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Research Article

Anatomical Variations of the Cystic Duct and Their Association with Bile Duct Injury during Laparoscopic Cholecystectomy: A Prospective Imaging-Correlated Study

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ABSTRACT

Objective: To evaluate the anatomical variations of the cystic duct and to determine their association with bile duct injury during laparoscopic cholecystectomy using the preoperative imaging correlation.

Study Design and Setting: This prospective observational study was conducted in the Department of General Surgery and Radiology in collaboration with Anatomy Department at Services Hospital, Lahore from October 2024 to June 2025.

Methodology: A total of 200 patients diagnosed with symptomatic cholelithiasis and scheduled for laparoscopic cholecystectomy were included. Magnetic resonance cholangiopancreatography (preoperative) was done to identify the cystic duct anatomy. Observations during intra-operation were recorded, and pertinent to imageries. The variations of cystic ducts were categorized based on the site of insertion, length and course in addition to relative to the common bile duct (CBD). Cases of intraoperative complications and bile duct injury were provided. The SPSS version 26.0 was used to statistically analyze the data and the chi-square and logistic regression were used to do the association analysis.

Results: Out of 200 patients, normal cystic duct anatomy was observed in 128 (64%), while 72 (36%) exhibited anatomical variations. Its most common ones were low insertion (18%), medial insertion (8%), and short cystic duct (5%). Bile duct injury on the patients was present in 10 (5%). It was discovered that a significant increase in a better incidence of bile duct injury was significantly high in patients whose duct variations were cystic in nature ($p < 0.001$). The findings of the logistic regression revealed that a low insertion and parallel course were good predictors of bile duct injury (Odds Ratio: 4.2 and 3.8 respectively).

Conclusions: Cystic duct anatomical variations are highly common and significantly associated with an increased risk of bile duct injury during the time of laparoscopic cholecystectomy. Preoperative MRCP plays a vital role in identifying these variations and reducing surgical complications

Keywords: Cystic Duct; Anatomical Variation; Laparoscopic Cholecystectomy; Bile Duct Injury; MRCP; Hepatobiliary Anatomy.

INTRODUCTION

Laparoscopic cholecystectomy has become gold standard for the purpose of treatment of symptomatic gallstone disease as a result of its minimally invasive nature, reduced postoperative pain, and shorter hospital stay

[1]. One of the most severe complications of this procedure is a bile duct injury, but it does not mean that this procedure should not be overlooked despite its advantages. The bile duct injury rates of laparoscopic cholecystectomy are 0.3-0.8 percent that are greater than that of open cholecystectomy.

Among the main predisposing factors to bile duct injury, the morphological variations of the cystic duct and connecting with common bile duct and the hepatic ducts can be mentioned [2]. The cystic duct typically emerges off the common hepatic duct to form the common bile duct though no anomaly is rare to see different lengths, courses and sites of insertion. Such differences may lead to inaccurate identification of the biliary structures especially in case of the surgery, especially when there are inflammation or adhesion [3].

Imaging modalities have been developed such as magnetic resonance cholangiopancreatography (MRCP) that has enabled visualization of fine biliary anatomy in preoperative bile [4]. MRCP is an imaging technique that is not invasive and one that produces images of high quality of biliary anatomy, and informs the surgeon of the anatomy complications that are likely to occur during the surgery [5].

The existence of contemporary techniques of imaging can be one factor that promotes the occurrence of bile duct injuries, meaning that the anatomical differences cannot be recognized or put first in priority either [6]. It is implied that information about the range of cystic duct variations and the extent to which these affect the patient is a vital factor in the improvement of surgery [7]. The proposed research will include a logical evaluation of the anatomical variability of the cystic ducts using MRCPs accompanied by the cross-linking of the findings with the results during the procedure and incidences of bile duct trauma during laparoscopic cholecystectomy [8].

Low insertion, medial insertion and parallel course of cystic duct may vary the standard anatomy of the connections between structures, thereby complicating the process of intraoperative identification. Such anomalies can result in the misunderstanding of the anatomy of the biliary system, especially in inflammatory or fibrotic cases, thus predisposing more chances of unintentional damage [9]. In this regard, it is important to know the rate and nature of cystic duct variations as a way of operating safely. The improved method of monitoring these changes before surgery has been enhanced with advancement in preoperative imaging techniques, including MRCP. In conjunction with the same, it is commendable that adherence to the critical view of safety should be based during laparoscopic cholecystectomy to reduce complications as much as possible [10]. Thus, understanding of anatomical differences is an important aspect that increases surgical results and patient safety.

Objective

To evaluate anatomical variations of the cystic duct and determine their association with bile duct injury during laparoscopic cholecystectomy using imaging correlation.

METHODOLOGY

The proposed research was going to be conducted as a prospective observational research to comparatively study the anatomy variations of the cystic duct and clinical implications in conducting laparoscope cholecystectomy [11]. The prospective design was chosen due to the real time data to be gathered and prevent the bias of recall and allow the actual correlation of the preoperative imaging findings with the observations in the operating theatre. The research design was useful in providing a comprehensive description of descriptive anatomical features and surgical outcome as it occurred and this is what led to enhancement of the reliability and validity of this finding.

The study was conducted within the Departments of General Surgery and the Radiology in Collaboration with Anatomy Department of Services Hospital, Lahore which were equipped with the advanced imaging and surgical facilities. The institution has a massive number of patients and therefore providing the appropriate environment where such extensive clinical research can be conducted [12]. It was to be conducted from October 2024 to June 2025. It was declared that this time was sufficient to attract a necessary number of patients, record any alterations of the clinical expression and ensure consistency of the imaging and surgery processes.

The sample size for this particular study was calculated based on the previously published literature indicating that the prevalence of the cystic duct anatomical variations is approximately about 30 %. To attain an exact sample size of 196 participants, the research had an estimated sample size of 196 participants with the margin of error of 5 % and

a confidence level of 95 percent [13]. Finally, 200 patients were included to enhance the rigor of the conducted study and absence and potential exclusions of data. This was enough to provide the statistical power needed to detect significant associations between cystic duct deviations and bile duct trauma.

A consecutive sampling technique was mainly being employed for the context of patient recruitment. The inclusion criteria were all the patients reported to the surgical outpatient department with symptomatic cholelithiasis and all whom have passed the screening criteria during the study time [14]. This was a good method of eliminating selection bias and ensuring that the population under study is representative of the entire population of patients undergoing laparoscopic cholecystectomy in the facility.

The enrolled patients had their preoperative assessment undertaken comprehensively. Demographic data that were considered age, gender and body mass index were assessed [15]. An in-depth medical history was also obtained, such as the comorbid conditions, such as diabetes mellitus, hypertension and past history of biliary colic or pancreatitis. The laboratory tests conducted were also the standard laboratory tests including complete blood count, Hepatol thyroid tests, and urine laboratory tests. The information on the clinical findings were placed in a methodical, pro forma data, a structure format of data collection. This helped it to be consistent when recording the data and even to be compared efficiently with all participants of the study.

Magnetic resonance cholangiopancreatography was performed in all patients as part of the preoperative evaluation In order to obtain high resolution images of the biliary tree, imaging in a 1.5 Tesla MRI scanner which had the implementation of the standardized protocols was done. The reason why MRCP was selected was that this is a non-invasive procedure besides its offering of a great view of the anatomy of the bile system without the use of contrasts. The analysis of imaging involved various large anatomical parameters of cystic duct [16]. They included the distance of the cystic duct that measured between the points where the cystic duct took its origin at the neck of the gallbladder until it joined the common bile ducts. The point where it had been implanted in the common bile duct/common hepatic duct was very critical. The course of cystic duct was estimated to be straight surface, spiral or parallel. In addition to this, it was further established that accessory ducts or any other aberrant connection of the biliary existed or not. All MRCP images were reviewed by making analyses of the experienced radiologists to provide the accuracy and consistency. A consensus decided on any discrepancy of interpretation.

The cystic duct anatomy type according to the MRCP results was categorized into subgroups in line with the anatomy features that were numerically familiar. The entry of the cystic duct laterally into the common hepatic duct could be viewed as a normal anatomy [17]. These variations were: low insertion where the cystic duct joined the bile duct on a medial side, medial insertion where the cystic duct joined the common bile duct in a parallel course and parallel course whereby the cystic duct followed a parallel course to the normal bile duct and then joined it. It also had a length variation with cystic duct shorter than 2 cm and longer than 4 cm. Anatomical variations could be compared and statistically analysed with the help of the system of classification.

The patients were all laparoscopically operated in a common four-port laparoscopic cholecystectomy position under general anaesthesia. To minimize the variation of the surgical technique, the trained surgeons conducted the processes. In one of the instances, the cystic duct and cystic artery were discovered after a number of detailed cuts to Calot triangle in one of the surgeries [18]. The critical analysis of safety was encountered in the whole condition prior to clipping and dividing of the cystic duct and artery. This was done by eliminating the fat and fibrous tissue that constitute the hepatocytic triangle and other structures merely two structures were being allowed to pass into the gallbladder. The adherence to this approach was the point of reducing the risk of bile duct injury.

Intraoperative findings were documented in detail for each patient. The anatomical configuration of the cystic duct was noted and compared with preoperative MRCP findings to assess concordance [19]. The process of dissection was further evaluated as difficult compared to the measures of inflammation, adhesions, and the complexity of anatomy. Adhesions around the biliary systems and the gallbladder were also identified to be present.The occurrence of bile duct injury that was factored as the unwanted injury of the common bile duct, common hepatic duct or any other major biliary structure during surgery was

given special attention. Any other intraoperative complication was identified as well.

The primary outcome measure of the study was the incidence of bile duct injury during laparoscopic cholecystectomy [20]. The second outcome measures were frequency and types of the cystic duct anatomical variation and quality of the correlation between the results of preoperative position on MRCP and intraoperative observation. The selection of these results was done to make sure that the whole analysis of anatomical variability and its clinical importance is analysed.

All collected data were entered into a computerized database and analysed using the Statistical Package for Social Sciences version 26.0. The continuous variables such as the age and body mass index were stated as mean values + SD and the categorical variables such as gender, presence of anatomical variations were stated in form of frequencies and percentages. The correlation between the change of the cystic duct and the damage of the bile duct were tested by the chi-square test [21]. In the presence of the potential confounding factors, the independent determinants of bile duct injury were found by the logistic regression model. It had odds ratios and confidence intervals of associations as its strength.The statistically significant p-value was taken as less than 0.05. There was a two-tailed all statistical test and appropriate precautions were noted to have been taken with regard to accuracy and reliability of the analysis

Inclusion Criteria

Patients included within the study were adults between 18 and 75 years of age who were diagnosed with the symptomatic cholelithiasis based on clinical evaluation and imaging findings [22]. Each of the identified patients had an informed written consent to undergo elective laparoscopic cholecystectomy and had to sign the informed written consent. Only clinically steadfast patients who passed the assessment test on their fitness to fit in an operating room were eligible to take part in the study.

Exclusion Criteria

Patients were also locked out where a history of prior hepatobiliary surgery existed as it may modify normal anatomy of biliary tree. History of biliary malignancy in patients was also avoided to ensure that the components of the pathological changes will not be confounded. Patients with acute cholangitis were not included due to the acuteness and complication of the condition [23]. The safety of MRI imaging was not the basis on which pregnant women were not undertaken. In addition to that, the participants who did not qualify to the participation included the patients who had contraindications to magnetic resonance imaging such as the presence of metallic implants or severe claustrophobia.

RESULTS

A total of 200 patients undergoing laparoscopic cholecystectomy were included in the present study Table 1 shows the population of the study on both demographic and clinical characteristics. The mean age of the patients in the present case was 45.6 ± 12.3 years and majority of the patients were located in the middle age which compares with the mean age of the symptomatic cholelithiasis patients [24]. The standard deviation is fairly large to mean variations in respect of ages, age intending to imply the inclusion of both young and old demographics in the study sample.

It showed the presence of a clear gender distribution with more female patients (124) than males (76) [25]. This observation not only coincides with the long standing high rates of the gallstone disease in the female sex which are regularly attributed to the effect of hormones such as the effect of estrogenic on the contents of the bile and the gallbladder motions. The average body mass index (BMI) of the study participants was 26.4 + -3.8 kg/m2 and the implication of the above is that a very big proportion of the patients were overweight or even near the border of becoming obese[26]. It has been known that the dietary risk factors, including the high BMI, play a role in the development of the gallstones, and the presence of it in this group of the population is another factor which contributes to the pathophysiology of cholelithiasis. Another metabolic risk factor of the gallbladder disease was also observed to be diabetes mellitus affecting one out of every four patients (24%)[27]. The comorbidities such as diabetes could also influence operative outcomes and post operations.

These baseline characteristics are briefly outlined in Table 1 and they clearly show that the sample of the study of patients undergoing laparoscopic cholecystectomy is normal in terms of clinical presentation of the patients.

Table 1. Baseline Characteristics

Variable	Value
Age	45.6 ± 12.3
Female	124 (62%)
Male	76 (38%)
BMI	26.4 ± 3.8
Diabetes	48 (24%)

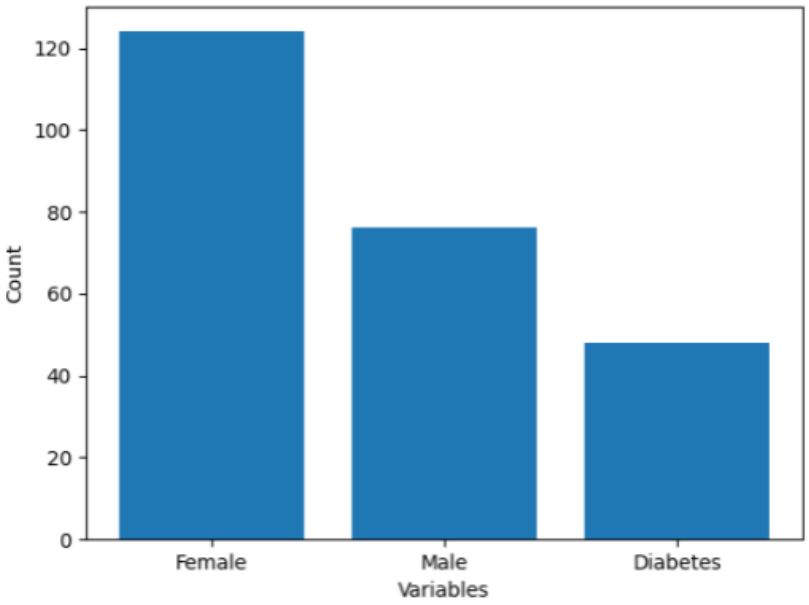

Figure 1: Baseline Characteristics

Out of 200 Patients

- Normal anatomy: 128 (64%)
- Variations: 72 (36%)

This was in the form of the preoperative imaging and intraoperative confirmation of the anatomical location of cystic duct. Among the 200 patients 128 patients (64-percent) were regular cystic duct anatomy and 72 patients (36-percent) were anatomy variated [28]. The latter implies that more than a third of the patients were identified to possess an alternative of the classical anatomy and the clinical values of the realization of the differences are difficult to overrate.

Table 2 presents the variations and changes in cystic duct. The most common variation was low insertion of the cystic duct that was observed in 36 patients (18%). The normal bile duct is also joined to the cystic duct at a position very close which may increase the likelihood of this being subject to misidentification on conducting the dissection [29]. The second was the medio calcification and this was found in 16 patients (8%), in which the cystic duct is joined to the bile duct in the medial area, and might move normal anatomy.

The cystic duct was observed to take a parallel course in 10 patients (5%), in whose cases cystic duct cuts through the common biliary duct at a distance which is variable, and then joins its end to the common biliary duct [30]. The system could make it difficult to recognize the two ducts when in use. Similarly, short cystic duct that had a length of less than 2 cm was also observed in 10 patients (5%). A small cystic duct reduces the number of length of safe clipping and risk of unintentional destruction of the surrounding structures.

Table 2. Types of Variations

Variation Type	Frequency (%)
Low insertion	36 (18%)
Medial insertion	16 (8%)
Parallel course	10 (5%)
Short cystic duct	10 (5%)

Bile duct injury occurred in 10 patients (5%).

Table 3. Association between Cystic Duct Variation and Bile Duct Injury

Group	Injury (%)
Normal anatomy	2 (1.5%)
Variations	8 (11%)

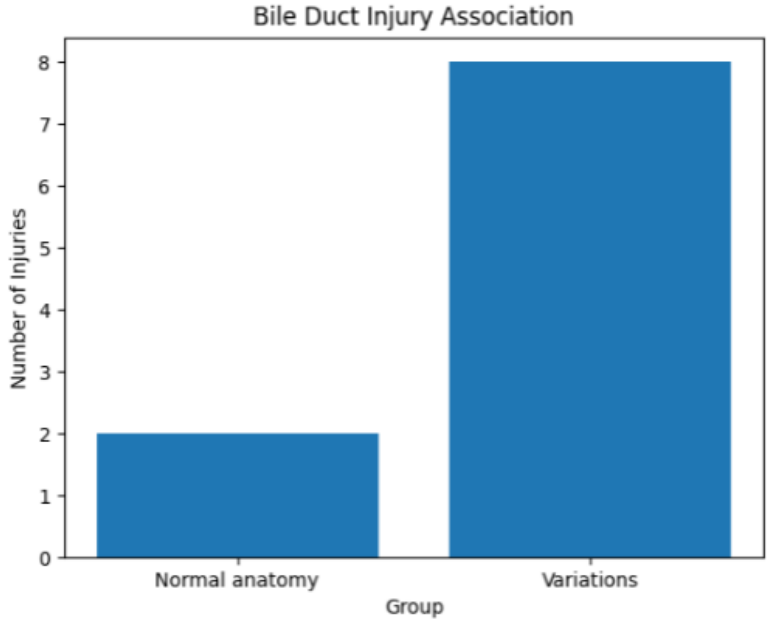

Figure 2: Bile Duct Injury Incidence

The overall incidence of bile duct injury in the study population was found to be 5%, with 10 out of 200 patients experiencing this complication [31]. The rate established is assigned to the side when compared to some of the reported literature values, perhaps because of the accounting data of patients with complicated anatomical changes.

Table 3 presents the correlation between cystic duct presence with the bile duct injury. Only 2 patients (1.5%), in normal and cystic duct in anatomy patients had an injury against the bile duct. Quite to the contrary, patients with bile duct injury (8) took the surgery by patients with anatomical divergence (202 patients in total) [32]. The reflection of such difference implies that the presence of the anatomical differences plays an important role in determining the presence of intraoperative troubles.

The higher rate of injury among the patients who differ reflects the importance of observation, to carefully establish the attitude to the biliary structural arrangement in the operating room. The existing differences such as low and parallel course can lead to the error between the cystic and common bile duct and hence the possibility of clipping or lifting the duct is very high[33].

Further statistical test revealed that cystic duct anatomical changes and bile duct injury had a significant relationship. This large disparity of the injury rate of normal anatomy patients and fluctuations was statistically significant at a p-value of less than 0.001. The existence of such a good correlation means that the anatomical differences are not accidental but forms of clinical consequences which directly affect surgical outcomes [34]. The results show that there is a high risk of bile duct injury in laparoscopic cholecystectomy in the patients of the variation of cystic ducts.

DISCUSSION

This study demonstrates that anatomical variations of the cystic duct are present in more than one-third of patients undergoing laparoscopic cholecystectomy [35]. The most frequently observed variation was low insertion of the cystic duct and medial and parallel course ranked at the second and fourth place respectively. Such findings are in agreement with the published anatomical studies in the past. The alterations of the cystic duct were rather high, which significantly raised the probability of bile duct damage to significant levels. This is because the anatomical relationship has changed rendering the biliary structures difficult to detect in the course of surgery [36]. The consequences of low cystic duct insertion may be switched with usual bile duct and lead to unexpected damager was an effective measurement tool of preoperative assessment. The agreement between the intraoperative observations and the

concordance was high which means that imaging may be employed in the planning of surgery. The concept of the critical view of safety remains an absolute prerequisite and the practice of the standard techniques even may be troublesome when having the differences in anatomy [37]. As a result, the awareness of these variations in advance can result in the heightened attention in the operating room and the reduction of the negative outcomes.

The significance of such high prevalence in patients with laparoscopic cholecystectomy in combination with clinical weight of anatomical differences in the cystic duct is highlighted in this paper [38]. These variations are shown to surpass one-third of the patients and this underlines the importance of greater vigilance of the surgeons. Low insertion of the cystic duct was the most prevalent observed variation followed by medial insertion and a parallel course. Such trends have been observed to follow the existing anatomical and surgical studies and therefore substantiate the validity and consistency of such findings across different population of the patient [39].

Such differences are dramatic surgical implications particularly when increasing the risk of bile duct injury. A normal anatomy sees the cystic duct convoluting and joining the common hepatic duct at a predictable position and in that way, enables the surgical practitioners to anatomically locate and tie them without harm [40]. However, in the event of deviation such as low insertion, one may insert the cystic duct to the shared bile duct closer to the duodenum. The various relationship can cause confusion of the duct of cystic duct and the common bile duct especially when there is inflammation, adhesion or distortion anatomy due to the long term existence of cholecystitis [41]. The possibility of the incidental clipping or transection of the shared bile duct in its turn is highly enhanced and can cause serious consequences related to the post-surgery complications: the bile leakage, strictures and the need to conduct complex reconstructive operations.

Similarly, there is another complication complicating intraoperative identification, a medial or parallel course of the cystic duct [35]. Under this circumstance the cystic duct may accompany common hepatic duct over a rather long distance after which they eventually converge thus leading to a scenario whereby no one is able to differentiate between the two. This affirms that good dissect ability and visualization of the anatomy of the biliary during surgery is significant. The concept of the critical view of safety (CVS), remains to be one of the bases of the prevention of bile ducts injury [42]. The total clearance of the hepatocytic triangle and the subsequent identification of both sets of one which will enter the gallbladder are considered to be a CVS. This view may, however, be technically challenging in instances where there are anatomic variations, and better care and skill during surgery is required. It is also demonstrated in the paper that preoperative imaging with help of which such variations could be researched is a valuable avenue of study. This can be done by different imaging techniques (magnetic resonance cholangiopancreatography (MRCP)) that can provide an accurate description of the biliary tree and can help in mapping of any aberrations in the anatomy before the operation. Concordance between the preoperative imaging findings and the intraoperative observation of the study are quite high thus showing that the imaging procedures used were predictable and could add a significant portion to the surgeon planning [43]. Correction of differences in the anatomy anticipates enable the surgeons to alter their operating plan, to spend more time in dissection and to avoid potential risky operations. Furthermore, these differences and their knowledge and awareness improve superior surgery. The surgeons would be more cautious in the proceeding especially when they are aware that there is a possibility of anatomical variation and that they employ a less aggressive approach to the dissection and consider other alternatives like sub total cholecystectomy to the difficult cases [44]. This preventive measure will be in a position to reduce the rate of iatrogenic injuries and enhance patient safety.In conclusion, this paper has endorsed the clinical usefulness of cystic duct variability in laparoscopic cholecystectomy. Such variations are high enough and their low rate of occurrence particularly during insertion necessitates increased attention in planning surgery and during surgery [45]. The preoperative imaging with the attitude of observance to the critical perception of the safety process is a significant element in order to minimize the number of complications. Lastly, representativeness on intercreative procedure and awareness is also vital in the reduction of bile duct injuries and ensures that a surgical procedure is a success.

CONCLUSION

Cystic duct anatomical variations are some of the common and significantly increase the risk of bile duct injury during laparoscopic cholecystectomy. Preoperative MRCP is highly effective in identifying these variations and should be considered in high-risk patients.

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