

MORPHOLOGICAL VARIATIONS OF THE CADAVERIC LIVER WITH ITS CLINICAL AND SURGICAL SIGNIFICANCE

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ABSTRACT

Background: Knowledge of morphological variations in human liver is considered valuable in improving the precise accuracy of surgical and diagnostic imaging as well as in better understanding of the pathology associated with hepatic diseases. **Aim:** The present study aims to determine the gross variations in the anatomy of liver and to discuss their clinical and surgical implications. **Materials and Methods:** This was a descriptive, cross-sectional, observational study, carried out on 46 formalin-fixed specimens of human liver obtained during the routine cadaveric dissection performed for undergraduate and postgraduate teaching from 2015 to 2026 in the Department of Anatomy, Baba Raghav Das Medical College, Gorakhpur. Each specimen was examined macroscopically for variations of the surfaces, borders, the fissures, lobes, and the gall bladder fossa. The variations were recorded, photograph were taken, and classification was done according to Netter's classification. **Results:** Accessory fissures were the commonest variant present in 24 livers (52%) and in 6 livers (13%) showed a complete accessory fissure that demarcated an accessory lobe. The fissure for the ligamentum teres normally extends from porta hepatis to inferior border, but in 25 livers (54%) it was extended upto the anterior surface. Diaphragmatic grooves and Rouvière's sulcus were each observed in 9 livers (19.5%), and pons hepatis was present in 9 livers (19.5%). Riedel's lobe, hypoplastic left lobe, elongated left lobe, papillary and caudate process variants, and gall bladder fossa anomalies were also documented. Netter type I was the predominant configuration in 9 livers (19.5%). **Conclusion:** A wide spectrum of morphological variations in cadaveric human liver was observed in the sample studied. Awareness of these variants helps radiologists avoid misinterpretation and misdiagnosis and assists surgeons in planning safe hepatobiliary surgeries, hepatic lobectomy and laparoscopic procedures.

INTRODUCTION

In the standard anatomical description, liver is a largest gland in human body. It is the largest solid viscera contributing roughly one-fiftieth of the total adult human body weight. It is wedge-shaped organ present in the right hypochondrium, the epigastrium and a variable part of the left hypochondrium. The attachment of falciform ligament on its smooth, dome-like diaphragmatic surface, divides it into right (RL) and left (LL) anatomical lobe. The RL being larger than the LL. On the visceral surface there is H-shaped arrangement of fossae and fissures, that

demarcates the caudate (CL) and quadrate lobes (QL) from RL and LL lobe.^[1] This classical morphological subdivision, however, bears no constant relationship to the internal functional architecture defined by the distribution of portal triads and hepatic veins. Claude Couinaud reconciled the two by partitioning the liver into eight segments that were functionally independent. Each segment supplied by its own portal pedicle and drained at its periphery by the hepatic veins, a scheme that remains the universal language of hepatic resection and transplantation.^[2] Against this background of a fixed textbook description, both cadaveric dissection and cross-

sectional imaging have repeatedly demonstrated that the external morphology of the liver is in fact highly variable. The variations principally involve the configuration of the fissures, the number of lobes, the depth of the impressions made by neighbouring viscera, and the presence of bridges of hepatic tissue across the normal fossae. Accessory fissures (AF) and grooves, which may lie on either the diaphragmatic or the visceral surface, frequently correspond to underlying vascular structures or to indentations produced by the diaphragm; they can alter the apparent lobar pattern and are a recognised source of error on imaging, where they may be mistaken for lacerations, infarcts or abscesses.^[3] In addition to the four classical lobes, accessory lobes (AL) such as Riedel's lobe and small pedunculated lobes may be encountered, while hypoplasia, elongation, or partial fusion of the lobes further widen the morphological spectrum.^[4]

Several of these surface features carry direct clinical and surgical importance. Rouvière's sulcus is a cleft on the visceral surface of RL lateral to porta hepatis. It is a reliable extrabiliary landmark for safely initiating dissection during laparoscopic cholecystectomy because it marks the plane above which the cystic structures can be divided without endangering the common bile duct.^[5] The pons hepatis is a bridge of hepatic parenchymal tissue crossing the ligamentum teres fissure, and it may obscure the access to umbilical portion of Left portal vein.^[4] On imaging, a prominent papillary process of caudate lobe can simulate a pancreatic mass or an enlarged lymph node. A Riedel's lobe descending below the costal margin is a classic cause of a spurious palpable right hypochondrial mass.^[6]

A detailed knowledge of the variations in the morphology of liver is therefore necessary for the anatomist and the radiologist who must distinguish normal variants from disease, and for the surgeon who must plan segmental resection, donor hepatectomy and minimally invasive biliary surgery. The present study analyses and classifies the variations of the surface morphology of the liver in human cadavers with particular emphasis on fissures, lobes, the gall bladder fossa and other surface features, to discuss and support the clinical and surgical significance of the findings.

MATERIALS AND METHODS

This was a descriptive, cross-sectional, observational study, carried out in the Anatomy Department of Baba Raghav Das Medical College, Gorakhpur, Uttar Pradesh. A total of 46 formalin-fixed liver specimens were studied. The specimens were taken from human cadavers used for the routine dissection for the teaching purpose of undergraduate and postgraduate medical students over a period of 2015 to 2026. All the cadavers were of adult individuals of both sexes. The exact age of every cadaver could not be retrieved uniformly for the archived specimens, which is

acknowledged as a constraint of a retrospective dissection-based sample.

Livers that were grossly damaged or distorted during removal, autolysed, or that showed gross pathology such as cirrhosis, space-occupying lesions or surgical alteration that would preclude reliable assessment of the surface morphology were excluded, so that only intact specimens suitable for morphological study were analysed. Each liver was removed in continuity, fixed in 10% formalin, washed thoroughly under running water, and the surrounding peritoneal folds, connective tissue and vascular pedicles were cleaned to expose the surfaces, borders and fissures clearly. Every specimen was then examined systematically by direct macroscopic inspection. The diaphragmatic surface was studied for its general shape, the falciform ligament's attachment, and for the presence of diaphragmatic grooves. The visceral surface was inspected for the arrangement of the H-shaped fissures, the ligamentum teres fissure and its extension over the anterior border, the ligamentum venosum fissure, porta hepatis, and Rouvière's sulcus. The right, left, quadrate and caudate lobes were each assessed individually. The variation in shape of lobes, the presence and number of accessory fissures, accessory lobes, Riedel's lobe and elongated (lingular processes) processes were looked for. The caudate lobe was further evaluated for the morphology of its papillary and caudate processes and for any bilobation, and the quadrate lobe for bilobation and for presence of pons hepatis. The gall bladder (GB) fossa for variations in its depth and in the size of the GB.

All variant's number and percentage were noted. In addition, classification was done according to the categories of Netter's classification of liver morphology variations.^[7] All specimens were photographed for documentation. The observations were tabulated and the results were expressed as simple frequencies and percentages.

RESULTS

Forty-six adult cadaveric livers were examined. A wide range of variations in the surface morphology was identified, involving the fissures, the gall bladder fossa and all four lobes. The principal findings are summarised below and in the accompanying tables.

Fissures and grooves

Most frequent finding was the Accessory fissures and was found in 24 specimen (52%). In 6 livers (13%) the accessory fissure was complete and gave rise to a clearly demarcated accessory lobe. The ligamentum teres fissure extended over liver's anterior surface in 25 specimens (54%) (figure 1), whereas in 9 specimens (19.5%) showed pons hepatis (figure 2). Diaphragmatic grooves were observed on the antero-superior surface in 9 livers (19.5%); the number of grooves per liver varied from one to four. Rouvière's sulcus was identified on the Rt lobe's visceral surface in 9 livers (19.5%). [Figure 2]



Figure 1: Arrow showing fissure for ligamentum teres on the anterior surface of the liver

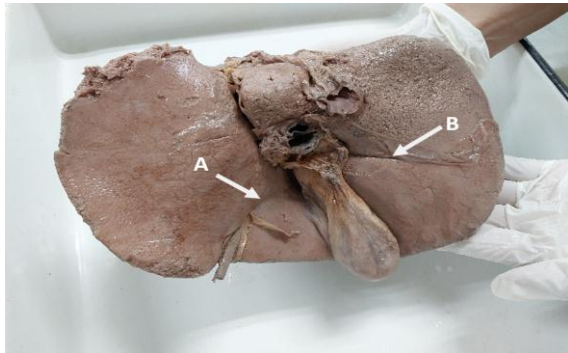


Figure 2: Inferior surface of the liver showing pons hepatis (A) and Rouvière's sulcus (B)

Right lobe

The RL showed accessory fissures in 13 livers. The number of fissures on right lobe ranged from one to three. One liver demonstrated a Riedel's lobe. [figure 3]



Figure 3: liver showing Riedel's lobe (marked as *)



Figure 4: Arrow showing elongated left lobe

Left lobe

In the LL, accessory fissures were noted in 5 livers. The LL was elongated in 9 livers (figure 4) and very small in 5 livers.

Gall bladder and its fossa

Variations related to the gall bladder were present in several specimens. A small gall bladder was observed in 3 livers and an elongated gall bladder in 5 livers, while one liver showed an unusually deep GB fossa (figure 6).

Caudate lobe

The caudate lobe showed accessory fissure in 10 livers. A prominent papillary (PP) process was found in 8 livers (17%) (figure 5); the PP was abnormally upturned in 2 livers, underdeveloped in 3 livers and absent in 1 liver. The caudate process was underdeveloped in 3 livers (figure 5) and prominent in 5 livers (10.8%). The caudate lobe was bilobed in 2 livers (4%). The various shapes of CL are shown in table 1.

Quadrato lobe

In 14 livers, the quadrato lobe (QL) presented with accessory fissures, and one of these livers showed a quadrato lobe bearing two accessory fissures. Bilobed QL was in 3 livers (6.5%) (figure 6). Pons hepatis was observed in 9 livers (19.5%) (figure 2 and 5). The various shapes of QL are shown in table 1.

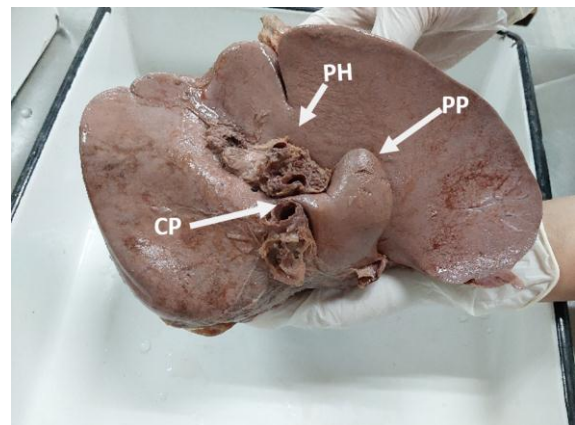


Figure 5: Showing prominent papillary process (PP), under developed caudate process (CP) and pons hepatis (PH)



Figure 6: bilobed quadrato lobe (A&B) and very deep gall bladder (GB) fossa

Table 1: Shape of the caudate lobe and quadrate lobe (n = 46 livers)

Caudate lobe			Quadrate lobe		
Shape	Number	Percentage	Shape	Number	Percentage
Rectangular	35	76%	Quadrangular	32	69.5%
Elongated	5	10%	Triangular	10	21.7%
Piriform	4	8.6%	Elongated	4	8.6%
Irregular	2	4%			

Netter classification⁷

When the specimens were grouped according to Netter's classification of the morphological variations

of the liver, the distribution shown in Table 5 was obtained. (Figure :7)

Table 2: Distribution of livers according to Netter's classification (n = 46 livers)

Type	Morphological feature	Number
Type I	Very small left lobe and deep costal impression	9
Type II	Complete atrophy of the left lobe	0
Type III	Transverse, saddle-like liver with a relatively large left lobe	2
Type IV	Tongue-like process of the right lobe	2
Type V	Very deep renal impression and corset constrictions	1
Type VI	Diaphragmatic grooves	7

**Figure 7(a): Type I****Figure 7(c): Type IV****Figure 7(b): Type III****Figure 7(d): Type V**



Figure 7(e): Type VI

DISCUSSION

The present human cadaveric study confirms that the surface morphology of the liver is highly variable, and that variations of the fissures and lobes are common rather than exceptional. Accessory fissures were the single most frequent variant, occurring in just over half of the specimens (52%).

Table 3

	Chauh an HM et al (2024) ^{4]}	Kumar Sambh av et al (2023) ^{8]}	Jasbir Kaur et al (2021) ^{9]}	Haoba m Rajajee Singh (2019) ^{10]}	Justin Chin et al (2018) ^{11]}	Heena J Chaud hari et al (2017) ^{13]}	Namrata Reddy (2017) ^{12]}	Mamath a Y (2014) ^{113]}	Sachin Patil et al (2014) ^{114]}	Present study (%)
AF	51.92	-	56.25	81.4	27	35	-	-	-	52
AL	-	-	12.5	-	24	36.25	-	-	10	13
AF in RL	17.30	72.5	-	51.43	-	-	-	10	-	28.26
AF in LL	-	30	-	11.43	-	-	-		-	10.86
AF in QL	11.53	17.5	18.75	32.86	-	-	56.25	10	-	30.4
AF in CL	25	57.5	37.5	27.1	-	-	43.75	12	-	21.7
Riedel's lobe	9.61	-	-	-	18.18	1.25	-	-	-	2.1
Elongated LL	5.76	-	-	12.86	-	1.25	-	4	-	19.5
Incomplete ligamentu m teres (pons hepatis)	9.61	5	18.75	22.86	-	-	-	-	10	19.5
Diaphragm atic groove	25	-	-	11.43	-	-	-	-	-	19.5
Rouvière's sulcus	-	Present	-	-	-	-	-	-	-	19.5

The relatively high prevalence in the present series therefore agrees with the consensus that accessory fissures are a normal anatomical variant rather than a rarity.

The clinical relevance of accessory fissures lies chiefly in cross-sectional imaging. Because an accessory fissure interrupts the smooth contour of the parenchyma, it can be mistaken on ultrasonography and computed tomography for a laceration in a trauma setting, for a perihepatic collection, or for the boundary between two segments, which may lead to inaccurate localisation of a focal lesion.^[15] The eight-segment scheme of Couinaud relies on the avascular planes of the hepatic veins and the central portal pedicles rather than on visible surface clefts,^[2] the recognised pitfalls of applying this scheme on transaxial images are compounded when an accessory fissure mimics a true intersegmental plane.^[16] Familiarity with the prevalence and appearance of accessory fissures thus helps the radiologist avoid both false-positive diagnoses and errors in segmental localisation before resection.

Six livers (13%) in the present series showed a complete accessory fissure demarcating an accessory lobe. Accessory lobes are generally regarded as developmental errors occurring during the third week of gestation, when faulty development and segmentation of the endodermal hepatic bud isolates a portion of parenchyma.^[17] Most accessory lobes are small and asymptomatic and are discovered incidentally at laparoscopy, laparotomy or autopsy; however, pedunculated accessory lobes are prone to torsion and can present acutely with pain, and accessory lobes have occasionally been reported to harbour focal nodular hyperplasia, adenoma or even hepatocellular carcinoma.^[18]

Riedel's lobe is a tongue shaped inferior projection of the Rt lobe to the right of the GB that corresponds to a hypertrophy of segments V and VI.^[6] Clinically, a Riedel's lobe is the classic cause of a spurious, mobile, palpable mass in the right hypochondrium that can be misinterpreted as hepatomegaly, a renal mass or a gall bladder lump; on imaging it must be recognised as normal parenchyma in continuity with

the right lobe so that needless investigation or intervention is avoided.^[19]

Variations of the left lobe were prominent in this series, with an elongated left lobe in 9 livers and a hypoplastic left lobe in 5. Elongated LL is also reported in study by Vinnakota S and Nayak BS in 1.72% and 1.81% cases respectively.^[15,20] The lingular process of the left lobe can simulate a gastric or splenic mass.^[8]

Rouvière's sulcus was identified in 9 livers (19.5%) in the present study. Although this is lower than the pooled prevalence of approximately 83% derived from a large meta-analysis combining cadaveric and laparoscopic data,^[21] the apparent under-representation in formalin-fixed cadaveric specimens is well recognised, because the sulcus is most clearly displayed under the carbon-dioxide insufflation and magnification of laparoscopy and may be collapsed or obscured in the fixed, deflated cadaver.^[5]

Pons hepatis was observed in 9 livers (19.5%), a figure that corresponds closely to some cadaveric series and to the prevalence described in recent Indian studies as shown in the table 3. Studies by

Nayak BS and Mamatha Y also reported the extension of fissure for ligamentum teres on the anterior surface of liver in 1.81% and 26% cases respectively where as in present study it found in 54% livers.^[13,20]

Accessory fissures on the caudate lobe (10 livers), a prominent papillary process (8 livers, 17%), and variants of the caudate process were all common, and the caudate lobe was bilobed in 2 livers. The papillary process deserves particular emphasis: when prominent or upturned it projects medially towards the lesser omentum and can closely mimic an enlarged portacaval or peripancreatic lymph node, a pancreatic head mass, or even a paracaval tumour on axial imaging, leading to unnecessary anxiety and investigation.^[22] Recognition of the papillary process as a continuation of normal caudate tissue, traced on contiguous sections, prevents this error. The predominantly rectangular shape of the caudate lobe (76%) in the present series is consistent with the rectangular shape reported as the commonest by Sambhav and colleagues.^[8]

Table 4

	Namrata Reddy et al (2017) ^[12]	Heena J Chaudhari et al (2017) ^[3]	Haobam Rajajee Singh (2019) ^[10]	Ibrahim Hassan Ibrahim (2020) ^[23]	Tapati Roy et al (2022) ^[24]	Kumar Sambhav et al (2023) ^[8]	Present study (%)
Bilobed CL	-	-	2.85	-	-	7.5	4
Prominent PP	8.75	1.25	4.29	42.86%	-	32	17
Prominent CP	-	-	2.86	-	-	15	10.8
Shape of CL							
Rectangular	78.75	-	-	73.21	37.25	40	76
Triangular	-	-	-	21.43	9.8	-	-
Elongated	-	-	-	-	-	7.5	10
Piriform	-	-	-	-	33.33	12.5	8.6
Irregular	-	-	-	5.36	-	7.5	4
Bilobed QL	-	-	7.14	-	-	5	6.5
Shape of QL							
Quadrangular	85	-	-	-	-	25	69.5
Triangular	-	-	-	-	-	17.5	21.7
Elongated	-	-	-	-	-	5	8.5
Rectangular	10	-	-	-	-	-	-

The quadrate lobe was most often quadrangular (69.5%), with triangular and elongated forms in the remainder, and bore accessory fissures in 14 livers. Variation in the quadrate lobe, which corresponds to segment IVb, is relevant when planning central or left medial sectionectomy and when interpreting the relationship of the gall bladder fossa to the parenchyma.^[25]

Gall bladder fossa variations were also documented, with small and elongated gall bladders also previously reported in 18.18% of the cases by Nayak BS^[20], the gall bladder was short and its fundus did

not project beyond the inferior border of the liver. One unusually deep fossa previously reported by K Sambhav,^[8] a deep or aberrant fossa, increases the technical difficulty of cholecystectomy and the risk of bleeding from the gall bladder bed.

Diaphragmatic grooves were present in 9 livers (19.5%). They are generally attributed to the pressure of hypertrophied diaphragmatic muscle slips or to costal indentation, and although they are clinically silent, they can be misread on imaging as subcapsular collections or as the contour irregularity of a pseudocirrhotic liver.^[26]

Table 5

Netter classification ^[7]	Nagato A C (2011) ^[27]	Sachin Patil (2014) ^[14]	Heena J Chaudhari et al (2017) ^[3]	Haobam Rajajee Singh (2019) ^[10]	Kumar Sambhav et al (2023) ^[8]	Chauhan HM et al (2024) ^[4]	Present study
Type I	8.19	2	17.5	1.42	10	3.84	19.5
Type II	1.64	--	--	--	--	0	--

Type III	6.56	10	--	12.86	17.5	1.92	4.3
Type IV	21.31	2	1.25		2.5	9.61	4.3
Type V	9.84	2	1.25		7.5	5.76	2.1
Type VI	6.56	2	7.5		7.5	25	19.5

Several limitations of the study should be acknowledged. It is a descriptive cadaveric study on formalin-fixed specimens, in which fixation and prior dissection may accentuate or obscure certain surface features, particularly soft clefts such as Rouvière's sulcus. The sample, though spanning a decade, was drawn from a single institution, and complete demographic data including age were not available for every archived specimen, precluding analysis of any age-related differences. The variants were assessed qualitatively and by simple morphology rather than by detailed three-dimensional or vascular casting techniques, and the surface findings were not correlated with the internal segmental vascular anatomy. Despite these constraints, the study provides useful regional reference data on the frequency of clinically important hepatic surface variants.

CONCLUSION

This cadaveric study of 46 livers demonstrates a broad spectrum of variations in hepatic surface morphology. Accessory fissures were the commonest finding, present in 52% of specimens, with a complete accessory fissure producing an accessory lobe in 13%. Rouvière's sulcus, diaphragmatic grooves and pons hepatis were each present in about a fifth of the livers, and a wide range of caudate and quadrate lobe variants, an elongated or hypoplastic left lobe, Riedel's lobe and gall bladder fossa anomalies were documented, with Netter type I as the predominant configuration. These variants are clinically and surgically significant: they may be mistaken for pathology on ultrasonography and computed tomography, they influence the localisation of focal lesions within the Couinaud segments, and they bear directly on the safety of laparoscopic cholecystectomy and on the planning of hepatic resection and living-donor transplantation. A sound knowledge of these morphological variations therefore helps radiologists avoid errors of interpretation and misdiagnosis and assists surgeons in selecting the safest and most appropriate operative approach.

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