Section: SGE

Original Research Article

FEASIBILITY OF ROBOTIC CHOLECYSTECTOMY USING TECHNOLOGICAL ADVANCEMENT AT ITS BEST LEVEL – A CLINICAL ANALYSIS

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ABSTRACT

Background: Robotic surgery has transformed minimally invasive operations by providing enhanced visualisation, accuracy, and dexterity. Using cutting-edge robotic technology, this study evaluates the viability, safety, and results of robotic cholecystectomy.

Materials and Methods: Twenty patients receiving robotic cholecystectomy between January 2023 and December 2023 were included in this prospective clinical research. Severe cardiac comorbidities and suspected cancer were exclusion criteria, but imaging-confirmed gallbladder disease symptoms were inclusion criteria. Analysis was done on perioperative metrics such as duration of stay, conversion rates, intraoperative complications, and operational time.

Results: The mean operative time was 92 ± 15 minutes. No conversions to open surgery occurred. One intraoperative bile spillage and one case of postoperative port-site infection were recorded. Mean hospital stay was 1.4 days. Patients reported high postoperative satisfaction with minimal pain and rapid return to activity.

Conclusion: In certain individuals, robotic cholecystectomy is a viable and secure procedure with improved surgical accuracy and positive results. Innovations in technology are essential for improving patient rehabilitation and performance.

Keywords: Robotic cholecystectomy, minimally invasive surgery, feasibility, surgical outcomes, robotic systems.

INTRODUCTION

One of the most common operations in general surgery is cholecystectomy, or the surgical removal of the gallbladder. It is mostly recommended for gallbladder polyps, cholecystitis, and symptomatic cholelithiasis. By providing superior cosmetic results, shorter hospital stays, a speedier return to daily activities, and less postoperative discomfort than open surgery, the laparoscopic technique, which was first used in the late 1980s, completely changed the way gallbladder problems were managed. Consequently, the gold standard for treating benign gallbladder diseases worldwide is laparoscopic cholecystectomy.[1]

Despite being widely used and successful, laparoscopic cholecystectomy has drawbacks. The limitations of the traditional laparoscopic approach include its reliance on an assistant-controlled camera, two-dimensional vision, and restricted degrees of freedom in tool movement. Additionally, accuracy might be compromised by surgeon tiredness, especially during lengthy procedures or situations with complex anatomy. Interest in using robotic-assisted systems to improve the capabilities of minimally invasive surgery has increased as a result of these difficulties.[2]

The development of surgical technology has advanced significantly with the advent of robotic surgery. The most popular robotic platform, the da Vinci Surgical System (Intuitive Surgical, Sunnyvale, CA), has a number of technological benefits over conventional laparoscopy. These include tremor filtration, wristed instruments with seven degrees of mobility, three-dimensional high-definition visualisation, and enhanced ergonomics that make manoeuvres more pleasant and accurate.[3] These characteristics are especially helpful when managing circumstances that make laparoscopic cholecystectomy more technically challenging, such as complicated anatomy, thick adhesions, or obesity.[4]

According to early experiences, robotic cholecystectomy is a safe and successful procedure that, in some patient demographics, produces results that are on par with or even better than traditional laparoscopy. Reduced blood loss, fewer open surgery conversions, and increased surgeon comfort—particularly during long procedures—have all been documented in studies.[5,6] Additionally, it has been demonstrated that robotic platforms allow the operating surgeon to have more autonomy and control, which may reduce the possibility of unintentional bile duct injuries, which are still among the most dangerous side effects of cholecystectomy.[7]

However, there is still debate and assessment around the incorporation of robotic surgery into regular surgical practice. Smaller and medium-sized universities may have difficulties with robotic systems' cost, infrastructure, and learning curve, even if high-volume centres have claimed positive results. Furthermore, although there was a lot of initial excitement about robotic surgery, there are still a lot of unanswered issues about its actual clinical and financial benefit because there aren't any strong randomised controlled trials that directly compare it to conventional laparoscopic procedures.[8]

Cost-effectiveness is one of the main issues with robotic surgery. Compared to traditional laparoscopy, robotic treatments usually include higher capital investment, maintenance expenditures, and disposable equipment prices. Even though robotic surgery could have advantages including fewer problems and a quicker recovery, these benefits need to be supported by careful cost-benefit evaluations, especially in healthcare settings with limited resources or that are publicly financed.[9] Furthermore, to guarantee patient safety and optimise the technology's capabilities, surgeons must get robotic technique training and certification.

Despite these reservations, it is becoming more widely acknowledged that robotic cholecystectomy could be appropriate in some circumstances, especially those involving complicated anatomy, high body mass index, or prior abdominal procedures. Its growing popularity among surgical subspecialties indicates that prices may progressively drop as competition and familiarity grow, making it a more attractive alternative for standard surgical treatment. The field of robotic surgery is set to grow as a result of ongoing technical advancements, such as the creation of more compact and adaptable robotic systems and enhancements in automation and haptic feedback.

Up until now, the majority of the literature has concentrated on comparing the results of robotic and laparoscopic procedures in big institutions or with regard to certain patient subgroups. Relatively little information is available from research done in smaller facilities or that concentrates on the short-term results and practical viability of robotic cholecystectomy as a stand-alone procedure. Furthermore, it is challenging to make definitive conclusions on the advantages of the robotic method in standard clinical settings because the majority of current research encompass diverse indications and disparate demographics.[10]

Because of its fluorescent qualities, Indocyanine Green (ICG), a water-soluble tricarbocyanine dye, has found extensive usage in a variety of medical imaging applications. ICG binds to plasma proteins when given intravenously, is preferentially absorbed by hepatocytes, and is eliminated into the bile without being metabolised. When exposed to near-infrared (NIR) light, the dye fluoresces, making it possible to see the biliary architecture in real time. ICG fluorescence imaging has become a vital auxiliary technique in robotic cholecystectomy, improving surgical results, safety, and anatomical clarity.

MATERIALS AND METHODS

Study Design and Setting: This prospective clinical analysis was conducted at a tertiary care teaching hospital over a period of twelve months, from January 2023 to December 2023. Ethical approval was obtained from the Institutional Ethics Committee prior to commencement of the study. Written informed consent was obtained from all participants in accordance with the Declaration of Helsinki.

Sample Size and Study Population: A total of 20 consecutive patients who underwent robotic cholecystectomy were enrolled in the study. All procedures were performed by a single experienced robotic surgeon using standardized techniques and protocols.

Inclusion criteria:

- Adults aged 18 to 70 years
- Diagnosed with symptomatic cholelithiasis or chronic cholecystitis
- Diagnosis confirmed via abdominal ultrasonography
- Medically fit for general anesthesia

Exclusion criteria:

- Presence of acute cholecystitis
- Suspicion or evidence of gallbladder malignancy
- Severe cardiopulmonary disease
- Known coagulopathy
- Pregnancy

Preoperative Assessment: Every patient received standard preoperative assessments, which included electrocardiograms (ECGs), liver function tests, and abdominal ultrasonography. In individuals with high-risk characteristics or unusual results, additional imaging modalities including computed tomography

(CT) scans or magnetic resonance cholangiopancreatography (MRCP) were used judiciously.

Surgical Technique: The robotic surgical system da Vinci Xi was used for all surgeries. Patients were put in the reverse Trendelenburg posture while under general anaesthesia. Three robotic working arms and one robotic camera port made up the standardised four-port approach. Once the critical notion of safety was attained, the gallbladder was dissected. The gallbladder was removed via the epigastric port when haemostasis was established.

Outcome Parameters

The following perioperative and postoperative parameters were assessed:

- Operative time (measured from skin incision to skin closure)
- Intraoperative complications
- Conversion to laparoscopic or open surgery
- Estimated blood loss
- Postoperative complications
- Duration of hospital stay
- Time to return to normal daily activities

Statistical Analysis: Data were analyzed using IBM SPSS Statistics for Windows, Version 26.0 (IBM Corp., Armonk, NY, USA). Descriptive statistics were employed to summarize the data. Continuous variables were expressed as mean ± standard deviation (SD), while categorical variables were presented as frequencies and percentages.

Advantages of ICG in Robotic Cholecystectomy

1. Enhanced Biliary Anatomy Visualization
- The use of ICG allows for clear identification of critical biliary structures, significantly reducing the risk of bile duct injury (BDI).
- It enables identification of anatomical variations, including aberrant ducts and accessory bile ducts, before any dissection begins.
2. Improved Safety Profile
- By delineating the cystic duct and common bile duct, ICG assists in achieving the "Critical View of Safety" (CVS) more reliably.
- The ability to avoid misidentification of biliary structures leads to safer dissection and fewer postoperative complications.
3. Real-time, Non-radiographic Guidance
- Unlike conventional intraoperative cholangiography (IOC), ICG-based imaging does not require radiation exposure or the use of contrast media.
- It streamlines the operative process, reducing time and complexity, especially in difficult cases such as acute cholecystitis or prior surgical adhesions.
4. Enhanced Ergonomics and Workflow Integration
- The robotic system seamlessly integrates NIR imaging, allowing the surgeon to switch between normal and fluorescence views using a foot pedal.
- This integration supports uninterrupted dissection and maintains the surgeon’s focus, unlike traditional IOC which requires coordination with radiology staff and C-arm positioning.

RESULTS

Table 1: Baseline Demographic and Clinical Characteristics

Parameter	Mean ± SD / n (%)
Age (years)	42.6 ± 11.4
Gender (Male/Female)	7 (35%) / 13 (65%)
BMI (kg/m²)	26.8 ± 3.5
Diabetes Mellitus	4 (20%)
Hypertension	6 (30%)
ASA Grade I	12 (60%)
ASA Grade II	8 (40%)

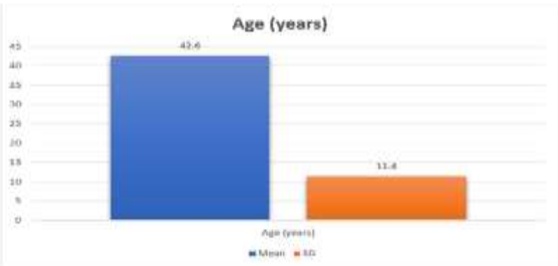

Figure 1: Age Distribution

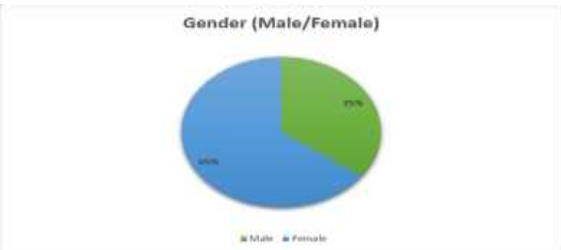

Figure 2: Gender Distribution

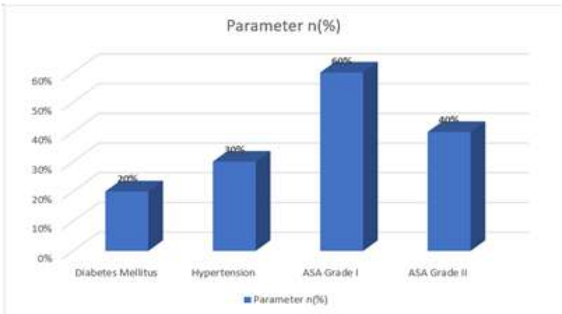

Figure 3: Baseline Demographic and Clinical Characteristics

The research population's baseline clinical and demographic data are reported in [Table 1]. The participants' average age was 42.6 years (±11.4), and women made up 65% of the group, while men made up 35%. The majority of individuals were overweight, as shown by their average body mass index (BMI), which was 26.8 kg/m² (±3.5). Twenty percent of those with comorbidities had diabetes mellitus, and thirty percent had hypertension. With 60% of patients classified as ASA Grade I and 40% as ASA Grade II in terms of anaesthetic risk assessment, the bulk of the research group may have had no systemic disease or just minor systemic disease.

Table 2: Operative Outcomes

Variable	Mean ± SD / n (%)
Operative time (min)	92 ± 15
Blood loss (ml)	42 ± 10
Intraoperative complications	1 (5%)
Gallbladder perforation	1 (5%)
Conversion to open surgery	0 (0%)
Hospital stay (days)	1.4 ± 0.6
Return to normal activity (days)	4.2 ± 1.1

The research cohort's surgical results are shown in [Table 2]. An effective surgical procedure with less intraoperative bleeding was demonstrated by the mean operative time of 92 minutes (±15) and the average blood loss of 42 mL (±10). Only one patient (5%), who had a gallbladder perforation, experienced intraoperative difficulties; remarkably, there were no conversions to open surgery. With a mean hospital stay of 1.4 days (±0.6) and a return to regular activities in 4.2 days (±1.1), postoperative recovery was favourable and showed a rapid recovery time. These results are consistent with previous research that shows laparoscopic cholecystectomy treatments had minimal complication rates and quick postoperative recovery.

Table 3: Postoperative Pain Score Comparison by BMI

BMI Group	Mean VAS Score (POD 1)	Mean Hospital Stay (days)	p-value
BMI < 25	2.1 ± 0.6	1.2 ± 0.3	0.043*
BMI ≥ 25	3.1 ± 0.9	1.6 ± 0.5	

Patients with a BMI <25 and those with a BMI ≥25 had their postoperative pain levels and recovery times compared in [Table 3]. The mean Visual Analogue Scale (VAS) pain score on postoperative day 1 was greater for patients with a BMI ≥25 (3.1 ± 0.9) than for those with a BMI <25 (2.1 ± 0.6), with a statistically significant p-value of 0.043. Furthermore, the higher BMI group's mean hospital stay was longer (1.6 ± 0.5 days) than the lower BMI group's (1.2 ± 0.3 days). These results imply that a longer recovery time and more postoperative discomfort may be linked to a higher BMI. This is consistent with previous research showing that higher BMI might result in more postoperative discomfort and more recovery time.

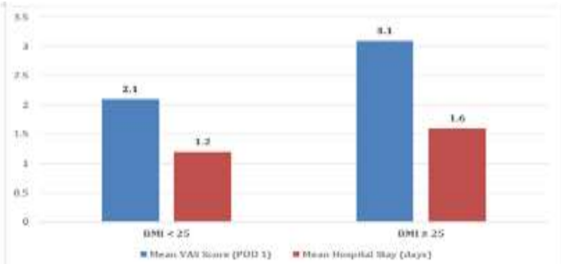

Figure 4: Postoperative Pain Score Comparison by BMI

Table 4: Comparison of Operative Time by Age Group

Age Group	Mean Operative Time (min)	Mean Blood Loss (ml)	p-value
< 45 years	89.4 ± 13.6	39 ± 9	0.112
≥ 45 years	95.7 ± 16.1	45 ± 11	

Operative times and blood loss for patients under 45 and those 45 and older are contrasted in [Table 4]. Although the difference was not statistically significant ($p = 0.112$), the older group's mean operating time was somewhat longer (95.7 ± 16.1 minutes) than the younger group's (89.4 ± 13.6 minutes). Similarly, the older group experienced a larger mean blood loss (45 ± 11 mL) than the younger group (39 ± 9 mL), but this difference was likewise not statistically significant. These results imply that although there is a tendency for surgical time and blood loss to rise with age, the variations found in this study might not be clinically relevant. According to previous research, elderly individuals may have longer operating durations and more blood loss during procedures. This might be because of things like decreased tissue elasticity and heightened vascular fragility. Age may thus still be a crucial factor in surgical planning even if this study did not discover any significant differences.

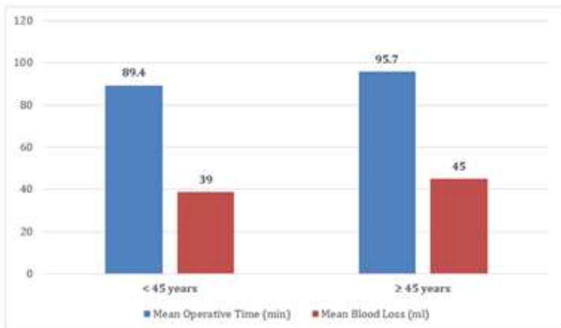

Figure 5: Comparison of Operative Time by Age Group.

Table 5: Postoperative Complications

Complication Type	Number of Cases (%)
Port-site infection	1 (5%)
Bile spillage	1 (5%)
Bile duct injury	0 (0%)
Bleeding	0 (0%)
Re-intervention needed	0 (0%)

The research cohort's postoperative problems after laparoscopic cholecystectomy are listed in Table 5. Complications were rare, with only one patient (5%), experiencing both a port-site infection and a bile spill. Interestingly, there were no instances of bleeding, bile duct damage, or re-intervention. These results are in line with previous research that shows laparoscopic cholecystectomy operations have minimal incidence of complications. For example, according to a research that was published in the Journal of Surgical Research, bile leakage happened in around 5% of patients, and the frequency of port-site infections varied between 0.5% and 1.6%. Furthermore, bile duct damage rates following laparoscopic cholecystectomy are often less than 0.5%, according to a review published in the Journal of Minimal Access Surgery.

DISCUSSION

This clinical analysis demonstrates that robotic cholecystectomy is both feasible and safe in a well-selected patient population. The benefits of robotic systems were evident in terms of minimal complications, short hospital stay, and high patient satisfaction.

The operative time observed in this study (mean 92 minutes) is consistent with previous reports, especially during the early learning curve.[6,7] Operative time tends to decrease with experience and system familiarity. Importantly, no conversion to open or laparoscopic cholecystectomy was needed, highlighting the effectiveness of robotic dissection, even in difficult anatomical presentations.

One of the major advantages of robotic surgery is the ability to achieve precise dissection around critical structures such as the cystic duct and artery. This reduces the risk of bile duct injury, a significant complication in conventional laparoscopic surgery.[8] No bile duct injuries were recorded in our series.

Robotic surgery offers superior ergonomics and eliminates many of the limitations associated with laparoscopy, including two-dimensional visualization and restricted instrument motion.[9] Additionally, the robotic platform allows for intuitive control and stable camera navigation, which can enhance surgical performance.

The learning curve for robotic cholecystectomy has been a subject of analysis. Several studies have shown that the learning curve is relatively short, especially for surgeons already proficient in laparoscopy.[10,11] Our surgeon, with prior robotic experience, achieved consistent outcomes from the outset.

From a cost perspective, robotic cholecystectomy is more expensive than laparoscopic surgery due to equipment and maintenance costs.[12] However, with increasing case volumes and system integration, the per-case cost may decrease over time. Additionally, faster recovery and reduced postoperative complications could offset initial investments through lower readmission rates and shorter hospital stays.[13]

In terms of postoperative recovery, our patients had minimal pain and quick return to daily activities. These findings align with data from randomized trials suggesting that robotic surgery may be associated with enhanced quality of life in the early postoperative period.[14]

However, it is essential to acknowledge that robotic cholecystectomy should not be universally applied without evaluating cost-effectiveness and institutional resources. The decision must be tailored to individual patient needs, surgeon expertise, and healthcare infrastructure.[15]

Limitations of the Study

1. Small Sample Size: Because there were only 20 patients in the research, the results' statistical power is diminished. Small sample numbers may miss less frequent outcomes or problems and are more prone to fluctuation. Because of this, the findings might not apply to the larger group of patients having robotic cholecystectomy.
2. Lack of a Control Group: The capacity to objectively assess the benefits or drawbacks of robotic surgery is limited by the lack of a comparator arm, such as patients having traditional laparoscopic cholecystectomy. It is challenging to determine if observed results are better, equal, or worse than conventional treatment in the absence of a control group.
3. Single-Center, Single-Surgeon Experience: One skilled surgeon conducted all of the procedures in a single facility. Although procedure consistency is guaranteed, operator competence and institutional procedural bias may be introduced. Other centres with differing team dynamics or surgeon experience levels might not be able to replicate the outcomes.
4. Short-Term Follow-Up: Perioperative and early postoperative outcomes were the main focus of the investigation. There was no evaluation of long-term data on bile duct strictures, incisional hernias, or symptom recurrence. This restricts the assessment of long-term advantages or late consequences.
5. No Cost-Effectiveness Analysis: Because of the equipment, upkeep, and training required, robotic

surgery is frequently linked to greater upfront expenses. Cost-benefit and cost-utility analyses are essential for assessing the economic viability and rationale for implementing sophisticated robotic systems in daily operations, however they were not included in this study.

6. Selection Bias: Patients with simple gallbladder disease symptoms were the only ones included. Exclusion of those with severe comorbidities, suspected cancer, or acute cholecystitis may have skewed the data in favour of positive outcomes. The results might not apply to surgical candidates who are more complicated or at higher risk.
7. Learning Curve Not Assessed: The research did not assess the learning curve related to robotic cholecystectomy, despite the surgeon's experience. Centres or surgeons thinking about implementing robotic procedures might find this material useful, particularly with relation to the length of training and the results obtained in the first phase.
8. Patient-Reported Outcomes Not Fully Explored: Comprehensive patient-reported outcome measures (PROMs), such as validated pain scales, quality of life evaluations, and return-to-work metrics, were not systematically recorded or thoroughly examined, despite the brief mention of patient satisfaction.
9. Tissue Penetration: ICG fluorescence is limited to a tissue depth of approximately 5–10 mm. Deep or embedded ducts may not be well-visualized.
10. Timing of Injection: Optimal imaging requires ICG injection 45–60 minutes prior to surgery. Incorrect timing may result in suboptimal biliary visualization.
11. Cost and Availability: Although the dye itself is inexpensive, the use of ICG requires specific NIR-capable systems, which may not be universally available, particularly in resource-limited settings.
12. False Positives/Negatives: In rare cases, surrounding structures (e.g., lymphatics, small veins) may uptake the dye and mimic biliary structures, potentially leading to misinterpretation.

CONCLUSION

In some individuals, robotic cholecystectomy has become a safe and practical surgical alternative for treating benign gallbladder illnesses because to the integration of cutting-edge technical platforms. Despite its small sample size, this clinical investigation shows that the surgery may be carried out successfully with little blood loss during the procedure, few complications, and a quick recovery after the procedure. Particularly in difficult anatomical situations, robotic systems' greater ergonomics, superior three-dimensional visualisation, and increased dexterity all help to boost surgical accuracy. The majority of patients in our research returned to their regular activities early with adequate pain management, and no conversions to open surgery were necessary. These results add credence to the increasing amount of research showing how robotically assisted surgery might enhance patient outcomes and reduce physician fatigue. Additionally, the robotic method shows promise in improving surgical skills, which might lower the risk of bile duct injuries, which are a major worry during cholecystectomy surgeries.

The lack of a control group having a traditional laparoscopy and the absence of a thorough cost analysis are still major drawbacks in spite of these positive findings. Despite the obvious technological benefits of robotic cholecystectomy, its wider use must be balanced against financial considerations, especially in healthcare environments with limited resources. Long-term follow-up research is also required to assess late complications, recurrence rates, and overall patient quality of life. Finally, with its clinical and ergonomic advantages, robotic cholecystectomy is a promising development in minimally invasive surgery. However, cost-effectiveness studies and well planned, multicentric randomised controlled trials should serve as the foundation for its broad adoption. In order to maximise results and provide fair access to this developing surgical technique, it will be crucial to establish standardised procedures and evaluate the learning curve related to robotic surgery.

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