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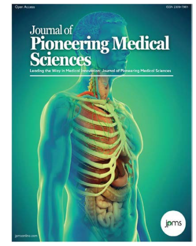

Robotic Versus Laparoscopic Liver Resection (2021–2025): An Updated Systematic Review with Evidence Synthesis

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Abstract **Background:** Robotic Liver Resection (RLR) was developed to address some of the technical challenges faced with Laparoscopic Liver Resection (LLR). Since 2021, more comparative evidence has emerged, including a first randomized trial and numerous large multicenter cohorts. **Objective:** To synthesize evidence from 2021-2025 comparing RLR with LLR regarding their perioperative outcomes and costs. **Methods:** A systematic review was conducted following PRISMA 2020 guidelines and by searching the PubMed, EMBASE and Cochrane libraries from January 2021 to August 2025. Eligible studies were RCTs, meta-analyses and comparative cohorts with propensity score matching and case-matching/entropy matching. Relevant outcomes included operative time, blood loss, conversion to open procedure, complications, Length Of Stay (LOS), readmissions, R0 margin and cost. **Results:** A 2024 meta-analysis showed that RLR reduces conversion and morbidity rates but was associated with a higher rate of readmissions. Conversely, a 2025 meta-analysis showed that RLR has a superior outcome in minimizing blood loss, conversion rates and R0 margins when compared to other procedures. Additionally, a 2024 bottom-up economic model showed that RLR has higher costs; however, high-volume centers can mitigate this. **Conclusion:** RLR is a safe and efficient procedure that reduces conversion and blood loss when compared with LLR. However, it may result in a slightly lower morbidity, increased readmissions and higher costs.

Key Words Robotic Surgical Procedures, Laparoscopy, Hepatectomy, Liver Neoplasms, Minimally Invasive Surgical Procedures

INTRODUCTION

Liver resection continues to play a fundamental role in the treatment of hepatocellular carcinoma, hepatic metastases of the colon and benign liver lesions. The adoption of Laparoscopic Liver Resection (LLR) as a crucial surgical approach for liver cancer has been associated with numerous benefits over traditional open surgery. This minimally invasive approach has gained acceptance due to its effectiveness, safety and the ability to perform complex procedures comparable to open techniques [1,2]. Despite the progress witnessed in the adoption of LLR, it remains technically challenging and dependent on the degree of complexity and tumor site and center expertise [3].

These issues are especially common in major hepatectomy and lesions located in the Poster Superior (PS) segments. Difficulty with instrument dexterity, angles of approach and ergonomic issues may lead to issues with exposure, transection of the hepatic parenchyma and potentially increase the intraoperative difficulty and risk of conversion [4]. Since conversion can decrease the advantages of minimally invasive surgery, there has been an interest, as well as desire, for instruments and systems which can improve dexterity and visual clarity of complex resections.

Robotic Liver Resection (RLR) is an advanced surgical approach that has become popular due to the limitations of LLR and serves as an alternative method to overcome these issues.

It provides improved precision, reduced blood loss and lower complication rates and therefore serves as a valid alternative for both benign and malignant lesions of the liver [5]. It serves as a major benefit for complex cases and provides better dexterity and precision while doing complex vascular dissection and intracorporeal suturing with perioperative results equivalent to or better than those observed with the conventional method of LLR and open surgery [6].

The present work aims at providing a systematic review of comparative data between RLR and LLR in key perioperative outcomes and costs in the 2021-2025 timeframe. Through the integration of data from randomized controlled trials, more recent meta-analysis studies and large multicenter matching cohort studies, this review aims to better understand the added value of the robotic platforms in comparison to the laparoscopic approach.

MATERIALS AND METHODS

This systematic review was performed following the PRISMA 2020 guideline [7]. An electronic database search for comparative studies between January 2021 and August 2025 was performed in PubMed, EMBASE and the Cochrane Library. Relevant studies were selected for the analysis based on the following inclusion criteria: comparative studies on adult subjects undergoing Robotic Liver Resection (RLR) versus Laparoscopic Liver Resection (LLR). These studies included adult subjects undergoing Robotic Liver Resection versus Laparoscopic Liver Resection and included comparative trials such as Randomized Controlled Trials, recent meta-analyses and comparative cohort trials that used either Propensity Score Matching or Coarsened Exact Matching techniques. Outcomes included operative time, blood loss, rate of conversion to open procedures, complications, hospital stay, readmission rates and margin and cost.

Risk of bias was assessed for the randomized data with the use of the RoB-2 tool, while for the cohorts, it was done with the Newcastle–Ottawa scale [8,9]. The process of synthesizing the data focused on the outcome of the two meta-analyses conducted in 2025, as they were cross validated with the use of the randomized trial as well as the multicenter cohorts with propensity score matching/coarsened extract matching (Figure 1).

RESULTS

In total, 20 comparative studies on the evaluation of Robotic Liver Resection (RLR) Vs Laparoscopic Liver Resection (LLR), which have been published from 2021 to 2025, have been included in the updated synthesis.

Randomized Evidence

The ROC’N’ROLL randomized trial of 80 participants found no difference between the two groups regarding quality of life, complications, or recovery.

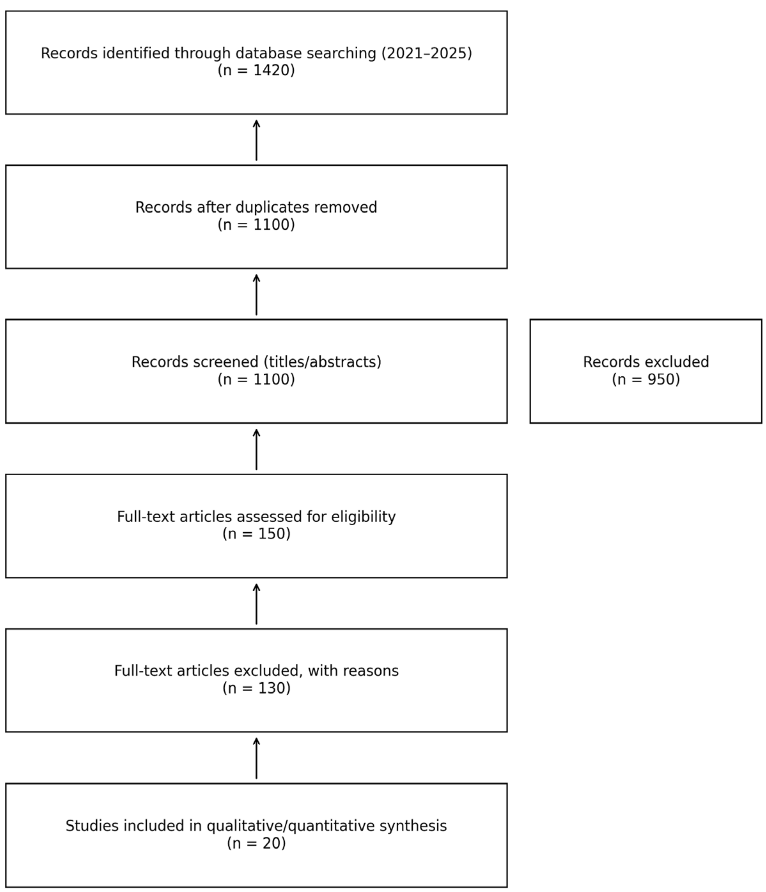

Figure 1: PRISMA 2020 Flow Diagram for Study Identification and Selection (2021–2025)

Table 1: Key Included Comparative Studies (2021-2025)

First author, Year	Design/Setting	Population	Main findings
Birgin *et al.* [10]	RCT, single center	80 pts, malignancy	No difference QoL or periop outcomes
Sijberden *et al.* [13]	Intl multicenter PSM	10,075 pts	↓EBL, ↓conversion, shorter OT with RLR
Liu *et al.* [14]	Intl multicenter PSM/CEM	4,822 major hepatectomies	↓EBL, ↓conversion
Chong *et al.* [15]	Intl PSM	Right/extended right	↓conversion, shorter LOS
Krenzien *et al.* [16]	Intl PSM	PS segments	↓EBL, ↓conversion, shorter OT
Chen *et al.* [17]	Single-center PSM	PS region	↓EBL, shorter OT
Chong *et al.* [18]	Intl PSM	LLS	Comparable outcomes
Kwak *et al.* [19]	Intl PSM	Hepatolithiasis	↓EBL, ↓conversion
D'Silva *et al.* [20]	Intl PSM/CEM	Limited PS resections	↓conversion with RLR
Balzano *et al.* [21]	Two-center PSM	Mixed resections	Feasible, safe
Li *et al.* [22]	Single-center PSM	HCC	Safe; OS comparable
Huang *et al.* [23]	Multicenter PSM	Complex HCC resections	↓EBL, ↓conversion
Denglos *et al.* [24]	Single center	PS resections	Comparable outcomes
Chen *et al.* [25]	Single-center PSM	Mixed	Comparable
Kadam *et al.* [26]	Intl PSM/CEM	Anterolateral resections	↓EBL, ↓MIS completion
Schmelzle *et al.* [27]	Single-center cohort	600 cases	Safe, feasible
Fagenson *et al.* [28]	NA cohort	Benchmarking	Adoption signals
Vancoillie *et al.* [29]	Single center	Repeat hepatectomy	Safe
Wang *et al.* [11],	Meta-analyses	Pooled estimates	↓conversion, variable EBL/LOS
Pilz da Cunha *et al.* [12]	Meta-analyses	Pooled estimates	↓conversion, variable EBL/LOS

Meta-Analyses

In the propensity-score-matched-only meta-analysis conducted by Wang *et al.* [11], RLR was associated with reduced blood loss (mean difference -86 mL), reduced conversion rates (odds ratio 0.51) and increased R0 resection rates (odds ratio 1.31) compared to LLR. In the broader meta-analysis conducted by Pilz da Cunha *et al.* [12], RLR was associated with reduced conversion rates (risk ratio 0.41), reduced morbidity (risk ratio 0.92), but also increased readmission rates (1.24). Significant large multicenter subgroup cohort signals RLR was also associated with decreased blood loss, conversion and operative time in a large multicenter propensity score-matched cohort study (Sijberden *et al.* [13], n = 10,075).

For major hepatectomies, Liu *et al.* ([14], n = 4,822) also found that the use of the RLR resulted in decreased blood loss and conversion. For the performance of the right or extended right hepatectomies, Chong *et al.* [15] found that the conversion was decreased and the length of stay was reduced when the RLR was used. For posterosuperior segment resections, Krenzien *et al.* [16] and Chen *et al.* [17] found that the blood loss, conversion and operative time were decreased when the RLR was used. More studies from various centers confirmed the safety of the RLR, with the majority showing a benefit regarding conversion and/or blood loss.

Costs

A bottom-up cost analysis of an economic evaluation [12] showed that when capital costs are excluded, similar cost-per-procedure estimates are obtained; when platform-related costs are included, higher cost estimates are obtained (Table 1).

DISCUSSION

RLR consistently demonstrates technical superiority over LLR as established by very recent studies published from 2021 to 2025. This position is confirmed by at least two meta-analyses conducted very recently [11,12] and by very large cohorts with propensity matched and coarsened precise (CEM) matched series [13–17]. The relevance of these results to the subject matter pertains to suggestions that open conversion may offset and may otherwise counterbalance some advances and gains by minimally invasive techniques. Several recent studies have shown improved feasibility and completion rates by minimally invasive techniques for major hepatectomy and Posterosuperior (PS) resections by comparing these with LLR and suggesting superiority by RLR [14,16,17]. These trends suggest that advances by robotic techniques may be most evident when anatomical access and parenchymal transection are technically challenging.

On the other hand, broader perioperative outcomes provide a more nuanced picture. A meta-analysis from 2025 reported modest reduction in overall morbidity with the RLR, although an increase in readmission rates was found in another study [11,12]. No difference could be found in quality of life or key perioperative outcomes in randomized ROC'N'ROLL trial [10]. This suggests that the magnitude of benefit may vary depending on case selection, institutional experience and the specific outcomes measured. Therefore, the evidence at the current level of understanding would suggest that the impact be interpreted conservatively: that the RLR approach does provide important technical superiority with possibly minor clinical advantage over conversion rates and intraoperative blood loss rates.

Operative time remains contingent on the specific case and center. A large multicenter matched data study indicated that RLR does not necessarily take longer to perform and may be shorter in certain contexts [13]. Contemporary cohorts in PS segment resections also reported favorable results in the operative time domain for the RLR technique [16,17], which could be attributed to improved ergonomics and instrument articulation in confined spaces. These observations align with the idea that learning curves and procedural standardization can mitigate docking and setup time, particularly in high-volume programs.

Cost factors remain a significant impediment in the adoption rate of robotic surgery. It appears that the bottom-up costs could be similar per procedure, yet when the actual cost of the equipment purchase and maintenance needs are considered, the costs become higher [12]. Consequently, cost-effectiveness is likely to be influenced by volume, with centers that can effectively utilize robotics across high caseloads and prioritize its use for complex resections, in which a reduction in conversion rates and blood loss can yield downstream benefits potentially being most favorable. This updated review offers the benefit of combining the first RCT, two more recent meta-analyses, as well as large multicenter retrospective studies undertaken by matching cohorts, which will then allow triangulation of the results. However, residual confounding in accounting of costs within observational studies, along with the lack of longer-term oncologic and patient outcomes, still exist. Future studies will need to strive towards greater consistency within the stratification of complexity, accounting of costs and longer-term end points regarding RLR durability.

CONCLUSION

Robotic Liver Resection (RLR) is a safe and effective procedure that consistently reduces conversion and blood loss compared to Laparoscopic Liver Resection (LLR). However, it may result in modest morbidity, increased readmissions and higher costs. Operative time is variable depending on the case and the specific center. Therefore, the adoption of RLR should be individualized based on the expertise of the surgical team, the complexity of the cases and the available resources.

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