

Comparative Anatomy of Pulmonary Lobation and Fissural Patterns in Adult Cadavers and Human Fetuses

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Abstract

Background: The adult lung's lobar and fissural architecture — three lobes on the right and two on the left, separated by oblique and horizontal fissures — is the end product of a gradual embryological process, yet comprehensive data correlating fetal morphological development with the eventual adult pattern remain limited.

Objective: To compare pulmonary lobation and fissural patterns between human fetal and adult cadaveric lung specimens from the same regional population.

Materials and Methods: An observational study was conducted in the Department of Anatomy, FMHS, SGT University, Gurugram. Fifteen fetal lung specimens (Group I, 6–16 weeks, n = 6; Group II, ≥17 weeks, n = 9) and 25 formalin-fixed cadaveric specimens yielding 50 lungs (25 right, 25 left) were examined for lung shape, number of lobes, completeness of the oblique and horizontal fissures, accessory fissures, and the azygos lobe. Cadaveric fissures were additionally graded using Craig and Walker's classification.

Results: Both the oblique and horizontal fissures were already visible in the youngest fetal group, with completeness not rising consistently with gestational age. Among cadaveric lungs, the right oblique fissure was complete in 64% and the left in 48%; the right horizontal fissure was the most variable structure (44% complete, 20% absent). Two lobes instead of three were found in 20% of right lungs, an undivided single lobe in 8% of left lungs, and an azygos lobe in 4% of right lungs. Most fissures graded as Craig–Walker Grade I or II, with only 8% reaching Grade IV.

Conclusion: Primary lobar clefts are established early in gestation, but their conversion into fully separated adult lobes is uneven and often remains incomplete into adulthood. A "textbook" lung was the exception rather than the rule, a finding with practical relevance for thoracic surgical planning and radiological interpretation, and one that adds original baseline data on lung lobation from a rural Haryana population.

Keywords: Pulmonary fissures; Lung lobation; Fetal lung development; Oblique fissure; Horizontal fissure; Azygos lobe.

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Introduction

The human lung develops through a well-defined sequence of embryological stages, and its gross morphology in fetal life differs substantially from the mature adult pattern encountered in cadaveric dissection. In the fully developed adult, each lung lies

free within its pleural cavity except at the hilum, with the right lung divided into three lobes by an oblique and a horizontal fissure, and the left lung divided into two lobes by a single oblique fissure^[1]. This definitive lobar architecture is not present from the outset of

development but is instead the end result of a gradual and carefully sequenced process that begins early in intrauterine life.

Fetal lung studies have shown that lobation and fissure formation are already visible in early gestation, with the size, weight, and surface features of the individual lobes changing consistently as gestational age advances [2]. These changes reflect the underlying histogenesis of the lung, which proceeds through recognizable stages, from the pseudo-glandular period, when the bronchial tree undergoes extensive branching, through the canalicular and saccular stages, during which the airspaces enlarge and thin in preparation for postnatal gas exchange. Histological evaluations of fetal lungs at different gestational weeks have documented these stage-specific changes in bronchial architecture and parenchymal maturation, providing a structural timeline against which fissural and lobar development can be assessed [3].

Cadaveric studies, by contrast, capture the fully matured lobar and fissural pattern together with its many normal variants. These include incomplete fissures, accessory fissures, and anomalies such as the azygos lobe, all of which represent, to varying degrees, an incomplete obliteration of embryonic clefts that were originally more extensive in fetal life [4]. Comparative work examining actual cadaveric lung anatomy against the idealized textbook description has further demonstrated considerable variability in the position, depth, and completeness of the major fissures, with direct implications for thoracic surgical planning and for the interpretation of thoracic imaging [5].

Taken together, these fetal and cadaveric observations suggest that the adult pattern of lobation and fissuration is not a fixed template present from the earliest stages of development, but rather the variable outcome of a progressive maturational process. Despite this, comprehensive data correlating fetal morphological development with the eventual adult pattern remain limited. Comparing morphological findings across fetal life and adulthood is therefore essential to understanding how the mature lobar and fissural pattern emerges from its embryonic precursor, and forms the basis for the present study.

MATERIALS AND METHODS

Study Design

An observational study was conducted in the Department of Anatomy, Faculty of Medicine and Health Sciences (FMHS), SGT University, Gurugram, Haryana, India. The study was carried out on preserved human fetal specimens of varying gestational ages and cadaveric lung specimens available in the departmental foetal bank and obtained by approval of ethical committee.

Study Sample

The study comprised a total of 40 specimens: 30 fetal lung specimens obtained from human abortuses (15 right and 15 left), and 25 cadaveric lung specimens that together yielded 50 individual lungs (25 right and 25 left) for detailed examination and measurement.

Source of Specimens

Fetal and cadaveric lung specimens were obtained from the Museum and Dissection Hall of the Department of Anatomy, Faculty of Medicine and Health Sciences, SGT University, Gurugram, Haryana, India.

Inclusion and Exclusion Criteria

Fetal specimens

Inclusion criteria:

- Human abortuses of varying gestational ages without obvious congenital anomalies.

Exclusion criteria:

- Abortuses with gross congenital anomalies.
- Fetuses of mothers with a documented history of HIV or Hepatitis B infection.
- Abortuses from mothers below 18 years of age.

Cadaveric specimens

Inclusion criteria:

- Well-preserved, formalin-fixed cadaveric lungs with intact external morphology.

Exclusion criteria:

- Lungs damaged during removal or preservation and with pathological lesions.

Determination of Gestational Age

The gestational age of each fetal specimen was estimated using standard fetal parameters:

- Crown-rump length (CRL): the maximum distance from the vertex to the buttocks with the fetus in the most straightened position, measured using a thread and measuring scale.
- Foot length (FL): measured from the posterior aspect of the heel to the tip of the longest toe using a Vernier caliper.

Based on these measurements, the fetal specimens were categorized into two groups:

- Group I: 6–16 weeks of gestation
- Group II: 17 weeks of gestation onward

The body weight of each fetal specimen was recorded using a digital weighing machine.

Morphological and Morphometric Examination

S.No.	Morphological and Morphometric Feature Assessed	Method of Assessment
1	Shape of the lung (normal, conical, distorted)	Gross visual inspection

S.No.	Morphological and Morphometric Feature Assessed	Method of Assessment
2	Number of lobes	Gross visual inspection
3	Oblique and horizontal fissures of the right lung – complete / incomplete / absent	Visual inspection
4	Oblique fissure of the left lung – complete / incomplete / absent	Visual inspection
5	Accessory fissures, if any	Visual inspection
6	Maximum length and breadth of the lung	Digital Vernier caliper
7	Thickness of individual lobes	Digital Vernier caliper
8	Length of fissures (where present)	Thread and measuring tape, to the nearest 5 mm
9	Weight of the specimen	Digital weighing machine

Table 1: Morphological and Morphometric Parameters Assessed in Fetal and Cadaveric Lungs

Data Analysis
Data were compiled and analyzed using Microsoft Excel. Descriptive statistics- mean, standard deviation, and percentage distribution were calculated to compare morphological and morphometric findings between the fetal groups and the adult cadaveric specimens.

RESULTS

This study comprised 15 fetal specimens — six in Group I (6–16 weeks of gestation) and nine in Group II (17 weeks of gestation onward) — together with 25

adult cadaveric specimens that yielded 50 adult lungs (25 right and 25 left) examined grossly for lobar and hilar morphology. Fetal and cadaveric findings are presented separately below and, where comparable data exist, are contrasted with previously published cadaveric series.

Key Findings

- Both major fissures were already discernible in the youngest fetal group examined (6–16 weeks), indicating that the primary lobar clefts are established very early in gestation.
- Usual (textbook) hilar arrangement was present in only 52% of adult right lungs and 36% of left lungs — the majority of cadaveric specimens showed at least one variant hilar structure.
- Complete right oblique fissure (64%) closely matched the 64.2% reported by West et al. [9], whereas complete left oblique fissure (48%) was well below their 81.5%.
- Two lobes instead of three were found in 20% of right lungs, and a single undivided lobe in 8% of left lungs.
- An azygos lobe, a normal variant formed by pleural invagination around the azygos vein, was identified in 4% of right lungs.

A. Fetal Lung Fissural Development

Table 1: Incidence of oblique and horizontal fissure variation in right and left fetal lungs by gestational group.

S.No.	Parameter	Group I (6–16 wk)		Group II (17 wk+)	
		Right	Left	Right	Left
1	Number of fetuses examined	6	6	9	9
2	Complete oblique fissure	2 (33.3%)	4 (66.7%)	3 (33.3%)	5 (55.6%)
3	Incomplete oblique fissure	1 (16.7%)	2 (33.3%)	0 (0%)	2 (22.2%)
4	Absence of oblique fissure	0 (0%)	0 (0%)	0 (0%)	1 (11.1%)
5	Complete horizontal fissure	1 (16.7%)	–	2 (22.2%)	–
6	Incomplete horizontal fissure	1 (16.7%)	–	2 (22.2%)	–
7	Absence of	1 (16.7%)	–	2 (22.2%)	–

	horizontal fissure				
8	Presence of horizontal (accessory) fissure	—	0 (0%)	—	1 (11.1%)

Group -1**Group-2**

Both the oblique and horizontal fissures were visible from the earliest gestational group examined. In Group I, the right oblique fissure was complete in 2 of 6 (33.3%) lungs, and a horizontal fissure (complete or incomplete) was already present in 2 of 6 (33.3%) right lungs. On the left side, the oblique fissure was complete in 4 of 6 (66.7%) lungs in Group I and 5 of 9 (55.6%) in Group II, with no consistent increase in completeness with advancing gestational age. Absence of the oblique fissure was not recorded in any right lung in either group and was seen in only 1 of 9 (11.1%) left lungs of Group II. These findings indicate that the primary lobar clefts are established well before 16 weeks of gestation, in agreement with Jaiswal et al. [5], who reported the oblique fissure of both lungs and the horizontal fissure of the right lung already present in fetuses as young as 15 weeks, with no consistent correlation to gestational age.

B. Fissural Pattern and Completeness

Table 2: Completeness of oblique, horizontal and accessory fissures in right and left cadaveric lungs (n = 25 each).

Lung	Fissure	Complete	Incomplete	Absent	Accessory
Right lung	Oblique	16 (64%)	4 (16%)	2 (8%)	0 (0%)
	Horizontal	11 (44%)	9 (36%)	5 (20%)	0 (0%)
Left lung	Oblique	12 (48%)	8 (32%)	2 (8%)	3 (12%)

Of the right oblique fissures, 16 (64%) were complete, 4 (16%) incomplete and 2 (8%) absent; the right horizontal fissure was complete in 11 (44%), incomplete in 9 (36%) and absent in 5 (20%). On the left side, the oblique fissure was complete in 12 (48%), incomplete in 8 (32%), absent in 2 (8%), and an accessory fissure was present in 3 (12%) (Table 2).



Completeness of the right oblique fissure (64%) closely matched the 64.2% reported by West et al. [9] in a cadaveric UK series, whereas complete left oblique fissure in the present series (48%) was appreciably lower than their 81.5%, and incomplete right horizontal fissure (36%) was lower than their 66.7%. Incomplete oblique fissure on the left side (32%) was broadly comparable to the 30% and 51.9% reported by Singh and Niranjana [6] and KC et al. [7] in Indian and Nepalese cadaveric series, respectively, while incomplete right horizontal fissure in the present study (36%) exceeded the 26.7% described by Singh and Niranjana [6].

C. Grading of Fissure Completeness — Craig and Walker's Classification

Table 3: Grade-wise distribution of oblique, horizontal and accessory fissures (Craig and Walker's classification).

Lung	Fissure	Grade I	Grade II	Grade III	Grade IV
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Right lung	Oblique	8 (32%)	4 (16%)	3 (12%)	2 (8%)
	Horizontal	11 (44%)	9 (36%)	6 (24%)	2 (8%)
Left lung	Oblique	9 (36%)	8 (32%)	7 (28%)	4 (16%)
	Accessory	0 (0%)	0 (0%)	3 (12%)	0 (0%)

Grade-I fissures were the most frequent category overall — 44% of right horizontal, 36% of left oblique and 32% of right oblique fissures. Grade-II fissures accounted for 36% of right horizontal 32% of left oblique and 16% of right oblique fissures. Grade-III fissures were seen in 28% of left oblique, 24% of right horizontal and 12% of right oblique fissures, and in 12% of left accessory fissures. Only 8% of right horizontal and left oblique fissures each reached Grade-IV (Table 3).

D. Accessory Fissures and the Azygos Lobe

Table 4: Incidence of accessory fissures in right and left cadaveric lungs.

Accessory fissure	Right lung	Left lung
Superior accessory fissure	0 (0%)	0 (0%)
Inferior accessory fissure	0 (0%)	2 (8%)
Left minor fissure	—	1 (4%)
Fissure separating azygos lobe	1 (4%)	—
Fissure in middle lobe	0 (0%)	—

An azygos lobe, demarcated by a fissure enclosing the azygos vein, was identified in 1 of 25 (4%) right lungs; no superior or inferior accessory fissure was seen on the right side. On the left, an inferior accessory fissure was present in 2 (8%) and a left minor fissure in 1 (4%) specimen; no fissure was observed in the middle lobe (Table 4). The azygos lobe represents persistence of an embryonic pleural invagination around the posterior cardinal (azygos) vein and, although anatomically silent in the present series, is of recognized radiological and surgical importance [8].

Discussion

The lung begins as a single endodermal outgrowth that divides repeatedly through intrauterine life, and the shallow clefts left behind by this branching are gradually smoothed over as the segments grow together. Only two of these clefts normally persist into the definitive oblique and horizontal fissures, while the rest fuse and disappear [1]. Because this fusion never proceeds at the same pace in every specimen, a fissure may end up fully open, partly closed, or completely obliterated, and this uneven process is the most likely explanation for the wide spread fissural patterns

recorded in both the fetal and the cadaveric groups of the present study.

Both the oblique and the horizontal clefts were already visible in the youngest fetal group examined (6–16 weeks), and their degree of completeness did not rise steadily with advancing gestational age. This matches the observation of Jaiswal et al. [5], who found the oblique fissure of both lungs, and the horizontal fissure of the right lung, is already laid down in fetuses as young as 15 weeks, again with no clear link to gestational age. Taken together with the staged, week-wise maturation of the bronchial tree and parenchyma described by Sahoo et al. [4] and by Swapna Kumari et al. [3], this suggests that the branching pattern responsible for the fissures is largely settled in by the pseudo-glandular stage, well before the process of fissure smoothing is complete — which is probably why fissure grading tracks poorly with fetal age. The parallel rise in gross lung size with gestational age reported by Mukhia et al. [2] indicates that, while the fetal lung continues to grow steadily in bulk, its qualitative fissural pattern behaves as an independent process.

Comparing the fetal and cadaveric halves of the present series directly gave some of the more informative findings. The right horizontal fissure was absent in three of the fifteen fetal right lungs (20%) — one in Group I and two in Group II — a figure that matches almost exactly the 20% absence rate recorded among the cadaveric right lungs. This near-identical proportion supports the idea that once a right horizontal fissure fails to form in utero, it tends to stay absent for life rather than appearing later. A similar continuity was seen on the left side: an accessory left-sided (horizontal) fissure was present in one Group II fetus (11.1%), and a comparable accessory left fissure was recorded in 12% of the cadaveric left lungs, implying that this uncommon variant cleft, once formed, is rarely resorbed.

The left oblique fissure was already complete in 60% of the fetal specimens taken together (9 of 15), a proportion that was not matched in the cadaveric group, where only 48% of left lungs had a fully complete oblique fissure. The right oblique fissure showed a different trend — complete in only about a third of fetal lungs but in 64% of cadaveric lungs. Given the small size of both groups, these figures should be read as preliminary rather than definitive, but it suggests two different possibilities: first that the oblique fissures do not mature completely in foetal life, and second that apparent "completeness" recorded in a fetal specimen does not always predict the fissural state that will be found in the same lung at maturity.

Among the cadaveric findings, the completeness of the right oblique fissure (64%) sat close to the 69.6% as reported by Medlar (1947) [10] and 64.2% as reported

by West et al. (2020) ^[9]. The agreement between two studies separated by more than seventy years and done on different populations suggests that the right oblique fissure is among the more developmentally conserved of the pulmonary clefts. The left oblique fissure told a different story: complete in only 48% of the present cadaveric specimens, well below the 82.1% recorded by Medlar ^[10] and the 81.5% recorded by West et al. ^[9], but reasonably close to the 30% incomplete rate reported by Singh and Niranjana in an Indian cadaveric series ^[6], against 32% incompleteness in the present study. The higher incompleteness of 51.9% reported among Nepalese cadavers by Sudikshya (KC) et al. ^[7] points toward a genuine population-level difference in how often this fissure completes its obliteration.

The right horizontal fissure was the least consistently formed structure in the present series, complete in only 44% of specimens, incomplete in 36%, and absent in 20%. The 36% incomplete rate exceeded the 26.7% reported by Singh and Niranjana ^[6] but was far below the 83.4% recorded by Jacob and Pillay ^[11], the highest incidence reported among the studies drawn on here, and also below the 66.7% reported by West et al. ^[9]. The 20% absence rate was, by contrast, considerably lower than the 45.2% documented by Medlar in 1947 ^[10]. Such wide swings in a single fissure across different series reinforce the general impression that the right horizontal fissure is the most variable component of the lobar pattern, consistent with its comparatively late and less robust embryological consolidation. In Vimla et al. ^[13] and Zareena et al. ^[14] study it is reported that fetal lung fissural variation appears to arise from altered embryologic obliteration and has practical relevance for imaging interpretation and pediatric thoracic surgery. The two attached studies agree most strongly on the high frequency of incomplete right horizontal fissures in fetuses, although the smaller study reports some right oblique fissure variation that was not seen in the larger series. Grading the fissures using the classification proposed by Craig and Walker ^[12] showed that most fissures in the present series fell into Grade I or Grade II, with only a small minority — 8% of right horizontal and left oblique fissures — reaching the deepest, most completely separated Grade IV. Since this grading system was originally devised to help predict the ease of interlobar dissection, the low proportion of Grade IV fissures indicates that, in most of these specimens, careful blunt or sharp dissection would still be needed to free the lobes rather than relying on a naturally deep cleft.

An azygos lobe, formed by persistence of an embryonic pleural fold around the azygos vein, was identified in one of the twenty-five right lungs (4%), matching the classical description of this variant given by Ndiaye et al. ^[8]. Although it produced no functional

disturbance in this specimen, an azygos lobe of this kind is well recognized for mimicking a linear opacity or an interlobar effusion on chest imaging, and its recognition is therefore of more than academic interest. The inferior accessory fissure and left minor fissure noted in a small proportion of left lungs in the present series likely represent the same spectrum of incomplete embryonic obliteration responsible for the more common oblique and horizontal fissure variants described above.

Two further lobar anomalies deserve comment: a right lung with only two lobes instead of three was seen in 20% of specimens, and a single, undivided left lobe was seen in 8%. Rather than being unrelated curiosities, these can be viewed as the extreme end of the same developmental spectrum that produces incomplete or absent fissures — in these cases, fusion between adjacent bronchopulmonary segments was extensive enough to erase the lobar boundary altogether rather than merely leaving it shallow or partial.

Taken as a whole, the present findings show that the primary lobar clefts are laid down early, well before mid-gestation, but that the process which converts these early clefts into the fully separated adult pattern is neither complete nor uniform by the time of birth, and continues to show considerable variation in the adult lung. This is broadly in line with the conclusion reached by West et al. ^[9], that a fully "textbook" lung — three complete fissures on the right and one complete fissure on the left — is in fact a minority finding rather than the rule. For radiologists and thoracic surgeons alike, this reinforces the practical value of anticipating fissural and lobar variation before interpreting imaging or planning a lobe-sparing resection, rather than assuming the standard pattern will be present.

Conclusion

The basic groove pattern of the lung is laid down very early in intrauterine life, but the process that turns these early grooves into fully separated lobes continues, unevenly, right through to adulthood. Even in the youngest fetuses examined, between 6 and 16 weeks of gestation, both the oblique and horizontal clefts could already be identified, and how complete these clefts were did not rise in step with gestational age — suggesting that fissure formation and overall lung growth, though occurring side by side, are largely separate biological events.

A "textbook" lung, with three neatly separated lobes on the right and two on the left, was therefore the exception rather than the rule in this series — a conclusion in line with several previously published cadaveric surveys, and one with practical weight: it argues against surgeons assuming a standard fissural plane during lobectomy or segmental resection, and

reminds radiologists that an incomplete fissure, an accessory lobe, or an unusual pattern of hilar branching can mimic disease unless first recognised as a normal variant. By examining fetal and adult specimens from the same regional population side by side, this study also adds original baseline data on lung lobation and fissural development from rural Haryana, a population not well represented in the existing literature. The sample size in both groups was modest, so these figures are best read as indicative rather than conclusive, and larger, multi-centric studies would help confirm whether the trends reported here hold true more broadly. Even with this caveat, the present findings make one point clear: anatomical variation in lung lobation is common enough that clinicians should expect it, rather than treat it as an exception.

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