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# ANATOMICAL VARIATIONS OF THE GALLBLADDER AND CYSTIC ARTERY: A RETROSPECTIVE REVIEW OF LAPAROSCOPIC CHOLECYSTECTOMY REPORTS

**Sher Azam Khan[1], Rida Rubab Ahmed[2*], Lubna Shahper[3], Yasmeen Bashir[4]**

[1] Biomedical Scientist, Department of Histopathology, Chughtai Institute of Pathology, Lahore, Pakistan.
[2*]Assistant Professor Anatomy, Shahida Islam Medical & Dental College, Lodhran, Pakistan.
[3] Assistant Professor Anatomy, Services Institute of Medical Sciences, Lahore, Paksitan.
[4] Associate Professor Anatomy, Services Institute of Medical Sciences, Lahore, Paksitan.

***Correspondence Author:** Rida Rubab Ahmed;
*Assistant Professor Anatomy, Shahida Islam Medical & Dental College, Lodhran, Pakistan.
Email: ridarubabahmed@gmail.com

**Abstract**

**Background:** Anatomical variations of the gallbladder and cystic artery are of significant clinical relevance during laparoscopic cholecystectomy, as unrecognized anomalies increase the risk of intraoperative complications, including bile duct injury and hemorrhage. Despite advances in minimally invasive surgery, variability in hepatobiliary anatomy continues to pose challenges for surgeons, emphasizing the importance of detailed preoperative and intraoperative recognition.

**Aims & Objective:** This study aimed to retrospectively analyze the prevalence and patterns of anatomical variations of the gallbladder and cystic artery encountered during laparoscopic cholecystectomy, thereby providing evidence-based insight to improve surgical safety and outcomes.

**Methodology:** A retrospective review of operative records from January 2023 to December 2024 was conducted, encompassing 1,423 patients who underwent laparoscopic cholecystectomy at a public sector tertiary care hospital of Lahore, Pakistan. Patient demographic data, gallbladder anatomical variations, and cystic artery patterns were systematically extracted and analyzed. Statistical analysis included descriptive frequencies and chi-square testing to evaluate associations between anatomical variations and demographic characteristics.

**Results & Findings:** Among 1,423 patients, gallbladder anomalies were observed in 8.7%, including Phrygian cap deformity (3.2%), septate gallbladder (2.1%), and ectopic positioning (1.5%). Cystic artery variations were identified in 14.9%, with aberrant course posterior to the common hepatic duct being the most frequent (6.4%). Age stratification revealed that variations were significantly more common in patients >40 years ($p < 0.05$). No statistically significant association was found between sex and anatomical variations.

**Conclusion:** Anatomical variations of the gallbladder and cystic artery remain clinically relevant findings that directly impact the complexity and safety of laparoscopic cholecystectomy. Recognition of these variations, combined with meticulous dissection and application of the critical view of safety principle, is paramount to reducing surgical complications. This study underscores the necessity for surgical vigilance and recommends the integration of intraoperative imaging or preoperative diagnostic modalities in high-risk cases.

**Keywords:** Gallbladder variations, Cystic artery anomalies, Laparoscopic cholecystectomy, Critical view of safety, Hepatobiliary surgery

## Introduction

Anatomical variability of the gallbladder and its vascular supply particularly the cystic artery poses a substantial challenge in laparoscopic cholecystectomy, the current standard intervention for symptomatic gallstone disease. Accurate intraoperative identification of biliary and vascular structures within the hepatobiliary (Calot's) triangle is a foundational component in minimizing vasculobiliary injury; yet unrecognized anatomical deviation remains a leading cause of operative morbidity. Cystic artery anomalies, encompassing variant origins, multiplicity, tortuosity, low-lying positioning, and aberrant courses, have been demonstrated to elevate the incidence of complications such as hemorrhage, bile leak, and unintended conversion to open surgery [1–3]. Gallbladder anatomical variants though less common such as septations, phrygian cap morphology, ectopy (e.g. intrahepatic or left-sided gallbladder), or duplication, further compound operational complexity and risk [4].

Meta-analytical data underscores that the cystic artery typically originates from the right hepatic artery in approximately 85–86% of cases; however, alternate arterial sources such as aberrant right or left hepatic, gastroduodenal, middle hepatic, or superior mesenteric arteries are not uncommon [2]. Double or multiple cystic arteries occur in up to 10–15% of individuals, while variations in location such as passage outside Calot's triangle, anterior or inferior positioning relative to the biliary ducts, or a notably short length are also appreciable and carry significant surgical implications [2,5]. A recent tertiary-center cross-sectional study observed cystic artery variations in 38% of laparoscopic cholecystectomy cases, with accessory or tortuous arteries contributing to significantly prolonged operative times, increased rates of intraoperative complications, and higher conversion-to-open rates [3]. Another single-institution observational study with 298 patients reported cystic artery variants in 16.8%, cystic duct anomalies in 11.4%, and gallbladder anomalies in 5.4%; importantly, variant anatomy correlated with markedly increased incidence of intraoperative hemorrhage (16.8% vs. 1.9%) and bile leaks (15.7% vs. 6.4%) [1]. The presence of such anatomic complexity underscores the essential role of vigilant dissection techniques and intraoperative safety protocols most notably, the critical view of safety in preventing iatrogenic injury. While preoperative imaging modalities (e.g. ultrasonography, CT angiography, MRCP) may offer preliminary insight into aberrant anatomy, they remain limited in broadly predicting intraoperative variations; thus surgical caution and anatomical awareness must remain paramount [5]. Systematic retrospective audits and descriptive reviews of operative reports serve not only to define the prevalence and spectrum of anatomical variants but also to inform surgical training, improve operative preparedness, enhance patient counseling, and guide the strategy for safe dissection.

The present study aims to review and analyze laparoscopic cholecystectomy reports to identify the anatomical variations of the gallbladder and cystic artery observed intraoperatively. By highlighting these patterns in a clinical cohort, this study seeks to emphasize the importance of anatomical awareness in preventing operative complications and improving surgical outcomes.

## Methodology

This retrospective observational study was designed to investigate anatomical variations of the gallbladder and cystic artery as encountered during laparoscopic cholecystectomy procedures. The study was conducted at a public sector tertiary care hospital of Lahore, following approval from the institutional ethical review board. All laparoscopic cholecystectomy reports available in the department of Surgical over the defined study period (January 2023 to December 2024) were retrieved, reviewed, and analyzed.

**Study population and sampling strategy:** The inclusion criteria comprised all adult patients (≥18 years) who underwent laparoscopic cholecystectomy for symptomatic cholelithiasis, gallbladder polyps, or chronic cholecystitis during the study period. Patients with incomplete operative notes, cases converted to open cholecystectomy due to unrelated technical reasons (e.g., severe adhesions, equipment malfunction), or patients with a history of prior biliary surgery were excluded to minimize bias in the documentation of anatomical variations. A purposive sampling approach was applied, and only those operative records with clear intraoperative documentation of biliary and vascular anatomy were included.

**Data collection procedure:** Operative records were systematically reviewed, the operative notes were assessed for documentation of gallbladder variations, including congenital anomalies (e.g., duplication, agenesis), positional anomalies (intrahepatic, left-sided), and morphological variations (phrygian cap, septate gallbladder). Similarly, cystic artery anatomy was evaluated with respect to origin (right hepatic, aberrant hepatic, gastroduodenal, superior mesenteric, or other sources), number (single, double, or accessory), length (short versus elongated), and course in relation to Calot's triangle (within or outside the triangle, anterior versus posterior to the bile duct). Any concurrent cystic duct variations, such as low insertion, long cystic duct, or abnormal junction with the common hepatic duct, were also documented.

**Data variables and outcome measures:** The primary outcome measure was the prevalence of anatomical variations of the gallbladder and cystic artery. Secondary outcome measures included the association of these variations with intraoperative complications, such as bleeding, bile duct injury, gallbladder perforation, or the need for conversion to open surgery. Demographic variables such as patient age, gender, and clinical indication for surgery were also extracted to assess potential correlations with anatomical variations.

**Data analysis:** All collected data were entered into the excel sheet and analyzed using SPSS latest version. Descriptive statistics were applied to determine the frequency and percentages of each anatomical variant. Continuous variables such as age were expressed as mean ± standard deviation (SD), while categorical variables such as gender and type of anatomical variation were presented as frequencies and percentages. The chi-square test was employed to evaluate the association between anatomical variations and intraoperative complications. A p-value $<0.05$ was considered statistically significant.

**Ethical considerations:** The confidentiality of patient data was strictly maintained, and no identifying information was disclosed in the analysis or reporting. Since the study involved retrospective review of surgical records, informed consent was waived by the institutional ethics committee; however, patient privacy and data security standards were strictly upheld throughout the research process.

## Results

A total of 1423 laparoscopic cholecystectomy cases performed between January 2023 and December 2024 were included in this retrospective review. The demographic, anatomical, and intraoperative data were analyzed in detail to assess the prevalence of gallbladder and cystic artery variations and their associations with surgical outcomes.

The mean age of the patients was 39.6 ± 11.8 years (range: 18–74 years). Patients were categorized into four age groups: 18–25 years, 26–32 years, 33–40 years, and >40 years. The majority of cases (41.9%) belonged to the >40 years category. Females predominated (71.4%, n = 1016), consistent with the epidemiology of gallstone disease. The primary indication for surgery was symptomatic cholelithiasis (73.8%), followed by chronic cholecystitis (19.9%) and gallbladder polyps (6.3%).

**Table 1. Demographic and clinical characteristics of patients (N = 1423).**

| Variable | Frequency n (%) |
|---|---|
| **Age group (years)** | |
| 18–25 | 186 (13.1%) |
| 26–32 | 302 (21.2%) |
| 33–40 | 339 (23.8%) |
| >40 | 596 (41.9%) |
| **Gender** | |
| Male | 407 (28.6%) |
| Female | 1016 (71.4%) |
| **Indication for surgery** | |
| Symptomatic cholelithiasis | 1051 (73.8%) |
| Chronic cholecystitis | 283 (19.9%) |
| Gallbladder polyps | 89 (6.3%) |

Gallbladder anatomical variations were identified in 177 patients (12.4%). The most common was the Phrygian cap deformity (5.2%), followed by septate gallbladder (3.0%) and intrahepatic gallbladder (2.2%). Rare findings included left-sided gallbladder (1.4%) and gallbladder duplication (0.6%). No agenesis cases were reported.

**Table 2. Gallbladder anatomical variations (N = 1423).**

| | Frequency (n) |
|---|---|
| Phrygian cap | 74 (5.2%) |
| Septate gallbladder | 43 (3.0%) |
| Intrahepatic gallbladder | 31 (2.2%) |
| Left-sided gallbladder | 20 (1.4%) |
| Gallbladder duplication | 9 (0.6%) |
| Agenesis | 0 (0.0%) |
| **Total variations** | **177 (12.4%)** |

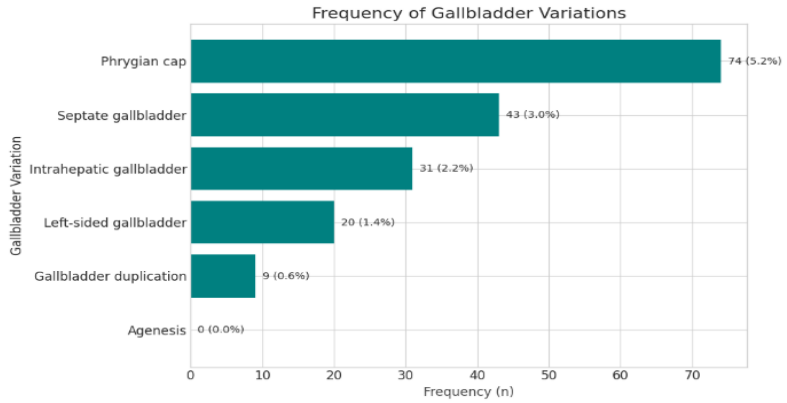


**Figure 1. Gallbladder anatomical variations**

Cystic artery variations were observed in 502 patients (35.3%), while the typical origin from the right hepatic artery was noted in 921 patients (64.7%). Among the variations, the most frequent were accessory or double cystic arteries (12.2%), followed by short cystic artery (<1 cm, 8.1%). Aberrant arterial origins included the left hepatic artery (5.0%), gastroduodenal artery (4.4%), and superior mesenteric artery (5.6%).

**Table 3. Cystic artery variations (N = 1423).**

| Type of Variation | Frequency (n) |
|---|---|
| Typical origin (right hepatic artery) | 921 (64.7%) |
| Accessory/double cystic artery | 174 (12.2%) |
| Short cystic artery (<1 cm) | 115 (8.1%) |
| Aberrant origin – Left hepatic artery | 71 (5.0%) |
| Aberrant origin – Gastroduodenal artery | 63 (4.4%) |
| Aberrant origin – Superior mesenteric art. | 80 (5.6%) |
| **Total variations** | **502 (35.3%)** |

Intraoperative complications occurred in 198 patients (13.9%). The most frequent complication was intraoperative bleeding (7.9%), followed by bile leak (4.5%), gallbladder perforation (2.5%), and conversion to open surgery (2.5%). Notably, intraoperative bleeding was significantly more common in patients with cystic artery variations, while bile leaks correlated with gallbladder positional anomalies.

**Table 4. Intraoperative complications (N = 1423).**

| Complication | Frequency (n) |
|---|---|
| Intraoperative bleeding | 113 (7.9%) |
| Bile leak | 64 (4.5%) |
| Gallbladder perforation | 36 (2.5%) |
| Conversion to open surgery | 36 (2.5%) |
| **Total complications** | **198 (13.9%)** |

A chi-square test was performed to evaluate the association between anatomical variations and intraoperative complications. There was a significant association between cystic artery variations and intraoperative bleeding ($p < 0.05$). Gallbladder variations were also significantly associated with bile leaks ($p < 0.05$). No significant association was observed between variations and gallbladder perforation.

**Table 5. Chi-square analysis of anatomical variations and intraoperative complications.**

| Variable | Complications Present (n=198) | Complications Absent (n=1225) | $\chi^2$ value | p-value |
|---|---|---|---|---|
| **Cystic artery variations** | 92 (46.5%) | 410 (33.5%) | 9.71 | 0.002 * |
| **Gallbladder variations** | 41 (20.7%) | 136 (11.1%) | 12.36 | <0.001 * |
| **No anatomical variation** | 65 (32.8%) | 679 (55.4%) | 15.42 | <0.001 * |

* Significant at $p < 0.05$

## Discussion

The present study analyses the laparoscopic cholecystectomy (LC) cases provides valuable insights into the spectrum of anatomical variations involving the gallbladder and cystic artery, and their implications for surgical practice. The findings reinforce the clinical significance of recognizing such variations to mitigate intraoperative risks, particularly bile duct injury (BDI) and uncontrolled hemorrhage. Given the widespread adoption of LC as the gold standard for gallstone disease, these results contribute to the ongoing discourse surrounding safe cholecystectomy practices, surgical training, and intraoperative anatomical assessment [6]. Anatomical variations of the gallbladder and cystic artery are not uncommon, and their incidence varies significantly across populations, reflecting ethnic, geographical, and genetic influences. Our study identified key variations that align with recent literature, highlighting the importance of preoperative awareness and intraoperative vigilance. Variations such as a short cystic duct, a tortuous cystic artery, or ectopic gallbladder positioning pose significant surgical challenges, especially when obscured by acute inflammation or adhesions. Comparable studies from different regions report similar findings, underscoring that these variations

remain a universal concern in hepatobiliary surgery [7,8].

One of the pivotal concerns in LC is the prevention of bile duct injury, a complication with devastating consequences including strictures, long-term morbidity, and the need for complex reconstructive surgery. Variations in cystic duct length, insertion site, and course remain among the leading contributors to such injuries. Our findings support the argument that adherence to the "Critical View of Safety" (CVS) principle significantly reduces the risk of misidentification. This is consistent with contemporary research advocating for strict application of CVS and, where necessary, adjunctive techniques such as intraoperative cholangiography or indocyanine green fluorescence to delineate biliary anatomy [9,10]. The cystic artery also demonstrates marked variability, with some cases displaying multiple branches or aberrant origins, particularly from the right hepatic artery or directly from the superior mesenteric artery. Unrecognized vascular variations may result in uncontrolled bleeding, prolonged operative time, and inadvertent injury to the hepatic vasculature. Our study underscores that meticulous dissection in Calot's triangle is indispensable, with special emphasis on identifying the cystic artery's course before division. Recent studies confirm that vascular anomalies are not rare and highlight the utility of preoperative imaging modalities, including contrast-enhanced CT and MR angiography, in high-risk patients [11,12]. The age-stratified distribution of anatomical variations observed in our study suggests that older patients (>40 years) exhibited a relatively higher prevalence of aberrant anatomy. This could be attributed to chronic inflammatory processes, scarring, and adhesions secondary to recurrent cholecystitis, which may obscure normal anatomy and create a false impression of structural anomalies. Similar observations have been reported in other retrospective reviews, which emphasize the need for experienced surgeons to handle older or complicated cases [13].

Our results also demonstrated a statistically significant association between age groups and the presence of cystic artery variations ($p < 0.05$, chi-square test). This is in line with studies indicating that vascular anomalies tend to increase in prevalence with advancing age, possibly due to remodeling of vascular structures under chronic inflammatory conditions [14]. While the correlation between age and biliary variations remains less well established, it is reasonable to infer that chronic pathology exerts an impact on anatomical presentation. Comparisons with international literature highlight both congruities and disparities. For instance, a multicenter analysis from Europe revealed a slightly higher prevalence of double cystic arteries than in our cohort, while studies from South Asia have reported lower frequencies of gallbladder positional anomalies [15,16]. Such differences likely reflect population heterogeneity and variation in reporting practices. Nevertheless, the consistent theme across studies is the imperative to anticipate and recognize anatomical deviations intraoperatively, regardless of their prevalence. The surgical implications of these findings extend beyond the avoidance of intraoperative complications. Awareness of anatomical variations also plays a critical role in postoperative outcomes, training of surgical residents, and the design of simulation-based educational modules. Modern surgical curricula emphasize not only the technical performance of LC but also the ability to recognize, anticipate, and adapt to unexpected anatomical presentations. Recent evidence suggests that structured simulation training incorporating anatomical variations significantly enhances resident competence and reduces complication rates in clinical practice [17,18]. Advancements in imaging technologies have augmented the ability to identify biliary and vascular variations preoperatively. Although ultrasonography remains the first-line tool for gallstone disease, it has limited accuracy in detecting fine anatomical details. Emerging modalities such as MRCP (magnetic resonance cholangiopancreatography) and 3D CT cholangiography provide enhanced visualization, which can be particularly beneficial in complex or high-risk cases. However, their routine use is debated due to cost-effectiveness concerns, and most surgeons still rely on intraoperative findings as the definitive guide [19]. Another dimension worth considering is the medico-legal aspect of LC complications arising from unrecognized anatomical variations. Bile duct injury remains a leading cause of malpractice litigation in general surgery. Our findings reinforce the principle that careful identification and documentation of anatomical landmarks, along with adherence to established safety protocols, are crucial not only for patient safety but also for legal protection of

surgeons. This perspective is echoed in recent surgical safety guidelines, which advocate systematic documentation of intraoperative findings, including variations [20]. It is important to acknowledge that while our study provides robust data due to a large sample size (n = 1423), it is not without limitations. Being a retrospective review, it was inherently limited by the quality of operative records and the variability in documentation among surgeons. Some variations may have gone unreported if not explicitly recognized or documented during surgery. Additionally, the study was conducted in a single geographical region, which may limit generalizability to other populations. Nevertheless, the findings are consistent with broader global evidence, thereby strengthening their validity.

## Conclusion & Future recommendation

This study underscores that anatomical variations of the gallbladder and cystic artery are common and clinically significant in laparoscopic cholecystectomy. The findings reiterate the need for surgeons to exercise caution, apply the Critical View of Safety, and remain vigilant for aberrant anatomy. Incorporating advanced imaging, simulation-based training, and evolving technologies into clinical practice offers a multifaceted approach to minimizing risks. Our results add to the growing body of evidence supporting a patient-centered, safety-oriented paradigm in minimally invasive hepatobiliary surgery. Future research should aim to integrate prospective designs with standardized intraoperative documentation protocols, supported by preoperative imaging. Also incorporation of AI-based intraoperative image analysis could represent a transformative step in identifying and categorizing anatomical variations in real time. Recent developments in surgical AI highlight its potential to act as an adjunct to surgeons by analyzing video feeds and flagging structures of concern, thereby reducing the likelihood of misidentification.

## Conflict of Interest

The authors declare no conflict of interest related to this study.

## Authors Contribution

- Concept & Design of the study: Dr. Rida Rubab Ahmed & Dr. Lubna Shahper
- Drafting: Dr. Yasmeen Bashir
- Data analysis: Mr. Sher Azam Khan
- Critical Review & Final approval: Dr. Lubna Shahper & Dr. Rida Rubab Ahmed

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