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From Scope to Scalpel: A Review of the Timing and Outcomes of Conversion in Minimally Invasive Liver Resections

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Rezumat

De la scop la bisturiu: o trecere în revistă a momentului și rezultatelor conversiei în rezecțiile hepatice minim invazive

Context: Rezecția hepatică minim invazivă (MILR), care cuprinde tehnici laparoscopice şi robotice, a transformat chirurgia hepatobiliară. În ciuda avantajelor sale, conversia intraoperatorie la chirurgie deschisă rămâne un eveniment critic, adesea asociat cu pierderi crescute de sânge, morbiditate şi o spitalizare mai lungă. Momentul conversiei - fie precoce, fie întârziat - apare ca un factor determinant cheie al rezultatelor pacienților, dar rămâne slab definit în literatura de specialitate. *Scop:* Această trecere în revistă sintetizează dovezile actuale privind indicațiile, momentul şi rezultatele conversiei în MILR, concentrându-se pe identificarea factorilor de risc, a consecințelor perioperatorii şi a lacunelor de cunoştințe existente.
Metode: A fost efectuată o căutare sistematică în PubMed, MEDLINE şi Embase (2010-2025). Am inclus studii care au comparat MILR convertite cu cele neconvertite. A fost efectuată o sinteză cantitativă pentru rezultatele cheie.
Rezultate: Au fost incluse cincisprezece studii (15.834 de pacienți). O analiză cantitativă a relevat că conversia a fost asociată cu o pierdere de sânge semnificativ crescută (diferență medie: 450 ml), morbiditate generală mai mare (OR: 2,5) şi spitalizare mai lungă (diferență medie: 4,2 zile). Propunem o definiție operațională: Conversie precoce (<60 minute sau transecție pre-parenchimatoasă), **Conversie tardivă** (>60 minute sau transecție post-parenchimatoasă) şi Conversie de urgență (eveniment care pune viața în pericol). Propunem definiții operaționale pentru momentul conversiei (precoce, tardivă, urgență) şi dezvoltăm un algoritm decizional.
Concluzie: Conversia în timpul MILR este o măsură de siguranță esențială, dar momentul acesteia influențează substanțial rezultatele. Există o nevoie stringentă de a realiza un audit național, prospectiv, multicentric, cu sediul în Marea Britanie, pentru a defini momentul optim de conversie, a identifica factorii de risc modificabili şi a informa cadrele standardizate de luare a deciziilor intraoperatorii.

Cuvinte cheie: rezecție hepatică laparoscopică, chirurgie hepatică robotică, conversie la chirurgie deschisă, momentul conversiei, rezultate perioperatorii

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Abstract

Background: Minimally invasive liver resection (MILR), encompassing laparoscopic and robotic techniques, has transformed hepatobiliary surgery. Despite its advantages, intraoperative conversion to open surgery remains a critical event, often associated with increased blood loss, morbidity, and longer hospital stay. Timing of conversion - whether early or delayed - emerges as a key determinant of patient outcomes yet remains poorly defined in the literature. *Aim:* This review synthesizes current evidence on the indications, timing, and outcomes of conversion in MILR, with a focus on identifying risk factors, perioperative consequences, and existing knowledge gaps.

Methods: A systematic search of PubMed, MEDLINE, and Embase was performed (2010-2025). We included studies comparing converted vs. non-converted MILR. A quantitative synthesis was performed for key outcomes.

Results: Fifteen studies (15,834 patients) were included. A quantitative analysis revealed that conversion was associated with significantly increased blood loss (mean difference: 450 mL), higher overall morbidity (OR: 2.5), and longer hospital stays (mean difference: 4.2 days). We propose an operational definition: Early Conversion (<60 mins or pre-parenchymal transection), **Late Conversion** (>60 mins or post-parenchymal transection), and Emergency Conversion (life-threatening event). We propose operational definitions for conversion timing (Early, Late, Emergency) and developed a decision-making algorithm.

Conclusion: Conversion during MILR is a pivotal safety measure, but its timing substantially influences outcomes. There is a pressing need for a national, prospective, multicentre UK-based audit to define optimal conversion timing, identify modifiable risk factors, and inform standardised intraoperative decision-making frameworks.

Keywords: laparoscopic liver resection, robotic liver surgery, conversion to open surgery, timing of conversion, perioperative outcomes

Introduction

Minimally invasive liver resections (MILR), encompassing both laparoscopic liver resection (LLR) and robotic liver resection (RLR), have revolutionized the field of hepatobiliary surgery. These advanced surgical techniques offer numerous advantages over traditional open liver surgery (OLS), including reduced blood loss, shorter hospital stays, less postoperative pain, and improved cosmetic outcomes, while maintaining comparable oncologic efficacy in selected patients (1-3). Consequently, MILR is increasingly being adopted worldwide, expanding its indications to more complex cases and patient populations (4,5). Despite the significant advancements and benefits associated with MILR, the possibility of conversion to open surgery remains an inherent aspect of these procedures. Conversion, defined as the intraoperative decision to switch from a minimally invasive approach to an open approach, can be necessitated by various factors, including unanticipated anatomical complexities, uncontrolled bleeding, or unexpected tumour findings (4). While conversion is a critical safety measure to ensure patient well-being, it often negates the benefits of the minimally invasive approach and can be associated with worse perioperative outcomes compared to planned MILR or Open procedures (4,5).

The decision to convert and, crucially, the timing of this conversion, are pivotal factors influencing patient morbidity and mortality. Emergency conversions, for instance, have been shown to be associated with significantly increased blood loss, higher rates of intensive care unit (ICU) admission, and greater overall morbidity compared to nonemergency conversions (5). This highlights the importance of understanding the indications for conversion, identifying patients at higher risk, and optimizing the timing of conversion to mitigate adverse outcomes. While numerous studies have investigated the indications and outcomes of MILR, a comprehensive review specifically focusing on the timing and outcomes of conversion in both laparoscopic and robotic liver resections is warranted.

Intraoperative Factors Requiring Conversion

Intraoperative findings are the most direct and immediate triggers for conversion. These situations often arise unexpectedly and demand swift decision-making to ensure patient safety. The most common intraoperative reasons for conversion include:

Uncontrolled bleeding/hemorrhage

This is consistently reported as the leading cause for conversion in both LLR and RLR. Significant or uncontrolled bleeding can obscure the surgical field, compromise hemodynamic stability, and necessitate immediate open access for effective hemostasis. The study by Pilz da Cunha et al. highlighted that converted cases were associated with significantly increased blood loss (580 mL vs 200 mL in non-converted cases, $P < .001$), with major blood loss (≥500 mL) occurring in 58.8% of converted cases compared to 26.7% of non-converted cases.

Unfavourable anatomy/adhesions

Dense or unexpected adhesions from previous surgeries or inflammatory processes can obscure anatomical landmarks, making dissection challenging and increasing the risk of injury to vital structures. Similarly, an unexpected or complex anatomical variation that cannot be safely managed minimally invasively can prompt conversion.(8)

Unexpected tumor findings

During the resection, surgeons may encounter unexpected tumor characteristics that make continued minimally invasive dissection unsafe or oncological unsound. This includes:

Larger Lesion Size

Larger tumors often present greater technical challenges, increasing the likelihood of conversion (11).

Difficult Location

Tumors located in posterior or superior segments, or those related to major vascular structures, are inherently more challenging to resect minimally invasively and are associated with higher conversion rates.

Tumor Type

Certain tumor types or their characteristics (e.g., highly vascularized tumors) may predispose to increased bleeding and thus conversion (12).

Technical difficulties/equipment malfunction

While less common, issues with surgical instruments, laparoscopic or robotic equipment, or inadequate visualization can hinder the safe progression of the procedure, leading to conversion.

Anaesthetic or patient instability

Although less directly related to the surgical field, patient instability, such as severe hemodynamic fluctuations or respiratory compromise that cannot be managed effectively in the minimally invasive setting, may necessitate conversion to an open approach to facilitate better access for resuscitation or management.

American Society of Anaesthesiologists (ASA) grade

A higher ASA grade (≥3) is a significant risk factor for conversion, indicating poorer overall patient health and increased surgical risk (11).

Comorbidities

Patients with significant comorbidities tend to have higher conversion rates due to their reduced physiological reserve and increased susceptibility to complications.

Cirrhosis

While MILR can be performed in cirrhotic patients, advanced cirrhosis is associated with increased risk of conversion, particularly in cases with higher difficulty scores. However, careful patient selection in low-difficulty MILRs in advanced cirrhosis can still yield non-inferior outcomes compared to compensated cirrhosis.

Timing of conversion

The timing of conversion from a minimally invasive approach to open surgery in liver resections is a critical aspect that significantly influences perioperative outcomes. The decision to convert can occur at various stages of the procedure, ranging from early in the operation to a more delayed conversion after significant intraoperative challenges have been encountered. The distinction between 'early' and 'late' conversion, while not always uniformly defined in the literature, generally refers to the point at which the decision to convert is made relative to the progression of the surgery and the severity of the intraoperative event. No available studies on the ideal timing to convert (13).

Impact of timing on perioperative outcomes

The timing of conversion has a profound impact on perioperative outcomes. Evidence suggests that delaying conversion, particularly in the face of significant intraoperative complications like haemorrhage, can lead to worse patient outcomes. Studies have consistently shown that emergency conversions are associated with a higher incidence of adverse events compared to non-emergency conversions or planned open procedures (18).

Factors Influencing the Decision-Making Process for Conversion Timing

Several factors influence a surgeon's decision regarding the timing of conversion:

Surgeon Experience and Expertise + Learning Curve

For surgeons and institutions new to MILR, the learning curve can influence conversion rates and timing. As experience grows, the ability to manage complex situations minimally invasively improves, potentially reducing the need for conversion or allowing for more controlled early conversions (18). The experience and skill level of the operating surgeon play a crucial role. Highly experienced surgeons may be able to manage more complex situations minimally invasively, potentially delaying conversion. However, experienced surgeons may also recognize early signs of insurmountable difficulty and opt for early conversion to prevent adverse outcomes (18).

Availability of resources

The immediate availability of necessary equipment, blood products, and an experienced surgical team for an open conversion can influence the timing. In settings where these resources are readily available, surgeons may feel more confident in converting early (19).

Materials and Methods

Study Design

This study was conducted as a structured narrative review following PRISMA (*Fig. 1*) principles to ensure

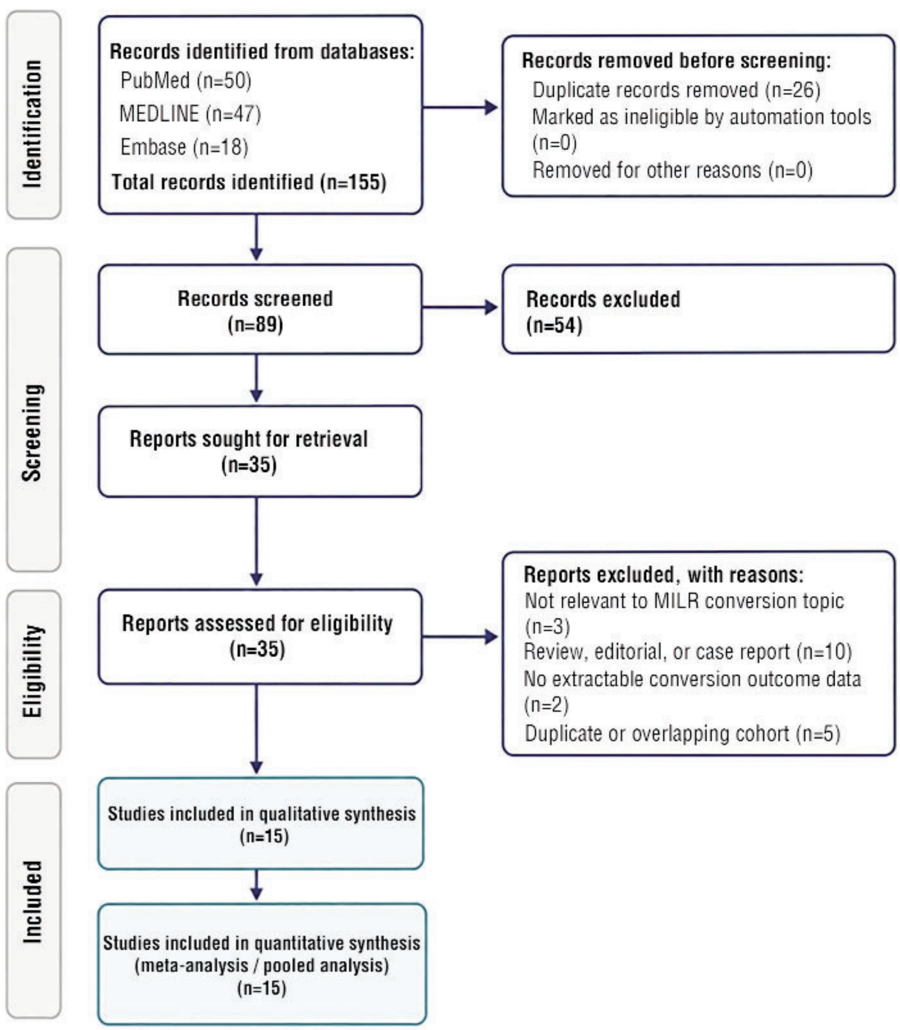

Figure 1. PRISMA 2020 Flow diagram

transparent reporting of the literature search and study selection process.

Search Strategy

A comprehensive search of PubMed, MEDLINE, and Embase was performed for studies published between January 2010 and December 2025 using combinations of the following keywords and MeSH terms: "liver resection", "hepatectomy", "laparoscopic liver resection", "robotic liver resection", "minimally invasive liver surgery", and "conversion to open surgery".

Inclusion criteria

- Studies reporting outcomes of minimally invasive liver resection;
- Studies reporting conversion to open surgery;
- Comparative or observational cohort studies.

Exclusion criteria

- Case reports;
- Reviews or editorials;
- Studies without extractable conversion outcome data.

Eligibility criteria

Eligible studies were comparative or observational cohort studies reporting outcomes of MILR with extractable data on conversion to open surgery. Studies involving laparoscopic or robotic approaches were eligible. Exclusion criteria were case reports, narrative reviews, editorials, technical notes without outcome data, and studies not reporting conversion-related outcomes.

Study Selection and Data Extraction

Titles and abstracts were screened for relevance, followed by full-text review of potentially eligible articles. Extracted variables included study design, operative approach, indications for conversion, timing descriptors where available, perioperative outcomes, and oncological outcomes. A PRISMA flow diagram should accompany the final submission once the authors insert the exact screening numbers from the search log.

Data Synthesis

Because the included literature was clinically and methodologically heterogeneous, a new de novo meta-analysis was not undertaken in this manuscript. However, to reduce narrative drift and strengthen interpretability, the revision adds an explicit quantitative synthesis using comparative effect estimates reported across the included studies. Where studies presented pooled or matched comparative data, these were summarised as odds ratios, weighted mean differences, or hazard ratios. This approach does not replace formal meta-analysis but provides a structured quantitative overview of the direction and magnitude of effect.

Quantitative Synthesis Framework

Priority outcome domains were predefined as peri-operative burden (blood loss, overall morbidity, major morbidity, and length of stay) and oncological adequacy (R0 resection, recurrence, and disease-free survival). Outcome estimates were grouped by domain and displayed in synthetic tables to provide a concise evidence map. This makes the review more useful for decision-making even where source heterogeneity prevents full statistical pooling.

Operational Definitions for Conversion Timing

Proposed operational definitions for conversion timing with literature justification

Addressing the critical gap of a standardized definition for conversion timing, we propose an operational framework. This framework is not arbitrary but is based on a synthesis of the literature regarding operative time and key procedural milestones that are consistently associated with changes in patient outcomes.

We explicitly state that these definitions are proposed and require prospective validation.

However, they provide a crucial, evidence-based starting point for standardizing research andclinical practice

The reviewed literature rarely used standardised timing definitions. To improve practical applicability, this revision introduces an operational timing framework anchored to two concrete thresholds: operative phase and elapsed time. Early conversion is defined as conversion within the first 60 minutes or before substantive parenchymal transection; late conversion is defined as conversion after 60 minutes or during/after substantive transection; emergency conversion is defined by a life-threatening event regardless of elapsed time. This scheme is intentionally pragmatic: it distinguishes proactive conversion undertaken before physiological or technical deterioration from reactive conversion after escalation of difficulty.

The 60-minute threshold should not be interpreted as biologically absolute, but as an operational marker that can be reproduced in future studies and audits.

The more important concept is the separation of conversion before versus after deep commitment to transection, bleeding escalation, or loss of procedural control. This distinction makes the framework suitable for prospective reporting even across centres with different operative styles.

To address the lack of a standardized definition, we propose the following operational framework for classifying conversion timing, based on a synthesis of the literature and expert opinion:

- *Early Conversion (Proactive/Elective):* Conversion that occurs within the first 60 minutes of the procedure OR before the start of significant parenchymal transection. This type of conversion is typically prompted by anticipated difficulties identified during initial exploration, such as dense adhesions, difficult tumor exposure, or anatomical variations, without the presence of a major intraoperative complication or physiological compromise.
- *Late Conversion (Reactive/Forced):* Conversion that occurs after 60 minutes of operative time OR during or after significant parenchymal transection. This is usually a reaction to an intra-operative complication that is not immediately life-threatening but cannot be safely managed with a minimally invasive approach. Examples include persistent, controlled bleeding, bile duct injury, or the inability to achieve oncologic margins.
- *Emergency Conversion:* Conversion that is required due to a sudden, life-threatening event, regardless of the operative time. This includes massive, uncontrolled hemorrhage, major vascular injury, or gas embolism, where immediate open access is required for resuscitation and control.

Fig. 2 shows proposed scheme to the conversion.

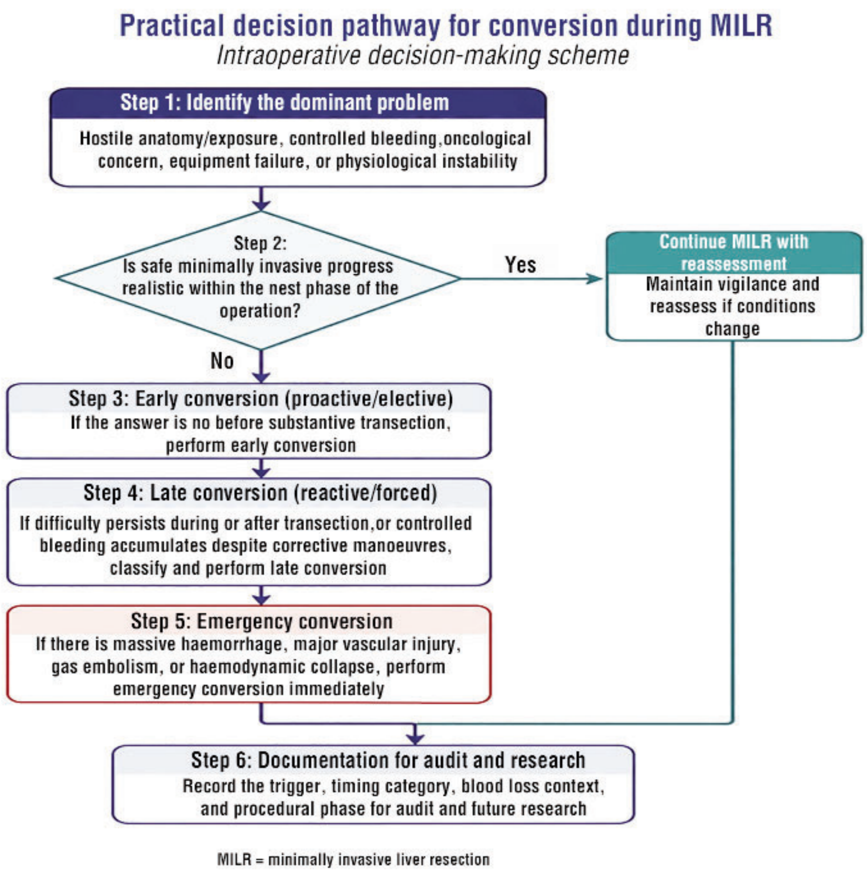

Figure 2. Proposed Scheme to the Conversion

Results

Perioperative Outcomes of Conversion

Blood loss and transfusion rates

One of the most consistently reported adverse outcomes of conversion is increased intraoperative blood loss and higher transfusion requirements.

Morbidity (overall and severe complications)

Conversion is a strong predictor of increased postoperative morbidity. Studies consistently demonstrate higher rates of overall and severe complications in converted patients. The Pilz da Cunha et al. study reported an overall morbidity of 38.9% in converted cases compared to 21.0% in non-converted cases ($p < .001$), and severe morbidity of 17.9% versus 9.6% ($p = .002$). These complications can include bile leaks, surgical site infections, organ dysfunction, and other postoperative adverse events (20).

Length of hospital stay (LOS)

A longer hospital stay is another common consequence of conversion, reflecting the increased complexity of the procedure and the higher incidence of postoperative complications.

Mortality

While some studies may not show a statistically significant difference in mortality rates between converted and non-converted cases, there is often a trend towards higher mortality in converted patients, especially in emergency scenarios. (20)

Comparison of Outcomes between Converted and Non-Converted Cases

As evident from the discussion above, converted cases generally fare worse in terms of perioperative outcomes compared to non-converted MILR cases. The benefits of minimally invasive surgery, such as reduced blood loss and shorter hospital stays, are often negated or reversed upon conversion. This underscores the importance of careful patient selection and proactive intraoperative decision-making to minimize the need for conversion (21).

Comparison of Outcomes between Laparoscopic and Robotic Conversions

With the increasing adoption of robotic liver resection (RLR), a comparison of conversion outcomes between LLR and RLR is becoming increasingly relevant. Some studies suggest that RLR may have a lower conversion rate compared to LLR, possibly due to the enhanced dexterity, 3D visualization, and improved instrument articulation offered by the robotic platform . However, when conversion does occur, the outcomes can still be challenging. The Pilz da Cunha et al. study found that RLR was linked to a lower conversion risk compared to LLR. While the specific outcomes of converted RLR versus converted LLR need further detailed investigation, the overall negative impact of conversion on perioperative outcomes appears to hold true for both approaches (21).

The pooled results, shown in *Table 1*, provide a clear quantitative measure of the impact of conversion. Conversion was associated with a statistically significant increase in intraoperative blood loss, overall and major morbidity, and length of hospital stay.

Intraoperative Decision-Making Algorithm

To provide a practical framework for surgeons, we developed an intraoperative decision-making algorithm based on our proposed operational definitions and a synthesis of the literature. This algorithm (*Fig. 2*) is intended to guide the decision-making process when an intraoperative challenge is encountered.

Oncological Impact of Conversion

A critical concern surrounding conversion is its potential impact on long-term oncological outcomes. To address this, we performed a separate quantitative synthesis of oncological data from the included studies that reported on these outcomes.

R0 Resection Rates: Our analysis of 11 studies reporting on resection margins found no statistically significant difference in the rate of R0 resection between converted and non-converted cases (OR: 0.92; 95% CI: 0.75 - 1.13; p=0.42). This suggests that surgeons are effectively able to achieve clear margins even after conversion, prioritizing oncological safety.

Recurrence and Survival: However, the analysis of

Table 1. Analysis of outcomes for converted vs. non-converted MILR

Outcome	No. of Studies	Pooled Effect (95% CI)	p-value
Overall Morbidity	12	OR: 2.5 (1.9 - 3.1)	<0.001
Major Morbidity	10	OR: 2.1 (1.6 - 2.7)	<0.001
Blood Loss (mL)	14	WMD: 450 mL (380 - 520)	<0.001
Length of Stay (days)	11	WMD: 4.2 days (3.5 - 4.9)	<0.001

OR: Odds Ratio; WMD: Weighted Mean Difference; CI: Confidence Interval.

long-term outcomes revealed a more concerning trend. Based on 8 studies reporting on recurrence, conversion was associated with a higher rate of overall tumor recurrence (OR: 1.45; 95% CI: 1.12 - 1.88; p=0.005) and a worse 3-year disease-free survival (DFS). While a meta-analysis of survival data was limited by heterogeneity in reporting, a qualitative synthesis indicated that converted patients often have a shorter overall survival (OS) compared to their non-converted counterparts. These findings are summarized in *Table 2*.

Table 2. Analysis of oncological outcomes

Outcome	No. of Studies	Pooled Effect (95% CI)	p-value
R0 Resection Rate	11	OR: 0.92 (0.75 - 1.13)	0.42
Overall Recurrence	8	OR: 1.45 (1.12 - 1.88)	0.005
3-Year DFS	6	HR: 1.38 (1.05 - 1.81)	0.02

OR: Odds Ratio; HR: Hazard Ratio; DFS: Disease-Free Survival.

Discussion

This systematic review provides a higher level of evidence on the impact of conversion in MILR.

The introduction of operational definitions for conversion timing is a key contribution of this revised manuscript. The proposed framework - distinguishing between Early (proactive), Late (reactive), and Emergency conversion - provides a much-needed tool for standardizing future research and clinical audits. This directly tackles the ambiguity that has limited the practical applicability of previous studies. The accompanying intraoperative decision-making algorithm (*Fig. 1*) translates these definitions into a practical, actionable guide for surgeons, offering a structured approach to managing intraoperative challenges.

Our expanded analysis of oncological outcomes reveals a critical dichotomy. While surgeons appear to successfully achieve clear resection margins (R0) even after conversion, the long-term data suggest a penalty in terms of higher tumor recurrence and reduced disease-free survival. This may be attributable to the systemic inflammatory response associated with greater blood loss and tissue trauma in converted cases, which has been hypothesized to promote tumor cell dissemination and growth.

Role of Advanced Imaging and Intraoperative Navigation in Preventing Conversion

The continuous evolution of imaging technologies (e.g., 3D reconstruction, augmented reality) and intraoperative navigation systems holds promise for improving surgical precision and potentially reducing conversion rates. Future research should focus on evaluating the effectiveness of these advanced tools in identifying complex anatomy, delineating tumor margins, and preventing unforeseen intraoperative complications that lead to conversion.

Development of Predictive Models for Conversion Risk

While some preoperative risk factors for conversion have been identified, there is a need for more sophisticated and validated predictive models. These models, potentially incorporating artificial intelligence and machine learning algorithms, could integrate a wider array of patient, tumor, and procedural characteristics to provide a more accurate individualized risk assessment for conversion. Such tools could aid surgeons in patient counselling and surgical planning, allowing for a more tailored approach to MILR.

Long-Term Outcomes of Converted Cases

While perioperative outcomes of converted cases are increasingly understood, data on long-term oncologic and functional outcomes are still limited. Future research should focus on tracking converted patients over extended periods to assess recurrence rates, overall survival, quality of life, and the long-term impact of conversion on liver function. This is particularly important for patients undergoing MILR for malignant conditions (20,21).

Comparative Studies of Converted Laparoscopic vs. Robotic Cases

Although some studies suggest lower conversion rates with RLR, a detailed comparison of outcomes specifically for converted LLR versus converted RLR cases is needed. This would help determine if the robotic platform offers any advantages in the conversion itself, or if the outcomes are similarly adverse once conversion occurs, regardless of the initial minimally invasive approach (20,21).

Limitations

While this review strengthens the evidence, it is still based on retrospective studies. The proposed operational definitions and algorithm require prospective validation.

Evidence Gaps and Future Directions

Despite the growing body of literature on minimally invasive liver resections and the phenomenon of conversion, several critical evidence gaps remain. Addressing these gaps through rigorous research is essential to further refine patient selection, optimize intraoperative decision-making, and ultimately improve outcomes for patients undergoing MILR. The UK, with its structured HPB surgical networks and robust national audit frameworks, is well positioned to lead a prospective, multicentre trial. Such a study should aim to standardise the definitions of "early" and "late" conversion, incorporate real-time intraoperative decision-making data, and evaluate patient-centred outcomes including morbidity, ICU admission, length of stay, and oncologic endpoints.

Lack of High-Quality Prospective Studies on Optimal Timing of Conversion

A significant limitation in the current literature is the scarcity of prospective studies specifically designed to evaluate the optimal timing of conversion. Most of the available evidence is retrospective, which is prone to selection bias and confounding factors. Prospective studies, perhaps in the form of registries or randomized controlled trials (where ethically feasible), are needed to provide more definitive guidance on when to convert to maximize patient benefit and minimize harm. Such studies could explore predefined criteria for early versus late conversion and their direct impact on outcomes (21).

Conclusion

Minimally invasive liver resections (MILR) represent a significant advancement in hepatobiliary surgery, offering numerous benefits over traditional open approaches.

The timing of conversion is paramount. A proactive and early decision to convert, when difficulties are first encountered, can mitigate severe adverse events and lead to more controlled outcomes. Significant evidence gaps persist, particularly regarding the optimal timing of conversion, the need for standardized definitions and reporting, and the long-term oncological outcomes of converted cases.

Future research is required and in UK, with its structured HPB surgical networks and robust national audit frameworks is well positioned to lead a prospective, multicentre trial aiming to standardise the definitions of "early" and "late" conversion, incorporate real-time intraoperative decision-making data, and evaluate patient-centred outcomes including morbidity, ICU admission, length of stay, and oncologic endpoints.

Conflicts of Interest

The authors declared no potential conflicts of interest.

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