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"IMPACT OF ANATOMICAL AND PHYSIOLOGICAL VARIATIONS IN THE CYSTIC ARTERY AND SURGICAL RISK IN LAPAROSCOPIC CHOLECYSTECTOMY: A CROSS-SECTIONAL STUDY"

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Abstract

Background: Laparoscopic cholecystectomy (LC) is a commonly performed surgical procedure for gallbladder diseases. Despite being minimally invasive, LC carries a risk of complications, primarily due to anatomical and physiological variations in the hepatobiliary system, especially the cystic artery. An understanding of these variations is crucial to reduce intraoperative bleeding, bile duct injury, and conversion to open surgery.

Objective: To assess the prevalence and types of anatomical and physiological variations in the cystic artery and their impact on surgical risk during laparoscopic cholecystectomy.

Methodology: This cross-sectional study was conducted over a period of 12 months from January to December 2024 at a tertiary care teaching Hospital Lahore. A total of 150 patients undergoing elective laparoscopic cholecystectomy were included. Intraoperative findings regarding the anatomy of the cystic artery such as origin, course, number, and relation to the cystic duct were documented. Data on intraoperative complications, conversion rates, and operative time were also recorded. Descriptive statistics and chi-square tests were used for analysis. A p-value of <0.05 was considered statistically significant.

Results: Anatomical variations of the cystic artery were observed in 38% of cases. The most common variation was a double cystic artery (16%), followed by low-lying artery (12%), and artery arising from the right hepatic artery with a tortuous course (10%). Intraoperative complications occurred in 22% of cases with variant anatomy, compared to 6% in those with typical anatomy ($p = 0.01$). Mean operative time was significantly longer in patients with anatomical variations (78 ± 15 min vs. 56 ± 10 min, $p < 0.001$). Conversion to open surgery was required in 4 cases (2.6%), all of which had complex arterial variations.

Conclusion: Anatomical and physiological variations in the cystic artery are common and significantly increase the risk of intraoperative complications during laparoscopic cholecystectomy. Preoperative planning and meticulous dissection techniques are essential to minimize surgical risks. Awareness and anticipation of such variations can improve surgical outcomes and reduce the rate of complications and conversion to open procedures.

Keywords: Cystic artery, anatomical variations, laparoscopic cholecystectomy, surgical risk, intraoperative complications, gallbladder surgery.

Introduction:

Laparoscopic cholecystectomy (LC) has become the gold standard treatment for symptomatic gallbladder diseases, particularly cholelithiasis, due to its minimally invasive nature, faster recovery time, and reduced postoperative morbidity compared to open cholecystectomy. However, despite being routinely performed, LC is not without risk. One of the main challenges during the procedure arises from anatomical variations within the hepatobiliary system, especially involving the cystic artery. These variations can significantly complicate surgical dissection, increase the risk of intraoperative bleeding, and lead to iatrogenic injuries to the bile duct or surrounding structures[1, 2].

The cystic artery is typically described as a branch of the right hepatic artery, passing posterior to the cystic duct in the Calot's triangle. However, numerous anatomical studies and surgical case reports have documented wide variability in the cystic artery's origin, number, course, and its relation to the biliary and vascular structures. These deviations from the classical anatomy are not merely academic curiosities; they hold direct clinical relevance. Intraoperative recognition of atypical arterial anatomy is crucial for safe ligation and dissection. Misidentification or inadvertent injury to variant arteries may result in severe hemorrhage, prolonged operative time, or conversion to open surgery[3, 4].

In addition to anatomical variations, physiological differences such as vessel size, wall fragility, and regional vascularization patterns may further influence surgical outcomes. These factors may be particularly pronounced in patients with chronic inflammation or previous abdominal surgery, where distorted anatomy is more likely. Thus, a thorough understanding of both normal and variant anatomy of the cystic artery is essential for surgeons performing LC, as it directly affects their ability to carry out the procedure safely and efficiently[5, 6].

Previous studies have reported cystic artery variations in 20–50% of individuals, with some rarer configurations posing considerable surgical risk. Despite these findings, there is a lack of comprehensive data correlating specific anatomical variations with surgical outcomes such as intraoperative bleeding, conversion rates, and postoperative complications in the context of laparoscopic cholecystectomy. Most available literature is based on cadaveric studies or small retrospective series, making it difficult to draw definitive conclusions applicable to real-time surgical settings[7, 8].

This study aims to bridge that gap by systematically evaluating the anatomical and physiological variations of the cystic artery in patients undergoing laparoscopic cholecystectomy. It also seeks to quantify the associated surgical risks, providing practical insights for surgeons. By identifying patterns and establishing correlations between anatomical variations and intraoperative difficulties, this research can contribute to safer surgical practices, better preoperative planning, and improved patient outcomes[9, 10].

Objective:

To assess the prevalence and types of anatomical and physiological variations in the cystic artery and their impact on surgical risk during laparoscopic cholecystectomy

Methodology:

This study was designed as a cross-sectional and observational analysis conducted over a period of 12 months from January to December 2024 at the Department of General Surgery in a tertiary care teaching hospital Lahore. The primary aim was to assess the anatomical and physiological variations of the cystic artery and their association with surgical outcomes in patients undergoing laparoscopic cholecystectomy. A total of 150 patients who underwent elective laparoscopic cholecystectomy for symptomatic gallbladder disease were enrolled in the study following informed written consent. Ethical approval was obtained from the institutional ethics committee prior to commencement.

Patients were selected using purposive sampling. The inclusion criteria comprised adult patients aged between 18 and 70 years who were diagnosed with symptomatic cholelithiasis or gallbladder polyps and were scheduled for elective laparoscopic cholecystectomy. Patients with a history of prior hepatobiliary or upper abdominal surgery, acute cholecystitis, malignancy known vascular anomalies identified on imaging, or coagulopathies were excluded from the study. Those with intraoperative findings of severe inflammation leading to unclear anatomy were also excluded from analysis to minimize bias.

All surgeries were performed under general anesthesia by experienced laparoscopic surgeons using a standardized four-port technique. Intraoperatively, careful dissection was carried out to expose Calot's triangle. Observations were meticulously recorded regarding the number, origin, course, and relationship of the cystic artery to surrounding structures, particularly the cystic duct and right hepatic artery. Variations were categorized based on standard anatomical classifications. In addition, physiological factors such as vessel size and ease of dissection were noted.

Surgical parameters including operative time (from first incision to closure), intraoperative complications (notably bleeding, bile duct injury, and vascular trauma), and the need for conversion to open cholecystectomy were documented. Postoperative outcomes were followed up to assess any early complications. Data were compiled and analyzed using SPSS software version 25. Descriptive statistics were used to summarize the data, and chi-square tests and ANOVA were employed to assess associations between anatomical variations and surgical outcomes. A p-value of less than 0.05 was considered statistically significant.

Results:

A total of 150 patients underwent elective laparoscopic cholecystectomy during the study period. Among them, 93 patients (62%) exhibited typical cystic artery anatomy, while 57 patients (38%) demonstrated one or more anatomical variations. The most commonly encountered variation was the presence of a double cystic artery in 24 patients (16%), followed by a low-lying cystic artery in 18 patients (12%), and a tortuous artery with an atypical course in 15 patients (10%).

Anatomical variations were significantly associated with increased intraoperative complications. Among the 57 patients with anatomical variants, 21 (36.8%) experienced complications such as excessive bleeding, difficult dissection, or inadvertent vascular injury. In contrast, only 6 out of 93 patients (6.5%) with typical anatomy encountered intraoperative complications, a difference that was statistically significant ($p = 0.01$). Mean operative time was also prolonged in the presence of anatomical variations. The average operative time in patients with typical anatomy was 56 ± 10 minutes, while those with variations required significantly more time, with an average of 76 ± 15 minutes ($p < 0.001$).

Four patients (2.6%) required conversion to open cholecystectomy, all of whom had significant arterial variations two had low-lying arteries and one each had a double artery and a tortuous artery.

Table 1. Frequency of Cystic Artery Variations (n = 150)

Cystic Artery Type	Number of Patients (n)	Percentage (%)
Typical Anatomy	93	62.0%
Double Cystic Artery	24	16.0%
Low-lying Cystic Artery	18	12.0%

Tortuous Cystic Artery	15	10.0%
Total	**150**	**100%**

Table 2. Intraoperative Complications by Artery Type

Artery Type	Number of Patients (n)	Complications (n)	Complication Rate (%)
Typical Anatomy	93	6	6.5%
Double Cystic Artery	24	8	33.3%
Low-lying Cystic Artery	18	7	38.9%
Tortuous Cystic Artery	15	6	40.0%
Any Variation (total)	57	21	**36.8%**

Table 3. Operative Time by Artery Type

Artery Type	Mean Operative Time (min)	Standard Deviation (SD)
Typical Anatomy	56	±10
Double Cystic Artery	78	±12
Low-lying Cystic Artery	74	±14
Tortuous Cystic Artery	76	±13
With Anatomical Variations	**76**	**±15**

Table 4. Conversion to Open Surgery by Artery Type

Artery Type	Number of Patients (n)	Conversions to Open Surgery (n)
Typical Anatomy	93	0
Double Cystic Artery	24	1
Low-lying Cystic Artery	18	2
Tortuous Cystic Artery	15	1
Total	150	**4 (2.6%)**

Discussion:

This study highlights the prevalence and clinical significance of anatomical variations in the cystic artery among patients undergoing elective laparoscopic cholecystectomy. Typical cystic artery anatomy was observed in 62% of cases, while 38% of patients exhibited one or more variations, with the most frequent being a double cystic artery (16%), followed by low-lying (12%) and tortuous arteries (10%).

These findings are consistent with previously reported anatomical studies, which indicate that cystic artery variations occur in approximately 20–40% of the population. The presence of such variations is clinically relevant, as demonstrated by the significantly higher incidence of intraoperative complications in patients with variant anatomy (36.8%) compared to those with typical anatomy (6.5%; $p = 0.01$). The most common complications included excessive bleeding, difficult dissection, and inadvertent vascular injury all of which can compromise surgical safety and outcomes[11, 12].

Furthermore, our results indicate that anatomical variations are associated with prolonged operative times. Patients with normal anatomy had an average operative time of 56 ± 10 minutes, whereas those with variations required significantly more time (76 ± 15 minutes; $p < 0.001$). This increase may be attributed to the added complexity of identifying and safely managing aberrant vessels, as well as increased caution by the surgical team[13].

The need for conversion to open cholecystectomy, although low (2.6%), occurred exclusively in patients with variant arterial anatomy. This further underscores the importance of recognizing and anticipating these deviations preoperatively or intraoperatively to avoid complications and conversion[14].

Our findings reinforce the importance of meticulous dissection in Calot's triangle and suggest that awareness of common anatomical variants can improve intraoperative decision-making. In some

cases, the use of intraoperative imaging techniques such as indocyanine green fluorescence cholangiography or preoperative CT angiography may be valuable in high-risk or complex cases[15, 16].

Limitations:
This study is limited by its single-center design and moderate sample size. Moreover, anatomical variations were documented intraoperatively, which may introduce some observer bias. Future studies with larger, multicenter cohorts and preoperative imaging correlation could provide more robust data.

Implication:
The findings of this study emphasize the critical importance of recognizing cystic artery anatomical variations during laparoscopic cholecystectomy. Surgeons should anticipate potential deviations from typical anatomy, as these variations significantly increase the risk of intraoperative complications and prolong operative time. Preoperative planning and meticulous intraoperative dissection are essential to reduce the likelihood of vascular injury, bleeding, or conversion to open surgery. Incorporating surgical training that highlights common anatomical variants and using intraoperative imaging in complex cases may enhance safety and outcomes. Ultimately, increased awareness can improve patient care and reduce procedure-related morbidity in laparoscopic biliary surgery.

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