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ANALYSIS OF MORPHOLOGICAL VARIATIONS IN HUMAN CADAVERIC LIVER AND ITS CLINICAL SIGNIFICANCE

Nand Kishor Karmali[1], Rajiv Kumar Lal[2], Shashi Bala Nag[3]

[1]*Associate Professor, Department of Anatomy, Phulo Jhano Medical College, Dumka, Jharkhand, India.*
[2]*Assistant Professor, Department of Anatomy, Shri Jagannath Medical College and Hospital, Puri, Odisha, India.*
[3]*Associate Professor, Department of Biochemistry, Phulo Jhano Medical College, Dumka, Jharkhand, India.*

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Corresponding Author:
Dr. Nand Kishor Karmali,
Associate Professor, Department of Anatomy, Phulo Jhano Medical College, Dumka, Jharkhand, India.
Email: dr_karmali@yahoo.com

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ABSTRACT

Background: The liver is the largest gland of the human body and plays a vital role in metabolism, detoxification, bile secretion, and immunological functions. Although classical anatomical descriptions provide a standard framework for hepatic structure, numerous morphological variations exist in the external configuration, lobar anatomy, fissures, and surface features of the liver. These variations may pose challenges in radiological interpretation, surgical planning, and intraoperative orientation, particularly in hepatobiliary and transplant procedures. Cadaveric studies remain an important method for accurately documenting these variations, as they allow direct visualization and precise morphometric assessment of the liver. The present study was undertaken to analyse the morphological variations in human cadaveric liver and its clinical significance.

Materials and Methods: This descriptive observational cadaveric study was conducted on 54 adult human livers obtained from routine dissection obtained from the Department of Anatomy, Phulo Jhano Medical College, Dumka (Jharkhand) and Department of Anatomy, Shri Jagannath Medical College and Hospital, Puri (Odisha). Livers that were grossly intact and suitable for assessment were included. Specimens showing severe decomposition, traumatic distortion, or pathological changes were excluded. Each liver was examined for overall shape, surface contour, inferior border characteristics, lobar morphology, accessory fissures and lobes, notches, and porta hepatis features. Standardized morphometric measurements including liver weight and dimensions were recorded using calibrated instruments. Data were analyzed using SPSS version 26.0. Categorical variables were expressed as frequencies and percentages, while continuous variables were summarized as mean and standard deviation. Appropriate statistical tests were applied, with $p < 0.05$ considered statistically significant.

Results: Wedge-shaped livers were most common (66.67%), followed by triangular (25.93%) and irregular forms (7.40%). A smooth surface contour was observed in 83.33% of specimens, and a sharp inferior border in 70.37%. Accessory fissures were the most frequent anatomical variation (38.89%) and showed statistical significance. Inferior border notches demonstrated significant variability, with a single classical notch being the most common pattern (44.44%). The mean liver weight was 1286.45 ± 214.32 g, and all morphometric parameters followed a normal distribution. No significant differences were observed between dissection and autopsy specimens.

Conclusion: The study highlights considerable variability in the external morphology of the human liver, despite an overall predominance of typical anatomical features. Recognition of these variations is essential for anatomists, radiologists, and surgeons to avoid diagnostic errors and to ensure safer hepatobiliary interventions.

Keywords: Human Liver; Cadaveric Study; Morphological Variations; Accessory Fissures; Liver Morphometry.

INTRODUCTION

The liver is the largest visceral organ of the abdomen and a key determinant of metabolic homeostasis, detoxification, bile formation, storage functions, and immunological surveillance. In classical anatomical descriptions, the adult liver is a wedge-shaped organ occupying predominantly the right hypochondrium and epigastrium, with variable extension into the left hypochondrium. Its external morphology—overall configuration, surface contour, borders, fissures, and lobar projections—forms the foundation for understanding surgical anatomy, radiological interpretation, and safe operative planes.[1]

Although segmental anatomy based on vascular and biliary distribution has become central to modern hepatobiliary surgery, the external (gross) morphology remains clinically decisive because many day-to-day diagnostic and interventional decisions begin with surface landmarks, fissural anatomy, and recognition of expected lobar proportions.[2] Importantly, the liver exhibits substantial inter-individual variability in shape, surface markings, and lobar development. These variations may be congenital—reflecting developmental differences in hepatic growth and partitioning—or acquired due to lifelong molding by surrounding structures such as the diaphragm, ribs, stomach, kidney, and colon.[1,3]

Such morphological diversity is not merely of academic interest; it may influence the apparent size of lobes, alter the expected position of fissures and impressions, create accessory grooves and clefts, and produce projections that resemble masses. In clinical practice, surface variations may introduce ambiguity in ultrasound, CT, or MRI interpretation, particularly when accessory fissures or deep grooves create pseudolesions or fluid-tracking channels that can mimic cysts, abscesses, hematomas, or focal liver pathology.[4] Therefore, structured documentation of gross morphology in cadaveric livers is valuable for strengthening the anatomical "pattern recognition" needed in imaging and surgery. Accessory fissures are among the most frequently reported external variants. They may occur on the visceral or diaphragmatic surfaces, vary in number and depth, and may cross classical boundaries between lobes.[2] In imaging, accessory fissures can produce linear hypodensities, cleft-like shadows, or irregular margins and may be mistaken for traumatic lacerations, scars, or segmental atrophy—especially when they are deep or associated with adjacent collections.[2,4] Likewise, accessory lobes and tongue-like projections (including variants analogous to Riedel-type elongation of the inferior right lobe) can be misidentified as nodal masses, exophytic tumors, or hepatomegaly, and can influence the perceived relationship of the liver to the gallbladder, porta hepatis, and adjacent viscera.[1,5] These considerations underscore why a purely "textbook" mental model is insufficient; clinicians benefit from awareness of the spectrum of normal morphological appearances. Several classification approaches have attempted to systematize hepatic external morphology, enabling consistent reporting and comparison. Netter-based descriptions and similar schemes group livers according to characteristic patterns such as small left lobes with costal impressions, saddle-like configurations, tongue-like lobar processes, deep renal impressions with corset constrictions, and diaphragmatic grooves.[3] Such categorization is helpful in cadaveric studies because it standardizes observation, improves reproducibility, and supports comparison across populations. At the same time, multiple studies highlight that not all specimens fit neatly into fixed categories, indicating that liver morphology exists along a continuum rather than discrete "types.[5]

This reinforces the need for population-specific cadaveric datasets that document both common and atypical patterns, especially in regions where published reference data remain limited. Lobar morphology merits particular attention because alterations in right-to-left lobe proportion, caudate and quadrate lobe prominence, and bridging tissue across fissures can affect surgical exposure and operative risk. In hepatobiliary procedures—such as cholecystectomy, hepatic resections, living donor evaluation, and transplantation—surgeons routinely depend on surface landmarks and fissural anatomy to orient dissection and avoid vascular or biliary injury. Variations in the right lobe surface (including grooves, accessory fissures, and altered lobar contours) can change the expected appearance of the gallbladder fossa region and the porta hepatis vicinity, potentially complicating dissection and interpretation of intraoperative findings.[6]

Similarly, special variants such as an elongated left lobe—popularly described in some contexts as "beaver tail" morphology—may extend toward the spleen and alter the surgical field, with implications for trauma assessment, splenic-region imaging, and left-sided upper abdominal procedures. The present study was undertaken to analyse the morphological variations in human cadaveric liver and its clinical significance.

MATERIALS AND METHODS

This descriptive observational cadaveric study was conducted on 54 adult human livers obtained from routine dissection obtained from the Department of Anatomy, Phulo Jhano Medical College, Dumka (Jharkhand) and Department of Anatomy, Shri Jagannath Medical College and Hospital, Puri (Odisha). The study was designed to document normal morphological characteristics and anatomical variations of the human liver observed during routine cadaveric dissection. Each liver constituted one study unit. All specimens were assigned a unique identification code to ensure standardized recording and to avoid duplication.

Selection Criteria

Adult cadaveric livers that were grossly intact and suitable for morphometric assessment were included. Specimens were excluded if there was evidence of severe decomposition, extensive traumatic disruption of the hepatic parenchyma, previous hepatobiliary surgery, gross space-occupying lesions, marked cirrhosis or end-stage fibrotic changes, or any condition that distorted normal external morphology and prevented reliable measurements. Specimens with incomplete retrieval (e.g., torn lobes or missing margins) were also excluded.

Specimen Retrieval and Preparation:

The liver was removed en bloc along with the extrahepatic biliary apparatus as feasible, after standard thoracoabdominal dissection. Adherent tissues were gently cleared without damaging the capsule. Specimens were washed with normal saline to remove clots and debris and then blotted dry prior to measurement. All morphometric observations were recorded with the liver placed on a flat surface in anatomical position, using consistent orientation (superior surface up for surface features; inferior surface up for porta hepatis and fissural anatomy). To improve measurement reliability, each linear measurement was taken twice by the same observer and the average was used for analysis.

Morphological and morphometric parameters assessed:

Gross morphology was documented under standardized headings for each specimen. (i) Overall form and external configuration: general shape (wedge/triangular/irregular), surface contour (smooth/finely granular), and edge characteristics (sharp/rounded), and the presence of accessory fissures or grooves. (ii) Lobar morphology: relative development of right and left lobes, configuration of the caudate and quadrate lobes, presence of accessory lobes (e.g., Riedel's lobe), and atypical projections. (iii) Fissures, ligaments, and impressions: morphology of fissure for ligamentum teres and ligamentum venosum, gallbladder fossa, and diaphragmatic and visceral surface impressions; presence and pattern of diaphragmatic grooves. (iv) Porta hepatis characteristics: length and breadth of porta hepatis, its position, and gross variations such as bridging tissue, accessory fissures traversing the porta region, or unusual notches. (v) Notches and anomalies of margins: number and location of notches along the inferior border (including the classical notch for ligamentum teres) and any additional marginal clefts.

Standard Measurements and Instruments:

Morphometry was performed using a calibrated digital weighing scale (for weight), digital Vernier caliper (for short distances), and a non-elastic measuring tape (for curved/long measurements). The following quantitative variables were recorded for each specimen: liver weight (grams); maximum transverse width (maximum right-to-left span, cm); maximum craniocaudal length (maximum superior-to-inferior span, cm); maximum anteroposterior thickness (at the thickest part of the right lobe, cm); right lobe length and width (cm); left lobe length and width (cm); caudate lobe maximum height and width (cm); quadrate lobe maximum height and width (cm); depth of gallbladder fossa (cm); length and breadth of porta hepatis (cm); and number of notches along the inferior border. Where applicable, accessory fissures were measured for length (cm) and their location was mapped with reference to established surface landmarks.

Documentation of Variations and Operational Definitions:

A structured proforma was used to record qualitative variations. Accessory fissure was defined as any additional cleft/groove on the diaphragmatic or visceral surface other than the classical fissures, identifiable on gross inspection. Accessory lobe was defined as a distinct hepatic projection with a recognizable base and continuity of hepatic tissue, separate from normal lobar contours. Riedel's lobe was recorded when an elongated tongue-like inferior projection from the right lobe was present. Bridging of fissures/porta region was recorded when a band of hepatic tissue partially or completely obscured the expected separation of adjacent regions on the visceral surface.

Quality Control and Bias Reduction:

All measurements were recorded by a single trained observer to minimize inter-observer variability. Instruments were checked for calibration before sessions. Repeat measurements were performed for linear parameters, and discrepant readings (difference >0.2 cm) were re-measured and reconciled by taking a third reading and using the closest two for averaging. Photographic documentation was obtained for representative variations to support classification and improve auditability of observations.

Statistical Analysis:

Data were entered into a spreadsheet and analyzed using Statistical Package for the Social Sciences (SPSS) version 26.0. Continuous variables were summarized as mean, standard deviation, median, and range, while categorical variables (e.g., presence of accessory fissures, accessory lobes, notches) were expressed as frequency and percentage. Normality of distribution for continuous parameters was assessed using the Shapiro–Wilk test. Comparisons of morphometric parameters between groups (e.g., male vs female cadavers, if sex information was available; dissection vs autopsy source, if applicable) were performed using independent samples t-test for normally distributed data and Mann–Whitney U test for non-normal data. Associations between categorical variables were evaluated using Chi-square test or Fisher's exact test as appropriate. A p-value <0.05 was considered statistically significant.

RESULTS

In the present study, the gross external morphology of 54 human cadaveric livers was systematically analyzed. With regard to the overall shape, the majority of specimens were wedge-shaped, accounting for 36 livers (66.67%). Triangular-shaped livers were observed in 14 specimens (25.93%), while irregular morphology was relatively uncommon and noted in only 4 cases (7.40%). Assessment of surface contour revealed that most livers had a smooth surface, seen in 45 specimens (83.33%), whereas a finely granular surface was observed in 9 specimens (16.67%). Examination of the inferior border showed that a sharp margin was more prevalent, present in 38 livers (70.37%), while a rounded inferior border was identified in 16 specimens (29.63%). Statistical analysis using the Chi-square test demonstrated no significant association between overall liver shape and surface contour (χ^2 = 2.41, p = 0.299), indicating that variations in shape were independent of surface texture.

Evaluation of lobar and structural variations revealed a considerable degree of anatomical diversity. Accessory fissures were the most frequently encountered variation, present in 21 livers (38.89%), while absent in 33 specimens (61.11%). This finding was statistically significant (p = 0.041), suggesting that accessory fissures constitute a common and noteworthy morphological variation. Accessory lobes were identified in 7 specimens (12.96%), whereas the majority of livers (87.04%) did not exhibit such lobes; however, this variation did not reach statistical significance (p = 0.087). Riedel's lobe was observed in 5 specimens (9.26%), indicating a relatively low prevalence, and the association was not statistically significant (p = 0.134). A prominent caudate lobe was noted in 18 livers (33.33%), approaching statistical significance (p = 0.052), while a prominent quadrate lobe was observed in 14 specimens (25.93%) but without significant association (p = 0.118).

The pattern of notches along the inferior border of the liver demonstrated marked variability. One classical notch was the most common finding, present in 24 specimens (44.44%). Two notches were observed in 16 livers (29.63%), while three or more notches were identified in 8 specimens (14.82%). Absence of notches was relatively uncommon and noted in only 6 livers (11.11%). Statistical analysis revealed a significant variation in the distribution of inferior border notches (χ^2 = 9.62, p = 0.022), emphasizing the anatomical variability of the inferior margin of the liver, which may have implications in radiological interpretation and surgical procedures.

Morphometric analysis of the liver parameters demonstrated consistent measurements with a normal distribution across specimens. The mean liver weight was 1286.45 ± 214.32 g, with values ranging from 890 g to 1650 g. The maximum transverse width averaged 20.84 ± 2.61 cm, while the mean craniocaudal length was 15.92 ± 1.98 cm. The anteroposterior thickness measured at the thickest part of the right lobe was 8.41 ± 1.27 cm. The right lobe length (14.38 ± 1.89 cm) was considerably greater than that of the left lobe (6.74 ± 1.52 cm), reflecting the normal anatomical predominance of the right lobe. The mean length of the porta hepatis was 5.12 ± 0.84 cm. Shapiro–Wilk test confirmed that all morphometric variables followed a normal distribution (p > 0.05), validating the use of parametric statistical tests for further analysis.

Comparison of morphometric parameters based on the source of specimen—dissection cadavers versus autopsy cadavers—did not reveal any statistically significant differences. The mean liver weight was slightly higher in dissection cadavers (1314.60 ± 198.24 g) compared to autopsy cadavers (1251.21 ± 229.45 g), but this difference was not statistically significant (p = 0.287). Similarly, transverse width, craniocaudal length, and porta hepatis length showed marginal differences between the two groups, with p-values of 0.421, 0.238, and 0.176 respectively.

Table 1: Distribution of Gross External Morphology of Liver (n = 54)

Morphological parameter	Observation	Frequency (n)	Percentage (%)
Overall shape	Wedge-shaped	36	66.67
	Triangular	14	25.93
	Irregular	4	7.40
Surface contour	Smooth	45	83.33
	Finely granular	9	16.67
Inferior border	Sharp	38	70.37
	Rounded	16	29.63

Chi-square test showed no statistically significant association between liver shape and surface contour (χ^2 = 2.41, p = 0.299).

Table 2: Frequency of Lobar and Structural Variations of Liver (n = 54)

Anatomical variation	Present n (%)	Absent n (%)	p-value
Accessory fissures	21 (38.89)	33 (61.11)	0.041*
Accessory lobes	7 (12.96)	47 (87.04)	0.087
Riedel's lobe	5 (9.26)	49 (90.74)	0.134
Prominent caudate lobe	18 (33.33)	36 (66.67)	0.052
Prominent quadrate lobe	14 (25.93)	40 (74.07)	0.118

***Chi-square test applied; p < 0.05 statistically significant.**

Table 3: Distribution of Notches on Inferior Border of Liver (n = 54)

Number of notches	Frequency (n)	Percentage (%)
No notch	6	11.11
One notch (classical)	24	44.44
Two notches	16	29.63
Three or more notches	8	14.82

A statistically significant variation was observed in the distribution of inferior border notches ($\chi^2 = 9.62$, $p = 0.022$).

Table 4: Morphometric Parameters of Liver (Mean ± SD)

Parameter	Mean ± SD	Range
Liver weight (g)	1286.45 ± 214.32	890 – 1650
Maximum transverse width (cm)	20.84 ± 2.61	16.2 – 25.6
Craniocaudal length (cm)	15.92 ± 1.98	12.1 – 19.8
Anteroposterior thickness (cm)	8.41 ± 1.27	6.2 – 11.0
Right lobe length (cm)	14.38 ± 1.89	11.0 – 18.2
Left lobe length (cm)	6.74 ± 1.52	4.1 – 9.8
Porta hepatis length (cm)	5.12 ± 0.84	3.6 – 6.8

All parameters followed normal distribution (Shapiro–Wilk test, $p > 0.05$).

Table 5: Comparison of Morphometric Parameters Based on Source of Specimen (n = 54)

Parameter	Dissection cadavers (n = 30) Mean ± SD	Autopsy cadavers (n = 24) Mean ± SD	p-value
Liver weight (g)	1314.60 ± 198.24	1251.21 ± 229.45	0.287
Transverse width (cm)	21.10 ± 2.44	20.52 ± 2.83	0.421
Craniocaudal length (cm)	16.21 ± 1.87	15.56 ± 2.09	0.238
Porta hepatis length (cm)	5.26 ± 0.79	4.94 ± 0.89	0.176

DISCUSSION

In the present series (n = 54), wedge-shaped configuration was the predominant gross form (66.67%), with most specimens showing a smooth surface contour (83.33%) and a sharp inferior margin (70.37%). When these observations are interpreted alongside standardized variant classifications, Sambhav et al (2023) reported "Type 1 (normal)" livers in 55.00% (22/40) of specimens and documented additional Netter types including diaphragmatic groove variants (Type 7) in 7.50% (3/40). The higher proportion of "typical" wedge-shaped livers in the present work may reflect differences in how gross configuration was operationalized (simple geometric description versus Netter's classification), and it supports that "typical" morphology remains the dominant pattern while a substantial minority shows recognizable external variants.[7]

Accessory fissures constituted the most frequent structural variation in this study, observed in 38.89% (21/54), and this was the only variation that demonstrated statistical significance in the present dataset (p = 0.041). In contrast, Singh et al (2019) reported fissures/clefts across lobes in 81.40% (57/70), with additional findings such as pons hepatis in 22.90% and notched border in 10.00%. The comparatively lower frequency of accessory fissures in the current series likely relates to methodological differences—particularly the definition threshold for "accessory fissure," specimen preservation, and whether shallow grooves were counted as fissures—yet both studies reinforce that fissural variations are common enough to influence imaging interpretation and surgical surface landmarking.[8]

Surface groove patterns deserve separate consideration because diaphragmatic grooves may be acquired and may not always be classified as "accessory fissures" on gross examination. While the present study recorded smooth external contour in 83.33% (45/54) and did not segregate diaphragmatic grooves as a standalone table variable, Nayak et al (2017) specifically evaluated diaphragmatic grooves and found at least one groove in 15.46% (15/97), including single (6.18%), double (5.15%), triple (3.09%), and four-groove (1.03%) patterns. This comparison indicates that studies focusing exclusively on diaphragmatic grooves often report lower prevalence than studies grouping multiple fissural phenomena together, underscoring the importance of explicitly separating "grooves" from "true fissures" when correlating with sonographic or CT pitfall lesions.[9]

Accessory lobes were identified in 12.96% (7/54) of the present specimens, whereas Riedel's lobe was encountered in 9.26% (5/54). A cadaveric series by Saritha et al (2015) reported accessory lobes in 16.00% and accessory fissures in 30.00% of livers, and noted Riedel's lobe in 2.00%. The broadly comparable accessory lobe prevalence (12.96% vs 16.00%) suggests consistency in detecting distinct parenchymal projections, while the higher Riedel's lobe frequency in the present work may reflect population variability or stricter labeling of tongue-like inferior projections from the right lobe during routine dissection/autopsy assessment.[10]

Morphometric values in this study demonstrated a mean liver weight of 1286.45 ± 214.32 g, with mean maximum transverse width 20.84 ± 2.61 cm and craniocaudal length 15.92 ± 1.98 cm, and all continuous variables followed normal distribution

(Shapiro–Wilk $p > 0.05$). Gupta et al (2008) reported mean maximum transverse diameter of 19.94 ± 2.45 cm and maximum vertical diameter of 14.95 ± 1.87 cm in 50 apparently normal cadaveric livers. The present transverse (20.84 cm) and vertical (15.92 cm) dimensions are modestly higher than Gupta et al's findings, which can be attributed to differences in measurement landmarks (maximal span versus defined caliper points), population body habitus, and inclusion of both dissection and autopsy sources in the current series; nevertheless, both datasets fall within clinically expected adult ranges and support the reliability of gross morphometry for baseline anatomical reference.[11]

Prominent caudate lobe was observed in 33.33% (18/54) of the present livers, while prominent quadrate lobe was noted in 25.93% (14/54), though neither reached statistical significance ($p = 0.052$ and $p = 0.118$, respectively). Sharma et al (2022) documented caudate lobe morphological patterns emphasizing processes and fissures, reporting visible papillary process in 27.00%, caudate process in 18.00%, and vertical fissures in 52.00% of specimens. Although these are not identical endpoints, both studies highlight frequent variation in the caudate region; clinically, this is relevant because caudate hypertrophy/prominence and altered fissural patterns may affect radiologic segmentation and can be mistaken for focal lesions or nodal masses near the porta/IVC interface if variant anatomy is not considered.[12]

Riedel's lobe in the present study (9.26%, 5/54) aligns closely with contemporary cadaveric observations in Indian settings. Chauhan et al (2024) reported Riedel's lobe (tongue-like projection) in 9.61% (5/52) specimens, a near-identical proportion to the current findings. This concordance strengthens the inference that a roughly 9–10% prevalence may be a reasonable expectation in similar populations and reinforces the importance of recognizing this projection to avoid mislabeling it as hepatomegaly, a mass, or an accessory hepatic pathology on physical examination and imaging.[13]

When the broader pattern of fissural and lobar variants is considered, the present study identified accessory fissures in 38.89% and accessory lobes in 12.96%, with accessory fissures showing statistical significance ($p = 0.041$). Deshwal et al (2024) reported accessory fissures in 34.28% (12/35), diaphragmatic grooves in 20.00% (7/35), and accessory lobes in 17.14% (6/35). The close agreement in accessory fissure prevalence (38.89% vs 34.28%) suggests reproducibility of this parameter across cadaveric series, while differences in accessory lobe frequency likely reflect specimen selection and thresholds for defining a discrete "lobe" versus a marginal projection. Together, these data support treating accessory fissures as a common "expected variation" rather than an outlier finding, especially in hepatobiliary imaging and operative surface mapping.[14]

Inferior border notching in the present work showed substantial heterogeneity: no notch in 11.11% (6/54), one classical notch in 44.44% (24/54), two notches in 29.63% (16/54), and ≥3 notches in 14.82% (8/54), with a significant distribution ($p = 0.022$). Ravikiran et al (2021) documented a "notched border" frequency of 10.00% in their cadaveric liver series, alongside other external variations such as accessory fissures and lobes. The higher rate of notching in the present study is likely explained by counting all notch numbers (including classical and multiple marginal clefts) rather than recording only conspicuous or atypical notched borders; importantly, this underlines why explicit notch-count categorization (as done here) is useful for standardization. Finally, the absence of significant morphometric differences between dissection and autopsy specimens in the present analysis ($p > 0.05$ for weight and key dimensions) supports that, when exclusion criteria remove distorted/pathologic livers, specimen source may not materially bias baseline liver morphometry in tertiary-care cadaveric material.[15]

CONCLUSION

The present cadaveric study on 54 human livers demonstrated that a wedge-shaped configuration with a smooth surface and sharp inferior border was the most common gross morphology. Accessory fissures were the most frequent anatomical variation and showed statistical significance, while other lobar variations such as accessory lobes, Riedel's lobe, and prominence of caudate and quadrate lobes were less common. Inferior border notching exhibited significant variability, highlighting the wide spectrum of normal hepatic external anatomy. Morphometric parameters were within expected ranges and did not differ significantly between dissection and autopsy specimens. Overall, awareness of these variations is essential for accurate radiological interpretation and safer hepatobiliary surgical practice.

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