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Original Research Article

Learning curve in laparoscopic cholecystectomy: a prospective observational study

Sudhir B. Kavad*

Department of Surgery, GMERS Medical College and Hospital, Gandhinagar, Gujarat, India

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***Correspondence:**
Dr. Sudhir B. Kavad,
E-mail: suodhirkavad37566@gmail.com

ABSTRACT

Background: Laparoscopic cholecystectomy is the gold standard treatment for cholelithiasis. However, mastering laparoscopic skills requires structured training and experience. Evaluation of operative time, intraoperative complications, conversion rate, and hospital stay helps define the learning curve in laparoscopic.
Methods: A prospective observational study was conducted on 36 consecutive elective laparoscopic cholecystectomy cases. Parameters assessed included operative time, intraoperative complications, conversion to open surgery, need for senior assistance, and duration of hospital stay. Sequential case analysis was performed to assess improvement in surgical performance over time.
Results: The overall mean operative time was progressive reduction in later cases. Conversion to open surgery occurred in 8.33% of cases, predominantly in early cases. Intraoperative complications were more frequent during the initial cases and declined with increasing experience. The requirement for senior assistance decreased progressively. The mean hospital stay was 2-3 days, with shorter stays observed in later cases.
Conclusions: A definite learning curve exists in laparoscopic cholecystectomy, with significant improvement in operative time, reduction in complications, and decreased conversion rates. Supervised training and gradual exposure to increasing case complexity are essential for safe skill acquisition.

Keywords: Conversion rate, Hospital stay, Laparoscopic cholecystectomy, Learning curve, Operative time, Surgical training

INTRODUCTION

Gallstone disease (cholelithiasis) is a common hepatobiliary disorder affecting approximately 10-20% of adults worldwide, with higher prevalence among females, older individuals, and those with obesity, metabolic syndrome, diabetes mellitus, and dyslipidaemia.[1,2] While many patients remain asymptomatic, gallstones may cause clinical manifestations ranging from biliary colic to severe complications such as acute cholecystitis, choledocholithiasis, gallstone pancreatitis, and obstructive jaundice.[3] Gallstones are crystalline formations within the gallbladder resulting from bile supersaturation with cholesterol or bilirubin, combined with impaired gallbladder motility that promotes crystal nucleation and growth.[4] Diagnosis is primarily established by abdominal ultrasonography, the first-line investigation due to its high sensitivity, non-invasive nature, and cost-effectiveness.[5] Laboratory tests, including liver function tests and complete blood count, are useful when complications are suspected, while advanced imaging such as MRCP or ERCP is indicated for evaluation of suspected bile duct stones.[6] Recent advancements in surgical techniques, imaging, perioperative care, and enhanced recovery protocols have significantly improved the safety and outcomes of cholecystectomy.[7]

Treatment

The definitive treatment for symptomatic cholelithiasis is cholecystectomy. Laparoscopic cholecystectomy is considered the gold standard due to reduced postoperative pain, shorter hospital stay, faster recovery, and fewer complications compared to open surgery.[8] Open cholecystectomy is reserved for complicated cases or when laparoscopic intervention is contraindicated. Early surgical intervention is recommended to prevent recurrent symptoms and complications such as acute cholecystitis, gallstone pancreatitis, and choledocholithiasis.[9]

Cholecystectomy

Cholecystectomy is one of the most performed abdominal surgeries and is the definitive treatment for symptomatic Cholelithiasis and its complications. Laparoscopic Cholecystectomy is the standard approach due to reduced pain, shorter hospital stay, and faster recovery. Indications include symptomatic cholelithiasis, acute and chronic cholecystitis, gallstone pancreatitis (after stabilization), and choledocholithiasis following bile duct clearance. Additional indications include gallbladder polyps >10 mm and porcelain gallbladder due to malignancy risk.[10]

Types of cholecystectomies

Laparoscopic cholecystectomy

Laparoscopic cholecystectomy is the gold-standard treatment for symptomatic gallbladder disease.[11] It is a minimally invasive procedure using a laparoscope through 3-4 small incisions with pneumoperitoneum, providing magnified visualization for safe dissection.[12] Compared to open surgery, it offers less pain, shorter hospital stay, faster recovery, and fewer wound complications.[13] However, it may be challenging in severe inflammation, adhesions, or distorted anatomy, requiring expertise. It remains the preferred approach complications cases and is increasingly used in emergency settings.

Open cholecystectomy

Open cholecystectomy involves removal of the gallbladder through a right subcostal (Kocher's) incision. It was the standard treatment before minimally invasive technique and remains important in complex cases. It is indicated in severe inflammation, dense adhesions, suspected malignancy, difficult anatomy, bile duct injury, or when laparoscopic surgery cannot be safely continued.[14,15] Open surgery provides direct visualization and tactile feedback, improving safety in advanced disease.

However, it is associated with more pain, longer hospital stays, higher wound complications, and delayed recovery compared to laparoscopy. Despite this, it remains a vital and sometimes lifesaving procedure in difficult gallbladder disease.

Conversion cholecystectomy

Conversion cholecystectomy is the intraoperative shift from laparoscopic to open cholecystectomy when safe continuation is not possible. It is a prudent safety decision, not a failure of technique.[16] Common indications include dense adhesions, severe inflammation, distorted anatomy, uncontrolled bleeding, suspected bile duct injury, or technical difficulties. Conversion allows better exposure, tactile feedback, and safer dissection in complex cases. It reduces the risk of major intraoperative injury and prioritizes patient safety over procedural completion. Hence, it is considered a protective strategy rather than a complication

Subtotal (Partial) Cholecystectomy

Subtotal cholecystectomy is a modified "bail-out" procedure used when safe dissection of Calot's triangle is not possible. It involves leaving a portion of the gallbladder wall behind to reduce the risk of bile duct injury. It is indicated in severe inflammation, dense adhesions, frozen Calot's triangle, or distorted anatomy where complete removal is unsafe. The procedure enables safe completion of surgery and prevents major biliary or vascular injury. However, it may lead to bile leaks, retained stones, or recurrent symptoms. Despite this, it remains an important safety option in difficult gallbladder surgery.

Single-incision laparoscopic cholecystectomy (SILC)

Single-incision laparoscopic cholecystectomy is an advanced minimally invasive procedure in which the gallbladder is removed through a single umbilical incision. A specialized port allows insertion of the laparoscope and instruments, avoiding multiple incisions. Its main advantage is superior cosmetic outcome with a concealed scar, along with possibly reduced postoperative pain. However, SILC is technically more challenging due to instrument crowding, limited triangulation, and restricted movement. This may lead to longer operative time and increased surgeon fatigue, requiring advanced laparoscopic expertise. Therefore, SILC is not routinely performed and is reserved for selected patients with uncomplicated diseases and favorable anatomy.

Robotic cholecystectomy

Robotic cholecystectomy is a minimally invasive technique performed using a robotic system controlled by the surgeon. It provides 3D magnified vision and articulated instruments for enhanced precision, dexterity, and ergonomics. It is particularly useful in complex cases, allowing meticulous dissection and reducing surgeon fatigue. However, its use is limited by high cost, longer setup time, and limited availability. Thus, fatigue (inly performed in specialized centers but remains a promising evolving technique in hepatobiliary surgery.

Learning phases in laparoscopic cholecystectomy

Laparoscopic cholecystectomy is considered the gold standard treatment for gallbladder disease; however, it demands acquisition of specialized psychomotor, visual, and cognitive skills that differ significantly from open surgery. The learning curve represents the period during which a surgeon gradually attains efficiency, safety, and consistency in operative performance.[17] This progression can be broadly divided into the following phases.

Early learning phase (initiation stage)

Early learning phase (initiation stage) of laparoscopic cholecystectomy involves initial supervised cases with careful dissection and strict selection of uncomplicated patients (e.g., symptomatic cholelithiasis, thin-walled gallbladder, minimal adhesions).[18] It is characterized by longer operative time, difficulty with depth perception and 2D visualization, and frequent need for guidance.[19] Key skills acquired include safe pneumoperitoneum creation, port placement, instrument handling, and basic anatomical understanding. The primary focus is on patient safety and prevention of bile duct injury rather than operative speed.

Consolidation phase (skill development stage)

Consolidation phase (skill development stage) of laparoscopic cholecystectomy is marked by increasing confidence and improved efficiency. There is gradual reduction in operative time, better camera navigation, improved instrument control, and enhanced hemostasis, with ability to handle mild adhesions.[20] Key skills include consistent achievement of the critical view of safety, secure clipping of the cystic duct and artery, and systematic dissection. Surgeons become more independent with improved recognition of anatomical variations and decision-making.

Proficiency phase (competency stage)

Proficiency phase (competency stage) of laparoscopic cholecystectomy is characterized by stable and reproducible outcomes. Surgeons demonstrate consistent operative time, low complication and conversion rates, and improved operative flow with effective teamwork.[21] They can manage moderately difficult cases, including inflamed gallbladders, adhesions, and distorted anatomy. There is early recognition of complications and sound judgment, including timely conversion to open surgery when required.[22]

Advanced expertise phase

Advanced expertise phase of laparoscopic cholecystectomy involves highly experienced surgeons managing complex cases with efficient and confident dissection. They can safely perform bailout procedures (e.g., subtotal cholecystectomy), prevent and manage bile duct injuries, and maintain minimal conversion rates. Beyond operative skills, they teach trainees, develop protocols, contribute to audits, and implement enhanced recovery pathways. This phase reflects mastery in both surgical performance and improvement of patient safety systems.[23]

Clinical Importance of Learning Curve Assessment

Evaluation of the learning phases is important in teaching hospitals because operative time, complication rates, conversion rates, and hospital stay often improve significantly after the initial learning period. Structured supervision, careful case selection, and adherence to safe dissection principles- particularly obtaining the critical view of safety- are essential to minimize morbidity during early experience. Understanding these phases helps in designing surgical training programs, optimizing patient outcomes, and objectively assessing surgeon competency.

METHODS

Study design

This was a prospective observational study conducted in the department of general surgery at a GMERS Medical College and hospital Gandhinagar.

Study period

The study was conducted over a one-month period from 1st August 2024 to 31st August 2024.

Study population

A total of 36 patients undergoing laparoscopic cholecystectomy were included in the study.

Inclusion criteria

Patients diagnosed with symptomatic cholelithiasis. Patients fit for laparoscopic surgery.

Exclusion criteria

Acute cholecystitis. Complicated gallstone disease. Previous upper abdominal surgery.

Study methodology

All procedures were performed by a postgraduate trainee under the supervision of an experienced consultant surgeon. The cases were arranged chronologically and divided into three groups to assess the learning curve:

Study groups (learning curve in laparoscopic cholecystectomy)

Group A (12 cases)- elective, uncomplicated cholelithiasis, thin-walled gallbladder. Group B (12 cases)- elective, mild chronic cholecystitis, moderate adhesions. Group C (12 cases)- elective, chronic cholecystitis, thickened wall, difficult Calot's triangle.

Assessment parameters

Intraoperative- operative time, complications (perforation, bile spillage, bleeding), need for senior assistance, conversion to open surgery

Postoperative- Pain score, surgical site infection, length of hospital stay.

Statistical analysis

Data were analysed using appropriate statistical tests. Continuous variables were expressed as mean±standard deviation. Comparisons between groups were performed, and the p value of <0.05 was considered statistically significant.

RESULTS

Distribution and demographic of cases

A total of 36 patients undergoing laparoscopic cholecystectomy were included in the study and divided equally into three groups representing progressive learning phases All patients included in the study were above 25 years of age. Male patients constituted the majority of the study population (69.4%). The demographic characteristics were comparable across all three groups, with no statistically significant difference observed.

Table 1: Distribution and demographic of cases.

Parameters	Group A (%)	Group B (%)	Group C (%)	Total (%)	P value
Mean age	32.4±4.1	36.2±5.3	39.1±6.2	35.9±5.5	0.184
Age>25 year	12	12	12	36	
Male	8 (66.7)	9 (75)	8 (66.7)	25 (69.4)	0.823
Female	4 (33.3)	3 (25)	4 (33.3)	11 (30.6)	0.823

Operative time across learning phases

The mean operative time showed a statistically significant decline across the three groups (Table 2). Group A had the longest operative time (79.33±8.11 minutes), followed by group B (61.42±7.20 minutes), while group C demonstrated the shortest operative duration (51.33±6.12 minutes). The difference was highly significant (p<0.001), indicating improved surgical efficiency with increasing experience.

Table 2: Operative time across learning phases in group.

Groups	Mean operative time (minutes)	SD	P value
Group A	79.33	8.11	<0.001
Group B	61.42	7.2	
Group C	51.33	6.12	

Intraoperative complications

Intraoperative complications were more frequent in the early phase (Table 3). Gallbladder perforation occurred in 4 cases in group A and 3 cases in group B, with none in group C. Bile spillage was highest in group A (6 cases), decreased in group B (2 cases), and was minimal in group C (1 case). Intraoperative bleeding also declined from 3 cases in group A to none in group C. Requirement for senior assistance was highest in group A (7 cases), decreasing in group B (2 cases) and group C (2 cases).

Table 3: Intraoperative complications in group.

Complications	Group A	Group B	Group C
Gallbladder perforation	4	3	0
Bile spillage	6	2	1
Bleeding	3	1	0
Senior assistance required	7	2	2

Conversion to open surgery

Conversion rates showed a progressive decline with experience (Table 4). Conversion occurred in 2 patients (16.67%) in group A and 1 patient (8.33%) in group B, while no conversions were required in group C. The overall conversion rate was 8.33%.

Table 4: Conversion to open surgery.

Group=36	Conversions	Percentage
Group A=12	2	16.67
Group B=12	1	8.33
Group C=12	0	0

Postoperative outcomes

Postoperative recovery improved significantly across the groups (Table 5). Mean hospital stay decreased from 4.2 days in group A to 3.1 days in group B and 2.4 days in group C (p=0.002). Surgical site infection occurred in 2 patients in group A, 1 patient in group B, and none in group C. Postoperative pain scores also showed a statistically significant reduction, declining from 6.8 in group A to 3.2 in group C (p<0.001).

Table 5: Postoperative outcomes.

Parameters	Group A	Group B	Group C	P value
Mean hospital stay (days)	4.2	3.1	2.4	0.002
Surgical site infection	2	1	0	
Postoperative pain score	6.8	4.9	3.2	<0.001

Overall, operative efficiency, intraoperative safety, and postoperative recovery improved progressively with increasing surgical experience.

DISCUSSION

The present study confirms that laparoscopic cholecystectomy follows a clear and progressive learning curve, as reflected by reductions in operative time, intraoperative complications, conversion rates, and hospital stay with increasing surgical experience. These findings are consistent with earlier landmark studies in laparoscopic biliary surgery.[24]

The early multicentre prospective analysis by the southern surgeons club first demonstrated that outcomes of laparoscopic cholecystectomy improve significantly with surgeon experience. Their study showed that initial cases were associated with longer operative time and higher complication rates, followed by progressive improvement as familiarity with the technique increased. A similar pattern was observed in our study, where operative time decreased markedly across the learning phases, accompanied by a decline in complications and conversions.

Technical safety principles in laparoscopic cholecystectomy were later emphasized by Strasberg, who highlighted that most complications occur due to misinterpretation of biliary anatomy rather than lack of technical ability alone.[8] Strasberg's emphasis on meticulous dissection and clear identification of anatomical structures explains the reduction in gallbladder perforation, bile spillage, and bleeding observed in later cases in our series, reflecting improved anatomical orientation and adherence to safe surgical technique.

Similarly, the work of Hugh demonstrated that operative efficiency stabilizes only after repeated procedural exposure, with complication rates and conversions declining as surgeons gain confidence and experience.[25] Our findings parallel this observation, as later cases showed significantly shorter operative time, absence of conversions, and reduced need for senior assistance, indicating progression toward surgical proficiency.

Studies focusing on training outcomes, such as those by Moore and colleagues, also reported that operative time, blood loss, and intraoperative difficulties decrease with increasing case numbers.[26] Their emphasis on appropriate case selection during the early learning period supports our approach of including simpler elective cases initially, which likely contributed to the safe progression observed in our study.

Further training-based analyses by Khan have shown that measurable improvement in operative performance is often seen after approximately 15-20 cases, with better postoperative recovery and shorter hospital stay as surgeons gain proficiency. This is consistent with our findings, where hospital stay and postoperative pain scores declined significantly in later cases.

Additionally, the structured training research of Christopher Vinden emphasized that supervised learning, simulation exposure, and graded increase in case complexity can shorten the learning curve while maintaining patient safety.[33] The progressive improvement seen in our study similarly underscores the value of supervised surgical exposure and stepwise training.

Overall, the present study aligns closely with the existing body of literature, reinforcing that laparoscopic cholecystectomy proficiency develops gradually with experience. The progressive improvement in operative efficiency, intraoperative safety, and postoperative recovery observed in our series supports the widely accepted view that structured supervision, appropriate early case selection, and gradual exposure to complex anatomy are essential for safe acquisition of laparoscopic surgical skills.

This study has several limitations that should be considered while interpreting the findings. First, the sample size was relatively small (36 patients), which may limit the generalizability of the results to larger populations. Second, the study was conducted at a single tertiary care center, and therefore the outcomes may not reflect practices in different institutional settings or varying levels of surgical expertise. Third, all procedures were performed by a single postgraduate trainee under supervision, which may introduce operator bias and limit the applicability of results to surgeons with different levels of experience. Additionally, the study design was observational without a control group, which restricts the ability to establish causal relationships. Another limitation is the short follow-up period, which did not allow assessment of long-term outcomes such as late complications or recurrence of symptoms. Furthermore, patient selection was restricted to elective and relatively uncomplicated cases in the initial phase, which may underestimate the true challenges of the learning curve in more complex scenarios.

Finally, certain factors such as variability in patient anatomy, intraoperative decision-making, and subjective assessment of difficulty were not fully quantified, which could influence the interpretation of the learning curve.

CONCLUSION

The present study confirms the existence of a well-defined learning curve in laparoscopic cholecystectomy, with progressive improvement in operative performance as surgical experience increases. A significant reduction in operative time was observed across successive case groups, reflecting enhanced efficiency and technical proficiency. Intraoperative complications such as gallbladder perforation, bile spillage, and bleeding were more frequent during the initial phase but declined markedly with experience. The need for senior assistance and conversion to open surgery also decreased progressively, indicating improved surgical confidence and decision-making. Postoperative outcomes showed notable improvement, with reduced pain scores, shorter hospital stay, and lower incidence of surgical site infections in later cases. These findings highlight the importance of structured training, careful patient selection in the early phase, and adherence to fundamental safety principles such as achieving the critical view of safety. Supervised learning and gradual exposure to increasing case complexity are essential to minimize complications during the learning period. Ultimately, acquisition of laparoscopic skills is a stepwise process, and achieving proficiency ensures not only better operative outcomes but also enhanced patient safety. This study reinforces the need for systematic training programs to optimize the learning curve and improve overall surgical quality.

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