e-ISSN: 0976-822X, p-ISSN:2961-6042

Available online on http://www.ijcpr.com/

International Journal of Current Pharmaceutical Review and Research 2025; 17(9); 1831-1836

Original Research Article

Anatomical Variations of the Cystic Artery in Relation to Calot's Triangle: A Multicentric Cadaveric and Radiological Study

Ashish Rai[1], Urwashi Rai[2], Sajjad Jafar[3]

[1]P.G. 1st Year, Department of Anatomy, Heritage Institute of Medical Science, U.P., Varanasi, India

[2]P.G. 3rd Year, Department of General Surgery, Narayan Medical college and Hospital, Jamuhar, Sasaram, Bihar, India

[3]Associate Professor, Department of Anatomy, Heritage Institute of Medical Science, U.P., Varanasi, India

Received: 28-07-2025 / Revised: 27-08-2025 / Accepted: 28-09-2025

Corresponding Author: Sajjad Jafar

Conflict of interest: Nil

Abstract:

Background: Anatomical variations of the cystic artery (CA) are of critical importance during laparoscopic cholecystectomy. Misidentification of these variants within Calot's triangle remains a significant cause of intraoperative bleeding and bile duct injury.

Objective: To determine the prevalence and patterns of cystic artery origin and course in relation to Calot's triangle using both cadaveric dissection and radiological evaluation.

Methods: A one-year multicentric cross-sectional study was conducted across three tertiary medical centres. The study included 54 adult patients who underwent contrast-enhanced CT angiography (CTA) or MR angiography (MRA) of the hepatobiliary region, and 24 formalin-fixed cadavers with intact hepatobiliary anatomy. Each cystic artery was assessed for its origin, course in relation to relation to the cystic duct, Calot's triangle, number of branches, and presence of Moynihan's hump.

Results: In the radiological group (n = 54), the CA originated from the right hepatic artery (RHA) in 81.5%, accessory RHA in 9.3%, common hepatic artery in 5.6%, and gastroduodenal artery in 3.7% of cases. The artery coursed within Calot's triangle in 75.9% and outside in 24.1%. A single CA was seen in 92.6% of cases, double arteries in 7.4%. The vessel was superficial to the cystic duct in 85.2% and deep in 14.8%. Moynihan's hump was observed in 11.1% of cases. Mean CA diameter at the gallbladder entry was 1.8 ± 0.4 mm, and the mean distance from origin to gallbladder neck was 24 ± 6 mm. Cadaveric dissections (n = 24) demonstrated comparable findings: RHA origin in 79.2%, accessory RHA in 12.5%, common hepatic in 4.2%, and gastroduodenal in 4.2%. The artery passed inside Calot's triangle in 75% and outside in 25%. Single arteries were present in 91.7% and double arteries in 8.3%. Moynihan's hump was identified in 12.5% of specimens. Mean CA diameter was 2.0 ± 0.5 mm and mean length 26 ± 7 mm.

Conclusion: The RHA is where the cystic artery most frequently originates, and it passes via Calot's triangle, but significant variations exist. Awareness of these patterns, particularly double arteries and Moynihan's hump, is essential for safe cholecystectomy. Radiological and cadaveric findings were consistent, emphasizing the reliability of pre-operative imaging for vascular mapping.

This is an Open Access article that uses a funding model which does not charge readers or their institutions for access and distributed under the terms of the Creative Commons Attribution License (http://creativecommons.org/licenses/by/4.0) and the Budapest Open Access Initiative (http://www.budapestopenaccessinitiative.org/read), which permit unrestricted use, distribution, and reproduction in any medium, provided original work is properly credited.

Introduction

The cystic artery (CA) is the principal vessel supplying the gallbladder and cystic duct. Its anatomy plays a decisive role in the safety of biliary surgery, particularly during laparoscopic cholecystectomy. The CA often originates from the right hepatic artery (RHA) within the hepatocystic or Calot's triangle, which is surrounded by the inferior surface of the liver, the cystic duct, and the common hepatic duct. Despite this classic description, wide variations in the artery's origin, number, and course have been reported. The CA may originate from alternative sources such as the common hepatic, gastroduodenal, superior mesenteric, or accessory right hepatic arteries. In certain cases, it may run outside Calot's triangle or pass deep to the cystic duct rather than superficial to it. Additional anomalies such as a double cystic artery or a tortuous right hepatic artery forming the so-called "Moynihan's hump" further complicate surgical identification. Unawareness of these patterns can lead to bleeding, bile duct injury, or conversion to open surgery, especially when inflammation or fibrosis obscures the usual landmarks.

Previous literature demonstrates considerable variation in the reported frequency of these patterns. Classical RHA origin of the cystic artery is noted in about 70–90% of cases, whereas non-RHA origins account for 10–30%. The artery generally courses within Calot's triangle, yet an extra-triangular path may be encountered in up to a quarter of individuals. A deep relation to the cystic duct has been documented in roughly one-fifth of cases, and double cystic arteries in 5–15%. The tortuous "Moynihan's hump" configuration of the RHA occurs in approximately 10% of specimens. These discrepancies are largely due to differences in sample size, population, and study technique. Cadaveric dissection allows direct visualization and precise measurement of the vessels but is limited by tissue shrinkage, embalming artefacts, and restricted numbers in single-centre studies. Conversely, modern imaging modalities such as multidetector computed tomography angiography (MDCTA) and magnetic resonance angiography (MRA) offer detailed, non-invasive, three-dimensional assessment of the hepatobiliary vasculature in living subjects. However, their accuracy depends on image resolution, timing of arterial phase acquisition, and the experience of the interpreter. Hence, data derived from isolated cadaveric or radiological studies often provide incomplete understanding of cystic artery variations.

To overcome these limitations, the present multicentric investigation integrates both anatomical and radiological methods to obtain a comprehensive view of cystic artery variations in relation to Calot's triangle. Conducted over a one-year period across several tertiary institutions, the study evaluates the prevalence of different origins, the course of the artery within or outside Calot's triangle, its superficial or deep relationship to the cystic duct, and the occurrence of double arteries and Moynihan's hump. Combining cadaveric findings with imaging observations enhances the accuracy and clinical relevance of the results, allowing validation of radiological interpretations against direct anatomical evidence. A multicentric approach further increases the diversity of the study population and strengthens the general applicability of the findings. Understanding these vascular variations is crucial for surgeons performing cholecystectomy and hepatobiliary procedures, as well as for radiologists involved in preoperative assessment and interventional procedures. By providing reliable data on cystic artery morphology, the study aims to contribute to safer operative techniques, improved pre-surgical planning, and a reduction in vascular and biliary complications during gallbladder surgery.

Materials and Methods

Study Design and Duration: A prospective observational study was conducted over one year (January–December) at three tertiary care teaching hospitals.

Study Population

- **Radiological arm:** 54 adult patients undergoing upper-abdominal CTA/MRA with adequate arterial-phase imaging. Exclusion criteria included previous hepatobiliary surgery, vascular malformations, or poor image quality.
- **Cadaveric arm:** 24 formalin-fixed adult cadavers with intact hepatobiliary regions and no prior abdominal surgery.

Imaging Technique: CTA was performed using a 64-slice scanner with bolus-tracked arterial phase acquisition, slice thickness 0.5–1 mm, and standard reconstruction protocols. For contrast allergy or renal contraindication, MR angiography was used. Images were evaluated independently by two radiologists, with discrepancies resolved by consensus.

Cadaveric Dissection: The hepatoduodenal ligament was made visible through a right subcostal incision. The liver's inferior surface, common hepatic duct, and cystic duct served as the boundaries of Calot's triangle. The cystic artery was traced from its origin to its entry into the gallbladder, noting its relation to the boundaries of Calot's triangle and the cystic duct. Measurements were taken using a Vernier caliper.

Parameters Studied

1. Origin of the cystic artery.
2. Course in relation to Calot's triangle (inside/outside).
3. Relation to cystic duct (superficial/deep).
4. Number of cystic arteries (single/double).
5. Presence of Moynihan's hump.
6. Length from origin to gallbladder neck (mm).
7. Diameter at the point of gallbladder entry (mm).

Statistical Analysis: Data were analyzed using SPSS v25. Categorical variables were expressed as percentages; continuous variables as mean ± SD. Differences between groups were compared using the Chi-square test and independent-sample t-test. Inter-observer agreement for radiological findings was calculated using Cohen's κ statistic; a value > 0.75 was considered excellent.

Ethical Considerations: Institutional Ethics Committees of all participating centres approved the study protocol. Written informed consent was obtained from all living participants; cadaveric dissections followed departmental ethical guidelines.

Results

Study Population: A total of 78 specimens were analysed across three tertiary centres during the one-year study period. The radiological group included

54 patients (30 females and 24 males) who underwent upper abdominal CTA or MRA, while the cadaveric group comprised 24 formalin-fixed adult cadavers with intact hepatobiliary regions. The mean age of the radiological subjects was 52 ± 13 years, and most had normal hepatobiliary anatomy without previous surgery or intervention. Image quality was satisfactory in all selected cases.

Radiological Findings: Every one of the 54 scans showed the cystic artery clearly. In the majority of cases, it originated from the RHA and coursed within Calot's triangle. Alternative origins included the accessory right hepatic, common hepatic, and gastroduodenal arteries. The artery most often crossed superficial to the cystic duct, but a deep course was also observed in a notable minority.

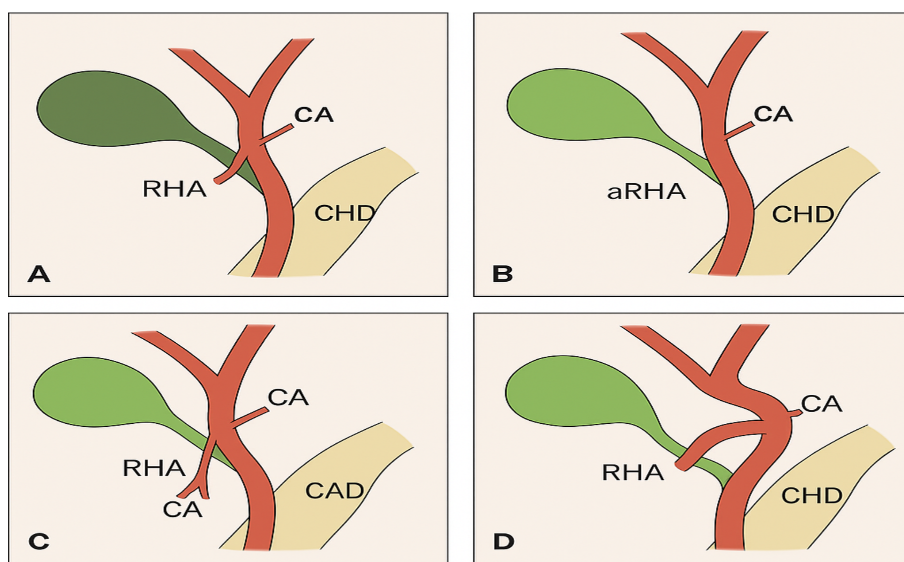
A single cystic artery was present in most patients; however, double arteries were encountered in four cases. The Moynihan's hump, characterized by a tortuous RHA close to the gallbladder neck, was detected in six individuals (Figure 1). Mean arterial diameter at the gallbladder entry measured 1.8 ± 0.4 mm, and the mean length from origin to gallbladder neck was 24 ± 6 mm. Inter-observer agreement between the two radiologists was excellent (κ = 0.82 for origin; ICC = 0.86 for diameter).

Cadaveric Observations: In the 24 cadavers studied, the classic RHA origin of the cystic artery was seen in 19 specimens (79.2%). Three (12.5%) arose from an accessory right hepatic artery, while one each originated from the common hepatic and gastroduodenal arteries. The artery passed within Calot's triangle in 18 specimens (75%) and outside it in 6 (25%). A superficial relation to the cystic duct was noted in 20 cadavers (83.3%), whereas four (16.7%) had a deep course. Double cystic arteries were found in two specimens (8.3%), and Moynihan's hump was identified in three (12.5%). The mean external diameter at gallbladder entry was 2.0 ± 0.5 mm, and the mean length from origin to the gallbladder neck was 26 ± 7 mm. The findings closely paralleled those obtained from the radiological analysis.

Comparison of Radiological and Cadaveric Data

Table 1: Comparison of cystic artery variations observed in radiological and cadaveric studies

Parameter	Radiological (n = 54)	Cadaveric (n = 24)	p-value
Origin from RHA	44 (81.5%)	19 (79.2%)	0.78
Origin from accessory RHA	5 (9.3%)	3 (12.5%)	0.67
Origin from common hepatic	3 (5.6%)	1 (4.2%)	0.81
Origin from gastroduodenal	2 (3.7%)	1 (4.2%)	0.94
Course inside Calot's triangle	41 (75.9%)	18 (75.0%)	0.93
Relation superficial to cystic duct	46 (85.2%)	20 (83.3%)	0.84
Double cystic arteries	4 (7.4%)	2 (8.3%)	0.89
Moynihan's hump	6 (11.1%)	3 (12.5%)	0.86
Diameter at GB entry (mm)	1.8 ± 0.4	2.0 ± 0.5	0.21
Length from origin (mm)	24 ± 6	26 ± 7	0.25



A. Covisic cysic aterior cosisting with Calot's trianglar

D. Moynihan's hump of right hepatic artivar looping close to gallbarder

Figure 1: Representative cystic artery variations observed in this study

Discussion

The findings from this multicentric study offer a comprehensive understanding of the cystic artery's course and origin in relation to Calot's triangle, derived from both cadaveric dissections and radiological observations. The results emphasize that while the RHA remains the predominant source of the cystic artery, a considerable proportion of specimens exhibit alternative origins and positional variations. The correlation between imaging and dissection outcomes strengthens the validity of using modern radiological techniques to evaluate hepatobiliary vascular anatomy before surgery. These results contribute to current anatomical literature by providing data that are consistent across multiple centres and by demonstrating the reliability of non-invasive imaging in identifying fine arterial branches.

In this series, the cystic artery arose from the right hepatic artery in about four-fifths of cases, a figure consistent with standard anatomical descriptions. The remaining arteries originated from sources such as the accessory right hepatic, common hepatic, or gastroduodenal arteries. This distribution corresponds with that reported by earlier researchers, who documented RHA origin in 75–90% of individuals. Such stability across populations suggests that the RHA continues to be the principal origin of the cystic artery, regardless of demographic or regional differences. The approximately 20% of variant origins observed, however, remain clinically important because they can alter the expected surgical landmarks within Calot's triangle. Recognition of these alternative sources is essential to prevent inadvertent vascular injury during cholecystectomy or hepatobiliary procedures.

Another key observation was that most cystic arteries traversed Calot's triangle, while roughly one-quarter were located outside it. Arteries with an extra-triangular course often stemmed from a lower arterial source, such as the gastroduodenal or common hepatic artery, and ascended behind the cystic duct toward the gallbladder. This pathway may expose the vessel to injury during posterior dissection or during attempts to separate adhesions near the hepatic hilum. Although such variations are not new to anatomical literature, their frequency in the present study underlines the need for surgeons to maintain orientation within the triangle rather than relying solely on anticipated patterns. The extra-triangular course was comparable to that documented by Balija and others, who found a similar prevalence in cadaveric and surgical studies. This consistency reinforces the universal relevance of careful dissection and identification of structures before ligation.

The relationship between the cystic artery and the cystic duct also demonstrated predictable but clinically significant variability. In most specimens, the artery ran superficial to the cystic duct, whereas a posterior or deep relation was identified in about one-sixth of cases. The superficial pattern corresponds to classical teaching, yet the deep variant carries important surgical implications. A posteriorly situated artery is often obscured by the duct and may bleed profusely if clipped inadvertently. Awareness of this pattern aids in achieving secure control of the vessel and in avoiding misidentification of the common hepatic duct as the cystic duct. Additionally, a small but consistent proportion of double cystic arteries was found. These duplicate arteries supplied both anterior and posterior surfaces of the gallbladder and can be easily overlooked if only one branch is ligated. Their presence explains certain cases of postoperative hemorrhage or persistent bleeding despite apparently adequate hemostasis. Recognition of such dual supply, therefore, remains an essential aspect of safe cholecystectomy.

One of the notable findings in this series was the presence of a tortuous RHA—commonly referred to as Moynihan's hump—in about one-tenth of cases. This configuration brings the RHA into close proximity with the gallbladder neck and cystic duct, creating a potential hazard during surgery. Although the overall frequency of this variation was modest, its clinical importance is substantial. Accidental clipping of the looped RHA can lead to hepatic ischemia or uncontrolled bleeding. The proportion observed here is similar to that reported in other studies, confirming that while uncommon, the Moynihan's hump should always be anticipated. The pattern is readily identified in arterial-phase imaging, allowing surgeons to plan a safer operative approach. This highlights the practical value of preoperative vascular mapping, especially in complicated gallbladder diseases where inflammation obscures the anatomy.

An important outcome of this investigation is the close agreement between the radiological and cadaveric arms. The concordant findings for origin, course, and relation validate the accuracy of multidetector CT angiography and MR angiography in defining the cystic artery. The high inter-observer agreement among radiologists demonstrates the reproducibility of these techniques when standard protocols are followed. Minor differences in measured diameter and length between imaging and dissection likely result from post-mortem changes in cadaveric tissues and physiological pulsation in living subjects. The dual-method approach adopted in this research thus serves as a cross-validation model, combining the precision of anatomical dissection with the practicality of non-invasive imaging. This approach not only strengthens

confidence in radiological findings but also enhances anatomical teaching by providing both static and in-vivo perspectives of hepatobiliary vasculature.

From a surgical standpoint, the observed variations have direct implications for intraoperative safety. In laparoscopic cholecystectomy, where visual magnification is high but tactile feedback is limited, an aberrant cystic artery can easily be mistaken for another structure. Bleeding from an injured artery obscures the field and increases the risk of bile duct injury. The relatively high occurrence of extra-triangular arteries, posterior courses, and double vessels demonstrated in this study serves as a reminder that every cholecystectomy demands deliberate exposure of Calot’s triangle and confirmation of the cystic structures before clipping. The data also support the selective use of preoperative CTA in patients with prior hepatobiliary surgery, complex anatomy, or suspicion of vascular anomalies. In interventional radiology, accurate identification of cystic artery origin is essential during procedures such as embolization for hemobilia or gallbladder artery aneurysm, where misplacement of the catheter can compromise hepatic perfusion. Thus, understanding these anatomical nuances benefits both surgical and radiological disciplines.

While the study provides valuable insights, certain limitations warrant mention. The number of cadaveric specimens was constrained by availability, and the radiological cohort consisted mainly of individuals undergoing imaging for diagnostic purposes, which may not fully represent the general population. Very small branches might remain undetected on imaging despite high resolution, and post-mortem shrinkage may slightly alter vessel dimensions. Nevertheless, the multicentric design, uniform methodology, and close agreement between dissection and imaging minimize the effect of these limitations. The strength of this research lies in its combined approach and in demonstrating that radiological findings correspond closely with actual anatomical variations. This methodological integration ensures that the observations are both anatomically precise and clinically relevant.

In conclusion, this multicentric assessment reaffirms that the RHA is the principal source of the cystic artery, yet meaningful variations occur with enough frequency to warrant careful attention. Approximately one in four arteries lies outside Calot’s triangle, and a similar proportion shows relations that may complicate surgery. Double arteries and tortuous RHA loops, though less common, carry significant surgical risk. The alignment between radiological and cadaveric findings establishes imaging as a reliable adjunct to anatomical study and a valuable preoperative tool. Familiarity with these vascular patterns is indispensable for surgeons’ performing cholecystectomy and for radiologists interpreting hepatobiliary imaging. By enhancing anatomical awareness and promoting meticulous operative technique, such understanding contributes directly to safer outcomes and improved patient care in hepatobiliary surgery.

Conclusion

According to this multicentric cadaveric and radiological study, the cystic artery usually runs within Calot's triangle and most frequently emerges from the RHA. However, a significant proportion of variations—including extra-triangular origins, posterior relations to the cystic duct, double cystic arteries, and tortuous right hepatic loops—were identified. The close agreement between radiological and cadaveric findings validates the accuracy of multidetector CT and MR angiography in depicting cystic artery anatomy. Recognition of these variations is essential to minimize intraoperative bleeding and biliary injury during cholecystectomy. Incorporating detailed anatomical knowledge with preoperative imaging assessment can enhance surgical precision, improve patient safety, and reduce complications in hepatobiliary surgery. These findings underscore the continuing importance of anatomical understanding even in the era of advanced minimally invasive and image-guided procedures.

References

1. Michels NA. Newer anatomy of the liver and its variant blood supply and collateral circulation. Am J Surg. 1966;112(3):337–347.
2. Daseler EH, Anson BJ. The cystic artery and constituents of the hepatobiliary triangle. Surg Gynecol Obstet. 1947;85(1):47–63.
3. Balija M, Huis M, Nikolic V, Stulhofer M. Laparoscopic visualization of the cystic artery anatomy. World J Surg. 1999;23(7):703–707.
4. Ding YM, Wang B, Wang WX, Wang P, Yan JS. New classification of the anatomic variations of the cystic artery during laparoscopic cholecystectomy. World J Gastroenterol. 2007;13(42):5629–5634.
5. Hugh TB, Kelly MD, Li B. Laparoscopic anatomy of the cystic artery. Am J Surg. 1992;163(6):593–595.
6. Singh S, Arora K, Choudhry R, Sharma M. Anatomical variations of the cystic artery in North Indian population: a cadaveric study. Clin Anat. 2010;23(7):778–784.
7. Suzuki T, Nakayasu A, Kawabe K, Takeda M, Hara S. Surgical significance of anatomical variations of the hepatic artery. Am J Surg. 1971;122(4):505–512.
8. Andall RG, Matusz P, du Plessis M, et al. The clinical anatomy of cystic artery variations: a

review of over 9800 cases. Surg Radiol Anat. 2016;38(5):529–539.
9. Chen TH, Shyu JF, Chen CH, et al. Variations of the cystic artery in Chinese adults: a study of 200 cases. Kaohsiung J Med Sci. 2000;16(4):182–188.
10. Sarker SK, Thompson JN. Operative anatomy of Calot's triangle and the cystic artery: a review. Clin Anat. 2010;23(1):15–28.
11. Ding Y, Zhou Q, Chen Y, Wang W. The cystic artery and its variations: an anatomical study. Surg Radiol Anat. 2013;35(7):597–603.
12. Strasberg SM, Hertl M, Soper NJ. An analysis of the problem of biliary injury during laparoscopic cholecystectomy. J Am Coll Surg. 1995;180(1):101–125.
13. Gupta V, Sood N, Kumar R. Anatomical variations of cystic artery: A study in North Indian cadavers. Int J Anat Res. 2015;3(2):1053–1057.
14. Iflazoglu N, Ozturk G, Ersoy Y, et al. Anatomical variations of the cystic artery and its surgical importance. J Morphol Sci. 2013;30(1):1–4.
15. Pushpalatha K, Ramesh RT. A study of cystic artery variations and their clinical significance. J Clin Diagn Res. 2015;9(3):AC08–AC11.
16. Adibelli ZH, Adatepe M, Esen OS, Yildirim M, Kantarci M. Cystic artery origin and course: evaluation with multidetector computed tomography angiography. Surg Radiol Anat. 2017;39(5):515–522.
17. Moosman DA, Coller FA. Prevention of injury to the bile ducts and hepatic arteries during cholecystectomy. Am J Surg. 1951;102(3):266–273.
18. Dandekar U, Dandekar K, Sharma A. An anatomical study of the cystic artery variations and their surgical implications. Indian J Surg. 2016;78(1):20–25.
19. Strasberg SM. A teaching program for the "critical view of safety" in laparoscopic cholecystectomy. Am J Surg. 2002;184(4):422–427.
20. Suwannaphisit S, Soonsawat T, Leelachaikul P, et al. 3D CT angiographic study of cystic artery variations and their relevance in laparoscopic cholecystectomy. Clin Anat. 2021;34(5):738–744.