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Propensity Score–Matched Analysis Comparing Robotic and Laparoscopic Right and Extended Right Hepatectomy

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IMPORTANCE Laparoscopic and robotic techniques have both been well adopted as safe options in selected patients undergoing hepatectomy. However, it is unknown whether either approach is superior, especially for major hepatectomy such as right hepatectomy or extended right hepatectomy (RH/ERH).

OBJECTIVE To compare the outcomes of robotic vs laparoscopic RH/ERH.

DESIGN, SETTING, AND PARTICIPANTS In this case-control study, propensity score matching analysis was performed to minimize selection bias. Patients undergoing robotic or laparoscopic RH/EHR at 29 international centers from 2008 to 2020 were included.

INTERVENTIONS Robotic vs laparoscopic RH/ERH.

MAIN OUTCOMES AND MEASURES Data on patient demographics, tumor characteristics, and short-term perioperative outcomes were collected and analyzed.

RESULTS Of 989 individuals who met study criteria, 220 underwent robotic and 769 underwent laparoscopic surgery. The median (IQR) age in the robotic RH/ERH group was 61.00 (51.86-69.00) years and in the laparoscopic RH/ERH group was 62.00 (52.03-70.00) years. Propensity score matching resulted in 220 matched pairs for further analysis. Patients' demographics and tumor characteristics were comparable in the matched cohorts. Robotic RH/ERH was associated with a lower open conversion rate (19 of 220 [8.6%] vs 39 of 220 [17.1%]; *P* = .01) and a shorter postoperative hospital stay (median [IQR], 7.0 [5.0-10.0] days; mean [SD], 9.11 [7.52] days vs median [IQR], 7.0 [5.75-10.0] days; mean [SD], 9.94 [8.99] days; *P* = .048). On subset analysis of cases performed between 2015 and 2020 after a center's learning curve (50 cases), robotic RH/ERH was associated with a shorter postoperative hospital stay (median [IQR], 6.0 [5.0-9.0] days vs 7.0 [6.0-9.75] days; *P* = .04) with a similar conversion rate (12 of 220 [7.6%] vs 17 of 220 [10.8%]; *P* = .46).

CONCLUSION AND RELEVANCE Robotic RH/ERH was associated with a lower open conversion rate and shorter postoperative hospital stay compared with laparoscopic RH/ERH. The difference in open conversion rate was associated with a significant decrease for laparoscopic but not robotic RH/ERH after a center had mounted the learning curve. Use of robotic platform may help to overcome the initial challenges of minimally invasive RH/ERH.

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Supplemental content

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Minimally invasive approach has been applied in liver resection (LR) for more than 2 decades.[1] While minimally invasive hepatectomy has become standard practice according to various consensus conferences, its role in major LR remains in the exploration phase.[2-5] Several meta-analyses have been performed to evaluate the effectiveness, safety, and efficacy of robotic vs laparoscopic hepatectomy.[6-11] However, most analyzed results from retrospective cases series and studied minor LR or LR at low difficulty level. These studies also included various types of LR resulting in additional confounding factors. Studies focusing on major hepatectomy eg, right hepatectomy (RH) or extended RH (ERH), are limited to date.[12]

Major hepatectomy is technically demanding, which hinders the development of minimally invasive surgery in LR. An analysis of the American College of Surgeons National Surgical Quality Improvement Program data showed that major LR was one of the risk factors for open conversion during minimally invasive hepatectomy.[13] The robotic system was developed to overcome some of the challenges in laparoscopic surgery. With the magnified view and the 7 degrees of movement of the EndoWrist (Intuitive Surgical), the robotic system allows fine dissection of individual vessels at the hilar region and the hepatocaval region during RH/ERH. It also allows easy suturing and knot tying in case of bleeding. In theory, the advantages of the robotic system might be more prominent in major LR at high/expert difficulty level. It has been reported that the use of robotic system allowed for an increased percentage of major hepatectomies to be performed in a purely minimally invasive manner.[14-16]

To study the true merit of the robotic system in a minimally invasive major hepatectomy, we performed the current study and focused specifically on RH/ERH for a more direct comparison. The objective of this study is to compare the surgical outcomes of robotic RH/ERH (R-RH/ERH) vs laparoscopic RH/ERH (L-RH/ERH).

Key Points

Question In patients undergoing major hepatectomy procedures, is either the robotic or laparoscopic technique superior?

Findings In this case-control study of 989 patients, robotic right or extended right hepatectomy (RH/ERH) was associated with a significantly lower open conversion rate and shorter postoperative hospital stay when compared with laparoscopic RH/ERH. The difference in open conversion rate was associated with a significant decrease for laparoscopic but not robotic RH/ERH after a center had mounted the learning curve.

Meaning Use of robotic platform may help to overcome the initial challenges of minimally invasive RH/ERH.

Methods

This is an international multicenter retrospective case-control analysis of patients undergoing L-RH/ERH or R-RH/ERH at 29 centers between January 2008 and December 2020. All institutions obtained their respective approvals according to their local center's requirements. This study was approved by the Singapore General Hospital institution review board, and the need for patient consent was waived. The deidentified data were collected in the individual centers. These were collated and analyzed centrally at the Singapore General Hospital.

In this study, only patients who underwent pure laparoscopic or robotic-assisted laparoscopic surgery were included. Laparoscopic-assisted (hybrid) and hand-assisted laparoscopic resections were excluded. Similarly, patients undergoing donor hepatectomy for transplant, associating liver partition and portal vin ligation for staged hepatectomy, and hepatectomy with bilio-enteric anastomoses were excluded. Data on race and ethnicity were not collected.

Definitions

RH was defined according to the 2000 Brisbane classification as resection of segments 5, 6, 7, and 8.[17] ERH included individuals who underwent RH and part or all of segment 4 and did not necessarily entail a complete trisectionectomy. Diameter of the largest lesion was used in cases of multiple tumors. Postoperative complications were classified according to the Clavien-Dindo classification and recorded for up to 30 days or during the same hospitalization and included 30-day readmissions.[18,19] The difficulty of resections was graded according to the Iwate score.[20,21]

Statistical Analysis

Propensity score matching was performed using a 1:1 nearest neighbor matching algorithm without replacement with distances determined by logistic regression. Propensity score matching was performed based on the following variables: sex, year of resection, age at operation, American Society of Anesthesiologists status, size of tumor, single or multiple tumors, malignant or benign tumors, Child-Pugh score, presence of portal hypertension, previous liver or abdominal operation, whether the hepatectomy was extended, multiple resections, concomitant noncholecystectomy operation, presence of cirrhosis, histological diagnosis, and Iwate difficulty grade. The optimal matching algorithm was used as a sensitivity analysis.

Absolute standardized mean difference in distances between patients undergoing robotic or laparoscopic RH were found to be balanced after conditioning on the propensity score, where a difference of less than 0.1 in absolute standard mean difference after matching was considered to indicate a good balance.

In the unmatched cohort, comparisons of patient characteristics and perioperative and postoperative details between patients undergoing robotic or laparoscopic RH were performed using the Mann-Whitney *U* test for continuous variables, while the Fisher exact test and Pearson χ^2 test were used for categorical variables. Comparisons in the matched cohorts took into account the paired nature of the data; hence, paired analyses such as Wilcoxon signed rank test, McNemar test and McNemar-Bowker test were respectively used for continuous, 2-by-2 categorical variables, and 3-by-3 categorical variables.

To reduce the confounding effect of the learning curve, a subset analysis of cases performed between January 2015 and December 2020 was performed with nearest neighbor matching of distances derived by logistic regression. Apart from omitting the year of resection, the logistic regression model used variables similar to that of the primary analysis. Furthermore, only cases performed after a center had acquired a cumulative experience of more than 50 minimally invasive liver resections was included. This conservative number of 50 cases was chosen based on the recently published systematic review,[22] which reported that the overall learning curve of L-LR was 50 cases and for R-LR was 25 cases. Furthermore, the learning curve for minimally invasive liver resection was reported to be decreasing from 48 cases in the 1990s to 24 cases in 2015. All analyses were done in R version 4.0.0 (R Foundation) with package 'MatchIt' and 'optmatch', and 2-sided $P < .05$ was regarded to indicate statistical significance.

Results

Comparison Between R-RH/ERH and L-RH/ERH in the Unmatched and Matched Cohorts

A total of 989 cases met study criteria, of which 220 underwent robotic and 769 underwent laparoscopic surgery during the study period. Nine patients (4.1%) and 54 patients (7.0%) received ERH in the robotic and laparoscopic arms, respectively ($P = .12$). The R-RH/ERH group was associated with a higher proportion of patients with American Society of Anesthesiologists score III/IV (87 of 220 [39.5%] vs 184 of 769 [24.0%]; $P < .001$), a lower proportion of patients with previous abdominal (75 of 220 [34.1%] vs 325 of 769 [42.3%]; $P = .03$) or liver surgery (8 of 220 [3.6%] vs 93 of 769 [12.1%]; $P < .001$), higher proportion of cirrhotic liver (56 of 220 [25.5%] vs 174 of 769 [22.6%]; $P = .38$), and a lower proportion of patients with multiple tumors (58 of 220 [26.4%] vs 307 of 769 [40.0%]; $P < .001$) and less multiple resections (6 of 220 [2.7%] vs 63 of 769 [8.2%]; $P = .005$) (**Table 1**). Regarding the perioperative outcomes, there were statistically significant differences in postoperative stay (median [IQR], 7.00 [5.00-10.00] vs 7.00 [6.00-11.00]; $P = .01$), overall postoperative morbidity (68 of 220 [30.9%] vs 295 of 769 [38.4%]; $P = .04$), and major morbidity (24 of 220 [10.9%] vs 129 of 769 [16.8%]; $P = .03$) in favor of robotic surgery.

Propensity score matching with 1:1 ratio resulted in 220 matched pairs for further analysis. Both groups were well balanced in all baseline clinicopathological characteristics in the matched cohort by nearest neighbor matching (Table 1; eFigures 1-3 in Supplement 1). Regarding the perioperative outcomes, R-RH/ERH was associated with a significantly lower open conversion rate (19 of 220 [8.6%] vs 39 of 220 [17.7%]; $P = .01$) (**Table 2**). With optimal matching, the baseline clinicopathological characteristics were comparable (Table 1; eFigures 4-6 in Supplement 1). The R-RH/ERH group had a lower conversion rate (19 of 220 [8.6%] vs 35 of 220 [15.9%]; $P = .03$) and a shorter postoperative hospital stay (median [IQR], 7.0 [5.0-10.0]; mean [SD], 9.11 [7.52] days vs 7.0 [5.75-10.0]; mean [SD], 9.94 [8.99] days; $P = .048$) compared with L-RH/ERH.

Comparison Between R-RH and L-RH/ERH in the Subset of Cases Performed Between 2015 and 2020

To minimize the confounder effect of the learning curve, we further analyzed a subset of 704 cases performed between 2015 and 2020 after a center had acquired a cumulative experience of more than 50 minimally invasive liver resection procedures. In the matched cohort, R-RH/ERH and L-RH/ERH groups had a comparable baseline clinicopathological characteristics (**Table 3**; eFigures 7-9 in Supplement 1). There was no longer a significant difference in open conversion rate (12 of 220 [7.6%] vs 17 of 220 [10.8]; $P = .46$) after matching. R-RH/ERH was associated with a significantly shorter median postoperative stay (median [IQR], 6.0 [5.0-9.0] days vs 7.0 [6.0-9.75] days; $P = .04$). There was no significant difference in other perioperative outcomes between the 2 groups (**Table 4**).

We further analyzed the open conversion rates of R-RH/ERH and L-RH/ERH over time. When we compared the open conversion rates of R-RH/ERH between 2008 and 2014 vs 2015 and 2020, there was no significant difference in the open conversion rates between the 2 time periods (7 of 62 [11.3%] vs 12 of 158 [7.6%]; $P = .38$). On the other hand, the open conversion rate of L-RH/ERH was significantly lower in the more recent time period compared with the earlier period (59 of 546 [10.8%] vs 41 of 223 [18.4%]; $P = .005$).

Discussion

With a large sample size from multiple international expert centers, this study demonstrated that R-RH/ERH was associated with a lower conversion rate and shorter hospital stay compared with L-RH/ERH. After reduction of the learning curve effect, R-RH/ERH was associated with a shorter hospital stay and similar perioperative outcomes. Our results imply that a robotic approach may help to overcome the learning curve in RH/ERH at the initial phase. To our knowledge, this study represents the largest series of minimally invasive RH/ERH reported to date and also the first to focus on the outcomes of R-RH/ERH vs L-RH/ERH.

Major hepatectomy remains a hurdle to the development of minimally invasive surgery in hepatectomy owing to its technical difficulties. Whether robotic or laparoscopic is a better approach for major hepatectomy remains unknown. Although numerous studies have compared the operative outcomes of robotic vs laparoscopic hepatectomy, most reports were dominated by minor hepatectomies.[14,23-27] Previous study demonstrated no significant difference in perioperative outcomes for hepatectomies at low and intermediate difficulty levels.[16] Two meta-analyses on this topic found no significant difference between 2 approaches.[11,28] However, the proportion of major hepatectomy was only 10% to 20% in the included studies. Data comparing robotic vs laparoscopic approaches in major hepatectomy are limited. Therefore, we conducted this study to compare the outcomes of R-RH/ERH and L-RH/ERH. RH/ERH was chosen for analysis because it allows standardized and comparable analysis.

Several authors had postulated that robotic LR may be associated with a shorter learning curve compared with the long

Table 1. Comparison Between Baseline Clinicopathological Characteristics of R-RH/ERH vs L-RH/ERH

Characteristic	No. (%) Unmatched cohort (n = 989) R-RH/ERH (n = 220)	L-RH/ERH (n = 769)	P value	1:1 Propensity score matching (nearest neighbor matching; n = 440) R-RH/ERH (n = 220)	L-RH/ERH (n = 220)	P value	1:1 Propensity score matching (optimal matching; n = 440) R-RH/ERH (n = 220)	L-RH/ERH (n = 220)	P value
Age, median (IQR), y	61.00 (51.86-69.00)	62.00 (52.03-70.00)	.33	61.00 (51.86-69.00)	61.00 (52.00-68.00)	.79	61.00 (52.00-69.00)	63.00 (55.00-71.00)	.07
Male	139 (63.2)	493 (64.2)	.78	139 (63.2)	148 (67.3)	.43	139 (63.2)	144 (65.5)	.71
Female	81 (36.8)	276 (35.9)		81 (36.8)	72 (32.7)		81 (36.8)	76 (34.5)	
Year of resection									
2008-2014	62 (28.2)	223 (29.0)	.81	62 (28.2)	58 (26.4)	.75	62 (28.2)	67 (30.5)	.69
2015-2020	158 (71.8)	546 (71.0)		158 (71.8)	162 (73.6)		158 (71.8)	153 (69.5)	
American Society of Anesthesiologists score									
I/II	133 (60.5)	584 (76.0)	<.001	133 (60.5)	133 (60.5)	>.99	133 (60.5)	128 (58.2)	.57
II/IV	87 (39.5)	184 (24.0)		87 (39.5)	87 (39.5)		87 (39.5)	92 (41.8)	
Previous abdominal surgery	75 (34.1)	325 (42.3)	.03	75 (34.1)	76 (34.5)	>.99	75 (34.1)	72 (32.7)	.84
Previous liver surgery	8 (3.6)	93 (12.1)	<.001	8 (3.6)	12 (5.5)	.39	8 (3.6)	11 (5.0)	.55
Malignant pathology	190 (86.4)	678 (88.2)	.47	190 (86.4)	190 (86.4)	>.99	190 (86.4)	194 (88.2)	.67
Pathology type									
HCC	106 (48.2)	312 (40.6)	.049	106 (48.2)	117 (53.2)	.69	106 (48.2)	104 (47.3)	>.99
CRM	57 (25.9)	263 (34.2)		57 (25.9)	48 (21.8)		57 (25.9)	59 (26.8)	
Other	57 (25.9)	193 (25.1)		57 (25.9)	55 (25.0)		57 (25.9)	57 (25.9)	
Cirrhosis	56 (25.5)	174 (22.6)	.38	56 (25.5)	58 (26.4)	.92	56 (25.5)	50 (22.7)	.59
Child-Pugh score									
No cirrhosis	164 (74.5)	595 (77.4)	.008	164 (74.5)	160 (72.7)	.22	164 (74.5)	169 (76.8)	.17
A	49 (22.3)	170 (22.1)		49 (22.3)	58 (26.4)		49 (22.3)	49 (22.3)	
B	7 (3.2)	4 (0.5)		7 (3.2)	2 (0.9)		7 (3.2)	2 (0.9)	
Portal hypertension	9 (4.1)	25 (3.3)	.55	9 (4.1)	6 (2.7)	.61	9 (4.1)	3 (1.4)	.15
Tumor size, median (IQR), mm	50.00 (30.00-70.00)	45.00 (28.00-75.00)	.75	50.00 (30.00-70.00)	46.50 (28.75-70.00)	.62	50.00 (30.00-70.00)	50.00 (30.00-75.00)	.88
Multiple tumors	58 (26.4)	307 (40.0)	<.001	58 (26.4)	48 (21.8)	.28	58 (26.4)	51 (23.2)	.46
Multiple resections	6 (2.7)	63 (8.2)	.005	6 (2.7)	6 (2.7)	>.99	6 (2.7)	4 (1.8)	.72
Concomitant operation noncholecystectomy	31 (14.1)	82 (10.7)	.16	31 (14.1)	28 (12.7)	.77	31 (14.1)	37 (16.8)	.48
Right hepatectomy	211 (95.9)	715 (93.0)	.12	211 (95.9)	209 (95.0)	.81	211 (95.9)	212 (96.4)	>.99
Extended right hepatectomy	9 (4.1)	54 (7.0)		9 (4.1)	11 (5.0)		9 (4.1)	8 (3.6)	
Iwate score									
Intermediate	0	6 (0.8)	.60	0	1 (0.5)	.97	0	1 (0.5)	.79
High	47 (21.4)	165 (21.5)		47 (21.4)	49 (22.3)		47 (21.4)	42 (19.1)	
Expert	173 (78.6)	598 (77.8)		173 (78.6)	170 (77.3)		173 (78.6)	177 (80.5)	

Abbreviations: CRM, colorectal metastases; HCC, hepatocellular carcinoma; L-RH/ERH, laparoscopic right hepatectomy/extended right hepatectomy; R-RH/ERH, robotic right hepatectomy/extended right hepatectomy.

learning curve reported for laparoscopic approach,[22,29,30] and it may also allow an increased proportion of hepatectomies at advanced difficulty level to be performed in a purely minimally invasive approach.[14-16] In this study, the open conversion rate was significantly lower for R-RH/ERH, particularly during the initial period of the study. Because the reported learning curves for laparoscopic and robotic LR were 50 and 25 cases, respectively,[22] we performed a subset analyses that only included cases after the center had performed 50 minimally invasive liver resection procedures to reduce the confounding effect of learning curve. The difference in conversion rate was not apparent in the subset analyses. This observation implied that the robotic approach may be associated with a shorter learning curve. Therefore, the conversion rate was shorter for robotic approach overall, but little improvement was observed once the center has passed the learning curve.

Concerning major hepatectomy, a recent systemic review and meta-analysis of 525 patients found no significant difference between robotic and laparoscopic major LR regarding overall morbidity and mortality rates, conversion to open hepatectomy, blood loss and blood transfusion rate, operative time, as well as length of hospital stay.[31] The authors concluded that both techniques were equivalent when performed in selected patients and high-volume centers. Similarly, Marino et al,[32] in a small retrospective study,

Table 2. Comparison Between Perioperative Outcomes of R-RH/ERH vs L-RH/ERH

Characteristic	No. (%)								
	Unmatched cohort (n = 989)			1:1 Propensity score matching (nearest neighbor matching; n = 440)			1:1 Propensity score matching (optimal matching; n = 440)		
	R-RH/ERH (n = 220)	L-RH/ERH (n = 769)	*P* value	R-RH/ERH (n = 220)	L-RH/ERH (n = 220)	*P* value	R-RH/ERH (n = 220)	L-RH/ERH (n = 220)	*P* value
Operating time, median (IQR), min	315.00 (241.50-461.25)	345.00 (260.00-431.00)	.70	315.00 (241.50-461.25)	346.50 (260.00-452.00)	.78	315.00 (241.50-461.25)	330.00 (260.00-418.50)	.35
Blood loss, median (IQR), mL	300.00 (100.00-600.00)	300.00 (150.00-500.00)	.80	300.00 (100.00-600.00)	300.00 (186.00-500.00)	.69	300.00 (100.00-600.00)	250.00 (150.00-500.00)	.29
Blood loss, mL									
<500	143 (65.0)	513 (70.2)	.15	143 (65.0)	147 (70.3)	.14	143 (65.0)	152 (72.0)	.21
≥500	77 (35.0)	218 (29.8)		77 (35.0)	62 (29.7)		77 (35.0)	59 (28.0)	
Intraoperative blood transfusion	35 (15.9)	100 (13.0)	.27	35 (15.9)	31 (14.1)	.68	35 (15.9)	31 (14.1)	.69
Pringle maneuver applied	93 (42.3)	343 (45.7)	.37	93 (42.3)	106 (49.8)	.16	93 (42.3)	108 (50.5)	.07
Open conversion	19 (8.6)	100 (13.0)	.08	19 (8.6)	39 (17.7)	.01	19 (8.6)	35 (15.9)	.03
Postoperative stay, median (IQR), d	7.00 (5.00-10.00)	7.00 (6.00-11.00)	.01	7.00 (5.00-10.00)	7.00 (5.50-10.00)	.15	7.00 (5.00-10.00)	7.00 (5.75-10.00)	.048
30-d Readmission	12 (5.5)	42 (5.6)	.91	12 (5.5)	12 (5.7)	>.99	12 (5.5)	13 (6.2)	>.99
Postoperative morbidity	68 (30.9)	295 (38.4)	.04	68 (30.9)	70 (31.8)	.91	68 (30.9)	75 (34.1)	.56
Major morbidity (Clavien-Dindo grade >2)	24 (10.9)	129 (16.8)	.03	24 (10.9)	33 (15.0)	.24	24 (10.9)	30 (13.6)	.46
Reoperation	4 (1.8)	33 (4.3)	.11	4 (1.8)	8 (3.6)	.39	4 (1.8)	5 (2.3)	>.99
Mortality									
In-hospital	3 (1.4)	11 (1.4)	>.99	3 (1.4)	0	.25	3 (1.4)	2 (0.9)	>.99
30-d	4 (1.8)	7 (0.9)	.28	4 (1.8)	0	.13	4 (1.8)	1 (0.5)	.37
90-d	6 (2.7)	14 (1.8)	.40	6 (2.7)	1 (0.5)	.13	6 (2.7)	2 (0.9)	.29

Abbreviations: L-RH/ERH, laparoscopic right hepatectomy/extended right hepatectomy; R-RH/ERH, robotic right hepatectomy/extended right hepatectomy.

Table 3. Comparison Between Baseline Clinicopathological Characteristics of R-RH/ERH vs L-RH/ERH Performed Between 2015-2020 After a Center's Learning Curve (50 Cases)

Characteristic	No. (%)					
	Unmatched cohort (n = 704)			1:1 Propensity matched cohort (n = 316)		
	R-RH/ERH (n = 158)	L-RH/ERH (n = 546)	*P* value	R-RH/ERH (n = 158)	L-RH/ERH (n = 158)	*P* value
Age, median (IQR), y	61.00 (51.00-68.75)	61.00 (52.00-70.00)	.30	61.00 (51.00-68.75)	61.00 (47.25-69.14)	.80
Male	98 (62.0)	347 (63.7)	.71	98 (62.0)	93 (58.9)	.63
Female	60 (38.0)	199 (36.4)		60 (38.0)	65 (41.1)	
American Society of Anesthesiologists score						
I/II	101 (63.9)	406 (74.5)	.009	101 (63.9)	98 (62.0)	.79
III/IV	57 (36.1)	139 (25.5)		57 (36.1)	60 (38.0)	
Previous abdominal surgery	49 (31.0)	213 (39.0)	.07	49 (31.0)	42 (26.6)	.45
Previous liver surgery	7 (4.4)	60 (11.0)	.01	7 (4.4)	7 (4.4)	>.99
Malignant pathology	130 (82.3)	483 (88.5)	.04	130 (82.3)	124 (78.5)	.45
Pathology type						
HCC	74 (46.8)	241 (44.2)	.002	74 (46.8)	71 (44.9)	.31
CRM	31 (19.6)	177 (32.5)		31 (19.6)	30 (19.0)	
Other	53 (33.5)	127 (23.3)		53 (33.5)	57 (36.1)	
Cirrhosis	41 (25.9)	136 (24.9)	.79	41 (25.9)	37 (23.4)	.67
Child-Pugh score						
No cirrhosis	117 (74.1)	410 (75.1)	.003	117 (74.1)	119 (75.3)	.07
A	34 (21.5)	133 (24.4)		34 (21.5)	39 (24.7)	
B	7 (4.4)	3 (0.5)		7 (4.4)	0 (0.0)	
Portal hypertension	8 (5.1)	21 (3.9)	.50	8 (5.1)	3 (1.9)	.23
Tumor size, median (IQR), mm	50.00 (30.00-75.00)	50.00 (30.00-78.00)	.63	50.00 (30.00-75.00)	60.00 (33.25-80.75)	.21
Multiple tumors	39 (24.7)	216 (39.6)	.001	39 (24.7)	45 (28.5)	.47
Multiple resections	5 (3.2)	42 (7.7)	.045	5 (3.2)	4 (2.5)	>.99
Concomitant operation noncholecystectomy	26 (16.5)	48 (8.8)	.006	26 (16.5)	25 (15.8)	>.99
Right hepatectomy	154 (97.5)	506 (92.7)	.03	154 (97.5)	156 (98.7)	.68
Extended right hepatectomy	4 (2.5)	40 (7.3)		4 (2.5)	2 (1.3)	
Iwate score						
Intermediate	0	5 (0.9)	.32	0	2 (1.3)	.55
High	30 (19.0)	125 (22.9)		30 (19.0)	27 (17.1)	
Expert	128 (81.0)	416 (76.2)		128 (81.0)	129 (81.6)	

Abbreviations: CRM, colorectal metastases; HCC, hepatocellular carcinoma; L-RH/ERH, laparoscopic right hepatectomy/extended right hepatectomy; R-RH/ERH, robotic right hepatectomy/extended right hepatectomy.

compared the outcomes of patients undergoing R-RH with L-RH and showed no significant difference between the 2 approaches in terms of operative time, estimated blood loss, conversion to open surgery, and overall morbidity. Our study demonstrated similar results when the analysis was restricted to cases performed after the center had passed the learning curve. These findings suggest that the robotic platform may offer some benefits especially at the initial period of the learning curve.

In a meta-analysis of 6 studies with 1093 patients, Hu et al[9] found that robotic approach was more commonly used for RH and is associated with longer operative time, larger tumor size, and lower open conversion rate. RH was more frequently done in the robotic group, while there was no significant difference in left hepatectomy and left lateral sectionectomy. Notably, the Iwate difficulty system does not distinguish between RH and LH as both will have a resection score of 4. However, it is universally accepted by liver surgeons that RH is more difficult than left hepatectomy owing to the wider transaction surface area and deep-seated location of the right lobe.[33] Our results demonstrated that the use of robotic approach was associated with a lower conversion rate and shorter hospital stay for RH/ERH.

The robotic approach has several potential advantages over the laparoscopic approach for RH/ERH.[34-38] The 7 degrees of freedom of the robotic system may theoretically overcome the problems of difficult access by rigid laparoscopic instruments. Robotic instruments may also facilitate the fine extrahepatic hilar dissection of individual hepatic artery and portal vein in RH/ERH. It may also enhance the dissection and control of short hepatic veins in the hepatocaval region and allow easier suture plication of bleeders during parenchymal

Table 4. Comparison Between Perioperative Outcomes of R-RH/ERH vs L-RH/ERH Between 2015-2020 (After Center's First 50 Cases)

Characteristic	No. (%) Unmatched cohort (n = 704) R-RH/ERH (n = 158)	L-RH/ERH (n = 546)	P value	1:1 Propensity score matching (n = 316) R-RH/ERH (n = 158)	L-RH/ERH (n = 158)	P value
Operating time, median (IQR), min	317.50 (236.00-435.25)	349.00 (260.00-434.00)	.48	317.50 (236.00-435.25)	347.50 (262.75-443.25)	.85
Blood loss, median (IQR), mL	300.00 (100.00-600.00)	270.00 (150.00-500.00)	.98	300.00 (100.00-600.00)	300.00 (200.00-450.00)	.30
Blood loss, mL						
<500	107 (67.7)	377 (71.8)	.32	107 (67.7)	116 (75.8)	.18
≥500	51 (32.3)	148 (28.2)		51 (32.3)	37 (24.2)	
Intraoperative blood transfusion	24 (15.2)	64 (11.7)	.25	24 (15.2)	16 (10.1)	.24
Pringle maneuver applied	76 (48.1)	288 (54.0)	.19	76 (48.1)	78 (51.0)	.65
Open conversion	12 (7.6)	59 (10.8)	.24	12 (7.6)	17 (10.8)	.46
Postoperative stay, median (IQR), d	6.00 (5.00-9.00)	7.00 (5.00-10.00)	.02	6.00 (5.00-9.00)	7.00 (6.00-9.75)	.04
30-d Readmission	11 (7.0)	33 (6.0)	.68	11 (7.0)	15 (9.5)	.56
Postoperative morbidity	50 (31.6)	186 (34.1)	.57	50 (31.6)	45 (28.5)	.63
Major morbidity (Clavien-Dindo grade >2)	15 (9.5)	85 (15.6)	.05	15 (9.5)	23 (14.6)	.22
Reoperation	2 (1.3)	18 (3.3)	.28	2 (1.3)	6 (3.8)	.29
Mortality						
In-hospital	3 (1.9)	6 (1.1)	.43	3 (1.9)	1 (0.6)	.62
30-d	4 (2.5)	3 (0.5)	.048	4 (2.5)	0	.13
90-d	6 (3.8)	9 (1.6)	.10	6 (3.8)	1 (0.6)	.13

Abbreviations: L-RH/ERH, laparoscopic right hepatectomy/extended right hepatectomy; R-RH/ERH, robotic right hepatectomy/extended right hepatectomy.

transection. Moreover, the operation time for RH/ERH is relatively long (approximately 5 hours in this series), and use of robotic system can alleviate a surgeon's fatigue during surgery.

The main drawbacks associated with robotic surgery compared with laparoscopy include the limited access to the platform and high costs of the procedure.[34,35] Results from this multicenter study found that robotic approach was associated with a shorter hospital stay without increase in operating time and other morbidities. It suggests that hospitalization costs may be possibly saved with robotic approach if the cost for robotic instruments can also be reduced. With several new models of surgical robots coming into the market, the barrier to access and cost of the robotic platform is likely to decrease.

It is also important to highlight that the advantages seen with robotic surgery may not be entirely attributable to the technical advantages of the platform. The length of stay after surgery is influenced by multiple confounding factors especially in this international multicenter study. It is well-known that global variation in factors such as local culture and health care systems have a major influence on postoperative stay. Similarly, although the study attempted to control for the institutional learning curve, detailed information of each individual surgeon's experience and hence learning curve was not available. Furthermore, many surgeons who perform robotic LR would have prior experience with LLR before embarking on robotic surgery or occasionally vice versa. Notably, it was not possible for us to control for this complex interplay of factors between individual surgeon and institution experience with both R-LR and L-LR as in real-world practice, many surgeons frequently perform both procedures.

Limitations

The major limitation of this study is its retrospective nature, which would be associated with information and selection bias. Although propensity score matching analysis was performed to minimize the selection bias, residual selection bias from unmeasured/unknown confounders was inevitable in the absence of randomization. As an international multicenter study, our study was also associated with differing experiences between the contributing centers and heterogeneity in the surgical technique adopted by the different centers. Nevertheless, it enhances the external validity and generalizability of this study as it reflects the current real-world practice. The large sample size generated from this multicenter study also allowed robust statistical analysis, which is important when we are studying a particular procedure whereby the expected difference is small as in this study.

Conclusions

In conclusion, R-RH/ERH was associated with a lower open conversion rate and shorter postoperative hospital stay compared with L-RH/ERH. However, there was no difference in open conversion rate after a center had mounted the learning curve. Use of the robotic platform may facilitate overcoming the challenges in minimally invasive RH/ERH especially during the learning curve.

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