

A Comprehensive Study on the Anatomy and Variations of the Cystic Duct in Human Cadavers

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ABSTRACT

Background: Anatomical variations of the cystic duct have great surgical importance due to their implications in cholecystectomy and other hepatobiliary procedures. A clear understanding of these variations helps reduce the incidence of intraoperative and postoperative complications.

Aim: The present cadaveric study aimed to examine the anatomy and morphological variations of the cystic duct in relation to the common hepatic duct.

Methods: Thirty en bloc liver and biliary tract specimens were collected from unclaimed cadavers and carefully dissected. Measurements were taken for the length and diameter of the cystic duct at three levels, and the type and level of its union with the common hepatic duct were recorded along with the course of the duct.

Results: The results showed that the angular type of union was the most common, observed in 70% of specimens, while the parallel type appeared in 30%. No specimen exhibited a spiral union. In all specimens, the cystic duct joined the common hepatic duct just caudal to the porta hepatis. The mean length of the cystic duct was 2.45 cm. The diameter progressively tapered from proximal (mean 2.8 mm) to distal end (mean 2.1 mm). An ascending course was observed most frequently (40%), followed by

descending and horizontal orientations (30% each).

Conclusion: The study highlights that although conventional anatomical patterns predominate, considerable variations exist that may influence surgical navigation. Knowledge of these variations is essential to prevent iatrogenic injuries and to improve the safety of biliary surgeries, especially in laparoscopic settings.

Keywords: Cystic duct, Anatomical variation, Common hepatic duct, Cholecystectomy, Biliary tree

INTRODUCTION

The biliary tree is a complex ductal system responsible for the transport of bile from the liver to the duodenum. It is divided into intrahepatic and extrahepatic components. The extrahepatic biliary system comprises the right and left hepatic ducts, the common hepatic duct, cystic duct, gallbladder, and the common bile duct.^[1] Among these structures, the cystic duct and cystic artery are of particular surgical relevance. Their anatomical variations—especially in length, course, and site of union with the common hepatic duct—can significantly influence the outcome of hepatobiliary surgeries.^[2] Misinterpretation of these variations is a leading cause of iatrogenic bile duct injuries during laparoscopic cholecystectomy, a

procedure now considered the gold standard for gallbladder removal.

Historically, interest in the cystic duct and artery intensified with the advent of more refined surgical techniques in the early 20th century. The extensive review study by Kettle et al. (2022) states that the first systematic description of biliary tree variations was by Ernst in 1908.^[3] Morris (1907) in his treatise later classified the union of the cystic duct with the common hepatic duct into angular, parallel, and spiral types, emphasizing the clinical implications of each configuration.^[4] Hamilton (1956) further contributed to the anatomical understanding by correlating these variations with surgical outcomes.^[5]

The introduction of laparoscopic cholecystectomy in the late 20th century revolutionized biliary surgery but also increased the risk of bile duct injuries due to limited tactile feedback and restricted visualization. This shift underscored the need for precise anatomical knowledge of the cystic duct and artery. Studies have shown that anatomical variations in the cystic duct occur in approximately 18–23% of individuals, while variations in the cystic artery are reported in up to 25–30% of cases.

For instance, Gupta et al. (2023) observed that aberrant cystic duct insertions and accessory ducts were associated with increased intraoperative complications, particularly in emergency settings.^[6] Similarly, Sengupta et al. (2024) emphasized that variations in the cystic artery—such as double arteries or atypical origins—could complicate dissection in Calot's triangle, increasing the risk of hemorrhage or bile leakage.^[7]

Given these risks, preoperative imaging and intraoperative cholangiography have been advocated in high-risk cases. However, cadaveric studies remain the gold standard for understanding the full spectrum of anatomical variability.

The present study aims to document and analyze the anatomical variations of the cystic duct in cadaveric specimens from the

North-Eastern region of India. By comparing our findings with classical and contemporary studies, we seek to contribute to the growing body of knowledge that supports safer surgical practice and anatomical education.

Aim and Objectives:

Aim: To study the anatomy and variations of the cystic duct in relation to the common hepatic duct.

Objectives:

1. To measure the length of the cystic duct, common hepatic duct, and common bile duct.
2. To observe the type and level of union between the cystic duct and common hepatic duct.
3. To identify any variations in the course and morphology of the cystic duct.

MATERIALS & METHODS

Thirty en bloc specimens consisting of the liver, hepatic ducts, cystic duct, gallbladder, bile duct, and duodenum were collected from unclaimed human cadavers obtained from the Departments of Anatomy and Forensic Medicine, Gauhati Medical College, Guwahati. Ethical and medicolegal formalities were duly observed.

Each specimen was preserved in 10% formalin. The hepatoduodenal ligament was dissected to expose the extrahepatic biliary apparatus. The cystic duct was traced from the neck of the gallbladder to its junction with the common hepatic duct. The following parameters were recorded:

- Type of union of cystic duct with common hepatic duct
- Level of union relative to the porta hepatis
- Lengths of the cystic duct, common hepatic duct, and common bile duct
- Measurements were taken using calipers. Observations were documented photographically, and results were tabulated for analysis and comparison with previous literature.

Statistical Analysis

All collected data were systematically recorded and entered into Microsoft Excel for analysis. Descriptive statistical methods were employed to summarize the findings. The number and percentage distribution of different anatomical variations, including types of cystic duct union, level of junction, and directional course, were calculated to present the frequency of each observation.

Mean values and ranges were determined for continuous parameters such as the lengths and diameters of the cystic duct at different levels. The results were then presented in tabular form to facilitate clear comparison with previous studies and to highlight patterns of anatomical variability.

RESULT

Table 1: Types of Union of the Cystic Duct with the Common Hepatic Duct (n = 30)

Type of Union	Number of Specimens	Percentage (%)
Angular type	21	70
Parallel type	9	30
Spiral type	0	0
Total	30	100

Table 1 shows the distribution of the types of union between the cystic duct and the common hepatic duct in 30 specimens. The angular type was the most frequently observed configuration, found in 21 specimens (70%). The parallel type was seen in 9 specimens (30%). The spiral type

was not observed in any specimen. These findings indicate that the angular union is the predominant anatomical variation in the present study sample. Figure 1 and 2 illustrates the angular and parallel type of union respectively.

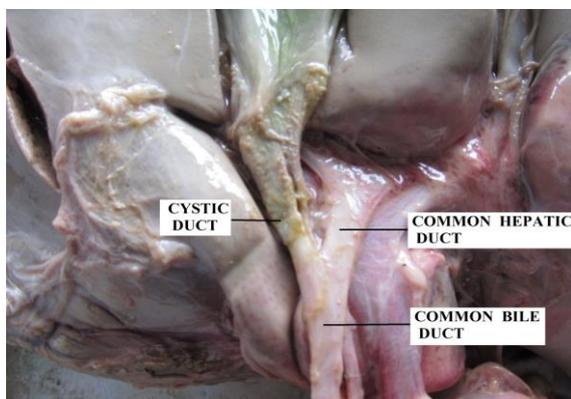


Figure 1: Angular type of union

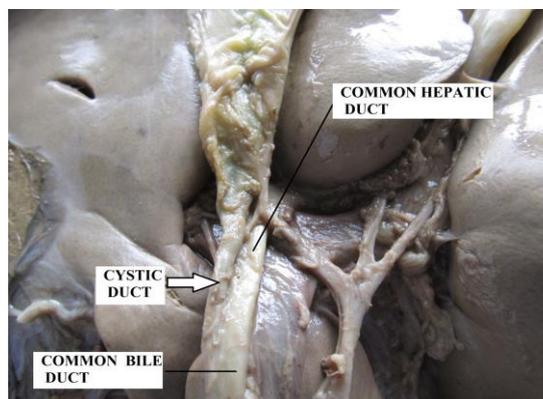


Figure 2: Parallel type of union

Table 2: Level of Union

Observation	Description	Number of Specimens	Percentage (%)
Site of union	Cystic duct joined the common hepatic duct just caudal to the porta hepatis	30	100
Low insertion	Not observed	0	0
High insertion	Not observed	0	0
Aberrant junction	Not observed	0	0

Table 2 presents that in all 30 specimens examined, the cystic duct joined the common hepatic duct just caudal to the porta hepatis, accounting for 100 percent of

the observations. No cases of low insertion, high insertion, or aberrant junction were identified.

Table 3: Mean Lengths of Ducts (n = 30)

Duct	Average Length (cm)
Cystic duct	2.45
Common hepatic duct	2.33
Common bile duct	6.83

Table 3 illustrates the cystic duct length ranged between 2.1 cm and 2.8 cm, with a mean of 2.45 cm. This is consistent with previous anatomical descriptions. The lengths of the common hepatic and common

bile ducts also fall within normal limits. These dimensions are of surgical importance during biliary exploration and imaging interpretation.

Table 4: Comparison of Cystic Duct Measurements with Previous Studies

Study	Mean Cystic Duct Length (cm)	Predominant Type of Union
Present study (2025)	2.45	Angular (70%)
Schaeffer (1953)	2.50	Angular
Ernst (1908)	2.30	Angular
Hamilton (1956)	2.40	Angular

Table 4 shows that the present findings closely align with classical studies, confirming the angular type as the predominant form of union and establishing the cystic duct length within the expected

range. Such consistency across decades underscores the reliability of the anatomical configuration of the extrahepatic biliary system.

Table 5: Diameter of the Cystic Duct at Different Levels (n = 30)

Level of Measurement	Range (mm)	Mean Diameter (mm)
Proximal (near gallbladder neck)	2.0 – 3.5	2.8
Middle portion	1.8 – 3.2	2.5
Distal (near common hepatic duct)	1.5 – 2.8	2.1

Table 5 provides the measurements of the cystic duct diameter at three different levels in a total of 30 specimens. The proximal region near the gallbladder neck showed the widest diameter, ranging from 2.0 to 3.5 mm with a mean value of 2.8 mm. The middle portion of the cystic duct measured slightly less, with a range of 1.8 to 3.2 mm

and a mean diameter of 2.5 mm. The distal end, located close to the common hepatic duct, recorded the narrowest diameter, ranging from 1.5 to 2.8 mm and a mean of 2.1 mm. These observations indicate a gradual decrease in cystic duct diameter from the proximal to the distal level.

Table 6: Direction and Course of the Cystic Duct (n = 30)

Course of Cystic Duct	Number of Specimens	Percentage (%)
Ascending (upward course)	12	40
Descending (downward course)	9	30
Horizontal (transverse course)	9	30
Total	30	100

Table 6 illustrates the direction and course of the cystic duct among 30 examined specimens. The most common course observed was an ascending or upward course, present in 12 specimens (40 percent). A descending or downward course

was noted in 9 specimens (30 percent), while another 9 specimens (30 percent) demonstrated a horizontal or transverse course. Overall, the findings highlight that the cystic duct most frequently ascends towards its junction with the common

hepatic duct, although descending and horizontal orientations are also seen with equal frequency.

DISCUSSION

The present study revealed that the angular type of cystic duct union with the common hepatic duct is the most frequent pattern (70%), followed by the parallel type (30%). The spiral configuration was absent. These findings are consistent with Kettle et al. (2022) and Morris (1907), who also observed angular unions as the predominant pattern in most cadaveric series.^[3,4] In a cadaveric study conducted at Government Tiruvannamalai Medical College, Tamil Nadu, Karthikeyan et al. (2021) reported the angular type as the most common configuration, observed in 68% of cases, followed by parallel (24%) and spiral (8%) types.^[8] The absence of spiral unions in the present study may reflect regional anatomical uniformity or sample-specific variation.

The mean length of the cystic duct in our study (2.45 cm) closely corresponds to those reported in earlier studies, ranging from 2.3 to 2.5 cm (3,4,5). The level of junction was typically just below the porta hepatis, aligning with the observations of Standring (2008).^[9]

Understanding such variations has immense surgical importance. During laparoscopic cholecystectomy, an unusually long or parallel cystic duct may obscure the anatomy of Calot's triangle, predisposing to bile duct injury. Moreover, unrecognized low insertion of the cystic duct could complicate biliary reconstruction or endoscopic procedures.

The absence of spiral type junctions in this series might reflect population-based anatomical constancy, though a larger multicentric study would better define regional variability.

The present study revealed a gradual tapering of the cystic duct from proximal to distal ends. The mean diameter at the proximal level was 2.8 mm, decreasing to 2.5 mm in the middle and 2.1 mm distally.

This pattern is consistent with previous cadaveric studies. Rajguru et al. (2018) reported a similar tapering trend, with proximal diameters ranging from 2.1 to 3.6 mm and distal diameters between 1.6 and 2.9 mm.^[10] Rubab et al. (2021) also observed a narrowing lumen toward the junction with the common hepatic duct, emphasizing its relevance in stent placement and ductal cannulation.^[11]

The gradual reduction in diameter may be attributed to the anatomical convergence of the duct toward the biliary tree, which facilitates bile flow regulation. From a clinical perspective, the distal narrowing poses a challenge during endoscopic retrograde cholangiopancreatography (ERCP), especially in cases of inflammation or anatomical distortion. Awareness of this tapering is essential for avoiding ductal injury during instrumentation.

The directional course of the cystic duct varied among specimens, with ascending orientation being most common (40%), followed by descending and horizontal courses (30% each). These findings align with the observations of Hamilton (1956), who described ascending courses as typical in standard biliary anatomy.^[5] Rajguru et al. (2018) found ascending ducts in 38% of cases, reinforcing its predominance.^[10]

However, the presence of descending and horizontal courses in 60% of specimens indicates significant anatomical variability. Rubab et al. (2021) reported similar proportions, noting that horizontal ducts may complicate laparoscopic visualization and increase the risk of misidentification. Such variability underscores the importance of preoperative imaging and intraoperative cholangiography to delineate ductal orientation.^[11]

The ascending course is generally considered favorable for surgical access, as it allows clearer visualization during dissection. In contrast, descending or transverse orientations may obscure the duct's trajectory, especially in inflamed or fibrotic tissues. Therefore, understanding

these variations is vital for minimizing complications during biliary procedures.

CONCLUSION

The present study reinforces that the anatomy of the cystic duct, although generally consistent, demonstrates noteworthy variations that hold important clinical implications. The angular union of the cystic duct with the common hepatic duct emerged as the predominant anatomical pattern, which is in agreement with established classical literature. Such predictability in morphology facilitates safe surgical dissection in Calot's triangle. However, the presence of parallel union in nearly one-third of the specimens signifies a potential risk zone where misidentification of biliary structures can result in bile duct injury.

Limitation of this study is the relatively small sample size of 30 cadavers derived from a single geographical region. Only formalin-preserved specimens were examined, which may not fully represent the elasticity and ductal behavior seen in living individuals during surgical procedures. Radiological correlations were not included, limiting the comparison between cadaveric and clinical findings.

Future studies should include a larger, multicentric sample to better assess regional and racial variations in the cystic duct anatomy. Incorporating radiological imaging such as MRCP or intraoperative cholangiography could further enhance clinical applicability. Additional research focusing on correlation with cystic artery variations may also strengthen anatomical knowledge that contributes to safer hepatobiliary surgeries.

Overall, this study contributes valuable regional anatomical data and supports the continued emphasis on meticulous dissection techniques and adequate visualization during hepatobiliary surgeries. A thorough understanding of cystic duct variations not only minimizes operative risks but also enhances surgical precision, ultimately improving patient outcomes.

Future studies involving larger and more diverse populations may help to further delineate regional differences and strengthen anatomical knowledge beneficial for surgeons and anatomists alike.

Declaration by Authors

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