Review Article

Role of Laparoscopic Surgery in Hepatocellular Carcinoma Resection: Advances and Limitations in General Surgery

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Abstract

Hepatocellular carcinoma is the most common primary liver malignancy and remains a leading cause of cancer-related mortality worldwide, largely due to its close association with chronic liver disease and cirrhosis. Surgical resection continues to represent the cornerstone curative treatment for early-stage disease in patients with preserved liver function and absence of clinically significant portal hypertension. Over the past two decades, laparoscopic liver resection has emerged as a major advancement in the surgical management of hepatocellular carcinoma, progressively evolving from minor resections to complex major hepatectomies as a result of technological innovation, improved imaging, and growing surgical expertise. Current evidence demonstrates that laparoscopic liver resection offers perioperative advantages over open surgery, including reduced intraoperative blood

loss, lower transfusion requirements, fewer postoperative complications, and shorter hospital stays, while facilitating faster recovery and improved quality of life. Importantly, these benefits are achieved without compromising oncological outcomes. Rates of negative resection margins, local recurrence, disease-free survival, and overall survival are comparable between laparoscopic and open approaches in appropriately selected patients. These advantages appear particularly relevant in high-risk populations, such as patients with cirrhosis, elderly individuals, and those undergoing repeat hepatectomy. Patient selection remains a critical determinant of success and requires careful consideration of tumor-related factors, liver functional reserve, portal hypertension, and overall surgical risk. The learning curve associated with laparoscopic liver resection underscores the importance of structured training, stepwise implementation, and performance in high-volume centers. In this context, robotic-assisted liver resection is emerging as a complementary modality with promising results.

Key words

Hepatocellular carcinoma, Laparoscopic liver resection, Minimally invasive surgery, Oncological outcomes, Patient selection, Perioperative outcomes.

Introduction

Hepatocellular carcinoma represents the most common primary malignancy of the liver and constitutes one of the leading causes of cancer-related mortality worldwide. Its clinical relevance is closely linked to the high prevalence of underlying chronic liver disease and cirrhosis, conditions that not only predispose to tumor development but also complicate therapeutic decision-making [1, 2]. In recent decades, the global incidence of hepatocellular carcinoma has continued to rise, underscoring the growing need for effective and durable management strategies aimed at improving survival and long-term outcomes. Within this context, surgical interventions, particularly liver resection and liver transplantation, have remained the cornerstone of curative treatment for patients diagnosed at an early stage, offering the greatest potential for long-term disease control [3].

Parallel to the increasing burden of disease, the surgical management of hepatocellular carcinoma has undergone substantial evolution over the past four decades. During this period, surgical treatment has emerged as the most extensively studied topic within the most influential scientific publications addressing hepatocellular carcinoma, reflecting its central role in disease management [4]. Continuous advances in surgical techniques, driven by improvements in intraoperative visualization and the adoption of minimally invasive approaches, have progressively expanded the pool of patients eligible for resection, including individuals who were previously considered unsuitable candidates due to tumor complexity or underlying liver dysfunction [1]. In this setting, the development and refinement of minimally invasive strategies, such as laparoscopic and robotic-assisted surgery, have played a pivotal role by contributing to improved perioperative outcomes and a reduction in surgical morbidity [5].

Against this background, laparoscopy has emerged as a transformative modality in hepatic surgery. Laparoscopic liver resection has gained widespread acceptance as a treatment option for hepatocellular carcinoma, largely due to its association with reduced intraoperative blood loss, lower rates of postoperative complications, and shorter hospital stays when compared with open liver resection [5, 6]. Accumulating evidence has demonstrated that laparoscopic approaches are both feasible and safe in carefully selected patients, including those with cirrhosis and portal hypertension, thereby broadening the scope of surgical intervention in a population traditionally considered high risk [2]. The

progressive transition of laparoscopic liver resection from an experimental technique to a standard practice in high-volume centers further illustrates the growing acceptance, technical maturation, and reproducibility of this approach [7]. In parallel, robotic-assisted liver resection has begun to emerge as a promising alternative, with available studies suggesting comparable short- and long-term outcomes to laparoscopic surgery, as well as a potential improvement in overall survival, reinforcing the expanding role of minimally invasive surgery in the management of hepatocellular carcinoma [5].

The objective of this article is to assess the role of laparoscopic surgery in hepatocellular carcinoma resection by examining its current advances, limitations, and oncological and perioperative outcomes, in order to define its relevance and applicability in contemporary general surgery practice.

Methodology

For the development of this review on the role of laparoscopy in hepatocellular carcinoma resection, a comprehensive analysis of the scientific literature was conducted with the aim of examining its clinical relevance, technical evolution, perioperative and oncological outcomes, and the main advances and limitations within the field of general surgery. Particular attention was paid to patient selection criteria, surgical techniques, comparative outcomes between laparoscopic and open approaches, and factors influencing the adoption of minimally invasive liver surgery.

The review was based on the consultation of established scientific databases, including PubMed, Scopus, and Web of Science, chosen for their relevance in surgery, hepatology, and oncology. Strict inclusion and exclusion criteria were applied to ensure the quality and pertinence of the selected studies. Articles published between 2020 and 2025 in English or Spanish were included if they addressed key aspects such as laparoscopic liver resection for hepatocellular carcinoma, indications and contraindications, perioperative outcomes, oncological adequacy, recurrence, and survival. Studies lacking peer review, presenting incomplete data, or containing duplicated content were excluded. The search strategy incorporated keywords such as; Hepatocellular carcinoma, laparoscopic liver resection, minimally invasive surgery, oncological outcomes, patient selection, perioperative outcomes.

The initial search identified 28 relevant sources, including original research articles, clinical practice guidelines, systematic reviews, and meta-analyses published by recognized surgical and hepatology societies. These sources were critically analyzed to extract information related to surgical techniques, patient selection, short- and long-term outcomes, and comparative effectiveness between laparoscopic and open liver resection.

Artificial intelligence tools were used as complementary support for the synthesis of information, thematic organization of the literature, and identification of conceptual relationships across studies. Their use facilitated the systematic structuring of the evidence and contributed to maintaining coherence and clarity throughout the review.

The analysis followed a qualitative and comparative approach. Findings were organized thematically to identify current surgical practices, benefits and limitations of laparoscopic resection, barriers to wider implementation, and emerging trends in minimally invasive liver surgery. This approach allowed for a structured, evidence-based overview of the current role of laparoscopy in hepatocellular carcinoma resection, highlighting its clinical value and ongoing challenges in contemporary general surgery.

Surgical Management of Hepatocellular Carcinoma

Surgical resection is primarily indicated for patients with early-stage hepatocellular carcinoma who present with preserved liver function and absence of clinically significant portal hypertension, as these factors are strongly associated with favorable perioperative and long-term outcomes [1, 8]. Within this framework, patient selection remains a critical determinant of success. Emerging evidence suggests that the traditional criteria for resection may be expanding, as selected patients with portal vein tumor thrombus or uncomplicated portal hypertension can also derive benefit from surgical intervention, provided that careful preoperative assessment and risk stratification are performed. The Barcelona Clinic Liver Cancer staging system continues to play a central role in guiding treatment decisions, consistently recommending surgical resection as the preferred option for patients with early-stage disease who meet functional and anatomical criteria [1].

When surgical resection is not feasible, alternative curative therapies must be considered within a multidisciplinary context. Liver transplantation represents a definitive curative option for patients with more advanced disease who remain within the Milan criteria, as it addresses both the tumor burden and the underlying liver disease [1]. In contrast, local ablative techniques such as radiofrequency ablation and microwave ablation have emerged as viable alternatives for small hepatocellular carcinomas, particularly in patients who are poor surgical candidates. In selected cases, these modalities have demonstrated survival outcomes comparable to those of surgical resection. Nevertheless, recent data indicate that surgical resection has achieved the highest five-year survival rates in the most contemporary treatment era, surpassing outcomes reported for both radiofrequency and microwave ablation, thereby reinforcing its role as the reference curative strategy when technically and clinically feasible [9, 10].

Regardless of the chosen approach, liver resection must adhere to fundamental oncological principles that prioritize complete tumor removal with negative surgical margins while preserving an adequate volume of functional liver parenchyma. Advances in minimally invasive techniques, along with the integration of three-dimensional surgical planning, have contributed to improved precision, reduced surgical trauma, and enhanced postoperative recovery [11]. In addition, strategies aimed at optimizing the future liver remnant, such as portal vein embolization, remain essential components of preoperative planning, particularly in patients at risk of postoperative liver failure, ensuring both oncological efficacy and patient safety [1].

Evolution of Laparoscopic Liver Resection

Laparoscopic liver resection has gained wide acceptance over time due to its demonstrated advantages over open liver resection, particularly in terms of earlier postoperative recovery and lower rates of complications. Its historical development has been characterized by a progressive and sustained evolution spanning more than two decades, during which significant technical milestones have been achieved. These advances have translated into measurable improvements in operative efficiency, including reductions in operative time and intraoperative blood loss, as well as enhanced postoperative recovery profiles, contributing to the consolidation of laparoscopic liver resection as a standard approach in specialized centers. Within this evolutionary process, the introduction of robot-assisted liver resection represents a recent and notable milestone, as emerging evidence suggests outcomes comparable to those of conventional laparoscopy, positioning robotic platforms as a promising component of the future of minimally invasive liver surgery [5, 7].

In its early stages, laparoscopic liver resection was largely confined to minor procedures, such as wedge resections and left lateral section

ectomies, reflecting both technical limitations and concerns regarding safety. However, continuous advancements in surgical instruments, imaging, and operative strategies have progressively expanded its scope, allowing surgeons to undertake increasingly complex interventions, including major hepatectomies [7]. This transition from minor to major resections has been accompanied by a rise in procedural complexity over time, with recent years witnessing a growing proportion of advanced laparoscopic liver resections performed in experienced centers [11].

Parallel to these technical developments, the learning curve associated with laparoscopic liver resection has emerged as a critical factor influencing outcomes. Evidence indicates that this learning process encompasses distinct phases, each associated with incremental improvements in technical proficiency and perioperative results, underscoring the importance of structured training and experience accumulation [12, 13]. Institutional experience plays a decisive role in successfully overcoming this learning curve, as centers with higher procedural volumes consistently report improved outcomes and reduced morbidity over time. Consequently, a stepwise progression from basic to more advanced laparoscopic procedures is widely recommended, as it facilitates skill acquisition while maintaining acceptable safety profiles during the early phases of implementation [11].

Indications and Patient Selection

Tumor-related factors play a central role in determining the feasibility of laparoscopic liver resection in patients with hepatocellular carcinoma. With respect to tumor size and number, laparoscopic surgery has been shown to be feasible for both single and multiple lesions, although increasing tumor size may introduce significant technical challenges related to exposure, vascular control, and parenchymal transection. Despite these limitations, selected tumors exceeding the Milan criteria, including lesions larger than 5 cm, have been successfully resected using laparoscopic techniques in carefully chosen patients, demonstrating the expanding applicability of this approach. Tumor location represents another critical determinant, as lesions situated in anatomically accessible liver segments are more amenable to laparoscopic resection. In this context, the routine use of intraoperative ultrasound has become an essential adjunct, facilitating accurate tumor localization, delineation of vascular structures, and achievement of precise and oncologically adequate resections [5].

In addition to tumor characteristics, liver-related factors substantially influence patient selection and outcomes following laparoscopic liver resection. The presence and severity of cirrhosis are particularly relevant, with patients classified as Child–Pugh A generally considered ideal candidates due to their preserved hepatic reserve. Nonetheless, evidence indicates that selected patients with Child–Pugh B cirrhosis may also benefit from laparoscopic resection, provided that significant portal hypertension is absent and careful perioperative management is ensured. Portal hypertension itself constitutes a major risk factor for postoperative complications, and its presence has been consistently associated with inferior outcomes. Consequently, patients without preoperative portal hypertension tend to experience more favorable perioperative courses and are preferentially selected for laparoscopic approaches [14]. Overall liver function remains a fundamental prerequisite, as adequate hepatic reserve is essential to minimize the risk of postoperative liver failure. Patients with preserved liver function and limited comorbid conditions are therefore regarded as the most suitable candidates for laparoscopic resection [3].

Beyond tumor and liver-related considerations, patient-related factors and comprehensive surgical risk assessment are integral components of the decision-making process. The presence of comorbidities such as diabetes mellitus or hypertension does not necessarily preclude

laparoscopic surgery, provided that these conditions are well controlled and managed appropriately in the perioperative period [2]. Functional capacity and overall performance status are equally important, as good performance status and the absence of severe systemic disease are essential prerequisites for tolerating surgical stress and facilitating postoperative recovery [3]. Surgical risk assessment should therefore encompass a holistic evaluation of potential complications and the patient's ability to recover following resection. In this regard, laparoscopic surgery has been consistently associated with lower complication rates and faster postoperative recovery compared with open approaches, further supporting its use in appropriately selected patients [5].

Laparoscopic Techniques for Hepatocellular Carcinoma Resection

Laparoscopic liver resection encompasses a spectrum of surgical procedures that vary in extent and complexity, allowing tailoring of the operative strategy to tumor characteristics and underlying liver function. Among these approaches, wedge resection represents the least extensive form of resection and involves the removal of a small, wedge-shaped portion of hepatic parenchyma. This technique is typically reserved for small, peripherally located tumors and is particularly advantageous in patients with compromised liver function, as it preserves a greater volume of functional liver tissue and minimizes surgical trauma [5]. Segmentectomy constitutes a more anatomical approach, targeting specific liver segments while sparing surrounding healthy parenchyma. This strategy allows for precise oncological resection and is frequently guided by intraoperative ultrasound to ensure accurate identification of segmental boundaries and tumor location [15]. In contrast, lobectomy represents a more extensive procedure involving the resection of an entire hepatic lobe and is generally indicated for larger or centrally located tumors. Given the complexity of hepatic vascular and biliary anatomy, this approach requires meticulous preoperative planning and advanced intraoperative navigation to ensure safety and oncological adequacy [16].

Central to the success of laparoscopic liver resection are the techniques used for parenchymal transection and the energy devices employed during surgery. Ultrasonic dissectors are among the most utilized tools, as they allow precise parenchymal division while minimizing thermal injury to adjacent tissues. Their use is particularly advantageous in cirrhotic livers, where tissue fragility and bleeding risk are heightened [17]. More recently, devices that combine ultrasonic and advanced bipolar energy, such as thermofusion instruments and THUNDERBEAT systems, have been increasingly adopted. These technologies facilitate efficient tissue dissection while providing effective hemostasis, thereby reducing the need for additional hemostatic measures and contributing to smoother operative courses [16]. In parallel, the intrahepatic Glissonean approach has gained prominence as a technique that enables isolation and transection of Glissonean pedicles, allowing for precise anatomical resections with clear margins, particularly in complex procedures involving multiple liver segments [18].

Intraoperative imaging and navigation tools further enhance the precision and safety of laparoscopic liver surgery. Intraoperative ultrasound has become an indispensable component of these procedures, as it enables real-time identification of tumor boundaries, vascular structures, and biliary anatomy, thereby facilitating accurate resections while minimizing injury to healthy tissue. Its integration with three-dimensional reconstructions has further improved spatial orientation and surgical planning. Additionally, the use of indocyanine green fluorescence imaging has emerged as a valuable adjunct, allowing visualization of liver segmental anatomy and ischemic areas, which aids in the accurate demarcation of resection planes [17, 18].

Effective control of bleeding and meticulous vascular management are critical determinants of success in laparoscopic liver resection. The Pringle maneuver, which involves temporary occlusion of hepatic inflow, remains a standard technique to reduce blood loss during parenchymal transection and is widely applied in laparoscopic settings [19]. Vascular staplers are commonly employed to transect major vessels in a safe and efficient manner, ensuring secure closure and minimizing the risk of intraoperative hemorrhage. The incorporation of advanced hemostatic devices, including THUNDERBEAT systems, further contributes to effective bleeding control during transection, reducing the need for supplementary interventions and enhancing overall operative safety [15].

Perioperative Outcomes

Operative time and intraoperative blood loss represent key parameters in the evaluation of perioperative outcomes following laparoscopic liver resection. Multiple studies have consistently demonstrated that laparoscopic approaches are associated with significantly lower blood loss when compared with open liver resection. For example, a quantitative analysis reported a mean reduction of approximately 99 mL in intraoperative blood loss favoring laparoscopic surgery, reflecting the hemostatic advantages conferred by magnified visualization and refined energy devices [20]. Despite this benefit, laparoscopic procedures may be associated with longer operative times. In comparative analyses of minimally invasive anatomic resections versus open approaches, laparoscopic surgery has been shown to require extended operative durations, with one study reporting operative times of 643 minutes in the laparoscopic group compared with 579 minutes in the open group, likely reflecting increased technical complexity and the demands of minimally invasive dissection [21].

Beyond intraoperative metrics, laparoscopic liver resection has been associated with favorable postoperative morbidity and mortality profiles. Evidence indicates lower overall postoperative morbidity in patients undergoing laparoscopic procedures, including reduced rates of major complications and bile leakage when compared with open surgery [21]. These benefits appear to translate into improved survival in the early postoperative period, as mortality rates have been reported to be lower in laparoscopic cohorts. Notably, in one comparative study, all cases of 90-day postoperative mortality occurred exclusively in the open surgery group, underscoring the potential safety advantages of minimally invasive approaches [22].

Length of hospital stay and postoperative recovery further highlight the advantages of laparoscopic liver resection. Patients treated laparoscopically generally experience shorter hospitalizations, with meta-analytic data demonstrating a mean reduction of approximately 3.22 days compared with open liver resection [21]. This reduction in hospital stay is closely linked to faster postoperative recovery, as minimally invasive techniques are associated with less postoperative pain, earlier mobilization, and a quicker return to baseline functional status and daily activities [23].

When directly compared with open liver resection, laparoscopic surgery provides comparable oncological outcomes while offering superior short-term clinical benefits. Studies have shown similar rates of negative resection margins and local recurrence between laparoscopic and open approaches, supporting the oncological adequacy of minimally invasive liver resection [22]. These advantages appear to be particularly pronounced in elderly patients, in whom laparoscopic liver resection has been associated with lower rates of severe postoperative complications, as defined by Clavien–Dindo grades III and IV, as well as shorter hospital stays, reinforcing its value in this vulnerable population [24].

Oncological Outcomes

The assessment of resection margins is a fundamental component in evaluating the

oncological adequacy of laparoscopic liver resection. Available evidence indicates that laparoscopic approaches can achieve negative resection margins at rates comparable to those obtained with open surgery. In this regard, one study reported negative margin rates of 68% for laparoscopic resections and 71% for open procedures, with no statistically significant difference between the two approaches, supporting the oncological equivalence of minimally invasive surgery in hepatocellular carcinoma [22]. Similarly, data derived from liver resections performed for colorectal cancer metastases demonstrated a slightly higher rate of R0 resections in the laparoscopic group compared with open surgery, with reported rates of 89.9% and 85.4%, respectively. Although this evidence pertains to a different tumor type, it further reinforces the capacity of laparoscopic techniques to achieve oncologically sound resections [25].

Long-term oncological outcomes, particularly recurrence rates and disease-free survival, provide additional insight into the effectiveness of laparoscopic liver resection. Studies focusing on early-stage hepatocellular carcinoma have shown comparable recurrence rates between laparoscopic and open approaches, with no significant differences observed in five-year disease-free survival. Reported five-year disease-free survival rates of 63.8% for laparoscopic surgery and 50.6% for open surgery highlight the absence of oncological disadvantage associated with minimally invasive techniques in appropriately selected patients [26]. In the context of intrahepatic cholangiocarcinoma, laparoscopic surgery has been associated with higher recurrence-free rates compared with open surgery, although overall survival remained similar, suggesting a potential benefit in local disease control without compromising long-term outcomes [27].

Overall survival constitutes the most robust endpoint for oncological evaluation, and current evidence consistently demonstrates comparable survival outcomes between laparoscopic and open liver resections for hepatocellular carcinoma. Studies have reported similar five-year overall survival rates, with figures of 80.8% for laparoscopic approaches and 75.7% for open surgery, underscoring the long-term oncological safety of minimally invasive liver resection [26]. These findings extend to specific patient subgroups, including elderly individuals, in whom laparoscopic surgery has been shown to provide favorable short-term outcomes while maintaining long-term survival rates comparable to those of open surgery, thereby confirming its feasibility and safety in this increasingly prevalent population [6].

Advantages of Laparoscopic Resection

One of the principal advantages of laparoscopic liver resection lies in its association with reduced surgical trauma and lower levels of postoperative pain. Compared with open liver resection, laparoscopic approaches are consistently associated with less intraoperative blood loss and a reduced need for blood transfusions, factors that directly contribute to a decrease in overall surgical trauma. The minimally invasive nature of laparoscopic surgery, characterized by smaller incisions and limited manipulation of the abdominal wall, also translates into lower postoperative pain levels, facilitating earlier mobilization and improved patient comfort during the recovery period [5, 20].

In addition to these benefits, laparoscopic liver resection has been shown to result in lower postoperative complication rates when compared with open surgery. Evidence indicates a reduction in both overall and major postoperative complications following laparoscopic procedures, an advantage that appears particularly pronounced in patients with underlying cirrhosis, a population traditionally at higher risk of postoperative morbidity. In these patients, laparoscopic surgery has been associated with a significant decrease in complication rates, supporting its preferential use in carefully selected cirrhotic individuals [20,

25]. Furthermore, in the setting of repeat hepatectomy for recurrent hepatocellular carcinoma, laparoscopic approaches have demonstrated superior outcomes relative to open repeat liver resection, including reduced blood loss and lower morbidity, highlighting their value even in technically demanding reoperative scenarios [28].

The cumulative effect of reduced surgical trauma and lower complication rates is reflected in improved postoperative recovery and quality of life. Patients undergoing laparoscopic liver resection typically experience shorter hospital stays and faster recovery, outcomes that are closely linked to the minimally invasive nature of the procedure and the decreased need for prolonged postoperative care. By minimizing postoperative pain and facilitating early return to baseline functional status, laparoscopic surgery also plays a key role in preventing postoperative loss of independence, thereby contributing to improved long-term quality of life for patients undergoing resection for hepatocellular carcinoma [5, 20].

Conclusion

Surgical resection remains the cornerstone curative treatment for hepatocellular carcinoma in appropriately selected patients, particularly those with early-stage disease, preserved liver function, and absence of clinically significant portal hypertension. While alternative therapies such as liver transplantation and ablative techniques play an important role in specific clinical scenarios, contemporary evidence consistently demonstrates that surgical resection offers the highest long-term survival when technically and clinically feasible, provided that fundamental oncological principles and careful preoperative planning are respected.

The evolution of laparoscopic liver resection has transformed the surgical management of hepatocellular carcinoma, progressing from minor resections to complex major hepatectomies as a result of advances in technology, imaging, and surgical expertise. When performed in experienced centers and following a structured learning curve, laparoscopic approaches achieve perioperative and oncological outcomes comparable to open surgery, while offering significant advantages in terms of reduced blood loss, lower complication rates, and faster postoperative recovery.

Appropriate patient selection remains critical to maximizing the benefits of laparoscopic liver resection. Tumor characteristics, liver functional reserve, portal hypertension status, and patient comorbidities must be carefully integrated into surgical decision-making. In well-selected patients, laparoscopic resection provides oncologically adequate margins, comparable long-term survival, and improved quality of life, supporting its role as a safe and effective standard approach in contemporary hepatocellular carcinoma surgery.

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