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LIVER RESECTION VERSUS RADIOFREQUENCY ABLATION FOR EARLY-STAGE HEPATOCELLULAR CARCINOMA: AN EVIDENCE-BASED NARRATIVE REVIEW OF ONCOLOGICAL OUTCOMES AND TREATMENT SELECTION

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ABSTRACT

Background: Surgical resection (LR) and radiofrequency ablation (RFA) are established curative options for early-stage hepatocellular carcinoma (HCC), yet their relative benefits remain debated, particularly regarding long-term survival, recurrence control, and patient selection.
Objectives: To synthesize contemporary evidence comparing liver resection and radiofrequency ablation for early-stage HCC, with a focus on oncological outcomes, recurrence patterns, perioperative safety, and clinically relevant subgroups.
Methods: An evidence-based narrative review was conducted using structured searches of PubMed/MEDLINE and the Cochrane Library. Systematic reviews, meta-analyses, randomized controlled trials, and high-quality observational studies comparing LR and RFA in early-stage HCC were included. Outcomes of interest comprised overall survival (OS), recurrence-free or disease-free survival (RFS/DFS), tumor recurrence, perioperative morbidity, and cost-effectiveness. Findings were synthesized qualitatively.
Results: Randomized controlled trials consistently demonstrated no statistically significant difference in overall survival between LR and RFA. In contrast, meta-analyses and propensity-adjusted observational studies suggested improved long-term survival following resection in selected patients with preserved liver function. Across comparative studies, recurrence-free survival and local tumor control consistently favored resection. Subgroup analyses indicated comparable survival outcomes between modalities in patients with very small tumors, impaired hepatic reserve (Child–Pugh class B), and elderly populations, while tumor size and anatomical location emerged as key modifiers of treatment efficacy.
Conclusions: Liver resection provides superior local tumor control, whereas overall survival remains largely comparable between modalities in carefully selected patients. Treatment selection should be individualized, integrating tumor characteristics, liver function, patient comorbidities, and procedural risk within a multidisciplinary framework.

KEYWORDS

Hepatocellular Carcinoma, Liver Resection, Radiofrequency Ablation, Early-Stage HCC, Recurrence-Free Survival, Treatment Selection

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Introduction

Hepatocellular carcinoma (HCC) remains one of the most common malignancies worldwide and a leading cause of cancer-related mortality. Owing to surveillance programs and advances in diagnostic imaging, an increasing proportion of patients are diagnosed at an early stage, when curative treatment options are feasible. According to the Barcelona Clinic Liver Cancer (BCLC) staging system, early-stage disease encompasses patients with limited tumor burden and preserved liver function, offering the possibility of long-term survival.

Early-stage hepatocellular carcinoma is most commonly defined according to the BCLC staging system, which integrates tumor burden, liver function, and patient performance status. Very early-stage disease (BCLC 0) is characterized by a single tumor ≤2 cm in diameter in patients with preserved liver function and no cancer-related symptoms. Early-stage disease (BCLC A) includes patients with a single tumor or up to three nodules ≤3 cm, preserved liver function, and good performance status. The definition and clinical characteristics of early-stage hepatocellular carcinoma according to the BCLC staging system are summarized in Table 1.

Patients within these stages are considered candidates for curative-intent therapies, including surgical resection, liver transplantation, and local ablative treatments. However, considerable heterogeneity exists within early-stage HCC with respect to tumor size, anatomical location, and underlying liver disease, which may significantly influence treatment outcomes and complicate direct comparisons between therapeutic strategies.

Surgical resection has traditionally been regarded as the treatment of choice for early-stage HCC in patients with adequate hepatic reserve. However, local ablative therapies, particularly radiofrequency ablation (RFA), have emerged as less invasive alternatives and are increasingly utilized in clinical practice. Advances in imaging guidance, ablation technology, and perioperative management have further expanded the role of ablation, especially in patients with small tumors, impaired liver function, or increased surgical risk.

Despite extensive investigation, the optimal treatment strategy for early-stage HCC remains controversial. Numerous randomized trials, observational studies, and meta-analyses have compared surgical resection and radiofrequency ablation, often yielding conflicting results. While resection is generally associated with improved local tumor control, overall survival differences between the two modalities are less consistent and appear to be influenced by tumor size, location, liver function, and patient-related factors. The heterogeneity of available evidence complicates clinical decision-making and guideline interpretation. Current international guidelines endorse both surgical resection and local ablative therapies as curative options for early-stage HCC, yet provide limited guidance on optimal treatment selection in specific clinical scenarios.

Given the growing body of literature and the evolving role of minimally invasive surgery and ablative techniques, a critical synthesis of contemporary evidence is warranted. This evidence-based narrative review aims to summarize and interpret data from systematic reviews, randomized controlled trials, and high-quality observational studies comparing surgical resection and radiofrequency ablation in patients with early-stage hepatocellular carcinoma. Particular emphasis is placed on oncological outcomes, recurrence patterns, perioperative safety, and patient selection, with the goal of informing individualized treatment strategies in clinical practice.

Table 1. Definition and clinical characteristics of early-stage hepatocellular carcinoma according to the BCLC staging system

BCLC stage	Tumor burden	Liver function	Performance status	Curative treatment options
BCLC 0 (Very early)	Single tumor ≤2 cm	Preserved (Child–Pugh A)	ECOG 0	Surgical resection, local ablation
BCLC A (Early)	Single tumor or up to 3 nodules ≤3 cm	Preserved (Child–Pugh A–B)	ECOG 0	Surgical resection, local ablation, liver transplantation
Subset within BCLC A	Solitary tumors 3–5 cm*	Variable	ECOG 0	Surgical resection (selected patients), ablation (selected cases)

* Tumors measuring 3–5 cm are frequently included in comparative studies despite representing a biologically heterogeneous subgroup.

Methods

Study design

This study was designed as a structured, evidence-based narrative review aimed at synthesizing current evidence comparing surgical resection and local ablative therapies for the treatment of early-stage hepatocellular carcinoma (HCC). The review focused primarily on systematic reviews, meta-analyses, randomized controlled trials, and high-quality observational studies, with an emphasis on clinically relevant oncological and perioperative outcomes.

Literature search strategy

A structured literature search was performed in PubMed/MEDLINE and the Cochrane Library to identify relevant publications comparing liver resection and radiofrequency ablation in patients with early-stage HCC. The search covered publications available from database inception to December 2025.

The PubMed search strategy combined Medical Subject Headings (MeSH) and free-text terms related to hepatocellular carcinoma and treatment modalities, including:

("hepatocellular carcinoma" OR HCC) AND (liver resection OR hepatectomy) AND (radiofrequency ablation OR local ablation OR microwave ablation) AND (systematic review OR meta-analysis OR randomized controlled trial).

The search was limited to English-language publications. Priority was given to articles published within the last 10–15 years, although seminal older studies were included when considered essential for contextual interpretation. The Cochrane Library was searched using similar keywords to identify relevant systematic reviews and background evidence. In addition, manual screening of reference lists of key articles was performed to identify further relevant studies not captured by the initial search strategy (snowballing).

Eligibility criteria

Inclusion criteria

Publications were considered eligible if they met the following criteria:

- addressed adult patients with early-stage hepatocellular carcinoma, including very early and early stages defined by the Barcelona Clinic Liver Cancer (BCLC) staging system;
- compared surgical liver resection with radiofrequency ablation or other local ablative techniques;
- reported clinically relevant outcomes such as overall survival (OS), disease-free or recurrence-free survival (DFS/RFS), tumor recurrence, perioperative morbidity, or treatment-related mortality;
- included systematic reviews, meta-analyses, randomized controlled trials, or high-quality observational studies, particularly those using propensity score matching, inverse probability weighting, or large population-based datasets.

Exclusion criteria

The following publications were excluded:

- narrative reviews without a clear methodological framework;
- clinical guidelines, expert opinions, editorials, and conference abstracts;
- studies focusing exclusively on advanced-stage HCC or non-curative treatments;
- studies lacking comparative analysis between resection and ablative therapies.

Study selection

Titles and abstracts retrieved through the search strategy were screened for relevance. Full texts of potentially eligible articles were subsequently assessed to determine final inclusion based on the predefined criteria. Priority was given to studies with contemporary patient cohorts and clearly defined early-stage disease. When multiple publications reported overlapping patient populations, the most comprehensive or methodologically robust study was preferentially included. Although formal duplicate screening was not performed, study selection followed predefined eligibility criteria and focused on methodological quality, clinical relevance, and applicability to contemporary practice.

Data extraction and synthesis

Relevant data were extracted from included studies with particular attention to study design, population characteristics, tumor size and location, liver function parameters (including Child–Pugh classification), treatment modality and surgical approach, reported oncological outcomes, and perioperative complications. Given the heterogeneity of study designs and outcome reporting, quantitative pooling of results was not performed. Instead, findings were synthesized qualitatively and grouped thematically.

Assessment of evidence and methodological considerations

Formal quality assessment tools (e.g. AMSTAR) were not applied, as the aim of this review was narrative synthesis rather than quantitative evidence appraisal. Instead, methodological rigor was evaluated qualitatively during interpretation of results. Greater weight was given to randomized controlled trials, systematic reviews with transparent methodologies, and observational studies employing advanced adjustment techniques such as propensity score matching or competing risk analyses. Potential sources of bias, including selection bias and confounding by indication, were explicitly considered in the interpretation of findings.

Results

Table 2. Summary of key comparative studies evaluating surgical resection versus radiofrequency ablation for early-stage hepatocellular carcinoma

Study	Year	Design	Population	Comparison	Key outcomes
Xu et al.	2017	Meta-analysis of RCTs	Small HCC	LR vs RFA	LR superior RFS; OS comparable at 1–3 years; worse 5-year OS after RFA
Yang et al.	2025	Systematic review & meta-analysis	Solitary ≤3 cm HCC	LR vs RFA	LR superior OS and RFS in cohort studies; OS comparable in RCTs
Hu et al.	2024	Meta-analysis (RCT + PSM)	Early-stage HCC	LR vs RFA	LR superior OS and DFS overall; OS comparable in BCLC 0 and solitary tumors <3 cm
Ng et al.	2017	RCT	Early HCC	LR vs RFA	OS and RFS comparable (no statistically significant difference); numerically higher survival estimates with resection
Song et al.	2024	RCT	Small HCC	Lap LR vs RFA	OS and RFS comparable (no statistically significant difference)
Chung et al.	2025	Cohort	Solitary 3–5 cm	LR vs RFA	OS comparable, LR superior RFS
Lee et al.	2025	Comparative study	Solitary HCC	Lap LR vs RFA	LR superior in unfavorable locations
Hatanaka et al.	2025	Cohort	Child–Pugh B	LR vs RFA	OS and RFS comparable
Kim et al.	2024	Cohort	Elderly ≥65	LR vs RFA	OS similar; lower recurrence after LR
Cucchetti et al.	2013	Economic analysis	Early HCC	LR vs RFA	RFA cost-effective ≤2 cm; LR cost-effective 3–5 cm
Liu et al.	2016	PSM cohort	Single ≤2 cm HCC	LR vs RFA	OS comparable; LR superior RFS
Hsiao et al.	2020	Single-center cohort	BCLC 0 HCC	LR vs RFA	OS comparable; LR superior RFS
Lee D. et al.	2021	PSM cohort	Small solitary HCC	Lap LR vs RFA	LR superior RFS; OS similar
Abdelgalil et al.	2024	Meta-analysis (observational)	Early & small HCC	Lap LR vs RFA	LR superior OS and RFS; higher morbidity
Chen et al.	2024	Meta-analysis (PSM)	Small HCC	Lap LR vs RFA	LR superior OS and RFS

Romano et al.	2024	Meta-analysis	BCLC A oligonodular	LR vs RFA/TACE	LR superior OS and RFS
Yoo et al.	2024	Systematic review & meta-analysis	Elderly HCC	LR vs RFA	OS comparable; LR lower recurrence; RFA safer

Overview of included evidence

The evidence base comprised randomized controlled trials, systematic reviews and meta-analyses, and high-quality observational studies, including propensity score–matched and population-based analyses. Most studies evaluated patients with solitary early-stage hepatocellular carcinoma, predominantly tumors ≤3 cm or 3–5 cm in diameter, corresponding to very early and early BCLC stages. Across studies, outcomes were reported for overall survival, recurrence-free or disease-free survival, patterns of tumor recurrence, and perioperative safety, allowing comparative assessment of both oncological efficacy and treatment-related risk [1–3].

Overall survival

Randomized controlled trials consistently demonstrated no statistically significant differences in overall survival between liver resection and radiofrequency ablation in patients with early-stage hepatocellular carcinoma. In the earliest randomized trial, overall survival estimates were numerically higher following resection without reaching statistical significance, likely reflecting limited statistical power and sample size [8]. This finding was subsequently corroborated by a contemporary randomized trial comparing laparoscopic liver resection with percutaneous radiofrequency ablation, which similarly reported no statistically significant differences in overall or recurrence-free survival, despite consistently higher long-term survival point estimates after resection [9].

In contrast, evidence derived from systematic reviews, meta-analyses, and high-quality propensity score–matched studies suggests that liver resection is associated with improved long-term overall survival, particularly in patients with preserved liver function and resectable disease [1–5]. This survival advantage appears more pronounced with extended follow-up and is primarily driven by improved disease control rather than differences in early postoperative mortality. However, subgroup analyses consistently demonstrate attenuation or disappearance of overall survival differences in patients with very small tumors (≤2–3 cm), very early-stage disease (BCLC 0), advanced age, or impaired liver function, in whom survival outcomes following resection and ablation are largely comparable [2,6,7,14,15].

Large population-based studies and contemporary cohort analyses further support the absence of a uniform survival advantage for either treatment modality after appropriate adjustment for confounding factors. Analyses from national registries and competing-risk models reported comparable overall survival between liver resection and radiofrequency ablation, particularly among patients with solitary tumors measuring 3–5 cm and those with increased non–cancer-related mortality risk [10,16,17]. Importantly, recent evidence indicates that anatomical tumor characteristics modify survival outcomes: laparoscopic resection was associated with superior overall survival for centrally located, perihilar tumors, whereas comparable outcomes were observed only in intermediate locations, underscoring the influence of tumor location on treatment efficacy [13].

Collectively, these findings indicate that while randomized evidence supports equivalence of overall survival between resection and ablation in selected early-stage hepatocellular carcinoma, observational and meta-analytic data suggest a potential long-term survival advantage of resection in carefully selected subgroups. This apparent discrepancy reflects the influence of patient selection, tumor size and location, liver function, and competing risks of mortality rather than uniform therapeutic superiority of one modality over the other [1–5,16–18].

Recurrence-free survival and tumor recurrence

In contrast to overall survival, recurrence-free survival consistently favored surgical resection across multiple meta-analyses and high-quality observational studies [1–3]. Pooled analyses demonstrated a statistically significant reduction in recurrence risk following resection, with hazard ratios for recurrence-free or disease-free survival consistently favoring surgery across contemporary comparative studies [1–3].

This benefit appears to be largely driven by lower rates of local tumor progression and intrahepatic recurrence after resection, as reported in multiple comparative studies [3,10–13].

Radiofrequency ablation was associated with higher rates of local tumor progression, especially in centrally located or perivascular tumors, which has been attributed to limited ablative margins and heat-sink effects compromising complete tumor destruction [12,13].

Nevertheless, several studies reported that recurrent disease following ablation was frequently amenable to repeat local treatment, which may partially mitigate differences in long-term overall survival despite inferior recurrence-free outcomes [7].

Influence of tumor size and location

Tumor size emerged as a major determinant of treatment efficacy. For tumors ≤3 cm, multiple studies reported similar overall survival between resection and ablation, although recurrence-free survival remained superior following resection [2,6]. In contrast, for tumors measuring 3–5 cm, surgical resection was generally associated with better oncological outcomes, including lower recurrence rates and improved local disease control [10,11].

Tumor location further influenced outcomes. Laparoscopic liver resection was associated with superior overall and recurrence-free survival for deeply located, centrally positioned, and perihilar tumors, reflecting improved margin control and anatomical resection [13]. Comparable outcomes between resection and ablation were observed only for tumors located in intermediate anatomical positions, whereas peripherally located lesions were predominantly managed surgically owing to favorable anatomical accessibility rather than demonstrated oncological equivalence between treatment modalities [13]. In addition, evidence from comparative cohort studies demonstrated that laparoscopic liver resection provided significantly better local tumor control than percutaneous radiofrequency ablation for small solitary hepatocellular carcinomas located in subcapsular, perivascular, and anteroinferolateral liver segments, suggesting that surgical resection may be the preferred option for tumors in these anatomical locations [12].

Impact of liver function and patient subgroups

Underlying liver function substantially modifies the balance between oncological benefit and procedural risk when choosing between liver resection (LR) and radiofrequency ablation (RFA). In patients with Child–Pugh class B cirrhosis, several comparative studies indicate that RFA achieves overall- and recurrence-free survival outcomes that are broadly comparable to those following resection while conferring lower perioperative morbidity and a reduced risk of post-operative hepatic decompensation, making it an attractive option in individuals with limited hepatic reserve [14]. Importantly, these findings remained consistent after adjustment for baseline imbalances in liver function parameters, tumor number and size, and clinical characteristics using inverse probability of treatment weighting, indicating comparable long-term survival outcomes between treatment modalities in this high-risk subgroup [14].

Among elderly patients (≥65 years), cohort studies specifically addressing older populations reported largely comparable overall survival between liver resection and radiofrequency ablation [15]. These findings are further supported by a recent systematic review and meta-analysis focusing specifically on elderly patients, which demonstrated no significant overall survival difference between treatment modalities, despite a trend toward improved local disease control after resection and a more favorable safety profile after ablation [19].

Collectively, these data highlight the substantial influence of competing non–cancer-related mortality and comorbidity burden on overall survival in older patients, attenuating the impact of treatment modality on long-term survival outcomes at the population level [16,17].

Perioperative outcomes and safety

Across randomized controlled trials, propensity score–matched studies, and population-based analyses, radiofrequency ablation was consistently associated with lower perioperative morbidity, shorter length of hospital stay, and reduced perioperative mortality compared with surgical resection [1,4,5,12,16]. These differences were primarily driven by lower rates of procedure-related complications, including bleeding, bile leakage, and postoperative liver dysfunction following ablation.

Although laparoscopic liver resection has substantially reduced surgical morbidity compared with open approaches, complication rates remain higher than those observed after radiofrequency ablation, reflecting the inherent invasiveness of surgical treatment despite advances in minimally invasive techniques [4,12].

Cost-effectiveness

Economic analyses suggested that radiofrequency ablation is more cost-effective for very early-stage disease and small tumors, particularly when repeat local treatments are feasible, whereas surgical resection may be more cost-effective for solitary tumors measuring 3–5 cm owing to improved long-term survival and reduced recurrence-related costs [18]. These findings, however, are influenced by healthcare system characteristics and underlying model assumptions.

Discussion

The present evidence-based narrative review synthesizes contemporary data comparing surgical resection and radiofrequency ablation for the treatment of early-stage hepatocellular carcinoma. The available evidence highlights important differences in oncological control between treatment modalities, particularly with respect to recurrence-free survival, while overall survival remains similar across several clinically relevant patient subgroups.

A key observation emerging from the literature is the discordance between recurrence-free survival and overall survival. Although surgical resection is consistently associated with lower rates of local tumor progression and intrahepatic recurrence, this advantage does not uniformly translate into improved overall survival [1–3]. This discrepancy likely reflects the multifactorial determinants of mortality in hepatocellular carcinoma, including the severity of underlying liver disease, competing non–cancer-related causes of death, and the feasibility of repeat locoregional treatment following recurrence, particularly after radiofrequency ablation [1–3,7]. Consequently, overall survival may represent a relatively insensitive endpoint for capturing differences in local oncological efficacy in selected early-stage disease.

Tumor-related factors play a central role in modifying comparative outcomes. The available evidence consistently demonstrates that both tumor size and anatomical location influence treatment efficacy. For tumors measuring ≤3 cm, overall survival appears similar between resection and ablation, although recurrence-free survival favors resection [2,6]. In contrast, for tumors measuring 3–5 cm and for lesions located in anatomically complex regions—such as perihilar, perivascular, or deeply situated segments—resection provides superior local disease control and, in some studies, improved long-term outcomes [10–13]. These findings emphasize the importance of anatomical considerations and margin control, particularly in settings where ablative efficacy may be compromised by heat-sink effects or limited ablative margins.

Patient-related factors further modulate the balance between oncological benefit and procedural risk. In patients with impaired hepatic reserve, particularly those with Child–Pugh class B cirrhosis, comparative studies using propensity-adjusted analyses demonstrate comparable overall and recurrence-free survival between resection and ablation, with radiofrequency ablation offering a more favorable perioperative safety profile [14]. These findings underscore the relevance of careful functional assessment when interpreting comparative outcomes in this high-risk subgroup.

Similarly, in elderly patients, cohort studies and a dedicated meta-analysis indicate largely equivalent overall survival between treatment strategies, despite differences in recurrence patterns and perioperative morbidity [15,19]. Population-based and competing-risk analyses further suggest that non–cancer-related mortality substantially influences overall survival in older patients, attenuating the observable impact of treatment modality on long-term outcomes [16,17].

Perioperative safety represents a consistent area of divergence between modalities. Across randomized trials, propensity-matched studies, and large registry analyses, radiofrequency ablation is associated with lower perioperative morbidity, shorter hospitalization, and reduced perioperative mortality compared with surgical resection, including laparoscopic approaches [1,4,5,12,16]. Although advances in minimally invasive surgery have narrowed this gap, the inherent invasiveness of resection continues to confer a higher short-term risk profile.

Economic considerations further refine treatment selection. Available cost-effectiveness analyses suggest that radiofrequency ablation is more cost-effective for very early-stage disease and small tumors, whereas surgical resection may offer greater long-term value for solitary tumors measuring 3–5 cm due to improved local control and reduced recurrence-related costs [18]. These conclusions, however, remain sensitive to healthcare system characteristics and underlying modeling assumptions.

Several limitations of the available evidence warrant consideration. Randomized controlled trials remain limited in number and are frequently underpowered to detect modest differences in overall survival. Much of the comparative evidence is derived from observational studies, which, despite the use of propensity score matching, inverse probability weighting, and competing-risk analyses, remain susceptible to residual confounding and treatment selection bias. Additionally, heterogeneity in patient selection, surgical expertise, ablative techniques, and follow-up strategies limits the generalizability of pooled estimates.

Future research should prioritize adequately powered randomized trials incorporating contemporary laparoscopic techniques, standardized ablation protocols, and patient-centered outcomes to further refine treatment selection in this heterogeneous population.

Conclusions

Surgical resection and radiofrequency ablation represent complementary treatment strategies for early-stage hepatocellular carcinoma. Across the available evidence, surgical resection provides superior local tumor control and recurrence-free survival, whereas overall survival remains largely comparable between treatment modalities in carefully selected patients.

The observed equivalence in overall survival reflects the multifactorial determinants of long-term outcomes in hepatocellular carcinoma, including underlying liver function, competing non–cancer-related mortality, and the feasibility of repeat locoregional treatment after recurrence. Tumor size and anatomical location significantly modify treatment efficacy, with resection offering clear advantages for tumors measuring 3–5 cm and for lesions located in anatomically complex regions, while ablation yields acceptable outcomes for small, favorably located tumors.

Patient-related factors further refine treatment selection. In individuals with impaired hepatic reserve, advanced age, or increased surgical risk, radiofrequency ablation provides comparable survival with a more favorable perioperative safety profile. Conversely, in patients with preserved liver function and resectable disease, surgical resection remains the preferred option when durable local disease control is prioritized.

Taken together, these findings underscore the necessity of an individualized, multidisciplinary approach to early-stage hepatocellular carcinoma, integrating tumor characteristics, liver function, patient comorbidities, and institutional expertise. Future research should focus on adequately powered randomized trials incorporating contemporary minimally invasive surgical techniques, standardized ablative protocols, and patient-centered outcomes to further optimize treatment selection in this heterogeneous population.

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