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(Citation)

Asian Journal of Surgery, 49(8):4533-4540

(Issue Date)

2026-08

(Resource Type)

journal article

(Version)

Version of Record

(Rights)

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(URL)

<https://hdl.handle.net/20.500.14094/0100505423>





Contents lists available at ScienceDirect

Asian Journal of Surgery

journal homepage: www.e-asianjournalsurgery.com

Original Article

Impact of laparoscopic liver resection with 0-mm surgical-adjacency to vasculature on short-term oncologic outcomes in hepatocellular carcinoma



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ARTICLE INFO

Article history:

Received 17 October 2025
Received in revised form
29 November 2025
Accepted 22 December 2025
Available online 10 January 2026

Keywords:

Hepatocellular Carcinoma (HCC)
Laparoscopic Liver Resection (LLR)
Surgical Margin Recurrence (SMR)
Vascular

ABSTRACT

Background: The impact of surgical margins on surgical margin recurrence (SMR) in laparoscopic liver resection (LLR) for hepatocellular carcinoma (HCC) remains unclear. This study investigated the association between LLR with a 0-mm surgical margin (SM0) of the vasculature and SMR.

Methods: This single-center retrospective cohort study enrolled patients with HCC who underwent initial LLR from January 2018 to December 2022—categorized into positive surgical margin (SM (+)), negative surgical margin (SM (−)), SM0-vascular, and SM0-parenchymal groups—with follow-up every three months until death or August 2024. The primary and secondary endpoints were the SMR ratio and cumulative recurrence rate.

Results: Of the 144 patients, 4, 99, 32, and 9 underwent LLR with SM (+), SM (−), SM0-vascular, and SM0-parenchymal, respectively. The SM0-vascular group had more multiple tumors ($p = 0.02$) and underwent more Pringle maneuvers (7 vs. 5; $p = 0.03$) than the SM (−) group. The 3 year-SMR and -cumulative recurrence rates were not significantly different between the SM (−) and SM0-vascular groups (5 % vs. 6 %, $p = 0.46$; 32 % vs. 46 %, $p = 0.09$, respectively).

Conclusion: An LLR with a 0-mm surgical margin for the vasculature may be an acceptable treatment strategy for the local control of HCC.

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1. Introduction

Hepatocellular carcinoma (HCC) is one of the most common malignant diseases worldwide and one of the leading causes of cancer-related deaths.¹ In patients with HCC, radical liver resection remains the most effective therapy. However, the indications for surgery should be carefully considered based on the patient's tumor factors and hepatic reserve. Although curative surgical resection without a remnant liver tumor is important for the potential cure of HCC, the optimal width of the surgical margin remains a topic of debate. Some studies have reported that narrow-

margin resection shortens the prognosis in open liver resection (OLR),^{2,3} while recent research has suggested that narrow-margin resection may be acceptable in patients who have a close association between HCC and major vasculature or in patients with impaired liver function.^{4,5}

Because HCC often has a tumor capsule, the tumor is sometimes detached from the vessels and preserved in clinical practice to avoid ischemic or congested areas in the remnant liver. Preserving remnant liver function is essential for reducing the risk of post-hepatectomy liver failure.⁶ Additionally, reducing remnant liver ischemia could help improve patient prognosis.⁷ However, the technique of detaching local tumors from the Glissonean pedicle or hepatic veins is often considered taboo and consequently overlooked by surgeons. The rationale for this taboo in the era of minimally invasive surgery remains unclear. Despite

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advancements in research on the efficacy of narrow-margin resection for HCC, the optimal margin for laparoscopic liver resection (LLR) has yet to be determined. Considering that the surgical margin in LLR can be more accurately visualized intra-operatively than in OLR because of the magnification effect of the laparoscope, the present study aimed to elucidate the short-term impact of LLR with a 0-mm surgical margin (SM0) for vascu-lature on short-term oncologic outcomes in HCC, with a focus on identifying the relationship between SM0 status and surgical margin recurrence (SMR).

2. Methods

This retrospective study was conducted in accordance with the ethical standards of the Declaration of Helsinki and was approved by the Institutional Review Board Ethics Committee of Kobe University Hospital in 2024 (Approval No: B240013). Informed consent was obtained from all participants using an opt-out form.

2.1. Study population and preoperative evaluation

This retrospective cohort study was conducted at Kobe University Hospital from January 2018 to December 2022 in patients with HCC who underwent initial LLR (Fig. 1). Consecutive patients were grouped into negative surgical margins (SM (–)), positive surgical margins (SM (+)), and SM0 groups based on laparoscopic videos. Based on video confirmation, the surgical team determined that SM0 resections were grossly free of tumor remnants. Additionally, the surgical videos were thoroughly reviewed by Y. S. and T. U. The following definitions for surgical margins were adopted:

- SM (–) resection: Cases with grossly negative margins as verified by reviewing the surgical videos (all cases with grossly negative resection margins were pathologically negative for margins (SM > 1 mm) in the present study).
- SM0-vascular resection: Detachment of part of the tumor from the major hepatic veins or Glissonean pedicles with SM0 (n = 32) (median age, 71 years; 27 [84 %] male and 5 [16 %] female).
- SM0-parenchymal resection: Unintentional dissection of the part between the tumor and liver parenchyma with an SM0 (n = 9) (median age, 67 years; 7 [78 %] male and 2 [22 %] female).
- SM (+) resection: pathologically positive for margins.

Accordingly, SM0 patients were categorized into two groups,

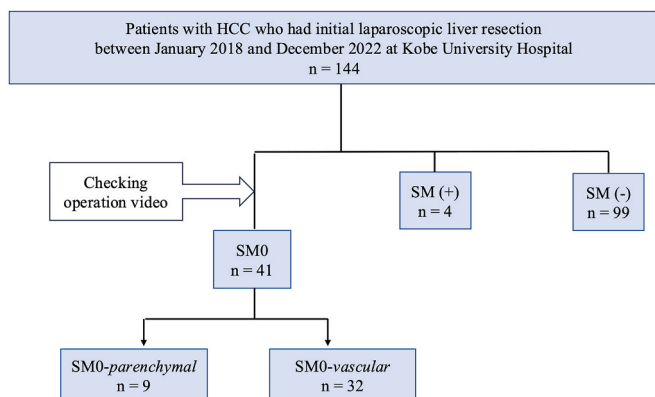


Fig. 1. Flowchart showing the patient selection criteria. All SM0 cases were video-reviewed to check for tumor margins.

SM0-vascular (n = 32) and SM0-parenchymal (n = 9), based on laparoscopic operation videos. In the SM0-vascular patients, pathological findings revealed 5 cases with a positive margin and 22 cases with a pathological SM0, including surgical margins that were difficult to distinguish between positive or SM0, and 5 cases with a margin of $0\text{ mm} < \text{SM} \leq 1\text{ mm}$. In SM0-parenchymal patients, pathological findings revealed eight cases with SM0, including surgical margins that were difficult to distinguish and one case with a margin of $0\text{ mm} < \text{SM} \leq 1\text{ mm}$.

Routine preoperative evaluations included laboratory blood tests, contrast-enhanced ultrasonography, dynamic computed tomography (CT), magnetic resonance imaging (MRI), and upper gastrointestinal endoscopy. In all patients, preoperative three-dimensional (3D) simulation images from dynamic CT images were reconstructed using a 3D workstation (SYNAPSE VINCENT; Fujifilm Medical, Tokyo, Japan) to evaluate the relationship between the tumors and the major intrahepatic vasculature. Laboratory data included viral serological test results, serum levels of alpha-fetoprotein, proteins induced by vitamin K absence or antagonist II, albumin, total bilirubin, and prothrombin time. Liver function was assessed using the Child–Pugh classification, indocyanine green retention rate at 15 min (ICGR15), and 99mTc-galactosyl human serum albumin scintigraphy. HCC was diagnosed based on specific radiological findings obtained using ultrasonography, dynamic CT, and MRI. The extent of hepatic resection was primarily determined by assessing the future remnant liver volume using ICGR15.

2.2. Surgical indication and procedure

The eligibility criteria for initial LLR for HCC were as follows: (i) technically laparoscopically resectable tumors and (ii) Eastern Cooperative Oncology Group performance status score of 0–2.⁸ We excluded patients with gross ascites, clinical signs of portal hypertension, and extrahepatic metastasis from the indications for liver resection. Patients were placed in the supine position for tumors in the left lobe or in the left hemi-decubitus position for tumors in the right lobe. The surgeon was positioned between the patient's legs. Pneumoperitoneum was established at 10 mmHg via the first trocar inserted at the umbilical site using an open approach, followed by four additional trocars. Parenchymal transection was performed using the clamp crushing method with ultrasonic shear (HARMONIC® HD 1000i of 1100 shears; Ethicon Endo-Surgery, Cincinnati, OH, USA) under intermittent clamping for 15–20 min. If the HCC was in contact with the major intrahepatic vessels (inferior vena cava, right hepatic vein, middle hepatic vein, left hepatic vein, and main segmental branches of the hepatic veins) or Glissonean pedicles (right main trunk, left main trunk, right anterior sectoral branch, posterior sectoral branch, and third-order Glissonean branches), detachment of the tumor from the vessels was performed by gentle dissection between the tumor and vessels using a suction device or peeling atraumatic teardrop forceps (Fig. S1) when no signs of infiltration were evident on preoperative CT and MRI.

Fig. 2 presents a representative case of centrally located HCC treated with laparoscopic SM0-vascular resection. Preoperative contrast-enhanced CT revealed that the tumor was compressing the dorsal side of the middle hepatic vein (Fig. 2a and b). Preoperative 3D simulation images were reconstructed (Fig. 2c and d).

The tumor protruded from the surface of Segment 4 (Fig. 3a). The tumor capsule was detached from the middle hepatic vein (MHV) and hepatic vein branches of Segment 5 (V5) (Fig. 3b). The drainage vein of the tumor was resected, and V5 was preserved (Fig. 3c and d) (Supplemental video). When the HCC was attached to the major intrahepatic vasculature, part of the tumor capsule

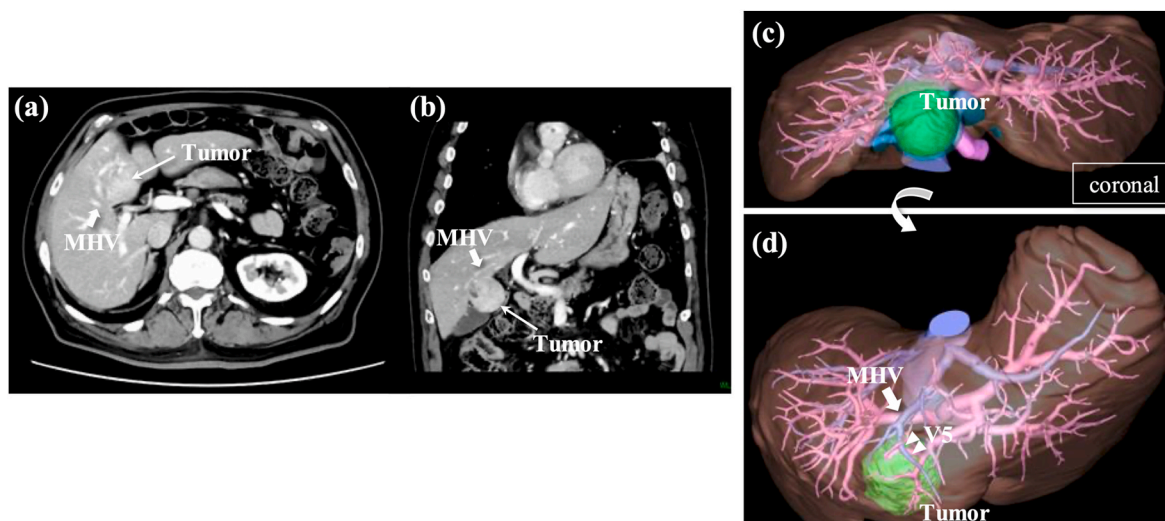


Fig. 2. Representative case of HCC treated with SM0-vascular resection. Preoperative computed tomography scans of the late phase shows a 5-cm tumor close to the middle hepatic vein (a, b). Preoperative three-dimensional simulation images from dynamic computed tomography (c, d). HCC, hepatocellular carcinoma; SM, surgical margin.

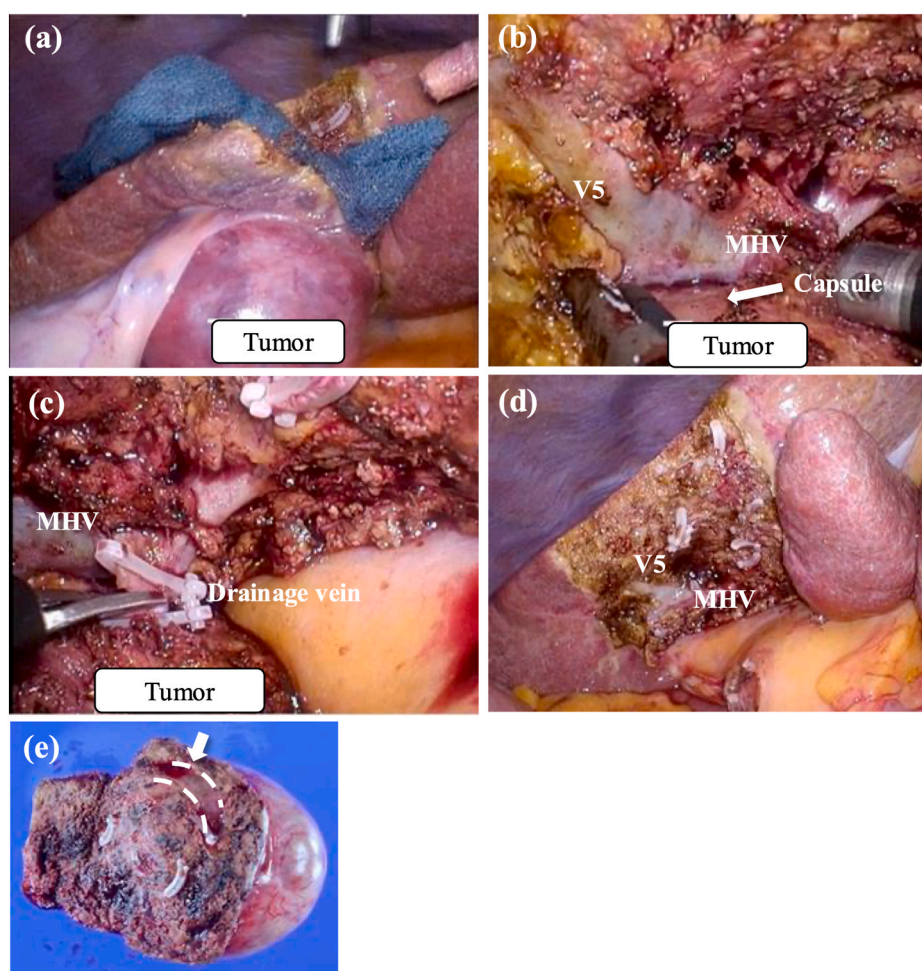


Fig. 3. Laparoscopic S4/5 partial resection. (a) Tumor is identified on the surface of segment 4. (b) The tumor capsule is detached from the middle hepatic vein (MHV) and hepatic vein branches of segment 5 (V5). (c) The drainage vein of the tumor is resected, and V5 is preserved. (d) MHV and V5 are exposed in the transection plane. (e) The resected specimen shows that part of the tumor capsule is exposed along the vascular run (arrow).

was exposed on the raw surface of the resected specimen along the shape of the vascular run (Fig. 3e).

2.3. Postoperative course and assessments

All patients were closely followed up every 3 months with CT or MRI and blood tests, including testing for tumor markers. The primary endpoint of the study was the SMR ratio of the SM (–) and SM0-vascular resection. The secondary endpoint was the cumulative incidence of recurrence of SM (–) and SM0-vascular resection. Patients were followed up until death or until August 2024. The relationship between margin status and short-term outcomes was evaluated. The cumulative incidence of recurrence was calculated as the time from surgery to the first intrahepatic or extrahepatic recurrence. SMR was defined as cut-edge tumor regrowth identified on follow-up CT or MRI.

2.4. Statistical analysis

The Kaplan–Meier method was used to estimate survival curves, and intergroup differences were evaluated using the log-rank test. A Cox proportional hazards model was used to identify independent predictors of survival. Statistical significance was set at $p < 0.05$. All data were analyzed using the JMP® 17 statistical package (SAS Institute, Cary, NC, USA). Quantitative and qualitative variables were analyzed using Student's *t*-test, Mann–Whitney *U* test, and chi-square test.

3. Results

3.1. Baseline characteristics

A total of 144 consecutive patients (median age, 73 years; 108/144 [75 %] male and 36/144 [25 %] female) were selected, comprising 99/144 patients (68.8 %) with SM (–) (median age, 73 years; 70/99 [71 %] male and 29/99 [29 %] female), 4/144 (2.8 %) with SM (+) (median age, 70 years; 0/4 [0 %] male and 4/4 [100 %] female), and 41/144 (28.4 %) with SM0 (median age, 70 years; 34/41 [83 %] male and 7/41 [17 %] female) based on laparoscopic videos (Fig. 1). A comparison of the clinicopathological characteristics between the two groups revealed that the SM0-vascular

group ($n = 32$) (median age, 71 years; 27/32 [84 %] male and 5/32 [16 %] female) had a higher number of tumors than the SM (–) group (Table 1). The maximal tumor diameter and tumor-node-metastasis staging did not differ significantly between the two groups. No significant differences were observed in other factors, such as general background and blood examination results, between the two groups (Table 1).

3.2. Surgical and postoperative outcomes

The SM0-vascular group required the Pringle maneuver more frequently than the SM (–) group (Table 2). The type and extent of liver resection, operative time, amount of blood loss, and rate of partial resection were not significantly different between the SM (–) and SM0-vascular groups. Postoperative peak serum aspartate transaminase, alanine transaminase, and total bilirubin levels were not significantly different between the two groups. Furthermore, no significant differences were observed between the incidence of Clavien–Dindo classification grade $\geq$ IIIa complications and the length of postoperative hospital stay. The breakdown of grade $\geq$ IIIa complications was as follows: in the SM (–) group, there was 1 case of pneumonia, 3 cases of bile leakage, 1 case of atelectasis, and 1 case of cerebral infarction. In contrast, the SM0-vascular group experienced 1 case of pneumonia, 2 cases of bile leakage, and 1 case of esophageal variceal rupture. The grade of fibrosis and rate of capsule formation were similar between the two groups (Table 2).

3.3. Results on early recurrence and short-term prognosis

The results regarding early recurrence, i.e., within one year and three years after surgery, showed no significant differences in the ratio of early intrahepatic tumor recurrence, SMR, or extrahepatic spread between the SM (–) and SM0-vascular groups (Table S1). In the SM (–) group, 4/99 cases (4 %) experienced recurrence within the same segment, 8/99 cases (8 %) in different segments, and 6/99 cases (6 %) of extrahepatic spread (four patients experienced two types of recurrences). Within one year after surgery, 1/99 patient (1 %) experienced SMR, and 13/99 (13 %) had some form of recurrence. In the SM0-vascular group, 3/32 cases (9 %) experienced recurrence within the same segment, 4/32 (13 %) in different

Table 1
Patient characteristics.

Variables	SM (–) [$n = 99$]	SM0-vascular [$n = 32$]	<i>p</i> -value ^a
Age, years ^a	73 (43–91)	71 (59–84)	0.09
Gender (male)	70 (71)	27 (84)	0.11
Underlying liver			0.24
HBV, HCV	46 (46)	18 (56)	
non-B, non-C	54 (54)	14 (44)	
TNM stage (I/II/III)	16/64/19	5/21/6	0.10
AFP, ng/mL ^a	7 (1–10136)	5 (2–1995)	0.23
Prothrombin time, % ^a	100.6 (45–130.7)	93.5 (62.9–118.1)	0.13
Platelet count, 10 ⁴ /μL ^a	17.5 (5.3–42.7)	16.6 (4.5–64.2)	0.21
AST, U/L ^a	27 (11–86)	26.5 (13–65)	0.81
ALT, U/L ^a	26 (6–143)	25 (11–77)	0.90
ALBI score ^a	–2.73 (–3.50 to –1.20)	–2.63 (–3.76 to –1.99)	0.98
Child–Pugh class (5A/6A/7B/8B)	84/13/1/1	29/3/0/0	0.68
ICGR15, % ^a	10.6 (1.2–60.5)	12.1 (3.8–33.6)	0.77
Tumor factor			
maximal tumor diameter, cm ^a	3.0 (1.0–13.0)	3.0 (1.0–8.0)	0.62
tumor number $\geq$ 2	15 (15)	11 (34)	0.02
macrovascular invasion	0 (0)	0 (0)	NA

Values in parentheses are percentages unless indicated otherwise.

AFP, alpha fetoprotein; ALBI, albumin–bilirubin.

^a values are median (range).

^a χ^2 test, except Mann–Whitney *U* test.

Table 2
Surgical and postoperative data.

Variables	SM (–) [n = 99]	SM0-vascular [n = 32]	p-value ^a
Type of liver resection			0.66
non-anatomical	60 (60)	18 (56)	
anatomical	39 (39)	14 (43)	
Extent of liver resection			0.97
major (≥3 segments)	6 (6)	2 (6)	
minor	93 (94)	30 (94)	
Length of operations, mins ^a	281 (100–739)	340 (184–729)	0.06
Pringle maneuver, times ^a	5 (0–15)	7 (1–18)	0.03
Blood loss, ml ^a	20 (0–950)	90 (0–760)	0.35
Postoperative complications	27 (28)	10 (31)	0.28
Clavien-Dindo ≥ grade IIIa	6 (6)	4 (13)	0.26
Blood examination			
AST max, U/L ^a	351 (45–5872)	416 (59–4537)	0.68
ALT max, U/L ^a	271 (17–2877)	417 (35–4517)	0.27
total bilirubin max, mg/dL ^a	1.4 (0.5–4.2)	1.5 (0.2–4.9)	0.48
Postoperative hospital stays, days ^a	11 (7–130)	10 (7–143)	0.92
Pathologic data			
tumor capsule formation	69 (70)	24 (75)	0.52
liver fibrosis stage ≥ grade 2	76 (79)	22 (69)	0.16

Values in parentheses are percentages unless indicated otherwise.

^a values are median (range).

^a χ^2 test, except Mann-Whitney U test.

segments, and 3/32 (9 %) experienced extrahepatic spread. Within one year after surgery, 0/32 (0 %) experienced SMR, and 8/32 (25 %) had some form of recurrence. The 3-year cumulative recurrence rates were 32 % in the SM (–) group and 46 % in the SM0-vascular group, with no significant difference between the groups ($p = 0.09$) (Fig. 4a) Table 1. In the SM (–) group, 8/99 cases (8 %) experienced recurrence within the same segment, 18/99 (18 %) in different segments, and 10/99 (10 %) experienced extrahepatic spread (5 patients experienced two types of recurrence). In the SM0-vascular group, 4/32 cases (13 %) experienced recurrence within the same segment, 11/32 (34 %) in different segments, and 3/32 (9 %) experienced extrahepatic spread (2 patients experienced two types of recurrence). The 3-year-SMR rate and overall survival (OS) showed no significant differences between the SM (–) and SM0-vascular groups (Fig. 4b). The 3-year-SMR rates were 5 % and 6 % for the SM (–) and SM0-vascular groups, respectively ($p = 0.46$). The 3-year-OS rates for the SM (–) SM0-vascular groups were 91 % and 86 %, respectively (Median survival time not reached, $p = 0.70$) (Fig. 4c).

4. Discussion

The present study evaluated the surgical outcomes of LLR with SM0-vascular for HCC and investigated their potential validity in detail using short-term recurrence data. Survival analysis confirmed no significant difference in the 3-year-SMR and the 3-year cumulative recurrence rates between LLR with SM (–) and SM0-vascular. To the best of our knowledge, this is the first study to compare the recurrence rates of patients who underwent LLR with SM (–) and SM0-vascular for HCC.

The literature recommends a surgical margin of at least 10 mm for non-anatomical liver resection. Studies have demonstrated that partial liver resection with a margin of 20 mm is superior to one with a margin of 10 mm in terms of tumor-related mortality,^{3,9,10} making it oncologically ideal in terms of surgical margins (SM (–)). However, surgeons are often faced with macroscopic complete resection of HCC along the tumor capsule while having to preserve the main intrahepatic vasculature and the maximum possible volume of the remnant liver¹¹ because the majority of

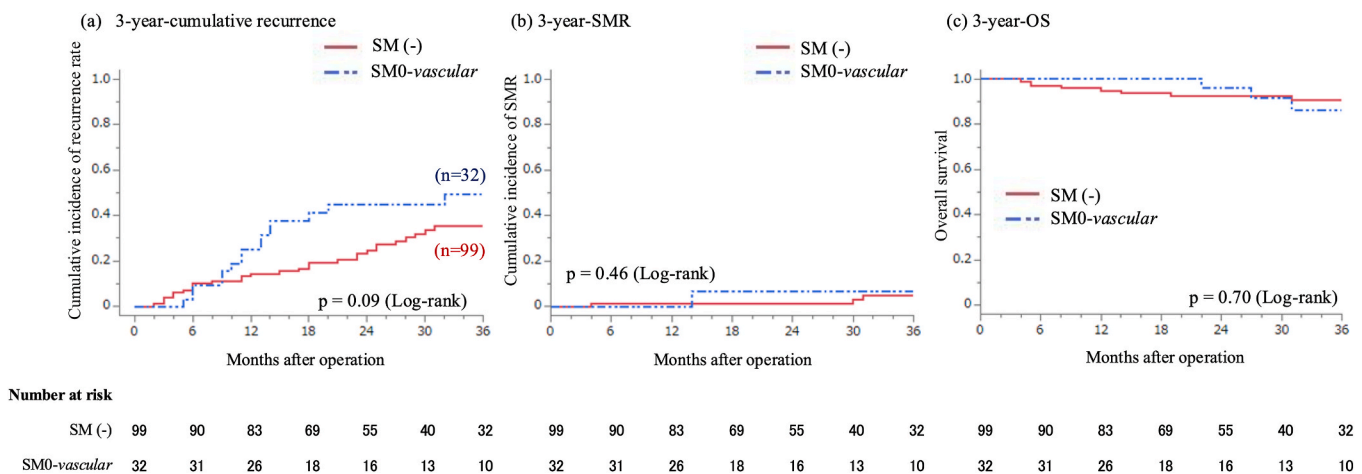


Fig. 4. Comparison of short-term prognosis after laparoscopic liver resection between SM (–) and SM0-vascular group. (a) The 3-year cumulative recurrence rates are 32 % for SM (–) and 46 % for SM0-vascular ($p = 0.09$). (b) The 3-year SMR rates are 5 % for SM (–) and 6 % for SM0-vascular ($p = 0.46$). (c) The 3-year OS rate for SM (–) is 91 %, and for SM0-vascular is 86 % (MST not reached, $p = 0.70$).

SM, surgical margin; SMR, surgical margin recurrence; OS, overall survival.

patients with HCC have underlying liver damage in clinical settings.¹² Consequently, triggering several investigations regarding the optimal surgical margin for HCC. Some studies have reported that narrow margins were associated with worse survival,^{2,3,13,14} while others reported otherwise.^{4,5,15,16} Aoki et al. reported that when compared with SM (–), non-anatomical resection with a 0-mm surgical margin was associated with less favorable recurrence-free survival (RFS).¹⁴ In contrast, Oguro et al. reported no significant difference in RFS and OS between a group that underwent macroscopic no-margin hepatectomy and a control group.¹⁵ Similarly, Donadon et al. reported that the detachment of HCC from the intrahepatic vessels (R1 vascular hepatectomy) is not associated with increased local recurrence or decreased survival.¹⁶ However, these results were reported for open surgery. It is difficult to determine whether optimal surgical margins and R0 resection are achieved macroscopically during OLR.

Our definition of SM0-vascular closely resembles the R1 vascular hepatectomy reported.^{16,17} The key distinction, however, is that we achieved SM0 using minimally invasive surgery. This study highlights the short-term impact of LLR with a 0-mm surgical margin on the vasculature. Laparoscopic SM0-vascular liver resection may be important for patients with HCC attached to the major intrahepatic vessels. We consider that the laparoscopic approach, the “minimally invasive approach,” has several advantages that could break the taboo. The layer between the tumor and vasculature is easily identified laparoscopically, resulting in all surgeons being subjected to the same vision in the surgical field, unlike in OLR. Additionally, LLR allows for meticulous dissection between the tumor capsule and vasculature, with the benefit of reduced blood loss due to pneumoperitoneum. Furthermore, ischemic or congested areas in the remnant liver can be minimized because of the preservation of the portal and/or hepatic vein branches, facilitating the retention of functional liver parts.

The RFS of SM0-parenchymal (referred to as R1-parenchymal) OLR was reported to be significantly inferior to that of SM (–) in patients with HCC,¹⁶ which may be oncologically reasonable. SM0-parenchymal resection is inadequate because it creates the possibility of tumor growth due to peritumoral micrometastases (satellite nodules) that may have been left behind. The present hypothesis could not be confirmed because of the small sample size of SM0-parenchymal cases in our study. The present study did not find a difference in the recurrence data between the SM (–) and SM0-parenchymal groups (Fig. S2a–c). However, SM0-vascular resection might be acceptable only when part of the tumor can be detached from the vasculature, as the vessel wall might curb tumor spread, except in cases of macroscopic vascular invasion. SM0-vascular resection may encompass SM0-parenchymal resection (referred to as SM0-*vasc* + *par*). However, it is difficult to distinguish between SM0-vascular and SM0-*vasc* + *par* based on pathological findings. Hence, the SMR ratio of SM0-vascular resection is expected to fall between that of R1-vascular and R1-*vasc* + *par*, with a 5-year SMR ratio of 4 % and 18 %, respectively.¹⁶ The 2/32 cases (6 %) with 3-year-SMR after SM0-vascular resection in our study were found to have negative surgical margins and might have had residual micro-intrahepatic metastases in the parenchyma near the tumor.

Oguro et al., in a single-center study, reported that no-margin hepatectomy showed a median RFS of 43 months.¹⁵ Additionally, Aoki et al. reported a median RFS of 28 months for non-anatomical SM0 resections and 39 months for anatomical SM0 resections in a nationwide study.¹⁴ Similarly, our study showed a median RFS of 39 months (data not shown) for SM0-vascular resection. This finding suggests that laparoscopic SM0-vascular resection may be beneficial regardless of the type or extent of liver resection performed.

In our study, the incidence of multiple tumors was higher in the SM0-vascular group than in the SM (–) group. Since the liver volume to be resected inevitably becomes larger for multiple tumors, and considering that the background liver functional reserve was similar in the two groups, it is speculated that the surgeons mainly opted for SM0-vascular resection to minimize ischemia and congestion of the remnant liver, thereby preventing postoperative liver failure. In some patients with multiple HCC, when the tumors are localized deep in the liver, combined vascular resection may be excessively invasive. Therefore, we believe that LLR with SM0-vascular is an ideal technique that may facilitate curative resection, even in such patients. Interestingly, no difference in recurrence data was observed between SM (–) and SM0-vascular when analyzing cases with a single tumor (Fig. S3a–c), suggesting that SM0-vascular resection may be beneficial regardless of the number of tumors. Additionally, the safety of our approach was demonstrated by its low major morbidity rate. Certainly, the number of Pringle maneuvers observed in our study was not negligible and was affected by patients who underwent SM0-vascular resection. However, as there were no significant differences in the length of the operation and postoperative blood examinations between the SM (–) and SM0-vascular groups, we believe that SM0-vascular resection can be safely performed. Regarding postoperative complications, the proportion of Grade $\geq$ IIIa events was slightly higher in SM0-vascular group than in the SM (–) group; however, the difference was not statistically significant. Notably, one case of bile leakage in the SM0-vascular group occurred when the tumor was located at the bifurcation of the anterior and posterior branches of the Glissonean pedicles. This finding suggests that detachment of the tumor from Glissonean bifurcations may require more meticulous technique.

Most HCCs are encapsulated, meaning that they are surrounded by fibrous tissue as a result of the host immune response against tumor cells.^{18–20} Consequently, the natural surgical margin should be based on the tumor capsule in HCC. However, SM0-vascular resection is a technically demanding procedure that could increase the risk of exposure, rupture of the tumor capsule, and microscopic tumor remnants compared to liver resection with a macroscopically sufficient margin. Therefore, meticulous dissection is essential to avoid damaging the main intrahepatic vasculature or tumor. Theoretically, when tumors do not have capsules, the surgical margin can be maintained by retaining the hepatic and cardiac Laennec's capsules on the tumor side.^{21–23} In this study, the presence or absence of a tumor capsule in SM0-vascular did not impact the recurrence data (Fig. S4a–c). Overall, we believe that tumors with definite capsule formation identified on preoperative MRI and patients with liver damage are optimal candidates for laparoscopic SM0-vascular resection.

The limitations of this study include its retrospective nature, single-center design, and treatment selection bias. First, it included a small number of patients. Second, in this study, the cumulative recurrence rate of SM0-vascular was increased compared to that of SM (–) nine months after liver resection, suggesting that the recurrence rate depends on tumor status (i.e., the number of tumors and microvascular invasion). Further studies with larger numbers of patients are required to assess the optimal surgical margins and long-term outcomes of minimally invasive liver surgery for HCC. Third, accurate assessment of the microscopic surgical margin is difficult after SM0 liver resection because the standard tissue section is thin. LLRs with SM0-vascular should be carefully performed because they can result in a positive surgical margin that deteriorates the prognosis. Indications for SM0 resection include poor liver function (e.g., cirrhosis), tumors with a capsule, multiple tumors, and small, deeply localized lesions. Thus, LLR with SM0-vascular is optional only in high-volume

centers. Fourth, variations in the accuracy of surgical video reviews make it challenging to compare the outcomes of open and laparoscopic SM0 resection. Finally, the risk of selection bias is heightened due to the difficulty in distinguishing between SM0-vascular and SM0-parenchymal resections based on pathology. Therefore, a definitive conclusion cannot be drawn from the present study, and the data should be interpreted cautiously. Nevertheless, this study is clinically significant as it provides evidence supporting a potentially effective therapeutic option for managing HCC using laparoscopy, considering that few reports have shown that detaching part of the tumor from the hepatic veins or Glissonian pedicles with SM0 can be performed safely.

In conclusion, no significant differences were observed in the 3-year SMR and 3-year cumulative recurrence rates between LLR with SM (–) and SM0-vascular in patients with HCC. In the evolving landscape of minimally invasive liver surgery, our study contributes to the growing evidence supporting the oncological safety of laparoscopic approaches in selected HCC cases. As surgical techniques continue to advance, a careful balance between complete tumor resection and preservation of functional liver tissue remains paramount. Our findings suggest that LLR with 0-mm vascular margins may offer this balance in carefully selected cases, potentially expanding the treatment options for patients with HCC.

Synopsis

This study found no significant difference in 3-year surgical margin recurrence and cumulative recurrence rates between laparoscopic liver resection (LLR) with negative surgical margins and LLR with 0-mm vascular margins for hepatocellular carcinoma. LLR with 0-mm vascular margins may be an acceptable strategy for local HCC control.

Reporting checklist

The authors have completed the STROBE Combined reporting checklist.

Ethical statement and informed consent

This retrospective study was conducted in accordance with the ethical standards of the Declaration of Helsinki and was approved by the Institutional Review Board Ethics Committee of Kobe University Hospital in 2024 (Approval Number #B240013). Informed consent was obtained from all participants using an opt-out form.

Data sharing statement

The datasets generated and/or analyzed during the current study are available from the corresponding author upon reasonable request.

Declaration of generative AI in scientific writing

There is nothing to disclose.

Funding

No sources of funding or financial support were used to assist in the preparation of this study.

Disclosures of conflicts of interest

Dr. Yuhi Shimura, Dr. Takeshi Urade, Dr. Shohei Komatsu, Dr.

Masahiro Kido, Dr. Hidetoshi Gon, Dr. Kenji Fukushima, Dr. Toshihiko Yoshida, Dr. Kentaro Tai, Dr. Keisuke Arai, Dr. Hiroaki Yanagimoto, Dr. Hirochika Toyama and Prof. Takumi Fukumoto have no conflicts of interest to disclose.

Acknowledgments

The authors would like to thank all investigators, clinicians, and research staff who supported this study, the patients who participated in this study, and their families.

Abbreviations

3D	three-dimensional
CT	computed tomography
HCC	hepatocellular carcinoma
ICGR15	indocyanine green retention rate at 15 min
LLR	laparoscopic liver resection
MHV	middle hepatic vein
MRI	magnetic resonance imaging
OLR	open liver resection
OS	overall survival
RFS	recurrence-free survival
SMR	surgical margin recurrence

Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.asjsur.2025.12.206>.

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