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Clinico-Anatomical Variations of Hepatobiliary Vasculature and Gallbladder Encountered during Laparoscopic Cholecystectomy

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ABSTRACT

Objective: To identify and document the clinico-anatomical variations of hepatobiliary vascular structures and gallbladder observed during laparoscopic cholecystectomy.

Methodology: This descriptive cross-sectional study was conducted at Fauji Foundation Hospital, Rawalpindi, Pakistan, from January 2024 to June 2025. A total of 350 patients who underwent elective laparoscopic cholecystectomy for symptomatic cholelithiasis were included. Intraoperative findings were carefully recorded to identify variations in the cystic artery, cystic duct, hepatic arteries, and gallbladder morphology.

Results: Out of the 350 patients who underwent laparoscopic cholecystectomy, 221 (63.1%) were female and 129 (36.9%) were male, with a mean age of 42.6±11.3 years. Clinico-anatomical variations were observed in 112 patients (32%). Cystic artery variations were noted in 84 patients (24%). The most common variation was a short cystic artery arising from the right hepatic artery (n=47; 13.4%), followed by a double cystic artery (n=21; 6%). In 16 cases (4.6%), the cystic artery originated from the aberrant right hepatic artery. Cystic duct anomalies were observed in 28 patients (8%), including low insertion (n=12; 3.4%), medial insertion (n=9; 2.6%), and short cystic duct (n=7; 2%). Anomalies in gallbladder position or shape were observed in 18 patients (5.1%). These included intrahepatic gallbladder (n=7), Phrygian cap deformity (n=6), and left-sided gallbladder (n=5).

Conclusion: Clinico-anatomical variations in hepatobiliary vasculature and gallbladder are frequently encountered during laparoscopic cholecystectomy. A thorough understanding of these variants is crucial for minimizing surgical risks and improving patient outcomes.

Keywords: Anatomic Variation, Bile Ducts, Cholecystectomy, Extrahepatic, Gallbladder, Hepatic Artery, Laparoscopic, Vascular System Abnormalities.

Authors' Contribution:
[1,2]Conception; Literature research; manuscript design and drafting; [3,4]Critical analysis and manuscript review; [5,6]Data analysis; Manuscript Editing.

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Introduction

Laparoscopic cholecystectomy is widely accepted as the gold standard for the treatment of symptomatic gallstones due to its minimally invasive approach, faster recovery, and reduced postoperative morbidity.[1] Despite its advantages, the procedure carries a risk of complications, primarily due to anatomical variations in the hepatobiliary region.[2] These include variations in the cystic artery, cystic duct, and gallbladder morphology, which can

increase the likelihood of intraoperative injuries, bleeding, or bile duct damage if not identified and managed appropriately.[3]

The cystic artery may show variations in origin, number, and course. It commonly arises from the right hepatic artery but may originate from aberrant sources such as the left hepatic artery, superior mesenteric artery, or directly from the celiac trunk.[4] Similarly, cystic duct anomalies such as low, medial, or high insertion into the common hepatic duct, or a short duct can complicate dissection and increase the risk of bile duct injury.[5] Gallbladder anomalies, though less frequent, such as intrahepatic gallbladder, Phrygian cap, or left-sided gallbladder, also pose diagnostic and operative challenges.[6]

Although preoperative imaging like MRCP may help detect some biliary anomalies, many vascular variations remain undetected until surgery. Therefore, surgeons must rely on meticulous dissection and identification techniques, such as achieving the critical view of safety (CVS), to minimize risks.[7] Regional studies are particularly valuable in understanding the prevalence and types of variations encountered in different populations.

In Pakistan, a few recent studies have documented the frequency of hepatobiliary anatomical variations. A study in Lahore reported cystic artery anomalies in 28% of cases, while another from Rawalpindi noted cystic duct and gallbladder anomalies in over 14% of patients undergoing laparoscopic cholecystectomy.[8,9] These findings highlight the importance of region-specific anatomical data for surgical planning and training.

This study aimed to identify and document the clinico-anatomical variations of hepatobiliary vasculature and gallbladder observed during laparoscopic cholecystectomy at a tertiary care hospital.

Methodology

This descriptive, observational study was conducted at the Department of General Surgery, Fauji Foundation Hospital (FFH), Rawalpindi, Pakistan, from January 2024 to June 2025. Ethical approval for the study was obtained from the Institutional Review Board (IRB) of the hospital, and informed consent was obtained from all patients before surgery. A total of 350 patients were included in the study through non-probability consecutive sampling. The sample size was calculated using the WHO calculator using the following parameters: 28% anatomical variations in cystic artery, 95% confidence level, and alpha error was 5%.[8] The study included adult patients aged 18 to 70 years who were admitted for elective laparoscopic cholecystectomy due to symptomatic cholelithiasis, gallbladder polyps, or chronic cholecystitis confirmed on ultrasound. Patients with a history of previous hepatobiliary or upper abdominal surgery, known congenital biliary anomalies, gallbladder carcinoma, or emergency cholecystectomy due to acute cholecystitis were excluded to avoid confounding intraoperative findings.

All patients underwent routine preoperative assessment, including complete blood count, liver function tests, and abdominal ultrasonography. In selected cases, magnetic resonance cholangiopancreatography (MRCP) was performed where gallbladder or ductal anomalies were suspected.

All procedures were performed by consultant general surgeons experienced in laparoscopic surgery using the standard four-port laparoscopic technique. Pneumoperitoneum was established using the open (Hasson) or Veress needle technique depending on the surgeon's preference. Dissection of the Calot's triangle was carried out carefully in all cases with emphasis on achieving the Critical View of Safety (CVS) before ligation and division of structures.

During surgery, the anatomy of the cystic artery, cystic duct, gallbladder morphology, and any accessory vessels or ducts were observed and documented. Particular attention was paid to variations such as short cystic duct, low or medial

insertion of the cystic duct, double cystic artery, aberrant origin of cystic artery (e.g., from left hepatic or superior mesenteric artery), intrahepatic gallbladder, and Phrygian cap. Photographs of variants were taken (with patient identity masked) for documentation and teaching purposes.

Data were collected on a pre-designed proforma by the operating team. This included demographic information, preoperative diagnosis, intraoperative findings (type of anatomical variation), operative time, need for conversion to open surgery, and intraoperative complications, if any. The collected data were entered into SPSS v 25 for analysis. Categorical variables were presented as frequencies and percentages. Continuous variables like age and operative time were presented as mean ± SD. Chi square test or independent t test was applied where appropriate, and a p-value of < 0.05 was considered significant.

Ethical issues were addressed in compliance with the ethical standards set by the **Ethical and Research Committee of Foundation University Islamabad Campus (Ref# FFH/SURG/15/24), HBS Medical College, (Ref# 09/HBSDC/IRB-2025), PAF hospital and Holy Family Hospital (157-HFH/IRB-2025)**

Results

A total of 350 patients underwent elective laparoscopic cholecystectomy during the study period. The mean age of patients was 43.7±12.5 years, with an age range of 18 to 70 years. Among them, 228 (65.1%) were female and 122 (34.9%) were male, reflecting the known higher prevalence of gallstone disease in females (Table 1).

Out of the 350 cases, clinico-anatomical variations in hepatobiliary structures were observed in 113 patients (32.3%), while 237 patients (67.7%) exhibited classical anatomy. The most frequently encountered variation involved the cystic artery, followed by cystic duct anomalies, and gallbladder morphological variations. Table 2 presents the distribution and types of anatomical variations documented during surgery. Cystic artery variations were identified in 77 cases (22.0%). The most common variation was a short cystic artery with early branching from the right hepatic artery. A double cystic artery was observed in a substantial subset, while some arteries had an aberrant origin such as from the left hepatic or gastroduodenal artery, or coursed anteriorly over the bile duct. Rare variations included cystic arteries originating from the left hepatic artery and gastroduodenal artery. These variations contributed to technical difficulty during dissection of Calot's triangle (Table 2)

The presence of cystic artery variations was significantly associated with increased operative time (mean: 64.2±11.7 minutes vs. 47.5±8.9 minutes, $p < 0.001$) and difficulty in achieving the critical view of safety (CVS).

Cystic duct anomalies were documented in 29 patients (8.3%). Among these, the most common was low insertion of the cystic duct into the common bile duct, followed by medial insertion and short cystic ducts. A parallel cystic duct course was seen in some cases (Table 2).

Patients with cystic duct anomalies had significantly longer operative times (mean: 61.4±10.6 minutes) compared to those with normal anatomy ($p < 0.05$). No bile duct injury was recorded, but conversion to open cholecystectomy was required in 2 patients (0.6%) due to unclear ductal anatomy.

Gallbladder morphological anomalies were seen in 17 cases (4.9%). These included: Phrygian cap deformity, Intrahepatic gallbladder, Left-sided gallbladder, and Septate gallbladder (Table 2).

In these cases, dissection was more challenging, and the critical view of safety was achieved with difficulty in 6 patients. No significant increase in complication rates was noted, but operative time was significantly prolonged (mean: 66.8±14.1 minutes, $p < 0.05$).

The mean operative time in the overall sample was 51.2±10.4 minutes. Patients with anatomical variations had significantly higher mean operative

times (62.1±11.2 minutes) compared to those with typical anatomy (45.6±7.9 minutes, p < 0.001) (Table 3). Conversion to open surgery was required in 4 cases (1.1%), all of which had complex anatomical variations. No major vascular or biliary injuries occurred. Minor complications such as gallbladder rupture or bleeding from Calot's triangle were recorded in 7 patients (2%), all managed laparoscopically.

Table I: Demographic characteristics of patients, (n=350)		
Variable	**Frequency**	**Percentage**
Gender		
Male	122	34.9
Female	228	65.1
Age group (years)		
18–30	78	22.3
31–45	142	40.6
46–60	94	26.9
>60	36	10.2
Mean Age (±SD)	43.7±12.5	

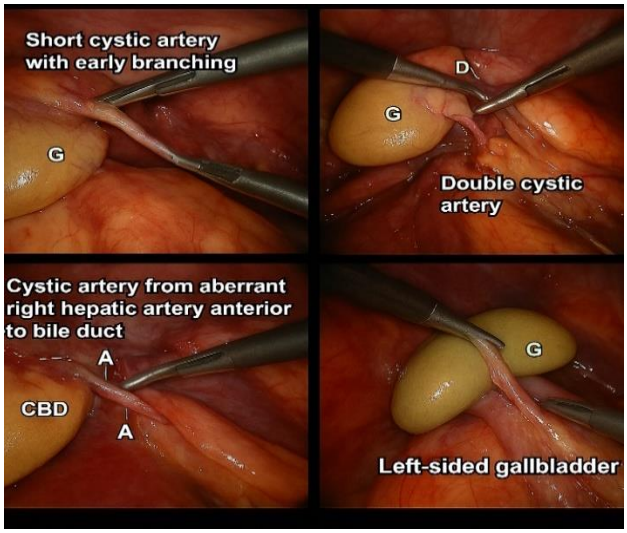

Figure 1: Intraoperative laparoscopic photographs showing anatomical variations of the hepatobiliary syste

Table II: Types and frequencies of anatomical variations, n=113	
Types of variation	**Frequency (Percentage)**
Cystic artery variations	
Short cystic artery	**36 (10.3)**
Double cystic artery	**18 (5.1)**
Aberrant right hepatic origin	**12 (3.4)**
Left hepatic artery origin	**8 (2.3)**
Gastroduodenal artery origin	**3 (0.9)**
Cystic duct variations	
Low insertion	**11 (3.1)**
Medial insertion	**9 (2.6)**
Parallel course	**3 (0.9)**
Gallbladder morphological variants	
Phrygian cap	**7 (2.0)**
Intrahepatic gallbladder	**5 (1.4)**
Left-sided gallbladder	**3 (0.9)**
Septate gallbladder	**2 (0.6)**

Table III: Operative parameters in patients with and without anatomical variations			
Parameter	**Variations present (n=113)**	**No variations (n=237)**	**p-value**
Mean operative time (minutes)	62.1 ± 11.2	45.6 ± 7.9	<0.001
Difficulty achieving CVS	28 (24.8%)	7 (2.9%)	<0.001
Conversion to open surgery	4 (3.5%)	0 (0%)	0.008
Minor complications	5 (4.4%)	2 (0.8%)	0.03

Discussion

This study evaluated the clinico-anatomical variations of hepatobiliary vasculature and gallbladder morphology observed during laparoscopic cholecystectomy. The anatomical variations were found in 32.3% of cases. The most

commonly encountered anomalies involved the cystic artery (22.0%), followed by the cystic duct (8.3%) and gallbladder morphology (4.9%). These findings are consistent with global literature, emphasizing the clinical importance of anticipating anatomical variations to reduce operative complications and improve patient safety. Our observation that cystic artery variations were the most frequent aligns with the results reported by Fateh et al who found cystic artery anomalies in 21.4% of patients undergoing laparoscopic cholecystectomy.[10] Similarly, Elshaer et al in a meta-analysis concluded that variations in the origin and course of the cystic artery were present in approximately 22% of cases, and were strongly associated with intraoperative challenges, especially during the dissection of Calot's triangle.[11]

The double cystic artery variant noted in 5.1% of our patients was nearly identical to the 5.3% reported by Hussain et al who highlighted the need for extra vigilance during clipping and ligation when this variation is present.[12] Importantly, our finding that a subset of cystic arteries originated from the left hepatic or gastroduodenal artery is consistent with anatomical studies by Courant et al which emphasized the potential for vascular injury in such configurations.[13] Regarding cystic duct variations, we noted a prevalence of 8.3%, with low insertion and medial joining being the most frequent types. This is comparable to the findings of Fujiwara et al who reported a 9.2% prevalence of cystic duct anomalies in their prospective cohort of laparoscopic cases.[14] Variations such as short cystic ducts or parallel cystic duct courses have been associated with bile duct injury risks if not clearly identified intraoperatively. Our data reinforce the importance of achieving the Critical View of Safety (CVS) prior to clipping to avoid such complications.

Morphological variations of the gallbladder were relatively less common in our study (4.9%), but still clinically significant. The most frequent variant was the Phrygian cap, followed by intrahepatic and left-sided gallbladders. These results are in agreement with the retrospective radiological study by Guimaraes et al, where gallbladder shape and position variants were noted in approximately 6.2% of patients, frequently leading to confusion in intraoperative orientation.[15] Similar challenges were highlighted by Ueda et al who noted that unusual gallbladder positions often necessitated longer dissection times and increased the risk of incomplete cholecystectomy.[16] In terms of operative outcomes, patients with anatomical variations had significantly longer operative times, greater technical difficulty in achieving CVS, and a higher rate of conversion to open surgery. These trends were mirrored in a recent audit by Alyan et al who observed that anatomical anomalies increased the operative time by 25–30% on average and were responsible for 90% of all conversions in their series.[17] Our findings highlight the value of intraoperative vigilance, preoperative imaging when feasible, and surgical training that emphasizes anatomical diversity. While modalities like MRCP may assist in selected cases, they are not routinely used due to cost and availability constraints, especially in low-resource settings. Although our study did not report any major bile duct or vascular injuries, the presence of anatomical variants clearly increased surgical complexity. This underlines the crucial role of meticulous technique, anatomical knowledge, and adherence to standardized safety protocols such as CVS, as also emphasized by Nichols et al in their analysis of surgical errors.[18]

Conclusion

This study highlights a high prevalence of clinico-anatomical variations in the hepatobiliary vasculature and gallbladder morphology among patients undergoing laparoscopic cholecystectomy, with one or more variations identified in nearly one-third of the cases. Cystic artery anomalies were the most frequently encountered, followed by cystic duct and gallbladder morphological variants. These variations were significantly associated with

increased operative time, technical difficulty, and a higher likelihood of conversion to open surgery.

Our findings underscore the critical importance of a thorough understanding of hepatobiliary anatomy and its variations for safe laparoscopic dissection. Routine use of the Critical View of Safety (CVS) technique, careful dissection of Calot's triangle, and intraoperative vigilance remain essential to minimize. The complications, especially in anatomically complex cases.

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