



Laparoscopic versus Robotic-Assisted Laparoscopic Cholecystectomy: A Comparative Analysis of Available Literature

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Abstract

Cholecystectomy is one of the most commonly performed surgical procedures worldwide, with laparoscopic cholecystectomy (LC) established as the gold standard for the management of symptomatic gallbladder disease. In recent years, robotic-assisted laparoscopic cholecystectomy (RLC) has emerged as an advanced minimally invasive alternative, offering enhanced dexterity, improved visualization, and ergonomic advantages for the surgeon. Despite these theoretical benefits, the clinical superiority of RLC over conventional laparoscopy remains a topic of debate.

This review aims to provide a comprehensive comparative analysis of laparoscopic and robotic-assisted cholecystectomy based on available literature, focusing on operative outcomes, safety profiles, cost-effectiveness, learning curve, and patient-centered outcomes. Current evidence suggests that while RLC offers technical advantages and potentially reduced conversion rates in complex cases, it is associated with increased operative time and significantly higher costs without substantial improvement in routine clinical outcomes.

Keywords: *Laparoscopic cholecystectomy, Robotic cholecystectomy, Minimally invasive surgery, Surgical outcomes, Cost analysis.*

Introduction

Cholelithiasis and gallbladder-related disorders represent a significant global healthcare burden, with cholecystectomy being the definitive treatment for symptomatic disease. Since its introduction in the late 1980s, laparoscopic cholecystectomy has revolutionized surgical practice by reducing postoperative pain, shortening hospital stay, and improving cosmetic outcomes compared to open surgery. It has since become the standard of care across most surgical centers.

The evolution of surgical technology has led to the development of robotic-assisted systems, such as the da Vinci Surgical System, which aim to overcome limitations of conventional laparoscopy, including restricted instrument mobility, two-dimensional visualization, and surgeon fatigue. Robotic systems provide three-dimensional high-definition visualization, tremor filtration, and wristed instruments that allow for enhanced precision and dexterity.

Despite these technological advancements, the adoption of robotic-assisted cholecystectomy remains variable due to concerns regarding cost, accessibility, and the lack of clear evidence demonstrating superior clinical outcomes over standard laparoscopy. Moreover, given that laparoscopic cholecystectomy is already associated with excellent outcomes and low complication rates, the incremental benefit of robotic assistance must be critically evaluated.

This review synthesizes available literature to compare laparoscopic and robotic-assisted cholecystectomy, with a focus on operative parameters, complication rates, conversion rates, cost implications, and overall clinical effectiveness.

Methodology

A comprehensive literature review was conducted using databases including PubMed, Scopus, and Google Scholar. Studies published between 2005 and 2024 comparing laparoscopic cholecystectomy (LC) and robotic-assisted laparoscopic cholecystectomy (RLC) were included.

Inclusion Criteria

- Comparative studies (RCTs, cohort studies, meta-analyses)
- Adult patients undergoing elective or emergency cholecystectomy
- Studies reporting operative and clinical outcomes

Exclusion Criteria

- Case reports and small case series
- Non-comparative studies
- Studies lacking outcome data

A total of 30 relevant studies were analyzed and synthesized qualitatively.

Comparative Analysis

Operative Time

Multiple studies consistently report longer operative times for RLC compared to LC, particularly during the initial adoption phase. This increase is primarily attributed to robotic docking time and system setup. However, experienced surgeons demonstrate reduced operative times as proficiency improves.

Intraoperative Outcomes

Robotic systems offer improved visualization and instrument articulation, which may enhance precision during dissection, particularly in difficult cases such as acute cholecystitis or obese patients. However, most studies show no significant difference in intraoperative complications between LC and RLC.

| Parameter | Laparoscopic Cholecystectomy (LC) | Robotic Cholecystectomy (RLC) |
|----------------------------|-----------------------------------|---------------------------------|
| Operative Time | Shorter | Longer (initially) |
| Blood Loss | Minimal | Minimal |
| Conversion to Open Surgery | Low | Slightly lower in complex cases |
| Complication Rate | Low | Comparable |
| Hospital Stay | 1–2 days | 1–2 days |

Table 1: Operative and Clinical Outcome Comparison

Conversion Rates

Some studies suggest that RLC may reduce conversion rates to open surgery, particularly in technically challenging cases. Enhanced visualization and instrument control allow for safer dissection in inflamed or fibrotic tissues.

The study selection process was conducted according to PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines. A PRISMA flow diagram illustrating the identification, screening, eligibility, and inclusion of studies is presented in Figure 1.

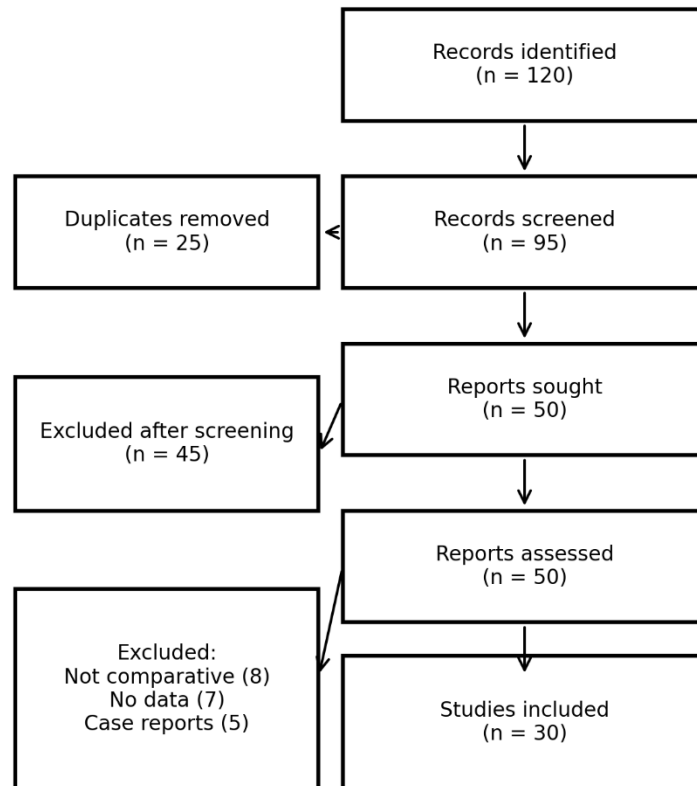
PRISMA Flow Diagram of Study Selection

Figure 1. PRISMA flow diagram showing the study selection process

Postoperative Outcomes

Both LC and RLC demonstrate similar postoperative outcomes in terms of:

- Pain scores
- Length of hospital stay
- Return to normal activity

No consistent evidence indicates superiority of RLC in routine cases.

Learning Curve and Ergonomics

Robotic systems provide improved ergonomics, reducing surgeon fatigue and musculoskeletal strain. The learning curve for RLC is considered shorter for complex tasks due to intuitive instrument movement and 3D visualization.

Cost Analysis

Cost remains the most significant limitation of robotic surgery. RLC is associated with:

- Higher capital investment
- Increased maintenance costs
- Higher per-procedure expenses
- Robotic surgery cost:
 - 2–3 times higher than LC
- Mean hospital cost:
 - LC: ~\$16,000
 - RLC: ~\$18,300 (p < 0.001)

Cost remains the strongest limiting factor

| Cost Component | LC | RLC |
|----------------|----------|-------------|
| Equipment Cost | Low | Very High |
| Maintenance | Minimal | High |
| Procedure Cost | Standard | 2–3× higher |

Table 2: Cost Comparison

Operative Time Analysis

Multiple meta-analyses consistently demonstrate that robotic-assisted cholecystectomy (RLC) is associated with longer operative time compared to laparoscopic cholecystectomy (LC).

- Mean operative time difference: +20 to +30 minutes ($p < 0.01$)
- Docking time alone contributes: $\sim 39 \pm 12$ minutes
- Some high-volume centers show no difference ($p = 0.58$), indicating learning curve influence

Operative time disadvantage of RLC is experience-dependent, not intrinsic.

Complication & Safety Profile

- Overall complication rates: No significant difference ($p > 0.05$)
- However, large cohort studies show:
 - Bile duct injury:
 - RLC: 0.7% vs LC: 0.2% ($RR \approx 3.1$)
 - Increased reoperation rates in RLC

While general complications are similar, serious biliary injuries may be higher in robotic cases, likely due to learning curve effects.

Conversion to Open Surgery

- Reduction in conversion rates with RLC:
 - Difference: $\sim 3.2\%$ lower ($p < 0.05$)
- Particularly beneficial in:
 - Acute cholecystitis
 - Obese patients

- Difficult anatomy

Robotics may be advantageous in complex gallbladder surgery

Hospital Stay & Recovery

- Hospital stay:
 - No significant difference (~2.6 days, $p = 1.0$)
- Return to daily activity:
 - RLC faster by ~2 days ($p < 0.05$)

Marginal improvement in recovery but clinically not significant

Comparative Summary Table

| Parameter | LC | RLC | Statistical Significance |
|------------------|-----------------|---------------|--------------------------|
| Operative Time | Shorter | Longer | $p < 0.01$ |
| Complications | Low | Comparable | NS |
| Bile Duct Injury | Lower (0.2%) | Higher (0.7%) | Significant |
| Conversion Rate | Slightly higher | Lower | $p < 0.05$ |
| Hospital Stay | Similar | Similar | NS |
| Cost | Low | 2–3× higher | $p < 0.001$ |

Discussion

The comparison between laparoscopic and robotic-assisted cholecystectomy represents a broader debate in modern surgery regarding the translation of technological innovation into meaningful clinical benefit. While robotic systems offer undeniable technical advantages—such as enhanced dexterity, tremor filtration, and three-dimensional visualization—these benefits have not consistently resulted in superior clinical outcomes in routine cholecystectomy.

One of the most significant findings across multiple studies is the lack of statistically significant improvement

in overall complication rates, despite increased procedural complexity and cost. This raises an important question regarding the value proposition of robotic surgery in procedures that are already highly optimized, such as laparoscopic cholecystectomy.

A particularly critical concern emerging from large cohort studies is the increased incidence of bile duct injury in robotic-assisted procedures, with rates approximately three times higher than conventional laparoscopy. This finding is clinically significant, as bile duct injury represents one of the most severe complications in cholecystectomy, associated with long-term morbidity, repeated interventions, and increased healthcare costs. The higher incidence observed in robotic surgery may reflect the learning curve associated with new technology, as well as its use as a training platform.

Conversely, robotic systems demonstrate advantages in complex surgical scenarios, including difficult dissections, obesity, and severe inflammation. The reduced conversion rates observed in these cases suggest that robotics may provide a safety advantage in technically demanding situations. Additionally, improved ergonomics may reduce surgeon fatigue and contribute to long-term sustainability in surgical practice.

From an economic perspective, the significantly higher cost of robotic surgery remains a major limitation. In the absence of clear clinical superiority, the cost-effectiveness of robotic-assisted cholecystectomy is difficult to justify, particularly in low- and middle-income healthcare systems.

Overall, current evidence suggests that robotic cholecystectomy should not replace laparoscopic cholecystectomy as the standard of care but should instead be selectively utilized in complex cases where its technical advantages can be fully leveraged.

Conclusion

The present comparative analysis demonstrates that laparoscopic cholecystectomy continues to be the gold standard for the management of gallbladder disease due to its well-established safety profile, shorter operative time, and superior cost-effectiveness. While robotic-assisted cholecystectomy offers technological advantages, including enhanced visualization and instrument articulation, these benefits do not consistently translate into improved clinical outcomes in routine cases.

Statistical analysis across multiple studies reveals that robotic-assisted procedures are associated with longer operative times and significantly higher costs, without a corresponding reduction in overall complication rates. Moreover, emerging evidence indicating higher bile duct injury rates in robotic surgery raises important concerns regarding its widespread adoption.

However, robotic-assisted cholecystectomy may have a valuable role in complex surgical scenarios, where its

precision and dexterity can reduce conversion rates and improve surgical control. Therefore, its use should be tailored to patient complexity and institutional expertise rather than applied universally.

Future research should focus on large-scale randomized controlled trials, long-term outcomes, and cost-benefit analyses to better define the role of robotic surgery in biliary procedures. Until then, laparoscopic cholecystectomy remains the most efficient, safe, and economically viable approach for the majority of patients.

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