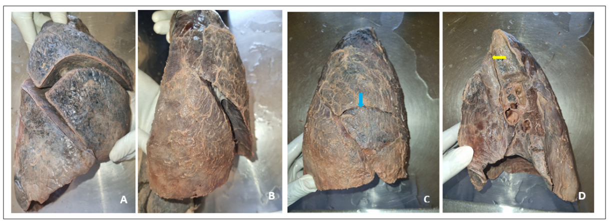


Figure 1) *Anatomical variations of the right lung.* ***A)*** *Complete development of the oblique fissure and horizontal fissure cutting deep to reach the hilum.* ***B)*** *Incomplete development of the oblique fissure. The oblique fissure is present but does not cut deep to reach the hilum.* ***C)*** *The horizontal fissure represented by blue arrow is incomplete.* ***D)*** *Medial surface of right lung showing accessory fissure.*

Figure 2) ***A)*** *A right lung with an accessory lobe on the diaphragmatic surface* ***B)*** *the mediastinal surface of the right lung. Green arrow pointing at the azygous fissure in the shape of a notch. Yellow circle delimiting the azygous lobe.* ***C)*** *Mediastinal surface of the right lung. Yellow arrow indicates the azygous fissure.* ***D)*** *Inferior accessory fissure indicated by the arrow.*

Figure 3) *Anatomical variations of the left lung.* ***A)*** *Left lung showing complete oblique fissure.* ***B)*** *Coastal surface of left lung showing incomplete oblique fissure (black arrow). Left minor fissure is indicated by the red arrow.* ***C)*** *Medial surface of the left lung. Red arrow pointing to the left minor fissure. The red circle delimiting the lingula of the left loe.* ***D)*** *Left lung lacking the oblique fissure.*

Discussion

The lung is divided into lobes by fissures (Figure 4). The fissures create a uniform expansion of the vital organ [14]. Variations in fissural architecture may alter the pattern of lung lobes and segments during development. Lung fissures form four weeks after conception when the airways begin to develop in intrauterine life. The lungs develop as lung bud, an endodermal outgrowth from the ventral wall of the cranial foregut, which then proceeds to differentiate into the various parts of the respiratory tree and parenchyma. Initially, the lung bud divides into two blind endodermal diverticula from which a monopodial ventral bud sprouts and later transforms into upper lobe bronchus. An early vascular plexus and a few mesenchymal cells surround the two entodermal pulmonary buds. The pulmonary buds contact the splanchnopleura of the intraembryonal coelom. The pleural sac arises from the cranial part of vertical limb of intraembryonic coelom. The developing lung invaginates it from the medial aspect. The coelomic membrane then sends mesenchymal cells toward the formation of the bronchi and the visceral pleura covering the lung tissue. The continued growth of bronchi occurs caudally and laterally, dividing into ten bronchi through eighteen generations of subdivisions. Following the dichotomous branching pattern, parts of the visceral pleura remain attached to the first bronchial divisions that make up the pulmonary fissures and the subsequent lobar arrangements. Epithelial tip-splitting and further branching is driven by portmanteau of wingless and int-1(Wnt), Fibroblast Growth Factor 10 and Sonic hedgehog gene. In later development, the formed bronchopulmonary buds completely fuse except in two planes where fissures form, dividing the right and left lungs into three and two lobes, respectively [15-17].

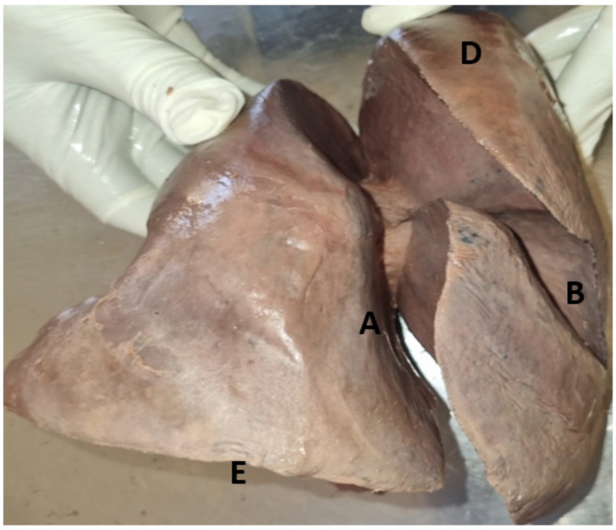


Figure 4) *Photograph of dissected right lung specimen showing: A. Oblique fissure; B. Horizontal fissure; D. Apex; E. Base.*

At the beginning of the sixth week of human development, differences in pulmonary lobulation between the left and right sides become apparent. Under influence of Fraser Syndrome 1 protein (Fras 1) or Insulin gene enhancer protein 1 (Isl1), homeobox protein Nkx 2.1 is essential for lobe formation of the lungs. By the fourteenth week, the bronchopulmonary tree's architecture is almost finished, by which time the pulmonary fissures are well formed. Lefty-1 appears to be in charge of regulating the difference between the right and left lungs. Conditions such as asplenia, polysplenia, and situs inversus viscerum had been linked to lobar pattern abnormalities, which are thought to be caused by a flaw in the normal process of determining the left-right asymmetry [4,15,18].

Position-wise, lung fissures are horizontal and oblique on the right but only oblique on the left. (Figure 5). It is not uncommon for the adult lungs to contain accessory bronchi and lobes because of the occasional monopodial branching of stem bronchi. When the fissures are incompletely obliterated, incomplete fissures are formed. When there is non-fusion of spaces between the bronchopulmonary buds, the accessory fissure will result [18-19] (Figure 6).

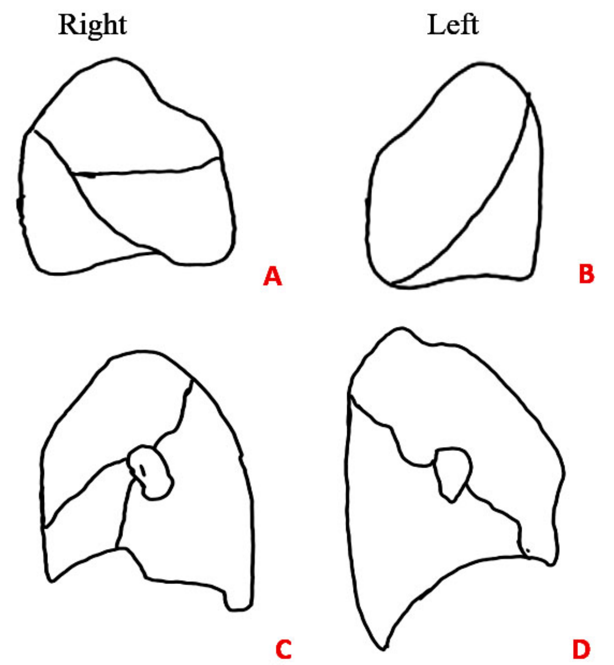


Figure 5) ***(A,B)*** *Lateral surface of right and left lung;* ***(C,D)*** *Medial surface of right and left lung normal anatomy.*

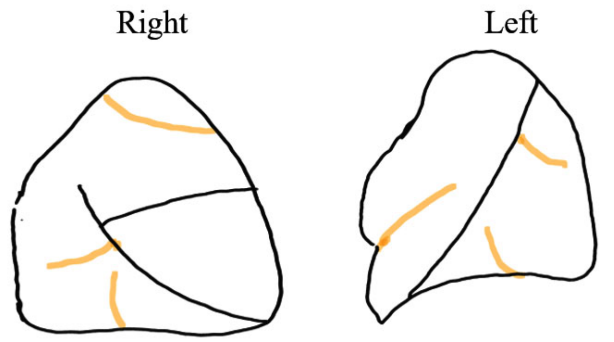


Figure 6) *Lateral surface of right and left lung. Accessory fissures in orange. The right lung shows azygos fissure close to the apex and superior and inferior accessory fissures in the lower lobe. The left lung shows the left minor fissure in the lingula, superior and inferior accessory fissures in the lower lobe.*

The oblique fissure is marked on body surface as a line passing from a point opposite the 3rd thoracic spine to the sixth costochondral junction. Furthermore, it corresponds to the medial border of the scapula when the arm is abducted above the head. On the other hand, the horizontal fissure of the right lung is represented by a horizontal line extending from the sternum along the right forth costal cartilage to meet the line of the oblique fissure [20].

Imaging modalities like the use of computed tomography have been employed in the study of the anatomy of interlobar fissures and their completeness. However, various studies have strengthened the belief that dissection is the best tool for learning anatomy, even in modern times. Despite reservations that the cadaveric population is mostly elderly individuals whose fissures may have undergone fusion during life, previous studies involving fetal specimens have reported incomplete fissure [21]. In support of this and to dismiss any speculations about fusion caused by formaldehyde, postmortem cases where no embalming intervention has demonstrated incomplete and absent fissures. Cadaveric studies, therefore, is better representation of the expected findings by thoracic clinicians [4,22,23].

Previous studies on cadavers and specimens have reported findings compared to the present study [23-33]. From these studies, it is clear that the absence or incompleteness of fissure is a common form of lung variation. Pulmonary variations observed in both the left and right lungs during the study are depicted in Figures 1-3. We found a higher incidence of complete oblique fissure in both the right and left lungs. Our study was relatively consistent with a study performed by Quadros et al. (2014) [3]. Regarding horizontal fissures in the right lungs, our study recorded a higher frequency than other studies [22-30,32].

In the present study, the incidence of incomplete oblique fissure in the right lung was 6.45%, whereas the incidence in the left was 10.81%. In previous studies, the incidence of incomplete oblique fissures varied considerably between the right and left lungs (3%-61% and 2.5%-51.48%, respectively) [3,6,22-33]. Table 3 summarizes the prevalence of published results concerning the current study. Some studies have reported a higher left lung preponderance of incomplete oblique fissure [11,24,27,28,30] while in other studies the right lung dominance was seen [3,6,22,23,25,26,29,31-33]. An equally prevalent bilateral incomplete oblique fissure was seen in a study done by Prakash et al. (2010) [25]. This was also observed in a study by Joshi et al. (2022) [5].

TABLE 3
Summary of results published studies showing a variation of lung fissures in cadavers.

Authors	Year	Right Lung						Left Lung		
		Oblique fissure			Horizontal fissure			Oblique fissure		
		Complete	Absent (%)	Incomplete (%)	Complete	Absent (%)	Incomplete (%)	Complete	Absent (%)	Incomplete (%)
Medlar et al. [23]	1947	69.6	4.8	25.6	37.7	45.2	17.1	82.1	7.3	10.6
Meenakshi et al [24]	2004	63.4	0	36.6	20.1	16.6	63.3	53.4	0	46.6
Prakash et al [25]	2010	53.6	7.1	39.3	42.86	7.1	50	53. 57	10.7	35.7
Dutta et al [26]	2013	26.92	11.54	61.54	26.49	34.62	38.89	44	8	48
Nene et al [27]	2011	96	2.0	6.0	-	14.0	8.0	-	0	12.0
Jacob and Pillay [6]	2013	46.6	3.4	50	10	6.6	83.4	61.1	0	38.9
Quadros et al [3]	2014	94.44	0	5.55	63.88	11.11	25	97.5	0	2.5
George et al. [28]	2014	96.93	0	3.07	61.55	3.07	35.38	84.94	0	15.06
Magadum et al [29]	2015	30	0	60	35	12.5	52.5	50	7.5	42.5
Kalai and Dhivya [30]	2016	72	0	28	36	20	44	68	0	32
Dhanalakshmi et al [22]	2016	30	18	52	68	0	32	62	0	38
Mamatha et al [31]	2016	50	0	50	85	0	15	65	5	35
Sudikshya et al [11]	2018	69.57	0	30.43	52.18	13.04	34.78	48.15	0	51.48
Mutua et al. [32]	2021	63.16	0	36.84	47.37	10.53	42.11	55.26	0	34.38
Hema [33]	2014	90	0	10	82	10	8	90	2	8
Present Study	2023	93.55	0	6.45	80.65	0	19.35	86.49	2.7	10.81

Hema (2014) [33] and West et al. (2021) [36], uniquely did not see the oblique fissure in 2% and 2.47% of the left lungs respectively. Our study found this feature in 2.7% of the left lung specimens. Other studies found it in 7.3%-10.7% of left lungs [23,25,26,29]. The right oblique fissure was present in all our samples, similar to most studies [3,27,29,30,33]. Few studies have reported the frequency of their absence varying between 4.8%-11.54% [6,23,25-27].

Incomplete horizontal fissure was seen in 19.35% of the right lung samples, close to the findings of Medlar et al. (1947) [23]. When horizontal fissure is deficient, the lung becomes imperfectly lobated. In previous research, its frequency varied widely, ranging from 21%-83% [3,6,11,23-33]. The highest incidence was reported by Jacob and Pillay (2013) (83.4%) [16].

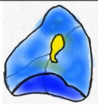
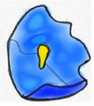
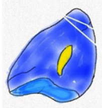
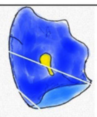
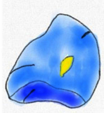
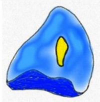
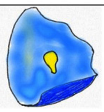
Comparatively, the incidence of the absent oblique fissure is high compared to that of the absent horizontal fissure in our study, consistent with several previously published reports [22,25,31].

We also looked for the prevalence of superior and inferior accessory fissures in the right and left lungs (shown in Table 2). Left minor fissure and azygos fissure were also descriptively observed and tabled. Nene et al. (2011) saw superior accessory fissure in 4% of the right lung and did not observe any in the left [27]. In the present study, we observed it in 9.68% of the right lung and 2.70% in the left lung. They saw inferior accessory fissure in 14% of the right lung and 44% of the left lungs. In the present study, inferior accessory recorded a lower prevalence of 3.22% and 4.15% on the right and left lungs, respectively. The incidence of superior and inferior accessory fissures have been reported to commonly occur in the right lung compared to the left [34]. This was consistent with our study.

Furthermore, we recorded the frequency of the left minor fissure to be 8.11%. Studies have proven that the left minor fissure has the highest incidence rate compared to other accessory fissures [34].

An adequate understanding of lung fissures and their supernumerary lobes cannot be overstated. Knowledge of the morphology and disparities of the significant fissures is essential for identifying their distinct imaging appearances and abnormalities. In the past, radiologists focused mainly on fissure completeness while relegating the frequency of incomplete fissures to academic controversy because of difficulty in their interpretation [35]. When interpreting skiagrams, a radiologist might mistake an unusual fissure for a pleural effusion because of their incompleteness, thick sections and plane of orientation [36,37]. Accessory fissure serve as a barrier to infection spread and help in differentiating pleural from parenchymal disease. Pleurisy can obliterate lung fissures, causing an infection to localize in the fissure and creating an abscess between the lungs. In cases where the accessory fissure is involved, it may form a sharp marginated pneumonia that may be misinterpreted as atelectasis or consolidation [34,38-40].

Cardiothoracic surgeons rely on the concept of pulmonary fissures during preoperative planning and while performing the segmental resection to minimize and avoid mortality and disease incidence [41]. Regarding epidemiology, accurate recognition of fissures in various populations, as seen by imaging techniques, may advance the knowledge of lung lesions and related illnesses and how they spread through the lung [42]. Craig and Walker (1997) [43] proposed a classification that was based on the degree of fissure completeness and the position of the pulmonary artery at the base of the oblique fissure (Figure 7). The suggested gradation of fissures was aimed at facilitating meaningful comparisons between various invasive procedures and to prevent postoperative leakage after surgery and other complications. When the major fissure is incomplete or absent, complications may arise during detection or classification of various diseases [43,44]. Incomplete fissure may permit collateral ventilation between the lobes, thereby compromising lobar exclusion. Also, the existence of incomplete fissure may alter the usual patterns of collapse seen in patient with endobronchial lesions, consequently leading to abnormal pleural effusions appearance [45]. Lung lymphatics drain centripetally from the pleura toward the hilum. A change in the course of major oblique fissure will alter the visceral pleura and eventually disrupt the normal drainage pattern of lymphatics [46].

Grade		Feature Right	Left	Illustration
Complete	I			Complete fissure with totally separated lobes
Incomplete	II			Complete visceral cleft. Parenchymal fusion observed at the base of fissure
Incomplete	III			Visceral cleft evident for a part of fissure
Absent	IV			Complete fusion of lobes with no evident fissural line

Mutua et al. (2021)

Figure 7) *Grading of completeness of a fissure (Craig and Walker classification).*

Conclusion

The variation in occurrence of oblique, horizontal and accessory fissures suggests that various genetic, ethnic and environmental factors may be responsible for developing pulmonary fissures. It is noteworthy that prior awareness and anatomical knowledge of the presence of such variations might explain the perplexing presentation of clinical cases concerning lung pathology. Furthermore, it may assist in correctly diagnosing, planning and execution of surgeries.

With wide ranges of variations of lung fissures being documented in a different population, more elaborative studies should be embraced on this topic by involving diverse populations and larger sample sizes which will shed more light on this vital topic.

Acknowledgement

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