

Morphological Variations of the Cystic Artery and Calot's Triangle: A Retrospective Cadaveric Study

Md Ehsan¹, Manoj Kumar², Seema Tabassum³

¹Tutor/Senior Resident, Department of Anatomy, Darbhanga Medical College, Laheriasarai, Darbhanga, Bihar, India

²Tutor/Senior Resident, Department of Anatomy, Darbhanga Medical College, Laheriasarai, Darbhanga, Bihar, India

³Professor and HOD, Department of Anatomy, Darbhanga Medical College, Laheriasarai, Darbhanga, Bihar, India

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Corresponding Author: Dr. Manoj Kumar

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Abstract:

Background: The cystic artery exhibits considerable anatomical variation in its origin, course, and relationship with Calot's triangle and the extrahepatic biliary ducts. Recognition of these variations is essential for preventing vascular and biliary complications during cholecystectomy.

Aim: To evaluate the morphological variations of the cystic artery and Calot's triangle and assess their relationships with the cystic duct and common hepatic duct.

Methodology: A retrospective cross-sectional cadaveric study was conducted on 60 embalmed human cadavers in the Department of Anatomy, Darbhanga Medical College, Laheriasarai, Darbhanga, Bihar, India, over 3 months. Standard abdominal dissection was performed to identify Calot's triangle, trace the cystic artery, and document its origin, course, ductal relationships, and branching pattern.

Results: The cystic artery originated from the right hepatic artery in 70.0% of cases. It was located inside Calot's triangle in 93.3% and outside in 6.7%. It passed posterior to the common hepatic duct in 88.3% and anteriorly in 10.0%. An anterior relationship with the cystic duct was observed in 6.7%, while double cystic artery/origin occurred in 3.3%.

Conclusion: Significant anatomical variations were observed, emphasizing the importance of detailed anatomical knowledge for safe hepatobiliary surgery.

Keywords: Cystic Artery, Calot's Triangle, Anatomical Variation, Cystic Duct, Common Hepatic Duct, Cadaveric Study.

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Introduction

The gallbladder is one of the major parts of the biliary system and its main function is to store and concentrate on the bile. The cystic artery is the chief duct, making it an important structure in the anatomy of the hepatobiliary region. The cystic artery is most frequently a branch of the right hepatic artery and is typically located in the "angle" between the common hepatic duct and cystic duct. But its origin is not always the same, and there are several anatomic variants reported. The cystic artery can take off from the left hepatic artery, proper hepatic artery, common hepatic artery, gastroduodenal artery, superior pancreaticoduodenal artery, or the superior mesenteric artery [1]. These differences in origin have important anatomical and surgical implications as the course of the artery and its relationship to the biliary ducts and other structures depends on its origin.

The cystic artery commonly runs through Calot's triangle but sometimes passes through differently. It is said to pass through the Calot's triangle in about 75–80% of the cases. Calot's triangle is an anatomical triangle that is traditionally formed by the cystic duct, common hepatic duct, and inferior surface of the liver.

The most important structures contained within this region include the cystic artery and cystic lymph node [2]. The triangle is an important anatomical landmark in gallbladder surgery as identification and dissection of the contents of the triangle is required prior to cystic artery and cystic duct ligation and division. Anatomical differences in this area can thus be important for the safety and success of gall bladder surgery. A knowledge of the normal anatomy and anatomical variations of the cystic artery

and its relation to the common hepatic duct and cystic duct is critical to the surgery of gallbladder removal. The cystic artery is usually thought to be found within Calot's triangle, but sometimes it can be found outside Calot's triangle.

In this instance, the artery may not be easily identifiable when dissecting the area and may be inadvertently damaged. A cystic artery anterior to the common hepatic duct is of particular concern because of the risk of vascular or biliary injury during the operative manipulation due to the close relationship between the two. Thus, knowledge of the different types of hepatobiliary arterial systems is important to avoid complications in this anatomically complex surgical area [3]. Cystic artery variations are of great clinical importance when the cystic artery and cystic duct are to be separated by the surgeon during laparoscopy cholecystectomy. Damage to vascular structures can cause massive intra-operative bleeding, and damage to the biliary system can cause bile leakage.

During laparoscopy cholecystectomy, damage to the blood vessels (cystic artery hemorrhage or bile leakage) has been reported to lead to conversion of laparoscopic procedure to open surgery up to 1.9% of patients and mortality rate of about 0.02%. These complications highlight the need for having adequate knowledge of the anatomy and careful identification of vascular and biliary structures prior to their surgical ligation. The anatomy of the cystic artery and the other structures that make up Calot's triangle is therefore not of purely academic interest but has a direct impact on operative safety [4]. The cystic artery and cystic duct have received a great deal of attention from the anatomists and surgeons due to their anatomical variations, which are relatively common. Cadaveric studies are especially useful in the assessment of such variations as it is possible to trace the complete course of the cystic artery and the origin and its relationship with Calot's triangle and surrounding ducts can be recorded accurately.

Kankhare et al. conducted a cadaveric study on 40 formalin fixed cadavers of Indian origin, in which they studied the origin of the cystic artery and its relationship with Calot's triangle, common hepatic duct, and cystic duct. In 70% of specimens the cystic artery originated from the right hepatic artery, in 5% from the left hepatic, in 10% from the gastroduodenal, in 7.5% from the proper hepatic, in 5% from the superior mesenteric and in 2.5% from the right gastric artery [5]. The same study showed that there was a significant variation in the course and location of the cystic artery. This artery was found in 95% of cadavers to be located in Calot's triangle and in 5% not located. In 90% it passed behind the common hepatic duct, and in 10% of the specimens, it passed in front of the common hepatic duct. Also, in 5% the artery was anterior to the cystic duct.

There were also variations in the number of the cystic artery and the branching of the cystic artery, in one of which it had doubled origin and in one instance it had both a superficial and a deep branch. The results clearly showed that during anatomical dissection or surgery it cannot always be counted on that the textbook description of a single cystic artery originating from the right hepatic artery and traversing predictably through Calot's triangle is true [6]. This variation in the cystic artery can be attributed to the intricate development of the hepatobiliary vascular system. Liver and gallbladder develop from the hepatic diverticulum, and they first get a rich vascular supply from primitive arterial channels.

With the progression of development, some vessels regress, others remain and grow to comprise the adult arterial system. The persistence and degeneration of this vascular system may vary which can lead to variation in the final origin, course, branching pattern and relationship of the arteries to the liver and gallbladder [7]. This developmental complexity provides an anatomical basis for the considerable variations observed in the cystic artery. Other anatomical studies have also shown the anatomic variation between the cystic artery and Calot's triangle and the common hepatic duct. The right hepatic artery was the most common origin of the cystic artery and 86.1% of the cystic arteries ran through Calot's triangle in a study of 72 autopsies by Chen et al. They also illustrated variations of the artery relationship with common hepatic duct and their position of origin. Such observations stress the need to evaluate the origin and course of the cystic artery as a whole rather than the origin alone [8].

Given the marked anatomical variations of the cystic artery and its close association with Calot's triangle and extrahepatic biliary ducts, systematic cadaveric review is essential to gain insight into anatomical patterns in the region. Hence, the present retrospective cadaveric study is carried out in Laheriasarai, Darbhanga, Bihar, India, to study the morphological variations of the cystic artery and Calot's triangle. Special attention will be given to the origin, course, relationship with Calot's triangle, common hepatic duct and cystic duct and variations in the branching pattern of the cystic artery. The results of the study can be added to the available anatomical literature, and it can be of value for anatomists and surgeons, especially for the safe performance of cholecystectomy and to avoid hepatobiliary complications during surgery.

Methodology

Study Design: The present study was designed as a retrospective cross-sectional cadaveric study to evaluate the morphological variations of the cystic artery and its anatomical relationship with Calot's triangle and adjacent biliary structures.

Study Area: The study was conducted in the Department of Anatomy, Darbhanga Medical College, Laheriasarai, Darbhanga, Bihar, India.

Study Duration: The study was carried out over a period of 3 months.

Sample Size: A total of 60 embalmed human cadavers (N = 60) were included in the study for anatomical evaluation.

Sample Population: The study population consisted of embalmed human cadavers of Indian origin available in the Department of Anatomy during the study period. The hepatobiliary region of each cadaver was examined for the origin and course of the cystic artery and its relationship with Calot's triangle and the cystic and common hepatic ducts.

Data Collection: Data was collected through systematic anatomical examination and direct observation of the hepatobiliary region of all 60 embalmed cadavers. Following exposure of the abdomen and careful removal of surrounding fat and connective tissue, the boundaries of Calot's triangle were identified, and the cystic artery was traced from its origin along its course. Information regarding the origin of the cystic artery, its relationship with Calot's triangle, its relationship with the cystic duct and common hepatic duct, and the contents of Calot's triangle were recorded for each cadaver. Any observed variations in the origin, course, number, or branching pattern of the cystic artery were also documented systematically.

Inclusion Criteria

- Embalmed human cadavers available in the Department of Anatomy during the study period.
- Cadavers of Indian origin.
- Cadavers in which the liver, gallbladder, cystic duct, common hepatic duct, and surrounding hepatobiliary structures were sufficiently preserved for dissection.
- Cadavers in which the origin and course of the cystic artery could be identified and traced.

Exclusion Criteria

- Cadavers with severe damage or decomposition of the hepatobiliary region.
- Cadavers in which the liver, gallbladder, cystic duct, or common hepatic duct was grossly distorted or damaged.
- Specimens in which the cystic artery could not be identified because of inadequate preservation or dissection-related damage.

- Cadavers with incomplete exposure of the hepatobiliary region preventing assessment of Calot's triangle.

Procedure: The cadaveric dissection was performed using standard anatomical dissection techniques. The abdomen was opened with the help of dissecting instruments such as scalpel, scissors, and forceps, and the surrounding fat and connective tissue over the liver, gallbladder, and duodenum were carefully cleared to expose the hepatobiliary structures. The boundaries of Calot's triangle were identified and defined, following which the cystic artery was carefully traced from its origin to its course toward the gallbladder. The source of origin of the cystic artery was recorded, and its relationship with Calot's triangle was assessed as either inside or outside the triangle. Its relationship with the cystic duct and common hepatic duct was also observed and categorized as anterior, posterior, or not related. The contents of Calot's triangle, particularly the cystic artery and cystic lymph node, were examined and documented. Any variation in the number, branching pattern, origin, or course of the cystic artery observed during dissection was systematically recorded for each cadaver.

Statistical Analysis: The collected observations were compiled and analyzed using descriptive statistical methods. The frequency and percentage of each anatomical variation were calculated. The distribution of the cystic artery according to its origin, relationship with Calot's triangle, relationship with the cystic duct and common hepatic duct, and contents of Calot's triangle were presented as frequencies and percentages. The findings were summarized in appropriate tables for clear presentation and interpretation".

Result

Table 1 shows the distribution of cystic artery according to its origin among the 60 cadavers examined. The cystic artery most commonly originated from the right hepatic artery, accounting for 42 cases (70.0%). This was followed by origin from the gastroduodenal artery in 6 cases (10.0%) and the proper hepatic artery in 5 cases (8.3%). Origin from the left hepatic artery was observed in 3 cases (5.0%), while the superior mesenteric artery accounted for 2 cases (3.3%). The least frequent origins were the common hepatic artery and right gastric artery, with 1 case each (1.7%). Thus, although the right hepatic artery was the predominant source, several variations in the origin of the cystic artery were observed.

Table 1: Distribution of Cadavers According to the Origin of the Cystic Artery (N=60)			
S. No.	Origin of cystic artery	No. of cadavers	Percentage (%)
1	Right hepatic artery	42	70
2	Left hepatic artery	3	5
3	Proper hepatic artery	5	8.3
4	Gastroduodenal artery	6	10
5	Superior mesenteric artery	2	3.3
6	Common hepatic artery	1	1.7
7	Right gastric artery	1	1.7
Total		60	100

Table 2 demonstrates the relationship of the cystic artery with Calot's triangle. In the majority of cadavers, 56 cases (93.3%), the cystic artery was located inside Calot's triangle, whereas in 4 cases (6.7%) it was found outside the triangle. The findings indicate that the cystic artery usually follows the expected

anatomical course through Calot's triangle; however, its presence outside the triangle in a proportion of specimens highlights an important anatomical variation that may have implications during surgical dissection.

Table 2: Relationship of the Cystic Artery with Calot's Triangle (N=60)			
S. No.	Position of cystic artery	No. of cadavers	Percentage (%)
1	Inside Calot's triangle	56	93.3
2	Outside Calot's triangle	4	6.7
Total		60	100

Table 3 presents the relationship of the cystic artery with the common hepatic duct. The cystic artery was found posterior to the common hepatic duct in 53 cases (88.3%), representing the most frequent relationship. In 6 cases (10.0%), the artery passed anterior to the common hepatic duct, while 1 case (1.7%)

showed no direct relationship. The predominance of the posterior course indicates the usual anatomical arrangement, whereas the anterior course represents a clinically important variation because it may increase the possibility of vascular injury during hepatobiliary surgery.

Table 3: Relationship of the Cystic Artery with the Common Hepatic Duct (N=60)			
S. No.	Relationship with common hepatic duct	No. of cadavers	Percentage (%)
1	Posterior to common hepatic duct	53	88.3
2	Anterior to common hepatic duct	6	10
3	Not related	1	1.7
Total		60	100

Table 4 describes the relationship of the cystic artery with the cystic duct. In the majority of specimens, 54 cases (90.0%), the cystic artery was not directly related to the cystic duct. An anterior relationship was observed in 4 cases (6.7%), whereas a posterior relationship was identified in 2 cases (3.3%).

Therefore, the usual finding was the absence of a direct crossing relationship between the cystic artery and cystic duct, while anterior or posterior courses were observed as relatively uncommon anatomical variations

Table 4: Relationship of the Cystic Artery with the Cystic Duct (N=60)			
S. No.	Relationship with cystic duct	No. of cadavers	Percentage (%)
1	Anterior to cystic duct	4	6.7
2	Posterior to cystic duct	2	3.3
3	Not related	54	90
Total		60	100

Table 5 summarizes the major anatomical findings concerning the contents and branching pattern of Calot's triangle. The cystic artery along with the cystic lymph node was identified in 55 cases (91.7%), representing the predominant finding. An additional arterial branch associated with the cystic

artery was observed in 3 cases (5.0%), while double cystic artery/origin was identified in 2 cases (3.3%). These findings demonstrate that, although the typical content of Calot's triangle was observed in most specimens, variations in the arterial branching pattern and number of cystic arteries were also present.

Table 5: Contents and Branching Pattern of Calot's Triangle (N=60)

S. No.	Anatomical finding	No. of cadavers	Percentage (%)
1	Cystic artery + cystic lymph node present	55	91.7
2	Cystic artery with additional arterial branch	3	5
3	Double cystic artery/origin	2	3.3
Total		60	100

Discussion

In the present study, there was found to be a great deal of variations in the origin and course of the cystic artery and its relationship with Calot's triangle and extrahepatic biliary ducts. The most common origin of the cystic artery was the right hepatic (42, 70.0%), followed by gastroduodenal (6, 10.0%), proper hepatic (5, 8.3%), left hepatic (3, 5.0%), superior mesenteric (2, 3.3%) and common hepatic (1, 1.7%) and right gastric (1, 1.7%). Right hepatic artery predominance is in keeping with the development and anatomy of the hepatobiliary arterial system. The liver and gallbladder are supplied during embryological development by primitive arterial channels, which may persist or regress in various ways creating different arterial origins and branching patterns. In their study of 1000 cases, Noussios et al. also noted the huge variations of the hepatic arterial system and its significance in hepatobiliary surgery" [9].

The distribution found in the present study thus confirms the fact that, while the right hepatic artery is the common site of origin, other origins of the cystic artery are not uncommon. The prevalence of the right hepatic artery origin in the present study (70.0%) was nearly equal to that of Daseler et al., (71.7%). They also reported in their study of 580 specimens, left hepatic artery (6.2%), common hepatic artery (2.7%), gastroduodenal artery (2.6%), superior mesenteric artery (0.35%) and an aberrant right hepatic artery (0.1%) [10]. The present study on the other hand, revealed that the gastroduodenal (10.0%) and superior mesenteric artery (3.3%) origins were a little higher, and the left hepatic artery was 5.0%. These differences could be due to variation in population studied and sample size. Flint reported an even higher frequency of RHA origin of about 98%, 1.5% arising from the left hepatic artery and 0.5% arising from the gastroduodenal artery. So, the current results show that the usual origin prevails and that the accessory origins can be quite different in different anatomical series. The relation of the cystic artery with Calot's triangle revealed 56 of 60 (93.3%) cases with an artery within Calot's triangle and 4 cases (6.7%) with an artery outside Calot's triangle. This result is generally similar to previous cadaveric observations. Flisinski et al. reported the cystic artery was found within the Calot's triangle 97.6% of the specimens and outside 2.94% [12]. Michels on the other hand reported less inside the triangle (81%) and more outside (19%) [13].

Thus, the present value of 93.3% is between these observations and the majority of cystic arteries follow the expected path through Calot's triangle. However, the outside of the triangle in 6.7% of the specimens is clinically relevant as the artery can be missed during surgery and injured. In the present study, the course of the cystic artery in relation to the common hepatic duct was also mainly found posteriorly. In 53 (88.3%) cases the artery was behind the common hepatic duct, in 6 (10.0%) cases the artery was in front of the common hepatic duct and in 1 (1.7%) there was no direct relationship. These results are comparable with the original cadaveric study by Kankhare et al. where 90% of the cystic arteries were found behind the common hepatic duct and 10% in front of it [14]. Given the increased number of cadavers used in the present study, the results are then quite similar. Gawali, however, reported significantly higher number of anterior relationships with cystic artery anterior to common hepatic duct in 46.66%, and posterior in 50% [15]. This difference proves that the course of the cystic artery relative to the common hepatic duct is a highly variable finding and suggests that the artery should be identified carefully during the operative dissection.

Regarding the cystic duct, in the present study, the cystic artery was not directly related with the cystic duct in 54 cases (90.0%), was anteriorly related in 4 cases (6.7%) and posteriorly related in 2 cases (3.3%). The anterior relationship presented in the current series is a bit higher than that reported by Flisinski et al. (2.94%) and a bit lower than that reported by (10%) [16]. Of surgical significance is the fact that the cystic artery is anteriorly placed and may be harder to identify and isolate during cholecystectomy, due to proximity of the cystic duct. It also emphasizes the need to follow the artery's course completely before ligating it, instead of relying on a constant anatomical relationship. As in the present study, there were also variations in the number of the cystic artery and its pattern of branching. In most specimens, there was only one cystic artery; in 3 cases (5.0%), there was an additional artery and in 2 cases (3.3%), a double cystic artery and double origin were observed. This incidence of double arteries was less than that recorded by Balija et al (21.1%) [17].

In a study of 18 neonates with double aortic arch, Suzuki et al. also observed two cystic arterial supplies in 11.1% of their cases [18]. The frequencies obtained in the present study might be attributed to variations in the sample size and the methodology

followed in the study as the present study was conducted on direct cadaveric dissection of 60 specimens. However, it is crucial to identify double or more one arterial branch as failure to do so may mean that the vessel is not completely controlled or postoperative bleeding may occur. In the present study, the finds of Calot's triangle were rather uniform. In most of the specimens the cystic artery and cystic lymph node were found within the triangle, the latter associated with the artery. This is consistent with the known anatomic description of Calot's triangle and confirms its role as a surgical landmark for identification of the cystic artery and cystic duct. The variations noted in the present study, especially the cystic arteries lying outside the Calot's triangle and the anterior course of the cystic and common hepatic ducts, are clinically important because the presence of these variants may render us more prone to vascular injury during cholecystectomy. Thus, the results of the current study underscore the need for thorough understanding of the morphology of the cystic artery and of the anatomy of Calot's triangle in hepatobiliary surgery to minimize iatrogenic complications.

Overall, the present study showed that the right hepatic artery was the most common site of the origin of the cystic artery (70.0%), most of the cystic arteries were within Calot's triangle (93.3%), and most of the cystic arteries were located behind the common hepatic duct (88.3%). Clinically significant variations however, were detected: cystic arteries outside Calot's triangle, anterior passage to the common hepatic duct, anterior or posterior relation with the cystic duct, and double or additional branches of the cystic artery. When compared to previous anatomical studies, the differences observed suggest that the frequency of variants of the cystic artery may vary from population to population. These findings stress the need for careful anatomical identification between the cystic artery and other structures to be ligated and divided during cholecystectomy.

Conclusion

The present cadaveric study showed there was significant variation in the origin and course of cystic artery with respect to Calot's triangle and the extra-hepatic biliary ducts. Although some unusual arterial origins of the cystic artery were seen, the most common was the right hepatic artery (70.0%). The most common anatomic patterns were for the cystic artery to be within Calot's triangle in 93.3% of cases and to be located posterior to the common hepatic duct in 88.3%. But variations of clinical importance were also detected such as an artery outside the Calot's triangle, anterior course of the common hepatic duct, variable relationship with the cystic duct, double or additional arterial branches. These observations highlight the variability of the cystic artery and Calot's triangle from their classic anatomic descriptions and their significance. Their knowledge is

thus very important for anatomical identification and to avoid vascular or biliary injury during cholecystectomy and hepatobiliary surgical procedures.

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