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Anatomical Insights into the Caudate Lobe: Morphological Diversity and Clinical Relevance from a Cadaveric Perspective

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ABSTRACT

Background: The liver, the largest gland of the human body, exhibits significant morphological diversity, especially in its caudate lobe (CL). Due to its independent vascularization and biliary drainage, the CL functions as a distinct anatomical unit, often termed the "third liver." Variations in its morphology and dimensions are clinically significant in hepatic surgery, radiology, and transplantation.

Materials and Methods: This cross-sectional descriptive study was conducted on 48 formalin-preserved adult human liver specimens obtained from the Department of Anatomy, University College of Medical Sciences, Delhi. Each liver was examined for caudate lobe morphology, including shape, fissures, and notches. Morphometric parameters—transverse and vertical diameters of both caudate and right lobes—were measured using a digital vernier calliper, and the caudate-to-right lobe ratio (Harbin's Index) was calculated.

Results: The caudate lobe was present in all specimens, with pyriform shape being the most common (67%), followed by rectangular (25%) and irregular (8%). Notches were observed in 38% and vertical fissures in 25% of specimens. The mean transverse and vertical dimensions of the caudate lobe were 30.2 ± 4.8 mm and 57.5 ± 5.3 mm, respectively, with a mean caudate-to-right lobe ratio of 0.14.

Conclusion: The observed morphological diversity and morphometric parameters of the caudate lobe provide vital reference data for surgical and radiological applications. Understanding these variations enhances accuracy in hepatic imaging and surgical interventions, aiding in the diagnosis of caudate lobe hypertrophy and cirrhotic changes..

Keywords: *Caudate lobe, Morphometry, Hepatic anatomy, Harbin's Index, Liver morphology*

1. INTRODUCTION

The liver, the largest gland of the human body, exhibits remarkable morphological diversity, both in its external features and internal architecture. Among its lobes, the caudate lobe (CL), located on the posterior surface of the liver between the inferior vena cava and ligamentum venosum, demonstrates considerable variability in size, shape, and demarcation. These variations are clinically significant because the CL has independent vascularization and biliary drainage, often functioning as a "third liver" in hepatic surgery and radiology (1,2).

Anatomical variations in the caudate lobe are crucial for segmental liver resections, living donor liver transplantation, and radiological interpretation of hepatic lesions (3,4). The hypertrophy of the CL is a known compensatory response in cases of liver cirrhosis or portal hypertension, serving as an important diagnostic marker in imaging studies (5,6). Despite its clinical importance, detailed morphometric data and morphological characterization of the CL remain limited, particularly in different populations.

Cadaveric studies provide reliable and direct means to document such variations, offering essential reference data for surgeons, radiologists, and anatomists. Understanding these variations contributes to improved surgical planning, minimizes intraoperative complications, and aids in accurate interpretation of radiological findings (7,8).

Hence, the present study aims to document the morphological variations and morphometric parameters of the caudate lobe of the liver in adult human cadavers and to discuss their clinical significance in anatomical, surgical, and diagnostic contexts

2. MATERIALS AND METHODS

This cross-sectional descriptive study was conducted on 48 formalin-preserved adult human liver specimens available in the Dissection Hall and Museum of the Department of Anatomy, University college of Medical Sciences (UCMS), Shadara, Delhi, over a period of six months (January–June 2010). The study aimed to analyse the morphological and morphometric variations of the caudate lobe of the liver in relation to the right lobe.

Inclusion and Exclusion Criteria

All liver specimens exhibiting normal anatomical features without evidence of pathology were included. Damaged, distorted, or pathological specimens showing cirrhosis, tumours, gross hepatomegaly, or post-surgical alterations were excluded from the study. This ensured that only structurally intact and morphologically representative livers were used for assessment.

Morphological Study

Each specimen was carefully examined for the shape of the caudate lobe, the presence or absence of fissures or notches, and the development of papillary and caudate processes. Based on established morphological descriptions, specimens were classified into three categories according to the shape of the caudate lobe—rectangular, Pyriform, and irregular—as described by Macchi et al. (1997) and Kumar et al. (2013) (9, 10).

Rectangular: The caudate lobe appeared nearly equal in transverse width both superiorly and inferiorly (Figure-1A).

Pyriform: The caudate lobe was wider at either the superior or inferior extent and narrower at the opposite end (Figure-1B).

Irregular: The lobe exhibited non-uniform margins and did not conform to the rectangular or Pyriform types (Figure-1C).

Figure-1: Morphological variations in the shape of the caudate lobe of the liver (*). (A) Rectangular type, (B) Pyriform type, and (C) Irregular type.

Morphometric Measurements

Morphometric assessment was performed using a vernier calliper with a precision of 0.01 mm. The following parameters were measured for each specimen:

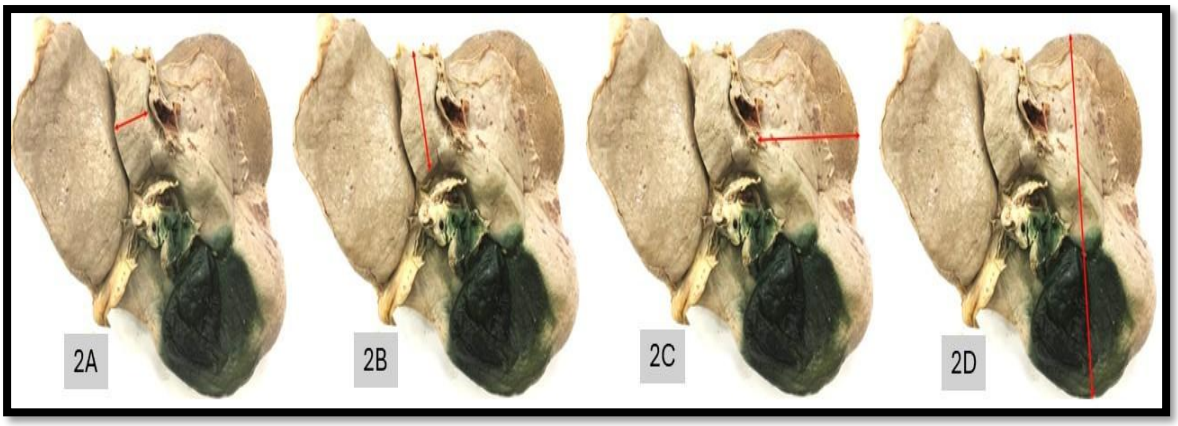
Maximum transverse diameter of the caudate lobe (CT): Measured from the most medial margin of the caudate lobe to the right lateral wall of the portal vein (Figure-2A).

Maximum Vertical diameter of the caudate lobe (CT): maximum vertical height from the inferior border of the caudate lobe just above the porta hepatis. (Figure-2B).

Maximum transverse diameter of the right lobe (RL): Measured from the right lateral wall of the portal vein to the most lateral margin of the right lobe (Figure-2C).

Maximum vertical diameter of the right lobe (RL): Vertical length was determined by taking mid-point of the transverse diameter as the reference (Figure-2D).

Figure-2: Morphometric measurements of the liver lobes. (A) Transverse diameter of the caudate lobe, (B) Vertical diameter of the caudate lobe, (C) Transverse diameter of the right lobe, and (D) Vertical diameter of the right lobe.



To ensure accuracy and reproducibility, all measurements were taken three times independently, and the mean values were recorded in a predesigned proforma. The Harbin's Index (CT/RL ratio) was then calculated by dividing the maximum transverse diameter of the caudate lobe by that of the right lobe. This ratio is an important morphometric indicator often used in radiological and anatomical assessments to evaluate caudate lobe hypertrophy (5).

Data Management and Statistical Analysis

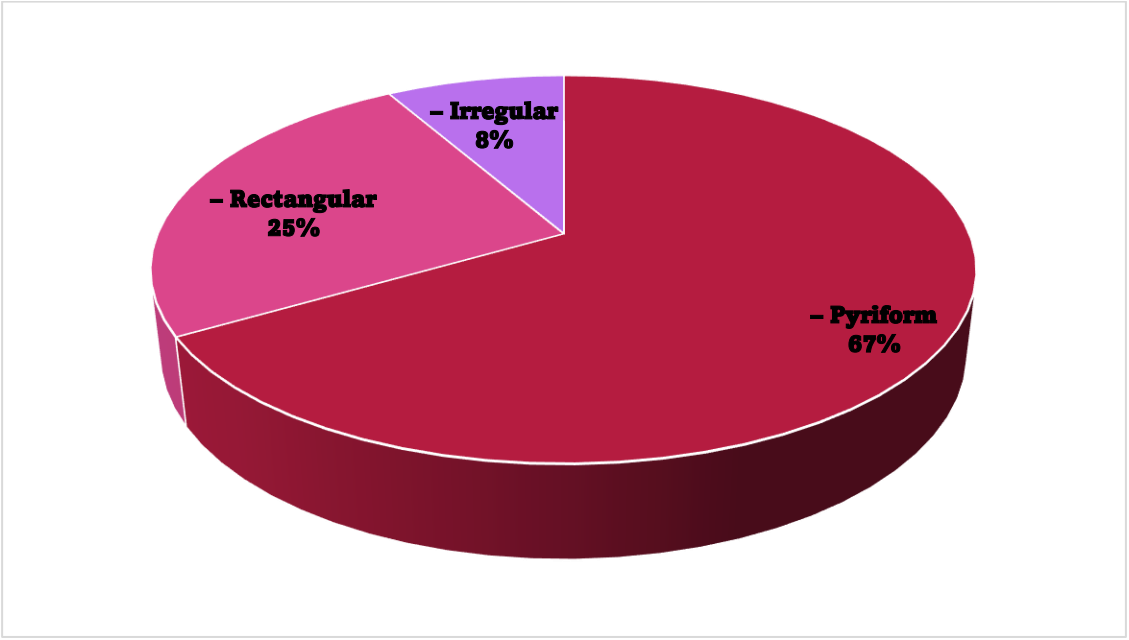
All recorded data were compiled in Microsoft Excel 2007 for statistical analysis. The mean, standard deviation (SD), and percentage frequencies of morphological variations were computed. The mean transverse diameters and Harbin's Index were compared with findings from previous morphometric studies of the caudate lobe. Descriptive statistics were used to summarize the data, as the study aimed primarily at documenting anatomical variations rather than inferential comparison.

3. RESULTS

Morphological Variations of the Caudate Lobe

The morphological assessment of 48 cadaveric liver specimens revealed a consistent presence of the caudate lobe in all samples (100%). However, its shape exhibited notable variation. Among the specimens, 32 (67%) displayed a pyriform configuration, making it the most prevalent form, followed by 12 (25%) with a rectangular shape and 4 (8%) showing an irregular outline (Graph- 1).

Graph-1: Morphological variations of the caudate lobe in 48 liver specimens, depicted as a pie chart.



A notch was observed in 18 specimens, accounting for 38% of cases, indicating that this feature is present in slightly more

than one-third of livers. A vertical fissure was identified in 12 specimens, representing 25% of the sample, suggesting it is a less common anatomical variant (Table 1). These variations are important for surgeons and radiologists, as recognition of such features can influence hepatic surgical approaches, resection planning, and interpretation of imaging studies.

Table 1. Frequency of morphological variations of the caudate lobe in 48 adult human liver specimens

Morphological Variation	Number of Specimens (n)	Percentage (%)
Presence of Notch	18	38
Presence of Vertical Fissure	12	25

These anatomical variations highlight the morphological diversity of the caudate lobe, which may have clinical significance in hepatic surgeries, liver transplantation, and radiological interpretation. Awareness of such variations is important for preoperative planning and accurate assessment of liver morphology.

Morphometric Analysis of the Caudate and Right Lobes

In Table 2, the data are presented as range and mean ± SD. The caudate lobe demonstrates significantly smaller transverse and vertical dimensions and area compared with the right lobe. The caudate-to-right lobe ratio indicates the relative contribution of the caudate lobe to overall liver size, which is clinically relevant for hepatic surgery, transplantation, and radiological assessment. The mean transverse and vertical dimensions of the caudate lobe were 30.2 ± 4.8 mm and 57.5 ± 5.3 mm, whereas the right lobe measured 91.0 ± 12.5 mm (transverse) and 127.5 ± 11.6 mm (vertical). Similarly, the mean area of the caudate lobe (1730 ± 325 mm²) was significantly smaller than that of the right lobe (11,620 ± 2,120 mm²).

The caudate-to-right lobe ratio (0.14 ± 0.03) underscores the relative contribution of the caudate lobe to overall liver size (Table 2). These morphometric variations are important considerations for hepatic surgeries, liver transplantation, and radiological assessment, as they may influence preoperative planning and accurate interpretation of imaging studies.

Table 2. Comparative morphometric data of the caudate and right hepatic lobes measured in 48 liver specimens

Parameter	Caudate Lobe (mm or mm²)	Right Lobe (mm or mm²)
Transverse diameter	20.0 – 42.5; 30.2 ± 4.8	62.0 – 110.0; 91.0 ± 12.5
Vertical length	50.0 – 69.5; 57.5 ± 5.3	110.0 – 148.5; 127.5 ± 11.6
Area (mm²)	1010 – 2390; 1730 ± 325	7400 – 11,500; 11,620 ± 2,120
Caudate-to-right lobe ratio	0.075 – 0.245; 0.14 ± 0.03	–

4. DISCUSSION

In the present study, the morphological and morphometric variations of the caudate lobe were analysed in 48 formalin-fixed adult human livers. The caudate lobe was identified in all specimens; however, its shape, surface features, and dimensions exhibited considerable variability. The mean transverse diameter of the caudate lobe was 30.2 ± 4.8 mm (range: 20.0–42.5 mm), while the corresponding measurement of the right lobe was 91.0 ± 12.5 mm (range: 62.0–110.0 mm). Similarly, the mean vertical length of the caudate lobe (57.5 ± 5.3 mm) was significantly shorter than that of the right lobe (127.5 ± 11.6 mm). The mean surface area of the caudate lobe (1730 ± 325 mm²) was markedly smaller than that of the right lobe (11,620 ± 2,120 mm²). The caudate-to-right lobe (CT/RL) ratio ranged from 0.075 to 0.245, with a mean value of 0.14 ± 0.03, indicating proportional consistency between the two lobes.

When compared with prior studies, these findings are consistent with the established anatomical relationship between the caudate and right lobes, though minor regional variations were noted. Harbin et al. (1980) and Awaya et al. (2002) reported comparable CT/RL ratios of approximately 0.12–0.16 in radiological assessments, suggesting that the present data fall within the normal anatomical range (5,11). Such subtle variations may arise from population differences, sample size, or methodological factors influencing morphometric accuracy.

The morphometric data obtained in this study—mean transverse diameter 30.05 ± 4.93 mm, vertical length 57.46 ± 5.26 mm,

and caudate lobe area 1728.62 ± 328.37 mm²—further confirm the proportional integrity of hepatic lobation in this population. The mean CT/RL ratio (0.14) closely aligns with the normative range reported in earlier literature (5,11).

Regarding shape variability, the pyriform configuration (67%) was most frequent, followed by rectangular (25%) and irregular (8%) forms. Additional features such as a notch were present in 38% and a vertical fissure in 25% of specimens. Previous research has documented wide inter-population variation in caudate lobe morphology. Sahni et al. (94.5%) (12), Joshi et al. (58%) (8), and Chavan et al. (48%) (13) identified the rectangular type as predominant, whereas the current study observed a lower prevalence (25–31%), indicating population-specific differences. Conversely, the predominance of the pyriform shape in the present series supports the findings of Nayak et al. (2013) (14). Irregular lobes, though infrequent, may represent developmental or adaptive morphological variations, as previously underreported in anatomical literature.

These findings collectively highlight the morphological diversity and morphometric variability of the caudate lobe, reflecting genetic, developmental, and population-specific influences on hepatic anatomy. Precise characterization of such variations has important implications in radiological interpretation, hepatic surgery, and transplantation planning, where accurate mapping of hepatic segments and vascular structures is critical for optimal outcomes (14). The results also correspond with earlier studies emphasizing the broad spectrum of caudate lobe morphology. Oguz and Gunduz (2023) reported pyriform lobes in 59.7% of CT-based samples, closely matching the present findings (15). Ibrahim (2020) found a predominance of rectangular lobes (46.4%) in Egyptian cadavers (16), whereas Sarala et al. (2015) documented rectangular lobes in 50%, pyriform in 36%, and irregular in 14% among Indian specimens (17). Such inter-population variability likely reflects differences in embryological development, hepatic segmentation, and vascular patterning.

In terms of morphometry, the present mean vertical length (57.75 mm) corresponds closely with the findings of Ibrahim (57.45 ± 4.74 mm) (16), while the mean transverse diameter (30.2 mm) is marginally greater than those reported in earlier cadaveric investigations (17,18). Smith et al. (2018) also reported significant inter-population differences in caudate lobe dimensions between North Indian and Caucasian samples (18). The combined evidence underscores that while the overall proportionality of hepatic lobes remains conserved, regional and ethnic factors can subtly influence caudate lobe morphology, which must be acknowledged in anatomical, radiological, and clinical practice.

Morphometric Interpretation

The morphometric parameters obtained in this study provide valuable baseline reference data for the anatomical assessment of the caudate lobe and its proportional relationship to the right hepatic lobe. The mean caudate-to-right lobe (CT/RL) ratio of 0.14 observed in the present analysis lies well within the normal range reported in previous literature (5,11). In contrast, radiological investigations have indicated that a CT/RL ratio exceeding 0.65 is a reliable indicator of caudate lobe hypertrophy, typically associated with hepatic cirrhosis and chronic parenchymal liver disease (5). Since the present study was performed on normal cadaveric livers, the lower CT/RL ratio observed reflects normal hepatic proportions and the absence of hypertrophic alterations, thereby representing a baseline anatomical standard for this population group.

In addition to morphometric data, several surface morphological features, such as notches and vertical fissures, were identified, although their occurrence was less frequent. The presence of these features may be attributed to variations in developmental vascular patterns, incomplete fusion of lobar tissues, or minor embryological remodelling phenomena. Similar findings were described by Sarala et al. (2015), who reported fissural extensions in approximately 30% of specimens, emphasizing that such features, though variable, represent normal anatomical variants rather than pathological anomalies (17). Recognition of these subtle morphological details is important for radiological interpretation and surgical orientation, particularly in segmental resections and donor hepatectomy planning.

Clinical and Radiological Significance

The clinical relevance of caudate lobe morphology lies primarily in its importance for radiological diagnosis, surgical planning, and segmental liver resections. The caudate lobe (Segment I) has independent vascularization and biliary drainage, making it functionally distinct. Enlargement of this lobe, often seen in cirrhosis, can be evaluated through the caudate-to-right lobe ratio, which serves as a reliable diagnostic index (5).

Radiological studies, including ultrasound, CT, and MRI, have demonstrated that a high caudate-to-right lobe ratio (>0.65) is a specific sign of cirrhosis, with a specificity of up to 100% (5, 11). Thus, normative morphometric data such as those provided in this study are critical for differentiating normal anatomical variations from pathological enlargement.

Furthermore, knowledge of caudate lobe morphology assists hepatobiliary surgeons during segmental resections, transplantation, and laparoscopic procedures. Unrecognized fissures or notches can lead to inadvertent injury to vascular or biliary structures or be misinterpreted as pathological defects on imaging. Awareness of these variants therefore contributes to safe surgical practice and accurate radiological interpretation.

Population-based data, such as those from the current study, are particularly valuable as caudate lobe size and configuration vary among ethnic and geographic groups (18). Such references enhance diagnostic accuracy in regional clinical settings.

5. LIMITATIONS AND FUTURE SCOPE

The present study is limited by its sample size (n = 48) and the use of preserved cadaveric specimens, which may differ slightly from living livers due to tissue shrinkage and fixation effects. Future research should include radiological correlations using CT and MRI scans to validate the morphometric parameters in vivo. Larger, multicentric studies across different populations would help establish standardized normative data and refine diagnostic cut-off values for liver pathologies.

6. CONCLUSION

The caudate lobe demonstrates significant variability in shape and morphometry. The predominance of the pyriform shape and a mean caudate-to-right lobe ratio of 0.14 represent normal characteristics of the studied population. Understanding these variations is crucial for radiologists and surgeons, as deviations from established morphometric values can serve as early indicators of pathological conditions such as hepatic cirrhosis. The morphometric data presented herein provide a reliable baseline reference for clinical, radiological, and anatomical applications.

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8. CONFLICTS OF INTEREST

The author declares no conflicts of interest. This work did not receive any external funding or grants.

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