



ANATOMICAL VARIATIONS OF THE EXTRAHEPATIC BILIARY APPARATUS AND THEIR CLINICAL SIGNIFICANCE

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Abstract

Background: Anatomical variations of the extrahepatic biliary apparatus (EHBA) are clinically important because they can pose diagnostic challenges and lead to iatrogenic injuries during hepatobiliary surgery. Regional morphometric data remain valuable for improving surgical safety and radiological interpretation.

Objectives: To document the gross anatomical variations of the gallbladder and EHBA in adult cadaveric specimens and to assess their clinical relevance.

Materials and Methods: A descriptive cross-sectional cadaveric study was conducted on 100 adult specimens obtained from the Indore region. Gross anatomical parameters of the gallbladder, including length, breadth, wall thickness, and shape, were examined. The EHBA was evaluated for the configuration of the hepatoduodenal ligament, cystic duct–common hepatic duct junction, level of cystic duct termination, accessory ducts, cystic artery variations, and the boundaries of Calot's triangle.

Results: Gallbladder length showed marked variability, with a mean of 8.81 ± 1.47 cm; most specimens measured between 7–10 cm. The transverse breadth was relatively consistent (mean 3.92 ± 0.81 cm). Wall thickness varied regionally, with the neck being thinner than the fundus and body. The pear-shaped gallbladder was predominant (87%), though several morphological variants were identified. An angular cystic duct–CHD junction was most common (87%), and high termination of the cystic duct was observed in 11% of specimens. Accessory ducts and vascular variations were infrequent but notable, and Calot's triangle was well defined in the majority of cases.

Conclusion: The study confirms that anatomical variations of the gallbladder and EHBA are common and clinically significant. Awareness of these variations, supported by careful preoperative imaging and meticulous surgical technique, is essential to minimize operative complications and improve outcomes in hepatobiliary procedures.

Key Words: Extrahepatic biliary apparatus, Gall bladder, bile duct, hepatic duct

Introduction

The extrahepatic biliary apparatus (EHBA) consists of the right and left hepatic ducts, the common hepatic duct (CHD), the gallbladder, the cystic duct, and the common bile duct (CBD) [1,2]. The right and left hepatic ducts drain bile from the corresponding physiological lobes of the liver and emerge at the porta hepatis, where they lie anterior to the branches of the portal vein and hepatic artery [1].

Near the right extremity of the porta hepatis, these ducts unite to form the common hepatic duct, which typically measures approximately 3 cm in length. The CHD is subsequently joined by the cystic duct to form the common bile duct, which conveys bile to the duodenum [2].

The gallbladder is a pear-shaped fibromuscular organ that serves as a bile reservoir and facilitates bile concentration. It is in the gallbladder fossa on the inferior surface of the right lobe of the liver [1,2]. The cystic duct arises from the neck of the gallbladder and joins the common hepatic duct to form the CBD. The cystic artery, most commonly originating from the right hepatic artery, passes through Calot's triangle—an anatomically and surgically important landmark [3]. The classical boundaries of Calot's triangle are formed superiorly by the inferior surface of the liver, medially by the common hepatic duct, and laterally by the cystic duct. Its contents usually include the cystic artery and the cystic (Lund's) lymph node [1,3].

From both anatomical and surgical perspectives, a comprehensive understanding of the normal anatomy and variations of the EHBA is of considerable importance [1,4]. Variations in the course, confluence, and spatial relationships of the biliary ducts and associated vascular structures carry significant clinical implications. Congenital anomalies of the EHBA are relatively common and, although developmental in origin, frequently present during adult life, where they may mimic acquired hepatobiliary diseases [4,5]. Many of these anomalies are associated with biliary calculi and ductal dilatation [5].

Anatomical variations involving the cystic duct, hepatic ducts, and the relationship between the cystic artery and the right hepatic artery are not uncommon [3]. Such variations represent a major predisposing factor for iatrogenic injury during cholecystectomy and other hepatobiliary surgical procedures [6]. Failure to recognize atypical anatomical relationships or the presence of accessory ducts can significantly increase postoperative morbidity and mortality. Accessory hepatic ducts, which are normal segmental ducts that drain directly into the extrahepatic biliary system rather than converging within the liver, are particularly vulnerable to injury during gallbladder surgery [7].

Biliary duct injuries may present clinically as postoperative bile leakage, bilioma formation, biliary peritonitis, or external biliary fistula, and may progress to sepsis or septic shock if not promptly recognized and treated [6,8]. Therefore, detailed anatomical studies of the EHBA and its variations provide essential guidance for surgeons, facilitate safer operative techniques with improved outcomes, and play a vital role in medical education and surgical training [7,8].

Materials & Methods

This descriptive, cross-sectional observational study was conducted in the Department of Anatomy at , Index Medical College, Hospital & Research Centre, Indore, M.P. The study focused on adult cadaveric specimens from the Indore region, aiming to generate region-specific morphometric data relevant to surgical landmarks of the hepatobiliary system.

Parameters Studied

A detailed examination of the gross anatomical features of the gallbladder and the extrahepatic biliary apparatus (EHBA) was undertaken. The parameters assessed for the gallbladder included its length, breadth, thickness and overall shape. Evaluation of the EHBA focused on the configuration of the hepatoduodenal ligament; the mode of union between the cystic duct and the common hepatic duct; the level of termination of the cystic duct; the presence of accessory biliary ducts; the origin and course of the cystic artery and right hepatic artery; and the anatomical boundaries of Calot's triangle.

Inclusion Criteria

The study included cadaveric specimens of both sexes in which the liver and gallbladder were macroscopically normal and undamaged. Only specimens with an intact gallbladder and well-preserved components of the extrahepatic biliary apparatus were selected for analysis.

Exclusion Criteria

Specimens were excluded from the study if any of the following conditions were present:

1. Evidence of previous hepatobiliary surgical intervention
2. History or signs of cholecystectomy
3. Traumatic injury to the liver involving the extrahepatic biliary apparatus
4. Gross morphological features suggestive of liver cirrhosis

Results

The length of the gallbladder among the examined cadaveric specimens showed considerable variation, ranging from less than 7 cm to 12 cm. The majority of specimens (68%) measured 7-10 cm, while 23% measured 10-12 cm; only 9% were shorter than 7 cm. The mean gallbladder length was 8.81 ± 1.47 cm, indicating moderate inter-individual variability with potential surgical relevance. (Table 1)

The transverse breadth of the gallbladder predominantly ranged from 3.0 to 4.5 cm in 76% of specimens. Nineteen percent exceeded 4.5 cm, whereas only 5% measured less than 3.0 cm. The mean breadth was 3.92 ± 0.81 cm, suggesting a relatively consistent dimensional pattern with implications for radiological assessment and hepatobiliary surgery. (Graph 1)

Gallbladder wall thickness varied by region. The fundus measured 1.35–1.68 mm and the body 1.29–1.75 mm, while the neck was comparatively thinner (0.45–0.96 mm). These regional differences are clinically relevant for imaging interpretation and surgical procedures, particularly due to the increased vulnerability of the neck region during dissection. (Table 2)

Analysis of 100 cadaveric specimens demonstrated variability in gallbladder morphology. The pear-shaped configuration was predominant, observed in 87% of cases. Less frequent forms included cylindrical (7%), retort-shaped (3%), hourglass-shaped (2%), and irregular (1%) gallbladders. Although the pear-shaped gallbladder represents the typical morphology, recognition of these variants is clinically important, as they may affect radiological interpretation and increase technical difficulty during procedures such as laparoscopic cholecystectomy. (Table 3)

Table 1: Length of Gall Bladder			
Length(cm)	Number of specimens	Percentage	Mean $\pm$ SD
<7	9	9%	8.81 ± 1.47 cm
7-10	68	68%	
10-12	23	23%	

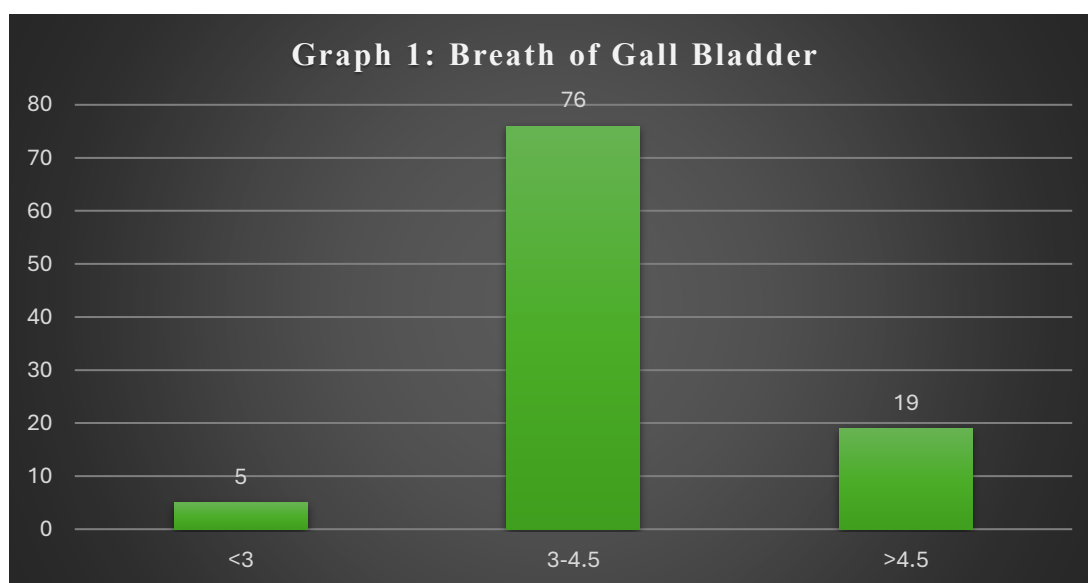


Table 2: Thickness of Gallbladder (mm)	
Fundus	1.35-1.68
Body	1.29-1.75
Neck	0.45-0.96

Table 3: Shapes of the gallbladder		
Shape	No. of specimens	Percentage
Pear	87	87%
Cylindrical	7	7%
Retro	3	3%
Irregular	1	1%
Hourglass	2	2%

In this cadaveric study of 100 specimens, the anatomy of the hepatoduodenal ligament and its related structures was systematically evaluated. An angular junction between the cystic duct and the common hepatic duct was observed in 87% of cases, while a parallel union was noted in 13%. The cystic duct terminated at the usual level in 89% of specimens, with high termination seen in 11%; no instances of low termination were identified.

The hepatoduodenal ligament exhibited a normal anatomical arrangement in 96% of specimens, whereas abnormal configurations were present in 4%. Accessory ducts were infrequent, with accessory cystic ducts identified in 2% and accessory right hepatic ducts in 5% of cases. The cystic artery showed a typical pattern in 95% of specimens; variations included double, accessory, or atypical courses in the remaining cases. The boundaries of Calot's triangle were well defined in 97% of specimens, with deviations noted in 3%. (Table 4)

Table 4: Gross anatomical features of the Extrahepatic Biliary Apparatus (EHBA)		
Hepatoduodenal ligament	Number(N=100)	Percentage
Type of union of the Cystic duct with the Common Hepatic Duct (CHD)		
Angular	87	87%
Parallel	13	13%
Level of termination of the cystic duct		
Normal	89	89%
High	11	11%
Low		
Hepatoduodenal ligament		
Normal	96	96%
Abnormal	4	4%
Accessory ducts		
Cystic duct (CD)	2	2%
Right hepatic duct (RHD)	5	5%
Cystic artery		
Normal	95	95%
Double	1	1%
accessory	2	2%
Abnormal course	2	2%
Calot's triangle boundaries		
Normal and well-defined	97	97%
Abnormal	3	3%

Discussion

Gallbladder Length and Breadth

In the present cadaveric study, gallbladder length ranged from <7 cm to 12 cm, with a mean length of 8.81 ± 1.47 cm. This finding is comparable to recent Indian imaging and cadaveric studies. Sureka et al. [4], using MRCP in an Indian population, reported gallbladder lengths predominantly between 7 and 10 cm, emphasizing moderate inter-individual variability similar to the present study [4]. Likewise, Sarin and Choudhury (2002) reported comparable ranges in Indian cadaveric material, although their study noted slightly lower mean values, possibly reflecting population or sample differences [9].

Internationally, recent radiological studies from Europe and North America have also documented gallbladder lengths most commonly between 7 and 11 cm, supporting the view that gallbladder length variability is a global anatomical characteristic rather than population-specific [5].

The transverse breadth in the present study most frequently ranged from 3.0 to 4.5 cm (mean 3.92 ± 0.81 cm). This finding is consistent with recent MRCP- and ultrasonographic-based studies, which have reported that gallbladder breadth is relatively constant compared with length [2,4]. Kapoor et al. (2012) highlighted that awareness of normal breadth variation is crucial in radiological practice to avoid misdiagnosing physiological distension as pathology [8].

Gallbladder Wall Thickness

The present study demonstrated regional variation in gallbladder wall thickness, with the fundus and body being thicker than the neck. Similar findings have been reported in recent imaging studies, where the neck region consistently shows a thinner wall due to its anatomical and functional continuity with the cystic duct [2,10]. **Cooperberg and Gibney**, although published earlier, remain relevant and are frequently cited in recent literature for establishing normal wall thickness parameters that continue to guide modern imaging interpretation [10]. The thinner neck region has also been identified as a surgically vulnerable area in recent laparoscopic studies [6].

Gallbladder Shape Variations

In the present study, the pear-shaped gallbladder was predominant (87%), with other shapes occurring infrequently. Recent Indian cadaveric and imaging studies have reported pear-shaped gallbladders in approximately 80–90% of cases, findings that closely match those of the present study [7,9]. International anatomical studies published in the last decade have similarly documented cylindrical, hourglass, and irregular gallbladders as uncommon but clinically relevant variants [1,5]. These variants have been associated with altered gallbladder orientation and increased technical difficulty during laparoscopic cholecystectomy [6].

Extrahepatic Biliary Apparatus

The angular union of the cystic duct with the common hepatic duct observed in 87% of specimens aligns well with recent MRCP-based studies by Sureka et al., who reported angular or oblique unions as the most common configuration in the Indian population [4]. Parallel unions, although less frequent, have been emphasised in recent surgical literature as a risk factor for bile duct injury if not recognised intraoperatively [6,11].

High termination of the cystic duct was observed in 11% of specimens, which falls within the range reported in recent Indian and international studies (8–20%) [4,5]. The absence of low termination in the present study contrasts with some MRCP-based studies that have reported low insertion in a small percentage of cases, suggesting possible population or sample-size variation [4].

Accessory ducts were infrequent in the present study. Recent cadaveric and imaging studies continue to report accessory right hepatic ducts more commonly than accessory cystic ducts, emphasizing their clinical importance due to the risk of postoperative bile leakage [2,7].

Vascular Variations and Calot's Triangle

The cystic artery showed a normal pattern in 95% of specimens, with variations in 5%. This finding closely corresponds with the large contemporary review by Andall et al., which reported cystic artery variations in 5–20% of cases worldwide [1]. Recent surgical literature continues to stress that unrecognized arterial variations remain a major cause of intraoperative haemorrhage [6,11].

Calot's triangle was well defined in 97% of specimens in the present study. This observation is consistent with recent surgical analyses by Strasberg and Brunt (2010) and subsequent studies, which emphasize that although major distortions are uncommon, even minor anatomical deviations can significantly increase the risk of bile duct injury [6,11].

Conclusion

This cadaveric study confirms that anatomical variations in the gallbladder and the extrahepatic biliary system are common and clinically important. Variability in gallbladder dimensions, wall thickness, and shape was observed, with most specimens measuring 7-10 cm in length, having a relatively uniform width, and predominantly taking a pear-shaped form. The neck of the gallbladder exhibited a thinner wall, indicating a region more susceptible to surgical complications.

While the hepatoduodenal ligament and Calot's triangle were well-defined in most specimens, variations in ductal and vascular anatomy were noted in a significant minority. These findings align with recent literature from India and internationally, highlighting their relevance in surgical practice. Recognizing these variations through a thorough understanding of anatomy, appropriate preoperative imaging, and adherence to established surgical safety principles is crucial for reducing iatrogenic injuries and improving outcomes in hepatobiliary procedures.

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