Original Article

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Textbook outcome and survival following laparoscopic versus open right hemihepatectomy for hepatocellular carcinoma: A propensity score-matched study

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SUMMARY: The role of laparoscopy for complex resections like right hemihepatectomy for hepatocellular carcinoma (HCC) remains contentious, and its assessment is often hampered by traditional metrics that fail to reflect the comprehensive quality of perioperative management. Therefore, this study used the textbook outcome (TO), a composite endpoint, to compare the laparoscopic (LRH) and open (ORH) approaches for HCC within a propensity score-matched (PSM) analysis. We retrospectively analyzed 435 patients who underwent curative-intent right hemihepatectomy. After 1:3 PSM, a final cohort of 121 patients who underwent LRH and 242 who underwent ORH was included for analysis. Results indicated that the rate of TO achievement was comparable between the LRH and ORH groups (62.0% *vs*. 65.3%, $p = 0.563$), with intraoperative complications (17.4%), post-hepatectomy liver failure (14.9%), and major postoperative complications (13.5%) as the primary barriers to achieving a TO. No significant differences in overall survival (OS) or disease-free survival (DFS) were observed, although the LRH group had a significantly shorter duration of hospitalization ($p = 0.006$). In multivariable Cox regression models, achieving a TO was confirmed as an independent protective factor for both OS (HR: 0.46, 95% CI: 0.34-0.63, $p < 0.001$) and DFS (HR: 0.44, 95% CI: 0.33-0.58, $p < 0.001$). For right hemihepatectomy, clinical practice should focus on maximizing the rate of TO achievement through systematic perioperative management, as a key strategy to improve long-term prognosis.

Keywords: liver cancer, minimally invasive surgery, textbook outcome, prognosis, postoperative complications

1. Introduction

Primary liver cancer (PLC) represents a significant global health burden, ranking as the sixth most common malignancy and the third leading cause of cancer-related mortality, with over 906,000 new cases diagnosed worldwide in 2020 (*1*). Hepatocellular carcinoma (HCC), the predominant histological subtype, comprises approximately 80% of the total PLC burden (*2*). For patients with HCC, surgical resection is the cornerstone of curative therapy for those with resectable lesions and well-preserved liver function, offering five-year survival rates of over 50% in selected cases (*3*).

With advances in minimally invasive principles and techniques, laparoscopic liver resection has emerged as a key alternative to open surgery, owing to its advantages in reducing perioperative trauma and shortening the duration of hospitalization, all while maintaining comparable oncological safety (*4,5*). However, the widespread use of laparoscopy in complex liver resections is limited by a steep learning curve and increased technical demands. Among hepatectomy procedures, right hemihepatectomy is particularly challenging due to its extensive resection volume and the intricate anatomy involved, posing significant demands on both the patient's physiological reserve and the surgeon's technical skill, which translates to heightened perioperative risks (*6*). Although studies have confirmed the safety and feasibility of laparoscopic hemihepatectomy (*7,8*), existing large-scale comparative analyses have largely focused on isolated perioperative endpoints. This fails to provide a comprehensive assessment of the overall quality of surgery and limits our understanding of how the perioperative course impacts the long-term prognosis.

Conventional quality assessment, which relies on single-outcome parameters, fails to capture the comprehensive characteristics of perioperative management (*9*). As a composite measure of multiple perioperative outcomes, the textbook outcome (TO) offers a more robust and comprehensive evaluation of overall surgical performance. In liver surgery, a standardized definition for the TO, established through an international Delphi consensus, includes five core domains: intraoperative incidents, general postoperative complications, liver surgery-related postoperative complications, mortality, and oncological resection margin (*10*). Crucially, the achievement of a TO is associated with improved long-term survival in patients undergoing hepatectomy (*11,12*). This association elevates the TO from a simple quality benchmark to a clinically significant prognostic factor.

Whether the laparoscopic approach confers an advantage in achieving the TO for liver surgery remains unclear. While some studies have suggested a benefit for the laparoscopic approach (*13*), other comparative analyses have reported no significant difference in the rate of TO achievement between the two approaches (*14,15*). Interestingly, evidence from a multicenter study suggests that although laparoscopic surgery results in a higher rate of TO achievement in minor liver resection, this advantage disappears with major liver resection (*16*). In addition, as the complexity of surgery increases, the rate of TO achievement tends to decrease (*17*). Collectively, these results suggest that the relationship between surgical procedures and the TO may be a complex dependency, indicating that a "one-size-fits-all" assessment is inadequate and that distinct procedures may have specific TO profiles.

To the extent known, no study has specifically evaluated the role of laparoscopy in achieving a TO within the challenging setting of right hemihepatectomy. Therefore, this study aimed to compare the rates of TO achievement and associated risk factors between laparoscopic (LRH) and open (ORH) right hemihepatectomy for HCC in a propensity score-matched cohort and to further explore the impact of the TO as a comprehensive outcome indicator on long-term survival.

2. Methods

2.1. Study population

This retrospective cohort study was conducted in accordance with the Declaration of Helsinki and adhered to the Strengthening the Reporting of Cohort, Cross-sectional, and Case-control Studies in Surgery (STROCSS) guidelines (*18*). The study protocol was approved by the Ethics Committee of West China Hospital, Sichuan University (Approval No. 2025-93), and the requirement for individual patient consent was waived due to the retrospective design. The study was registered with ClinicalTrials.gov as NCT06950827.

We retrospectively analyzed the clinical data on consecutive patients who underwent curative-intent LRH or ORH for HCC at our center between January 2018 and January 2023. The inclusion criteria were as follows: (i) age ≥ 18 years; (ii) pathologically confirmed HCC confined to the right hemiliver; (iii) elective surgery; and (iv) Child-Pugh class A or B liver function and an American Society of Anesthesiologists (ASA) classification of I, II, or III. The exclusion criteria were: (*i*) pathologically confirmed cholangiocarcinoma, combined hepatocellular-cholangiocarcinoma, or metastatic liver malignancies; (*ii*) history of previous upper abdominal surgery; (*iii*) concomitant resection of adjacent organs (other than the gallbladder) or major vascular/biliary reconstruction; (*iv*) presence of adjacent organ invasion (other than the gallbladder), major vascular or biliary tumor thrombus, or distant metastases; and (*v*) incomplete or missing critical data.

2.2. Perioperative strategy and surgical procedure

A standardized perioperative management strategy was adopted. Preoperatively, the surgical plans for all complex cases were discussed by a multidisciplinary team (MDT). The perioperative assessment of liver function reserve included Child-Pugh and albumin-bilirubin (ALBI) grading, the indocyanine green retention rate at 15 minutes (ICG-R15) test, and computed tomography (CT) volumetry measurement.

Right hemihepatectomy was performed using a standardized anterior approach (*19*). For the LRH group, following routine surgical exploration and cholecystectomy, intraoperative laparoscopic ultrasonography was utilized to define the anatomical relationship between the lesions and key structures, particularly the middle hepatic vein (MHV). The hepatic hilum was then dissected to isolate the right Glissonean pedicle, which was temporarily clamped to delineate a clear ischemic line. Alternatively, indocyanine green fluorescence staining technique could be applied to visualize the intersegmental boundaries. Using the demarcated border and the MHV as primary anatomical landmarks, parenchymal transection proceeded in a caudal-to-cranial direction. The parenchymal transection continued deep to the level of the hilar plate, where the right hilar structures were dissected. The transection then progressed superiorly, culminating in the dissection of the main trunk of the right hepatic vein (RHV) at the second hepatic hilum. The right hemiliver was mobilized by dissecting the perihepatic ligaments, the short hepatic veins, and any surrounding adhesions. The specimen was placed in a retrieval bag and extracted through an accessory incision in the lower abdomen. After ensuring hemostasis and absence of bile leakage from the cut surface, an abdominal drain was placed in the surgical field. The procedure for the ORH group, performed through a reverse "L" or right subcostal incision, was similar to that for the LRH group. For both groups, blood inflow was controlled by intermittent use of the Pringle maneuver as required.

Postoperatively, patients were managed following an established Enhanced Recovery after Surgery (ERAS) pathway, which included intensive care for high-risk individuals, dynamic fluid resuscitation, hepatoprotective therapy, thrombosis prophylaxis, and meticulous drainage management.

2.3. Definitions and outcomes

We used electronic medical records to retrospectively analyze the clinical data on patients, including their baseline characteristics, oncological information, intraoperative details, and pathological results. A comprehensive list of variables and a comparison of them between groups is detailed in Table 1. Preoperative liver function reserve was assessed using the ALBI score, calculated with the formula: (log10 bilirubin [μmol/L] × 0.66) - (albumin [g/L] × 0.085), and patients were stratified into three grades (*20*). The Barcelona Clinic Liver Cancer (BCLC) staging system was used for tumor staging (*21*). Major vascular or biliary invasion was defined as tumor involvement of the main hilar structures or invasion into the inferior vena cava or the confluence of the three main hepatic veins. Resection margin status was classified based on the shortest distance from the tumor to the transection plane, with an R0 resection (negative margin) defined as a tumor-free margin of ≥ 1 mm. The primary outcome was the achievement of a TO. A TO was considered to have been achieved if all of the following criteria were simultaneously met: absence

Table 1. Characteristics of HCC patients who underwent open or laparoscopic right hemihepatectomy before and after PSM

Variables	Before PSM			After PSM		
	ORH (*n* = 309)	LRH (*n* = 126)	*p* value	ORH (*n* = 242)	LRH (*n* = 121)	*p* value
Baseline Characteristics						
Age (years)	53 (46-64)	55.0 (48-64)	0.335	54 (47-64)	55 (48-64)	0.706
Sex (male)	270 (87.4)	106 (84.1)	0.359	210 (86.8)	102 (84.3)	0.525
BMI (kg/m²)	22.7 (20.9-24.7)	22.4 (20.2-24.5)	0.370	22.7 (20.7-24.8)	22.5 (20.2-24.5)	0.624
Diabetes mellitus	28 (9.1)	16 (12.7)	0.293	22 (9.1)	16 (13.2)	0.275
HBV infection	261 (84.5)	104 (82.5)	0.666	203 (83.9)	101 (83.5)	1.000
HCV infection	9 (2.9)	8 (6.3)	0.105	8 (3.3)	8 (6.6)	0.177
ALT (U/L)	39 (25-58)	36 (22-59)	0.356	36 (25-56)	36 (22-59)	0.455
Cirrhosis	186 (60.2)	68 (54.0)	0.240	142 (58.7)	67 (55.4)	0.574
ALBI grade			0.430			0.779
I	244 (79.0)	104 (82.5)		194 (80.2)	99 (81.8)	
II&III	65 (21.0)	22 (17.5)		48 (19.8)	22 (18.2)	
Tumor characteristics						
Tumor size > 5 cm	219 (65.8)	67 (53.1)	**< 0.001**	155 (64.1)	67 (55.4)	0.110
Multiple tumors	85 (27.5)	22 (17.5)	**0.028**	53 (21.9)	22 (18.2)	0.492
AFP > 400 ng/mL	122 (39.5)	39 (31.0)	0.101	83 (34.3)	38 (31.4)	0.637
BCLC stage			**< 0.001**			0.080
0&A	163 (52.8)	92 (73.0)		152 (62.8)	87 (71.9)	
B	46 (14.9)	17 (13.5)		32 (13.2)	17 (14.0)	
C	100 (32.4)	17 (13.5)		58 (24.0)	17 (14.0)	
Tumor differentiation			0.209			0.606
Well-differentiated	6 (1.9)	5 (4.0)		5 (2.1)	4 (3.3)	
Moderately differentiated	159 (51.5)	72 (57.1)		134 (55.4)	70 (57.9)	
Poorly differentiated	144 (46.6)	49 (38.9)		103 (42.6)	47 (38.8)	
Microvascular invasion	90 (29.1)	28 (22.2)	0.155	63 (26.0)	27 (22.3)	0.519
Preoperative therapy	71 (23.0)	18 (14.3)	**0.049**	48 (19.8)	18 (14.9)	0.312
Subsequent therapy	207 (67.0)	86 (68.3)	0.823	155 (64.0)	84 (69.4)	0.348
Operative details						
Operating time (min)	215 (180-260)	260 (226-292)	**< 0.001**	214.5 (180-260)	260 (227-293)	**< 0.001**
Blood loss (mL)	300 (200-500)	300 (200-400)	**0.019**	300 (200-500)	300 (200-450)	0.159
Blood transfusion	53 (17.2)	14 (11.1)	0.143	34 (14.0)	14 (11.6)	0.622
Resection margin < 1 cm	178 (57.6)	61 (48.4)	0.090	135 (55.8)	58 (47.9)	0.181
Conversion to open	/	13 (10.3)		/	13 (10.7)	
Outcomes						
Intraoperative complication	62 (20.1)	24 (19.0)	0.895	39 (16.1)	24 (19.8)	0.381
Bile leak	17 (5.5)	3 (2.4)	0.210	12 (5.0)	3 (2.5)	0.402
Post-hepatectomy liver failure	56 (18.1)	23 (18.3)	1.000	32 (13.2)	22 (18.2)	0.215
Major complication	53 (17.2)	14 (11.1)	0.143	36 (14.9)	13 (10.7)	0.330
Readmission	22 (7.1)	5 (4.0)	0.276	19 (7.9)	5 (4.1)	0.262
In-hospital mortality	13 (4.2)	4 (3.2)	0.788	8 (3.3)	3 (2.5)	0.758
Margin-positive resection	31 (10.0)	9 (7.1)	0.464	18 (7.4)	9 (7.4)	1.000
Textbook outcome achieved	180 (58.3)	79 (62.7)	0.451	158 (65.3)	75 (62.0)	0.563
Duration of hospitalization (days)	9.0 (7.0-10.0)	8.0 (6.0-10.0)	**0.002**	8.0 (7.0-10.0)	8.0 (6.0-10.0)	**0.006**

AFP, alpha-fetoprotein; ALBI, albumin-bilirubin; ALT, alanine aminotransferase; BCLC, Barcelona Clinic Liver Cancer; BMI, body mass index; HBV, hepatitis B virus; HCV, hepatitis C virus; IQR, interquartile range; LRH, laparoscopic right hemihepatectomy; ORH, open right hemihepatectomy; PSM, propensity score matching. Data are presented as n (%) or median (IQR). Values in bold were statistically significant.

of intraoperative grade ≥ 2 incidents (*22*); absence of a postoperative grade B or C bile leak or post-hepatectomy liver failure (PHLF) (*23,24*); absence of major postoperative complications (defined as Clavien-Dindo grade ≥ III) (*25*); absence of 90-day readmission, in-hospital, or 90-day mortality and an R0 resection margin (*10*). Secondary outcomes included overall survival (OS) and disease-free survival (DFS). OS was defined as the interval from the date of surgery to death from any cause or the date of the last follow-up. DFS was defined as the interval from the date of surgery to the first documented tumor recurrence or death from any cause. In addition, the duration of hospitalization was defined as the total number of days from the date of admission to the date of discharge.

Patients underwent follow-up assessments at 1 and 3 months after surgery, and every 3 to 6 months thereafter, or more frequently if clinically indicated. Standard evaluations included serum tumor marker levels, liver function tests, and imaging (typically contrast-enhanced CT, MRI, or contrast-enhanced ultrasound). Tumor recurrence was defined as the appearance of new intrahepatic lesions, local recurrence at the resection margin, or distant metastases on routine follow-up imaging. The data cutoff date for this study was January 1, 2025. Patients who were alive and who had not experienced an endpoint event by this date were censored at the time of their last follow-up.

2.4. Statistical analysis

Continuous variables are expressed as the mean ± standard deviation (SD) or median with interquartile range (IQR) based on their distribution, and they were compared using the Student's *t*-test or Mann-Whitney *U* test, respectively. Categorical variables are expressed as numbers (n) and percentages (%), and they were compared using the Pearson's χ^2 test or Fisher's exact test, as appropriate. To minimize selection bias inherent in this non-randomized study, a 1:3 propensity score matching (PSM) was performed. A binary logistic regression model was constructed to calculate a propensity score for each patient, including baseline covariates that could influence the choice of surgical approach. These covariates were: age, sex, BMI, presence of cirrhosis, ALBI grade, maximum tumor size, presence of multiple lesions, AFP > 400 ng/mL, and history of preoperative therapy. We used a nearest-neighbor matching algorithm without replacement, with a caliper width set at 0.1. The balance of covariates before and after matching was assessed using the standardized mean difference (SMD), with an SMD < 0.1 considered indicative of a satisfactory balance. To explore the independent predictors for achieving a TO and for survival outcomes, multivariable logistic regression and Cox proportional hazards regression models were constructed, respectively (*15,16*). The variable selection process for these models followed a two-step method: variables with statistical significance ($p < 0.1$) in univariate analysis were subsequently entered into the multivariable models (*12*). The proportional hazards assumption for all Cox models was verified. All statistical analyses were performed using the software R (version 4.3.0, R Foundation for Statistical Computing, Vienna, Austria). For all analyses, a two-tailed *p*-value < 0.05 was considered statistically significant, unless otherwise specified. For pairwise subgroup comparisons in the survival analysis, the Bonferroni correction was applied to account for multiple comparisons, and a *p*-value < 0.0125 was considered statistically significant for these specific analyses.

3. Results

3.1. Patient characteristics

A total of 435 patients who underwent curative-intent right hemihepatectomy for HCC were included in the initial cohort for this study (Figure 1). The cohort was predominantly male (n = 376, 86.4%), with a median age of 54 years (IQR, 47-64). Most patients had a background of chronic hepatitis B (83.9%), and liver function reserve was generally well-preserved, with 80.0% of patients classified as ALBI grade I (n = 348). In terms of oncological features, 58.6% of patients had BCLC stage 0 or A, the median maximum tumor diameter was 6.5 cm (IQR, 4.5-9.5 cm), and 24.6% presented with multiple tumors. Detailed clinical characteristics are shown in Table 1.

Prior to PSM, the cohort consisted of 126 patients who underwent LRH and 309 who underwent ORH. Significant imbalances were observed between the two groups across several variables (Table 1). Specifically, compared to the ORH group, the LRH group presented with smaller tumors (tumor size > 5 cm: 53.1% *vs*. 65.8%, $p < 0.001$), fewer multiple tumors (17.5% *vs*. 27.5%, $p = 0.028$), an earlier BCLC stage ($p < 0.001$), and a lower frequency of preoperative therapy (14.3% *vs*. 23.0%, $p = 0.049$). After PSM, a final cohort of 121 patients in the LRH group and 242 patients in the ORH group was generated for analysis. Following matching, all baseline variables were well-balanced, with all *p*-values > 0.05 and SMDs < 0.1 for all matching covariates (Table 1; Supplemental Figure S1, *https://www.biosciencetrends.com/action/getSupplementalData.php?ID=267*).

3.2. Perioperative outcomes and TO achievement

The perioperative outcomes for the matched cohort are detailed in Table 1. The LRH group was associated with a longer operating time compared to the ORH group (median: 260 *vs*. 214.5 min, $p < 0.001$). However, the two groups were comparable in terms of intraoperative blood loss, blood transfusion rates, and the incidence of

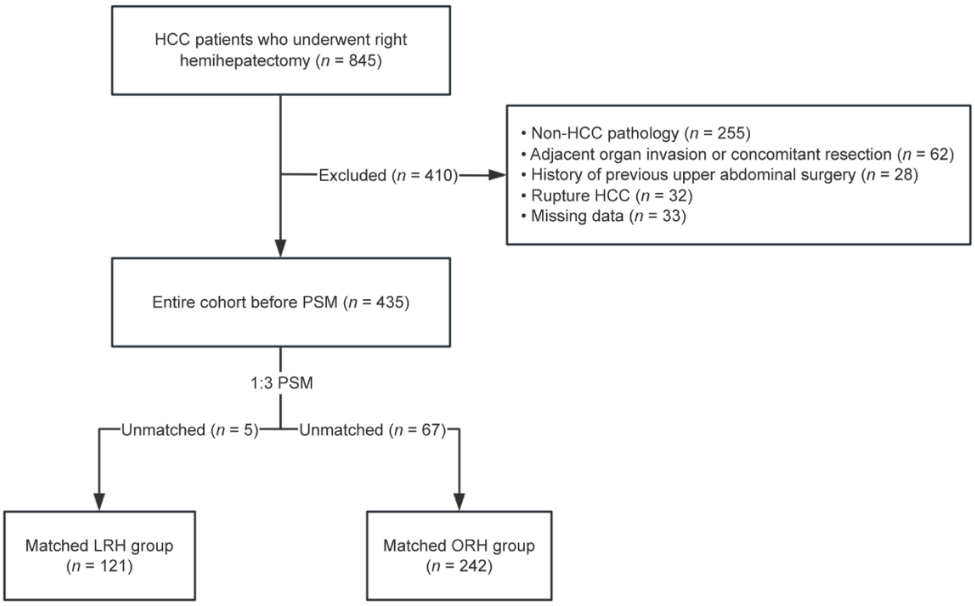

Figure 1. Flow diagram for patient selection.

narrow margins. Of the 121 patients in the LRH group, 13 (10.7%) required conversion to open surgery due to intraoperative difficulties.

In the entire matched cohort (n = 363), the overall rate of TO achievement was 64.2% (n = 233). An analysis of the individual components precluding a TO revealed that intraoperative complications were the primary barrier, affecting 17.4% of patients, followed by post-hepatectomy liver failure (PHLF) (14.9%) and major postoperative complications (13.5%) (Table 1 and Figure 2). When the two surgical approaches were compared, there were no significant differences in the rates of any individual TO components, which culminated in a comparable overall rate of TO achievement between the LRH and ORH groups (62.0% *vs*. 65.3%, p = 0.563). Notably, although the median duration of hospitalization was identical at 8 days for both groups, the Mann-Whitney U test revealed a significant difference in the overall distribution of the duration of hospitalization (p = 0.006), favoring the LRH group.

To investigate the risk factors for TO achievement, a logistic regression analysis was performed (Table 2). After adjusting for competing variables, the multivariable model demonstrated that factors such as intraoperative blood loss > 400 mL (OR: 0.22, 95% CI: 0.13-0.39, p < 0.001), BCLC stage C (*vs*. 0/A; OR: 0.26, 95% CI: 0.13-0.49, p < 0.001), the presence of cirrhosis (OR: 0.51, 95% CI: 0.30-0.86, p = 0.012), poorer liver function (ALBI grade 2/3 *vs*. 1; OR: 0.54; 95% CI:, 0.29-0.99; p = 0.046), and a tumor size > 5 cm (OR: 0.55, 95% CI: 0.30-0.98, p = 0.043) were each independently associated with lower odds of achieving a TO. Notably, the surgical approach was not an independent predictor of TO achievement (p = 0.536).

3.3. Survival analysis

The median follow-up for the matched cohort was 66.2 months (95% CI: 64.5–67.9 months). An initial Kaplan-Meier analysis was performed to directly compare the impact of the two surgical approaches on long-term survival (Figure 3). This analysis showed that although the LRH group tended to have better outcomes in both median OS and DFS, these differences were not statistically significant (median OS: 44.7 *vs*. 35.0 months, p = 0.179; median DFS: 20.7 *vs*. 16.6 months, p = 0.181). The comparable 5-year OS rates (39.1% *vs*. 37.4%) and 5-year DFS rates (24.2% *vs*. 21.4%) further corroborated this finding. To further explore the interactive effects of the surgical approach and TO on prognosis, a stratified four-subgroup survival analysis was performed (Figure 4). After applying a strict Bonferroni correction for multiple subgroup comparisons (significance level: p < 0.0125), we found that regardless of the surgical approach used, patients in whom a TO was achieved had significantly better DFS and OS than in those whom it was not achieved. The 5-year OS rate for patients in whom a TO was achieved was 49.9%, in stark contrast to only 17.5% for those in the non-TO group (Log-rank p < 0.001). A similarly large difference in DFS was observed (5-year DFS rate: 31.5% *vs*. 6.6%; p < 0.001). In contrast, there were no statistically significant differences in OS and DFS between the two surgical approaches, either within the group in whom a TO was achieved or in the group in whom it was not achieved.

In order to identify independent prognostic factors for long-term survival, Cox proportional hazards regression analysis was performed (Tables 3 and 4). For OS, the multivariable analysis identified the achievement of a

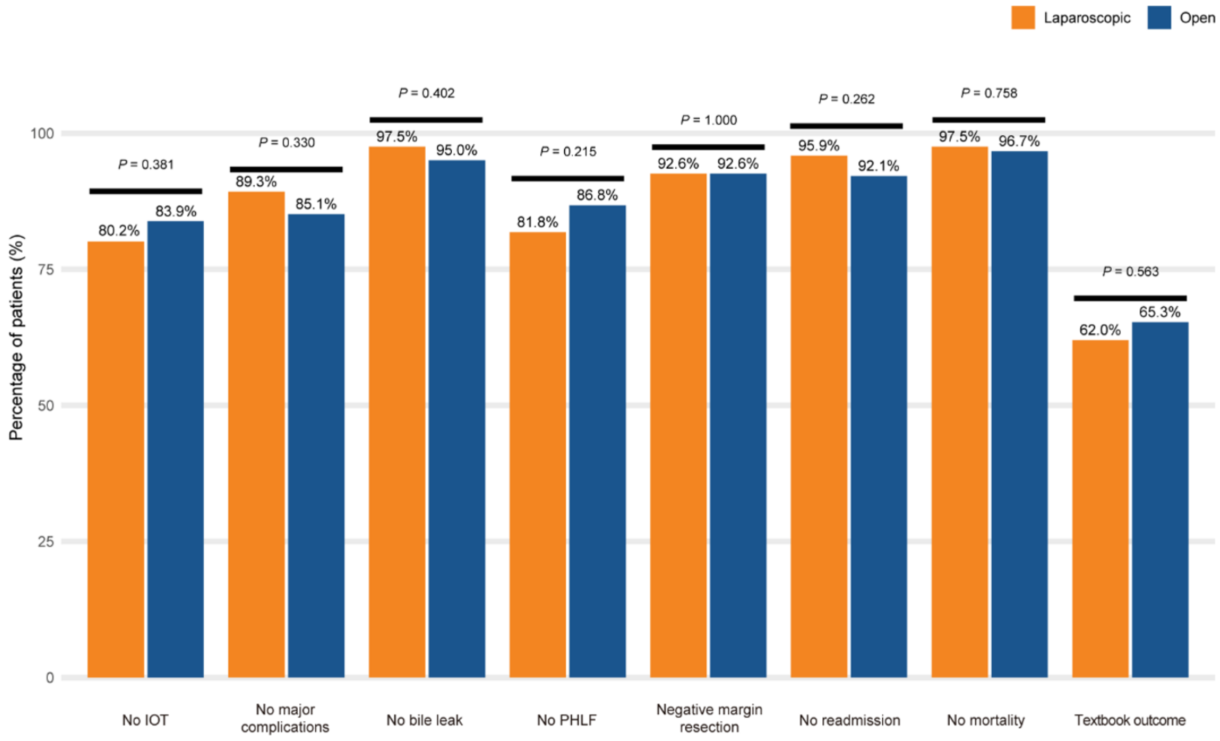

Figure 2. Textbook outcome individual components after PSM: Comparison between laparoscopic and open right hemihepatectomy for HCC. PSM, propensity score matching; HCC, hepatocellular carcinoma; IOT, intervention other than tumor resection; PHLF, post-hepatectomy liver failure.

Table 2. Univariate and multivariate logistic regression analyses to predict textbook outcome in right hemihepatectomy for HCC

Variables	Univariate analysis		Multivariate analysis	
	OR (95% CI)	*p* value	OR (95% CI)	*p* value
Age (> 65 years)	0.99 (0.59-1.70)	0.970		
Sex (male)	1.18 (0.64-2.16)	0.585		
BMI (≥ 25 kg/m²)	0.84 (0.50-1.42)	0.517		
Diabetes mellitus	0.66 (0.33-1.31)	0.228		
HBV infection	0.75 (0.40-1.35)	0.354		
HCV infection	0.71 (0.26-2.02)	0.500		
Cirrhosis	0.52 (0.33-0.80)	0.004	0.51 (0.30-0.86)	**0.012**
ALBI grade II&III *vs*. I	0.45 (0.26-0.76)	0.003	0.54 (0.29-0.99)	**0.046**
Tumor size (> 5 cm)	0.49 (0.31-0.78)	0.003	0.55 (0.30-0.98)	**0.043**
Multiple tumors	0.65 (0.39-1.09)	0.098	0.37 (0.13-1.04)	0.060
AFP (> 400 ng/mL)	0.96 (0.61-1.53)	0.877		
BCLC stage				
B *vs*. 0&A	0.54 (0.29-1.04)	0.062	1.10 (0.33-3.68)	0.873
C *vs*. 0&A	0.17 (0.10-0.30)	< 0.001	0.26 (0.13-0.49)	**< 0.001**
Tumor differentiation				
moderately differentiated *vs*. well-differentiated	1.26 (0.26-4.94)	0.751		
poorly differentiated *vs*. well-differentiated	0.59 (0.12-2.31)	0.463		
Microvascular invasion	0.65 (0.40-1.07)	0.087	1.13 (0.62-2.10)	0.690
Preoperative therapy	0.90 (0.52-1.57)	0.699		
Operating time (> 300 min)	0.31 (0.16-0.57)	< 0.001	0.52 (0.24-1.10)	0.087
Blood loss (> 400 mL)	0.19 (0.11-0.31)	< 0.001	0.22 (0.13-0.39)	**< 0.001**
Resection margin (< 1 cm)	0.51 (0.32-0.78)	0.002	0.70 (0.42-1.18)	0.183
Surgical approach (LRH *vs*. ORH)	0.87 (0.55-1.37)	0.536		

AFP, alpha-fetoprotein; ALBI, albumin-bilirubin; BCLC, Barcelona Clinic Liver Cancer; BMI, body mass index; CI, confidence interval; HBV, hepatitis B virus; HCV, hepatitis C virus; LRH, laparoscopic right hemihepatectomy; OR, odds ratio; ORH, open right hemihepatectomy. Variables with $p < 0.1$ in univariate analysis were included in the multivariate model. Values in bold were statistically significant ($p < 0.05$) in multivariate analysis.

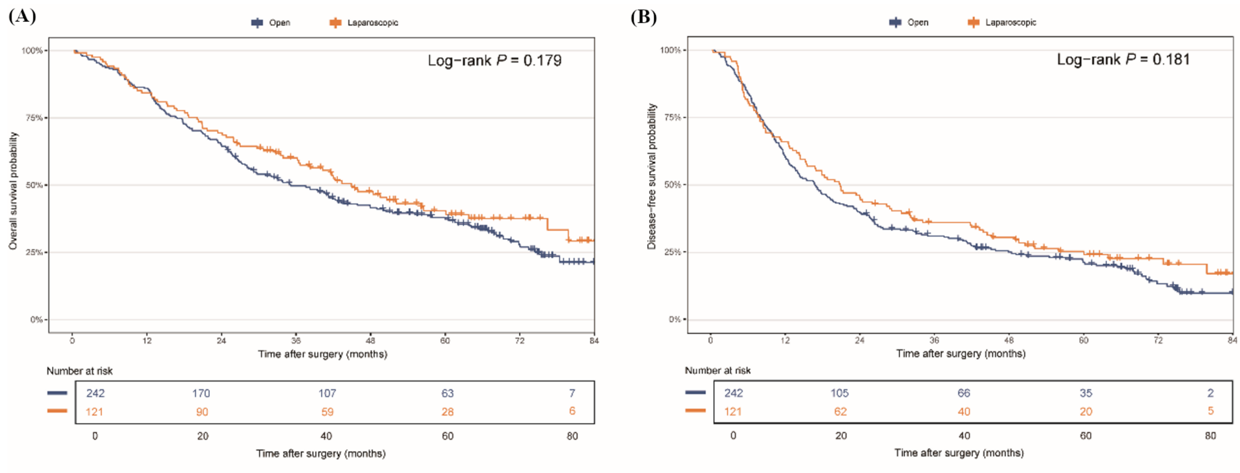

Figure 3. Kaplan-Meier survival curves after PSM: (A) overall survival and (B) disease-free survival comparing laparoscopic versus open right hemihepatectomy for HCC. LRH, laparoscopic right hemihepatectomy; ORH, open right hemihepatectomy; PSM, propensity score matching; HCC, hepatocellular carcinoma.

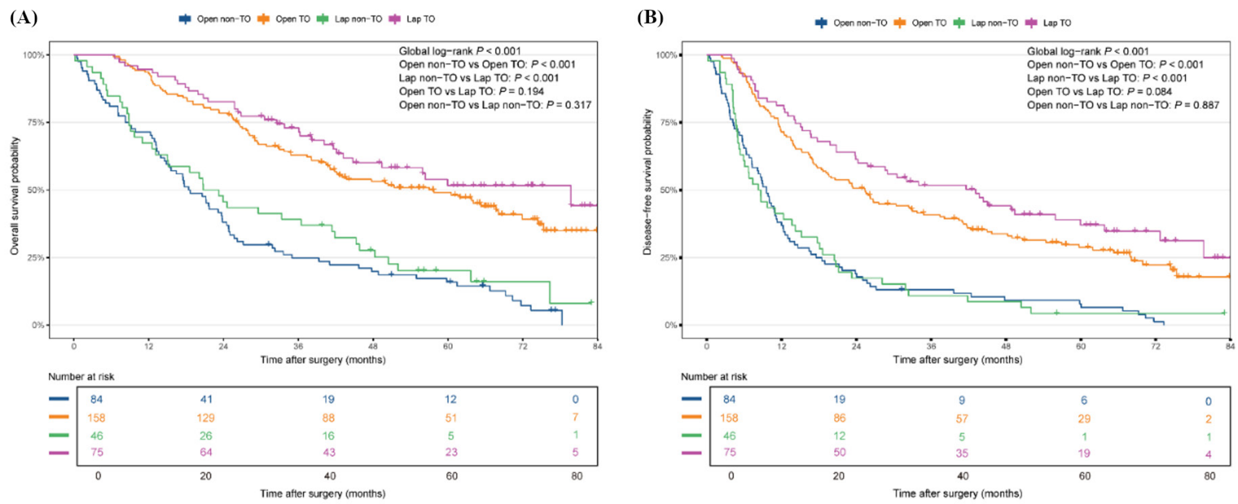

Figure 4. Kaplan-Meier curves for (A) overall survival and (B) disease-free survival, stratified by surgical approach and textbook outcome achievement. TO, textbook outcome; Lap, laparoscopic right hemihepatectomy; Open, open right hemihepatectomy; PSM, propensity score matching; HCC, hepatocellular carcinoma.

TO as an independent protective factor (HR: 0.46, 95% CI: 0.34-0.63, $p < 0.001$). Concurrently, BCLC stage C (HR: 1.86, 95% CI: 1.31-2.65, $p < 0.001$), microvascular invasion (HR: 1.66, 95% CI: 1.23-2.23, $p < 0.001$), and a resection margin < 1 cm (HR: 1.36, 95% CI: 1.03-1.80, $p = 0.030$) were identified as independent risk factors for OS. Regarding DFS, the multivariable analysis similarly confirmed that achievement of a TO was an independent protective factor (HR: 0.44, 95% CI: 0.33-0.58, $p < 0.001$). Independent risk factors associated with worse DFS were: the presence of cirrhosis (HR: 1.42, 95% CI: 1.10-1.83, $p = 0.007$), multiple tumors (HR: 1.84, 95% CI: 1.15-2.95, $p = 0.011$), BCLC stage C (HR: 1.79, 95% CI: 1.27-2.51, $p < 0.001$), poor tumor differentiation (HR: 2.70, 95% CI: 1.08-6.73, $p = 0.033$), microvascular invasion (HR: 2.46, 95% CI: 1.85-3.27, $p < 0.001$), and a resection margin < 1 cm (HR: 1.42, 95% CI: 1.11-1.83, $p = 0.006$).

4. Discussion

TO, a standardized multidimensional metric in liver surgery (*10,17*), provides a robust tool for comprehensively measuring the optimal clinical course for patients postoperatively. In recent years, laparoscopic techniques have been widely adopted in liver surgery, owing to advantages such as smaller incisions and superior high-definition, variable-angle visualization (*8,19*). However, their use in right hemihepatectomy, a procedure hampered by a steep learning curve and the risk of major postoperative complications, remains limited to high-volume centers, and the perioperative evaluation metrics in related cohort studies have often been one-dimensional. The current study focused specifically on the homogeneous, standardized, and complex procedure of right hemihepatectomy for HCC.

Table 3. Univariate and multivariate Cox regression analyses to predict overall survival in right hemihepatectomy for HCC

Variables	Univariate analysis		Multivariate analysis	
	HR (95% CI)	*p* value	HR (95% CI)	*p* value
Age (> 65 years)	1.16 (0.85-1.59)	0.337		
Sex (male)	0.92 (0.65-1.32)	0.657		
BMI (≥ 25 kg/m²)	1.21 (0.89-1.64)	0.231		
Diabetes mellitus	0.95 (0.62-1.47)	0.826		
HBV infection	1.15 (0.80-1.65)	0.445		
HCV infection	1.10 (0.58-2.07)	0.773		
Cirrhosis	1.49 (1.14-1.94)	0.003	1.14 (0.86-1.51)	0.377
ALBI grade II&III *vs*. I	1.28 (0.94-1.75)	0.122		
Tumor size (> 5 cm)	1.73 (1.31-2.28)	< 0.001	1.20 (0.89-1.62)	0.232
Multiple tumors	1.22 (0.89-1.67)	0.209		
AFP (> 400 ng/mL)	1.25 (0.96-1.63)	0.102		
BCLC stage				
B *vs*. 0&A	1.66 (1.13-2.43)	0.010	1.30 (0.88-1.94)	0.191
C *vs*. 0&A	3.41 (2.53-4.59)	< 0.001	1.86 (1.31-2.65)	**< 0.001**
Tumor differentiation				
moderately differentiated *vs*. well-differentiated	1.67 (0.62-4.54)	0.311		
poorly differentiated *vs*. well-differentiated	3.00 (1.10-8.15)	0.031	2.39 (0.86-6.60)	0.094
Microvascular invasion	2.15 (1.62-2.84)	< 0.001	1.66 (1.23-2.23)	**< 0.001**
Preoperative therapy	1.29 (0.94-1.79)	0.118		
Operating time (> 300 min)	1.37 (0.96-1.95)	0.084	0.80 (0.54-1.18)	0.255
Blood loss (> 400 mL)	1.67 (1.27-2.18)	< 0.001	1.20 (0.88-1.64)	0.241
Resection margin (< 1 cm)	1.70 (1.31-2.21)	< 0.001	1.36 (1.03-1.80)	**0.030**
Surgical approach (LRH *vs*. ORH)	0.83 (0.63-1.09)	0.179		
Textbook outcome	0.34 (0.26-0.44)	< 0.001	0.46 (0.34-0.63)	**< 0.001**

AFP, alpha-fetoprotein; ALBI, albumin-bilirubin; BCLC, Barcelona Clinic Liver Cancer; BMI, body mass index; CI, confidence interval; HBV, hepatitis B virus; HCV, hepatitis C virus; HR, hazard ratio; LRH, laparoscopic right hemihepatectomy; ORH, open right hemihepatectomy. Variables with $p < 0.1$ in univariate analysis were included in the multivariate model. Values in bold were statistically significant ($p < 0.05$) in multivariate analysis.

Our primary finding was that mature laparoscopic and open approaches had comparable performance in achieving a TO. A distinct advantage for the laparoscopic group, however, was observed in quicker postoperative recovery, which aligns with ERAS principles, as evinced by a significantly shorter duration of hospitalization. Consistent with previous findings, we confirmed that neither the difference in surgical approach nor the speediness of recovery translated directly into a significant long-term survival benefit. More importantly, we found that, irrespective of the approach, patients in whom a TO was achieved had far superior long-term survival, then establishing TO achievement as an independent prognostic factor *via* multivariable survival regression analyses. Therefore, these findings suggest that when evaluating and selecting options for complex liver surgery, the clinical focus should systematically shift from the choice of surgical approach alone to fostering a perioperative environment conducive to achieving a TO, thereby improving long-term prognosis.

Previous studies have reported a considerable variation in the rate of TO achievement following liver surgery, ranging from 22.1% to 80.5% (*12-14,26-29*). Whether laparoscopy results in a higher rate of TO achievement remains open to discussion, with some studies considering it advantageous (*13,28*) and others not (*14,26*). This heterogeneity in findings appears to be closely linked to the amalgamation of different types of procedures and complexities in study cohorts (*16,30*), as a laparoscopic benefit is more readily observed in studies with a higher proportion of patients with early-stage disease and undergoing minor hepatectomy. This underscores the need to evaluate outcomes within specific procedural contexts. Our study, conducted at a high-volume liver surgery center, focused exclusively on right hemihepatectomy. In this specific setting, the overall rate of TO achievement in the matched cohort was 64.2%, and performance between the laparoscopic and open groups was comparable (62.0% *vs*. 65.3%, $p = 0.563$). The reasons for this finding of equivalence are multifaceted. First, the inherent technical difficulty, high physiological impact (*6,29*), and potentially heavy tumor burden of right hemihepatectomy likely act as the primary determinants of the outcome (*12*). This may create a "ceiling effect," largely diluting the theoretical advantages of a minimally invasive approach that are more evident with simpler procedures (*16*). Our data also confirmed that intraoperative events, PHLF, and major complications are the main challenges hindering the achievement of a TO in patients in this cohort. Secondly, the dimensions of TO and the differences in TO standards among different studies also warrant consideration (*14,31*). The standard used in our study derives from a Delphi consensus (*10*). However, the

Table 4. Univariate and multivariate Cox regression analyses to predict disease-free survival in right hemihepatectomy for HCC

Variables	Univariate analysis		Multivariate analysis	
	HR (95% CI)	*p* value	HR (95% CI)	*p* value
Age (> 65 years)	1.00 (0.75-1.33)	0.984		
Sex (male)	1.06 (0.76-1.49)	0.712		
BMI (≥ 25 kg/m²)	1.11 (0.84-1.46)	0.482		
Diabetes mellitus	1.04 (0.72-1.51)	0.820		
HBV infection	1.18 (0.85-1.62)	0.322		
HCV infection	1.35 (0.79-2.32)	0.270		
Cirrhosis	1.61 (1.26-2.04)	< 0.001	1.42 (1.10-1.83)	**0.007**
ALBI grade II&III *vs*. I	1.15 (0.87-1.53)	0.336		
Tumor size (> 5 cm)	1.55 (1.22-1.98)	< 0.001	1.24 (0.94-1.64)	0.128
Multiple tumors	1.56 (1.19-2.06)	0.001	1.84 (1.15-2.95)	**0.011**
AFP (> 400 ng/mL)	1.23 (0.97-1.57)	0.090	1.05 (0.81-1.36)	0.727
BCLC stage				
B *vs*. 0&A	1.82 (1.30-2.54)	< 0.001	0.81 (0.47-1.41)	0.460
C *vs*. 0&A	3.41 (2.57-4.53)	< 0.001	1.79 (1.27-2.51)	**< 0.001**
Tumor differentiation				
moderately differentiated *vs*. well-differentiated	2.08 (0.85-5.09)	0.108		
poorly differentiated *vs*. well-differentiated	3.61 (1.47-8.86)	0.005	2.70 (1.08-6.73)	**0.033**
Microvascular invasion	3.21 (2.47-4.16)	< 0.001	2.46 (1.85-3.27)	**< 0.001**
Preoperative therapy	1.29 (0.96-1.74)	0.095	1.20 (0.88-1.64)	0.257
Operating time (> 300 min)	1.26 (0.90-1.75)	0.173		
Blood loss (> 400 mL)	1.33 (1.03-1.71)	0.027	0.90 (0.67-1.20)	0.477
Resection margin (< 1 cm)	1.57 (1.24-1.98)	< 0.001	1.42 (1.11-1.83)	**0.006**
Surgical approach (LRH *vs*. ORH)	0.84 (0.66-1.08)	0.182		
Textbook outcome	0.35 (0.28-0.45)	< 0.001	0.44 (0.33-0.58)	**< 0.001**

AFP, alpha-fetoprotein; ALBI, albumin-bilirubin; BCLC, Barcelona Clinic Liver Cancer; BMI, body mass index; CI, confidence interval; HBV, hepatitis B virus; HCV, hepatitis C virus; HR, hazard ratio; LRH, laparoscopic right hemihepatectomy; ORH, open right hemihepatectomy. Variables with $p < 0.1$ in univariate analysis were included in the multivariate model. Values in bold were statistically significant ($p < 0.05$) in multivariate analysis.

variable "no extended duration of hospitalization" did not reach the 80% expert consensus threshold when this consensus was reached and was therefore not included in the final criteria. This precisely explains an important phenomenon in our study, that is, there was no TO advantage in the LRH group, but it had a significantly shorter duration of hospitalization, confirming its value in ERAS that exists outside the current TO definition (*26*). While some studies incorporate duration of hospitalization in the TO, its judgment criteria (such as the median or 75th percentile) are readily affected by variations in different diseases, regional levels of medicine, and cultural beliefs. Finally, our use of PSM effectively controlled for the common selection bias of assigning patients with smaller tumor burdens to the LRH group, thus reducing the risk of false-positive results and providing a more realistic analysis. The results for intraoperative blood loss reflect this matching effect. While the LRH group had a more favorable distribution of blood loss before matching ($p = 0.019$), this advantage was offset after PSM, which may be related to the balance of patients at risk of intraoperative bleeding between the two groups. The concept of a TO is valuable for identifying weak links in specific medical processes. At our center, intraoperative incidents, PHLF, and major postoperative complications were the three primary challenges hindering achievement of a TO (Figure 2). Multivariable logistic regression analysis (Table 2) further confirmed that the achievement of a TO was independently associated with several clinical factors, including patient condition (cirrhosis, ALBI grade 2/3), tumor burden and aggressiveness (BCLC stage C, tumor size > 5 cm), and intraoperative blood loss > 400 mL, which is consistent with previous studies (*27,32,33*). Crucially, these factors for a TO are also, to a large extent, well-established risk factors for long-term survival. This provides a clear mechanistic explanation for why TO so effectively predicts prognosis (*12,34*) (Figure 4). Cox regression analyses (Tables 3 and 4) revealed that achieving a TO was an independent protective factor for both OS and DFS. The independent risk factors for DFS constituted a comprehensive profile of tumor biology, including cirrhosis, BCLC stage C, multiple tumors, poor differentiation, MVI, and a resection margin < 1 cm. This is logical, as these factors point to a higher potential for residual disease or early recurrence. In contrast, the list of risk factors in the multivariable model for OS was more refined, consisting of BCLC stage C, MVI, and a resection margin < 1 cm. In summary, the evidence chain linking the "barriers to a TO", "predictors of a TO", and the "prognostic value of a TO" indicates that a procedure that successfully navigates these short-term risks to achieve a TO is inherently more likely to yield long-term survival benefits. To improve the quality of complex liver surgery, a systematic perioperative strategy centered on achieving a TO should be adopted (*34*).

To the extent known, this is the first cohort study to systematically compare the impact of laparoscopic versus open techniques on both TO achievement and survival in the context of right hemihepatectomy for HCC. We also acknowledge that our study had several limitations. First, this was a retrospective study; even though we controlled for measurable confounders with PSM, we cannot entirely rule out the potential for unmeasured bias. Second, the statistical power for some subgroup analyses was limited by sample size, which may explain why some notable clinical trends did not reach statistical significance. Finally, our study's evaluation lacks data on cost-effectiveness and patient-reported outcomes.

In conclusion, this cohort study of right hemihepatectomy for HCC demonstrated that the laparoscopic and open approaches have comparable performance in achieving a TO and in survival, although laparoscopy offers an advantage in shortening the duration of hospitalization. Our findings confirm that, irrespective of the chosen approach, the achievement of a TO is an independent protective factor that determines prognosis. Therefore, fostering a perioperative environment conducive to achieving a TO is an effective management strategy to improve long-term prognosis. Future studies should be conducted to further refine and standardize the criteria for a TO in liver surgery and to explore its characteristics across different liver diseases and procedures.

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