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Morphometric variation in the human liver and its clinical implication: a cadaveric study

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ABSTRACT

Background: The most frequently encountered morphological variations of the liver include alterations in its form and shape, as well as the presence of accessory lobes, accessory fissures, and atypical ligaments. Awareness of these anatomical anomalies is essential for clinicians in differentiating pathological conditions, for surgeons performing segmental liver resections, and for radiologists when interpreting hepatic imaging findings.

Objectives: This study aimed to characterize morphological variations of the liver, perform detailed morphometric analysis, and elucidate their clinical significance.

Methodology: Morphological variations of the liver—including alterations in size and shape, the presence of accessory or hypoplastic lobes, and the occurrence of fissures, notches, and grooves—were systematically documented in 42 formalin-fixed specimens. Each liver was examined for external morphology and associated variants, photographed, and the findings were recorded and tabulated. **Results:** Liver morphometry and morphology in the specimens revealed variable lobe dimensions, frequent accessory fissures, diaphragmatic grooves, and Type 1 predominance, highlighting significant anatomical diversity relevant for surgical and radiological considerations.

Conclusion: The findings of this study may aid surgeons and radiologists in minimizing interpretative errors and potential misdiagnoses, while also supporting the selection and planning of appropriate surgical approaches.

Keywords: *Accessory fissures, accessory lobe, Liver, Morphological Variations, Netter's Classification*

1. INTRODUCTION

The liver is the largest gland in the human body and occupies the right hypochondriac, epigastric, and part of the left hypochondriac regions of the upper abdominal cavity. Anatomically, it is divided into right and left lobes by the falciform ligament anterosuperiorly, the fissure for the ligamentum venosum posteriorly, and the fissure for the ligamentum teres hepatis inferiorly. In addition to these primary lobes, the liver comprises two accessory lobes: the caudate lobe, which includes the caudate and papillary processes on the posterior surface, and the quadrate lobe located on the inferior surface [1].

Comprehensive knowledge of normal hepatic anatomy and its variations is essential for surgeons in preoperative planning and intraoperative decision-making, for radiologists to avoid diagnostic errors, and for anatomists to document and interpret newly identified morphological variants. The liver exhibits considerable anatomical complexity, largely attributable to its wide range of morphological variations. These variations may be congenital or acquired and can manifest as alterations in lobar shape, the presence of additional fissures, congenital anomalies such as agenesis, atrophy or hypoplasia, and the development of accessory lobes or atypical enlargement of specific lobes. Such congenital deviations typically result from disruptions during critical stages of embryonic development [2,3]. In contrast, acquired variations often arise from diaphragmatic or ligamentous anomalies, as well as from mechanical influences exerted by adjacent organs throughout life. Although most accessory fissures undergo remodeling and regress during the postnatal period, some may persist in adulthood

[4]. Accurate identification of major fissures is essential for understanding lobar anatomy and for precise localization of hepatic lesions [5]. Furthermore, metastatic deposits may occasionally occupy these spaces, thereby simulating primary focal lesions [6].

Knowledge of liver variations can be helpful to anatomists and morphologists for novel modifications, embryologists for novel growing flaws, clinicians to exclude illnesses, doctors through segmental resection of the liver, and radiology practitioners when construing liver radiologic results in the age of imaging and nominally invasive tactics. Although the segmental anatomy of the liver has been comprehensively investigated, fewer research concerning the exterior dissimilarities of the liver are available. Therefore, a thorough investigation of the comprehensive composition of cadaveric livers can subsidize the determination of significant structural variants. Hence this paper was undertaken to examine the form & occurrence of morphological disparities in cadaveric livers.

2. MATERIALS AND METHODS

This research used a total of 42 liver samples gathered for this research of teaching undergraduate learners. The Department of Anatomy and Neurobiology, College of Medicine and Health Sciences (COMHS), National University of Science and Technology (NUST), Sohar, Oman, collected these samples regardless of age, gender, or ethnicity. The specimens were provided and organized by the Division of Anatomy, West Virginia University, United States. These samples were taken from cadavers and glycerinated after being fixed in a 10% buffered formalin solution. Livers with macroscopic evidence of pathological conditions were excluded from the study. An anthropometric assessment of human livers was performed to obtain standardized liver weight measurements. Only well-preserved specimens without gross pathological alterations were included. Each liver was carefully cleaned of extraneous tissues and blotted dry before weighing. Liver weights were recorded using a calibrated digital weighing scale with an accuracy of 0.1 g. All measurements were taken by the same investigator to minimize inter-observer variability, and each value was documented in a predesigned data sheet for subsequent statistical analysis.

The liver was maintained in its anatomical position with the inferior vena cava oriented vertically for morphological assessment. The vertical and transverse diameters of the right lobe, left lobe, caudate lobe, and quadrate lobe of the liver were systematically measured.

Maximum vertical length of the liver was measured along the greatest convexity of the right lobe, extending from its superior to inferior margins.

Maximum horizontal length of the liver was recorded from the most convex point on the left lobe margin to the corresponding convex point on the right lobe margin.

Left lobe measurements:

Vertical length: measured from the superior to inferior borders.

Horizontal length: measured between its leftmost and rightmost margins.

Right lobe measurements:

Vertical length: recorded from the upper to lower borders.

Horizontal length: measured across its right and left margins.

The measurements of the caudate and quadrate lobes were obtained as follows:

Vertical diameter: Measured at the level of the porta hepatis.

Transverse diameter:

Caudate lobe: measured ½ inch above the level of the porta hepatis.

Quadrate lobe: measured ½ inch below the level of the porta hepatis.

All morphometric measurements were recorded in inches using a standard measuring tape. The dimensions (length and width) of the caudate and quadrate lobes were measured using a digital Vernier calliper. Two observers took all these measurements independently to minimize Inter-observer and intra-observer bias.

The external morphological characteristics of the liver specimens were systematically assessed to identify and categorize macroscopic variations. Each liver was examined in the anatomical position, with particular attention to overall shape and the presence of structural deviations. Observations included accessory fissures, accessory lobes, additional processes, lobar atrophy, and impression grooves. Based on the morphological types established by Netter's (2000), the livers were classified into six groups [7]. The grouping of the liver as per Netter's was [7]:

Type 1	Tiny left lobe, deep coastal impressions.
Type 2	Comprehensive atrophy of left lobe

Type 3	Oblique saddle-like liver with comparatively large left lobe
Type 4	Tongue like the progression of the right lobe (Reidel's lobe)
Type 5	Profound renal dip & corset compression
Type 6	Diaphragmatic grooves

A measuring scale, measuring tape, thread, and digital Vernier calliper were employed for all morphometric assessments. The morphology and variations of each liver specimen were systematically documented. High-resolution photographs were taken from multiple angles to provide a comprehensive visual record of all observable features, with a scale included in each image to indicate reference size. All observations and morphological classifications were independently verified by two experienced anatomists to ensure accuracy, reliability, and consistency of the data. Comprehensive morphological characteristics of each liver specimen were systematically recorded and tabulated in Microsoft Excel. Quantitative analyses were subsequently performed to evaluate the prevalence of the observed anatomical variations. For each parameter, descriptive statistics, including mean, standard deviation, and range, were calculated to summarize the data.

3. RESULTS AND OBSERVATIONS

Morphometric analysis of 42 liver specimens demonstrated variability in lobe dimensions (Table 1). The right lobe was the largest, with vertical and transverse lengths ranging from 4.2–7.8 cm and 2.5–5.0 cm, respectively, while the left lobe measured 2.8–5.6 cm vertically and 2.4–4.9 cm transversely. The caudate and quadrate lobes were smaller, with vertical lengths of 1.1–3.9 cm and 1.0–3.2 cm, and transverse lengths of 0.5–2.2 cm and 1.0–2.8 cm. Overall liver dimensions ranged from 4.4–8.4 cm vertically and 6.0–10.3 cm transversely. Fissures were observed in all lobes, indicating anatomical variability.

Table 1. Vertical and transverse dimensions of the liver lobes and the whole liver in 42 cadaveric specimens (measured in inches).

Measurement Type	Right Lobe (V / T)	Left Lobe (V / T)	Caudate Lobe (V / T)	Quadrate Lobe (V / T)	Whole Liver (V / T)
Minimum	4.2 / 2.5	2.8 / 2.4	1.1 / 0.5	1.0 / 1.0	4.4 / 6.0
Maximum	7.8 / 5.0	5.6 / 4.9	3.9 / 2.2	3.2 / 2.8	8.4 / 10.3
Average	6.2 / 3.8	4.3 / 3.7	2.5 / 1.3	2.1 / 1.9	6.4 / 8.2
Mean ± SD	5.7 ± 0.9 / 3.6 ± 0.7	4.4 ± 0.8 / 3.5 ± 0.6	2.8 ± 0.7 / 1.2 ± 0.4	2.4 ± 0.8 / 1.4 ± 0.5	5.8 ± 0.9 / 7.9 ± 0.8

Note: V = Vertical length, T = Transverse length.

Morphological variations were observed in all 28 liver specimens (Table 2). Fissures were most frequent in the right lobe (50.0%), quadrate lobe (32.1%), and caudate lobe (25.0%) (Figure 1). Other variations included grooves (10.7%), lobulations (3.6%), conical right lobes (17.9%), elongated left lobes (14.3%), and accessory lobes (14.3%) (Figure 2). Quadrate lobe anomalies included tongue-like projections (7.1%), bilobed forms (7.1%), and pons hepatis (21.4%) (Figure 3). The caudate and papillary processes showed occasional underdevelopment or hypertrophy, highlighting considerable anatomical diversity (Figure 4).

Table 2. Morphological variations of the liver observed in the study sample (n = 28).

S. No.	Variation	Number (n)	Percentage (%)
1	**Fissures**		
	Right lobe	14	50.0
	Left lobe	3	10.7
	Caudate lobe	7	25.0

	Quadrate lobe	9	32.1
2	**Groove in the anterior surface**	3	10.7
3	**Lobulations in the anterior surface**	1	3.6
4	**Conical shaped right lobe**	5	17.9
5	**Notched border**	3	10.7
6	**Elongated left lobe / Beaver's lobe**	4	14.3
7	**Caudate process**		
	Underdeveloped	1	3.6
	Hypertrophied	1	3.6
8	**Papillary process**		
	Abnormally upturned	0	0.0
	Enlarged	1	3.6
	Underdeveloped	0	0.0
9	**Quadrate lobe**		
	Tongue-like projection	2	7.1
	Bilobed	2	7.1
	Pons hepatis	6	21.4
10	**Accessory lobe**	4	14.3

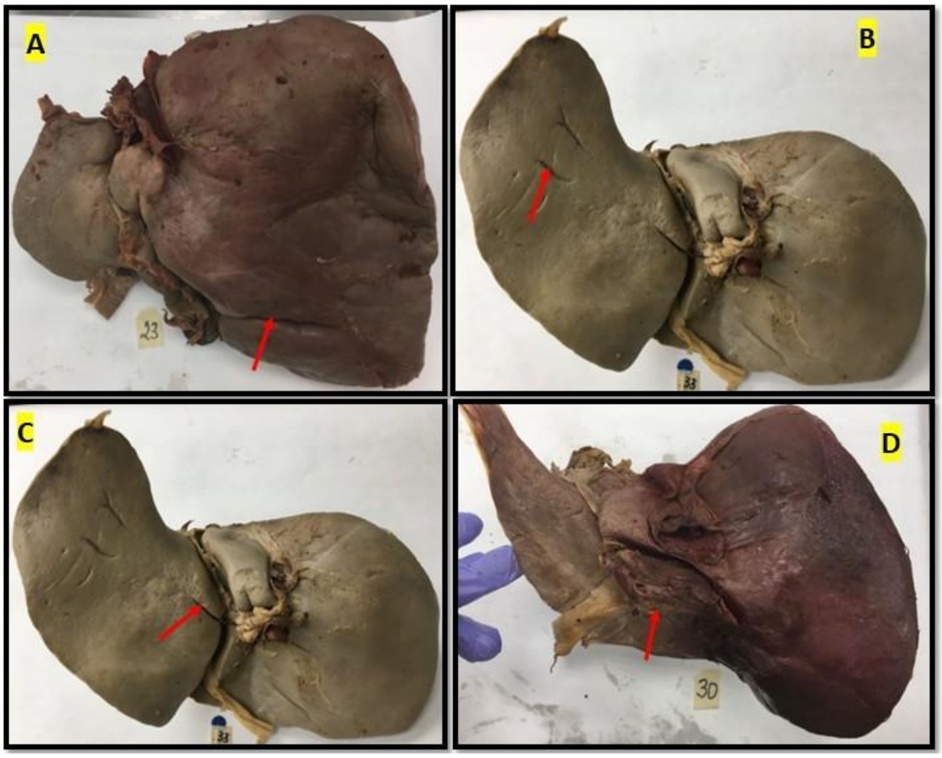

Figure 1: Morphological fissures of the human liver. Arrows indicate: (A) right lobe, (B) left lobe, (C) caudate lobe, and (D) quadrate lobe

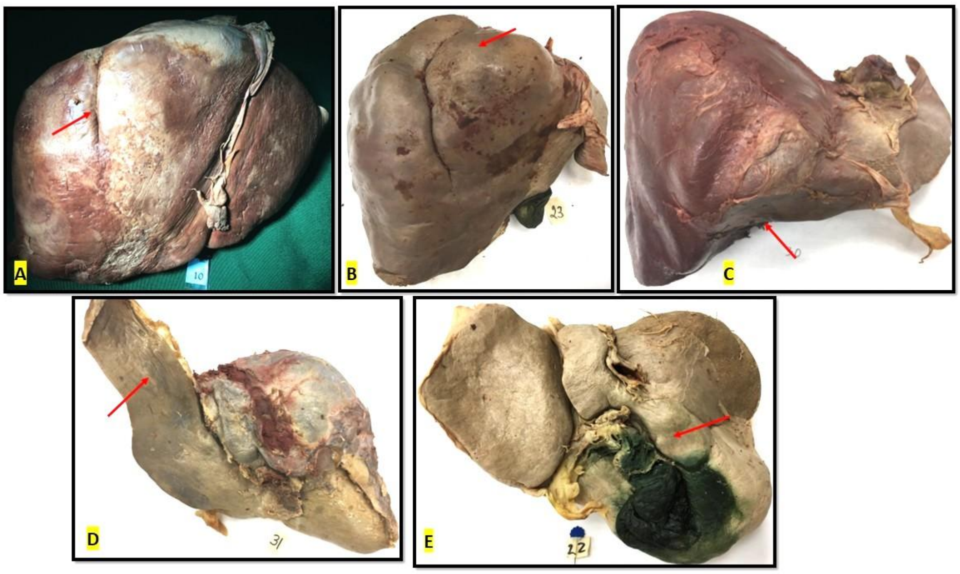

Figure 2: Morphological variations of the human liver observed in this cadaveric study. Arrow-marked structures indicate: (A) groove on the anterior surface, (B) lobulation on the anterior surface, (C) conical right lobe, (D) elongated left lobe, and (E) accessory lobe.

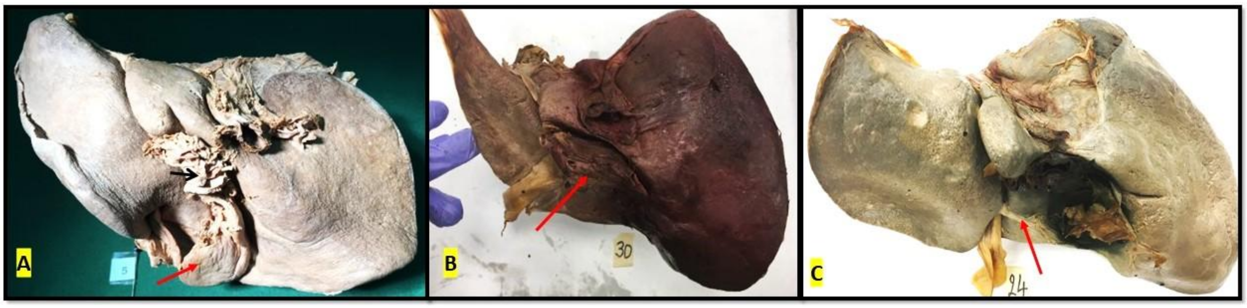

Figure 3: Morphological variations of the quadrate lobe of the liver. Arrow-marked structures indicate: (A) tongue-like projections, (B) bilobed forms, and (C) pons hepatis

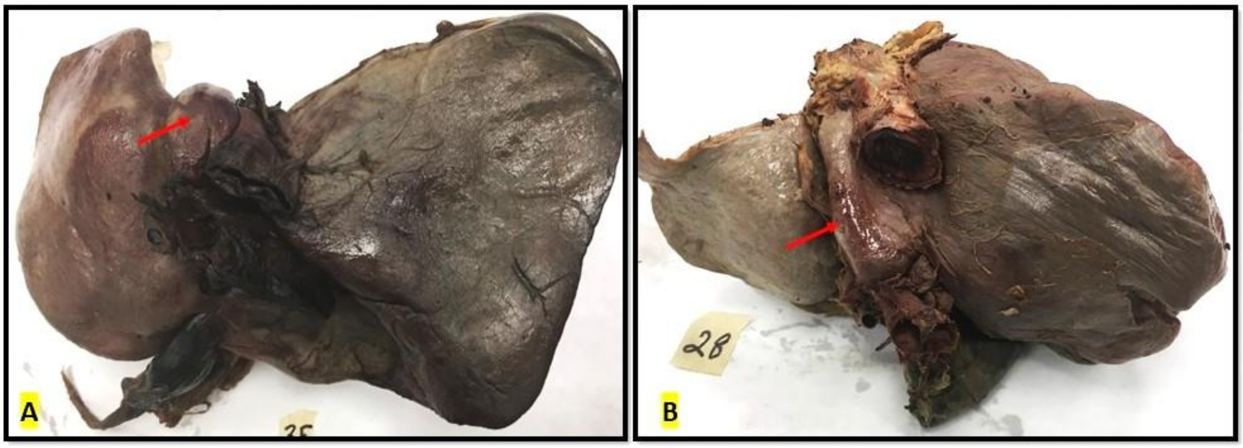

Figure 4: Morphological variations of the caudate lobe of the liver. Arrow indicates the caudate lobe: (A) underdeveloped caudate lobe, (B) hypertrophied caudate lobe

According to Netter's anatomical classification (Figure 5), the majority of livers in this study were classified as Type 1, characterized by a markedly small left lobe with pronounced costal impressions, representing 21.4% of cases. Type 3 livers, distinguished by a transverse saddle-like configuration and comparatively large left lobes, were identified in 7.1% of specimens. Type 4 livers, presenting a tongue-like projection of the right lobe, were infrequent, observed in only 3.6% of cases. Type 5 livers, defined by markedly deep renal impressions with a corset-like constriction, accounted for 10.7%, while Type 6 livers, exhibiting diaphragmatic grooves, were noted in 14.3% of specimens. Notably, no specimens demonstrated complete atrophy of the left lobe (Type 2) (Table 3).

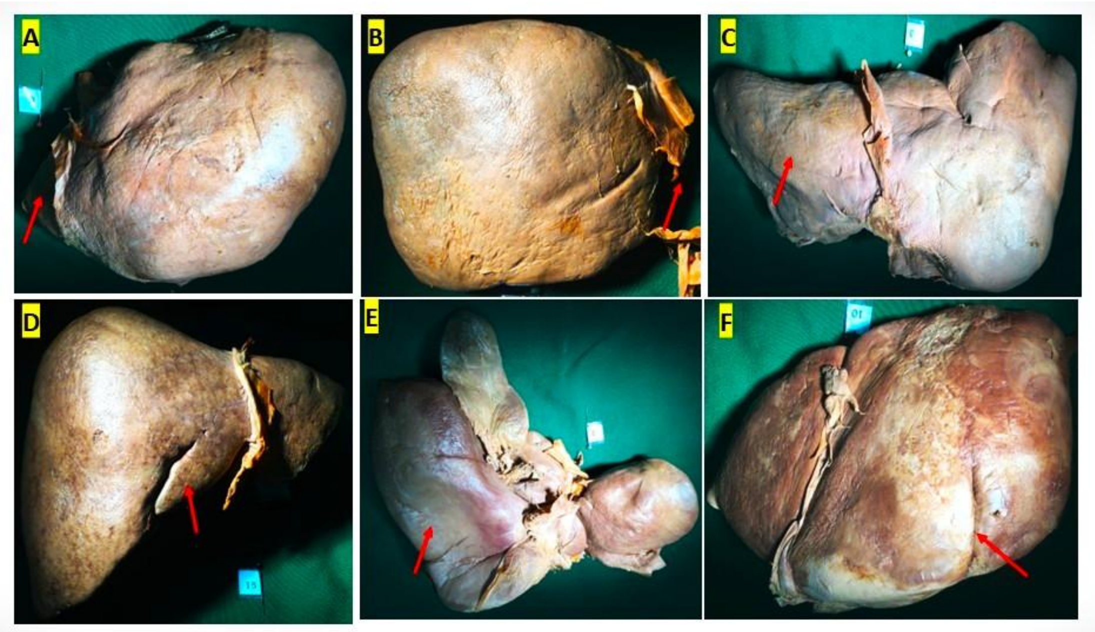

Figure 5: Multiple views of the hepatic surface illustrating Netter's anatomical classification of the liver: 1A, Type I; 1B, Type II; 1C, Type III; 1D, Type IV; 1E, Type V; 1F, Type VI

Table 3. Distribution of liver types based on Netter's classification (n = 28).

Type	Characteristic Features	Number of Specimens	Percentage (%)
Type 1	Very small left lobe, deep costal impressions	6	21.4
Type 2	Complete atrophy of left lobe	0	0.0
Type 3	Transverse saddle-like liver, relatively large left lobe	2	7.1
Type 4	Tongue-like process of right lobe	1	3.6
Type 5	Very deep renal impression and corset constriction	3	10.7
Type 6	Diaphragmatic grooves	4	14.3

4. DISCUSSION

The normal liver morphology features a right lobe constituting approximately 65% of total hepatic volume, with a smooth surface, sharp inferior edge, four lobes, and four major fissures. Congenital or acquired malformations may include absent or hypoplastic lobes or segments, deformed or smaller lobes, accessory fissures, and lobar atrophy [8,9]. These anomalies arise from disrupted hepatic parenchymal development, often linked to altered expression of growth factors, and may be associated with abnormalities of surrounding structures such as the diaphragm and hepatic suspensory apparatus. The extent of morphological alteration depends on the severity of developmental disturbance. While most variations originate during critical pre-natal periods, some may develop postnatally due to trauma or surgery. Subtle changes identified on modern imaging may represent true anatomical variations or pseudo-lesions [10].

Comparison of Liver Morphometry with Previous Studies

The morphometric analysis of 42 liver specimens revealed that the right lobe was the largest, with mean vertical and transverse lengths of 5.7 ± 0.9 cm and 3.6 ± 0.7 cm, respectively. The left lobe measured 4.4 ± 0.8 cm vertically and 3.5 ± 0.6 cm transversely, while the caudate and quadrate lobes were smaller (caudate: 2.8 ± 0.7 / 1.2 ± 0.4 cm; quadrate: 2.4 ± 0.8 / 1.4 ± 0.5 cm). The overall liver dimensions averaged 5.8 ± 0.9 cm vertically and 7.9 ± 0.8 cm transversely (Table 4). These findings are consistent with previous studies that report the right lobe as the largest, followed by the left, caudate, and quadrate lobes [11,12]. Minor differences in absolute dimensions likely reflect population-specific variation, sample size, and measurement techniques.

The present results corroborate the notion of inherent variability in liver morphology, as highlighted by Standring and Moore et al., with clinical implications for hepatic surgery and radiological assessment [13,14]. Population-specific morphometric data, as provided here, serve as valuable anatomical references for both clinical and educational purposes.

Clinical Significance

Morphological variations of the liver, particularly in lobe sizes and fissures, are of considerable clinical importance. Accurate knowledge of liver dimensions assists surgeons in planning hepatic resections, lobectomies, and transplantation procedures, minimizing the risk of intraoperative complications. Radiologists also rely on these normative data to differentiate true anatomical variants from pathological lesions in imaging studies, reducing the likelihood of misdiagnosis. Additionally, understanding lobe-specific variations can guide interventional procedures, such as percutaneous biopsies and placement of drainage catheters, enhancing patient safety and procedural efficacy.

Table 4. Comparative morphometric measurements of the hepatic lobes (in inches).

Liver /Lobes	Present Study (Mean ± SD, V/T)	Raut et al., 2016 (Mean V/T)	Singh & Garg, 2017 (Mean V/T)
Right Lobe	5.7 ± 0.9 / 3.6 ± 0.7	5.8 / 3.7	5.9 / 3.8
Left Lobe	4.4 ± 0.8 / 3.5 ± 0.6	4.5 / 3.4	4.6 / 3.5
Caudate Lobe	2.8 ± 0.7 / 1.2 ± 0.4	2.9 / 1.3	3.0 / 1.4
Quadrate Lobe	2.4 ± 0.8 / 1.4 ± 0.5	2.5 / 1.5	2.6 / 1.5
Whole Liver	5.8 ± 0.9 / 7.9 ± 0.8	5.9 / 8.0	6.0 / 8.1

V = Vertical length; T = Transverse length

Morphological Variations of the Liver

In this study of 28 liver specimens, accessory fissures were the most prevalent anomaly, observed in 51.92% of cases. The right lobe was predominantly affected (50.0%), followed by the quadrate lobe (32.1%) and caudate lobe (25.0%). Pons hepatis was noted in 21.4% of specimens, Riedel's lobe in 9.61%, and elongated left lobes (Beaver's lobe) in 14.3%. Diaphragmatic grooves and accessory lobes were present in 25% and 14.3% of livers, respectively (Table 5). Deep renal impressions were observed in 5.76% of specimens.

When compared with previous studies, the present cohort exhibited a higher frequency of accessory fissures and diaphragmatic grooves, while other variations such as Riedel's lobe and elongated left lobes were within previously reported ranges [1–10].

Table 5. Comparative liver morphological variations: present study versus previous reports with clinical relevance

Morphological Feature	Present Study (n=28)	Reported in Previous Studies (%) [References]	Clinical Significance
Accessory fissures (any lobe)	27 (51.92%)	10–51.43 [15–19]	May mimic pathological lesions; critical for hepatobiliary surgery.
Fissures in right lobe	14 (50.0%)	17–51.43 [17,18]	Alters surgical landmarks during right hepatectomy or cholecystectomy.
Fissures in left lobe	3 (10.7%)	11.43–12.86 [17,20]	Relevant for imaging and left lobe resections.

Fissures in caudate lobe	7 (25.0%)	6.66–27.14 [21,22]	May complicate access to retrohepatic structures.
Fissures in quadrate lobe	9 (32.1%)	4–22 [15,16,17]	Influences segmental anatomy during resections.
Pons hepatis	6 (21.4%)	8–30 [17,19,23]	May create bridges over fissures; affects imaging and surgery.
Riedel's lobe	5 (9.61%)	1.25–18.18 [20,21,24]	Can mimic hepatomegaly; affects gallbladder surgery approach.
Elongated left lobe (Beaver's lobe)	4 (14.3%)	5.76–12.5 [16,17]	Alters imaging interpretation; relevant in left lobe procedures.
Diaphragmatic grooves	7 (25%)	5–15.72 [20,24]	May mimic pathology on imaging; affects contour assessment.
Deep renal impressions	2 (5.76%)	6–20 [19,21]	May affect orientation during posterior liver surgery.
Accessory lobes	4 (14.3%)	0.625–16 [20,22,24]	Can complicate imaging and surgery; may harbor accessory biliary structures.

The present study highlights significant morphological variability in human livers, with accessory fissures and diaphragmatic grooves being particularly frequent. Compared with earlier reports, the frequency of these variations in the current population was higher, suggesting potential population-specific anatomical differences. Such discrepancies may also result from variations in sample size, cadaveric preservation, and observational methods [15–24].

Accessory fissures and lobes are clinically important as they may be mistaken for pathological lesions on imaging, potentially leading to misdiagnosis. Riedel's lobe and elongated left lobes can mimic hepatomegaly, while diaphragmatic grooves and deep renal impressions may alter the apparent liver contour on radiographs, CT, or MRI. Knowledge of these variations is critical for hepatobiliary surgeons to plan resections, cholecystectomies, and liver transplantation procedures safely, minimizing intraoperative complications and ensuring accurate identification of anatomical landmarks.

The high prevalence of accessory fissures and diaphragmatic grooves underscores the necessity for thorough preoperative imaging and careful intraoperative assessment. Additionally, recognition of pons hepatis, accessory lobes, and other subtle variants can prevent misinterpretation of imaging findings and facilitate safe surgical approaches.

Comparison of Liver Morphological Variations with Previous Studies and Clinical Significance

In the present study of 28 liver specimens (Table 6), Type 1 livers, characterized by a very small left lobe and deep costal impressions, were the most frequent (21.4%), consistent with Mehrae et al. (21.2%) but higher than Nagato et al. (8.19%) and Sachin et al. (2%) [25,26,28]. Type 2 livers, representing complete atrophy of the left lobe, were absent, in agreement with Sachin et al. and Mehrae et al., but slightly lower than Nagato et al. (1.64%) and Sangeeta et al. (3%) [25-28]. Type 3 livers (7.1%) were comparable to previous reports (6.06–10%). Type 4 livers, exhibiting a tongue-like projection of the right lobe, were rare (3.6%) compared with Nagato et al. (21.31%) and Sangeeta et al. (9%) [25, 27]. Type 5 livers, showing deep renal impressions and corset constriction, were observed in 10.7% of specimens, similar to Nagato et al. (9.84%) and Mehrae et al. (9.09%). Type 6 livers with diaphragmatic grooves were unique to the present study (14.3%) [25, 28].

Clinical Significance by Liver Type:

Type 1 (Small left lobe with deep costal impressions): May influence planning for left lobectomy or segmental resections; important for preoperative imaging interpretation.

Type 2 (Complete atrophy of left lobe): Though absent in this study, awareness is crucial as it may affect vascular anatomy and surgical approaches.

Type 3 (Minor morphological variations): Usually incidental; relevant in radiology to distinguish normal variants from pathological findings.

Type 4 (Tongue-like projection of right lobe): Can be misinterpreted as a mass on imaging; important for surgeons during right lobectomy.

Type 5 (Deep renal impressions and corset constriction): May simulate pathological indentations on imaging; careful assessment needed during retroperitoneal procedures.

Type 6 (Diaphragmatic grooves): Unique variant; may be mistaken for traumatic or pathological lesions in radiological exams; awareness prevents unnecessary interventions.

These findings underscore both the consistency and population-specific variation in liver morphology, emphasizing the importance of anatomical knowledge for hepatobiliary surgery, transplantation, and radiological evaluation.

Table 6. Comparison of liver morphotypes according to Netter's classification in the present study versus previous studies.

Netter's Type	Present Study (n=28)	Nagato et al. [25]	Sachin et al. [26]	Sangeeta et al. [27]	Mehrae et al. [28]
Type 1	6 (21.4%)	8.19%	2%	7%	21.2%
Type 2	0 (0%)	1.64%	0%	3%	0%
Type 3	2 (7.1%)	6.56%	10%	7.1%	6.06%
Type 4	1 (3.6%)	21.31%	2%	9%	3.03%
Type 5	3 (10.7%)	9.84%	2%	6%	9.09%
Type 6	4 (14.3%)	-	-	-	-

5. CONCLUSION

Liver structural variations are common, yet systematic studies on their prevalence and clinical relevance remain limited. Understanding normal and variant lobular architecture is essential for accurate diagnosis, safe surgical planning, and effective management of hepatic lesions. Such variations may be congenital or acquired, highlighting the importance of anatomical knowledge across all stages of life. Awareness of accessory fissures and atypical lobular patterns is critical for radiologists and surgeons to avoid diagnostic errors and optimize patient outcomes. This study documents key variations in liver lobules and clefts, providing practical guidance for imaging interpretation and surgical intervention.

6. ETHICAL APPROVAL

Ethical approval was granted by an Institutional research and ethics committee (IREC). The registration number for the ethical approval is NU/COMHS/EBC0066/2025.

7. CONFLICT OF INTEREST

The authors declare no conflict of interest.

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