

Robotic Versus Open Minor Liver Resections of the Posterosuperior Segments: A Multinational, Propensity Score-Matched Study

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ABSTRACT

Background. Minor liver resections of posterosuperior segments (1, 4A, 7, 8) are challenging to perform laparoscopically and are mainly performed using an open approach. We determined the feasibility of robotic resections of posterosuperior segments and compared short-term outcomes with the open approach.

Methods. Data on open and robotic minor (≤ 3 segments) liver resections including the posterosuperior segments, performed between 2009 and 2016, were collected retrospectively from four hospitals. Robotic and open liver resections were compared, before and after propensity score matching.

Results. In total, 51 robotic and 145 open resections were included. After matching, 31 robotic resections were compared with 31 open resections. Median hospital stay was 4 days (interquartile range [IQR] 3–7) for the robotic group, versus 8 days (IQR 6–10) for the open group ($p < 0.001$). Median operative time was 222 min (IQR 164–505) for robotic cases versus 231 min (IQR 190–301) for open cases ($p = 0.668$). Median estimated blood loss was 200 mL (IQR 100–400) versus 300 mL (IQR 125–750), respectively ($p = 0.212$). In the robotic group, one patient (3%) had a major complication, versus three patients (10%) in the open group ($p = 0.612$).

Readmissions were similar—10% in the robotic group versus 6% in the open group ($p > 0.99$). There was no mortality in either group.

Conclusion. Minor robotic liver resections of the posterosuperior segments are safe and feasible and display a shorter length of stay than open resections in selected patients at expert centers.

Open approach liver resection results in significant morbidity attributable to incisional pain, a large postoperative wound, and pulmonary infections.¹ Recent studies suggest that the introduction of minimally invasive surgery approaches for the liver is improving postoperative outcomes. A meta-analysis of retrospective case series and a recently published randomized controlled trial demonstrated superiority of the laparoscopic approach over open liver resections with respect to postoperative complications and length of stay;^{2,3} however, the laparoscopic approach is limited by anatomic location of certain tumors and the inflexible laparoscopic instruments.

The 2008 Louisville Statement presented the international expert consensus on laparoscopic liver resections selectively recommending the laparoscopic approach as standard practice for resections of anterolateral hepatic segments (2, 3, 4B, 5 and 6).⁴ In contrast, this statement, and its 2014 Morioka update, classified resections of the ‘difficult’ posterosuperior segments (1, 4A, 7, and 8) as ‘major liver resection’, and recommended against laparoscopic surgery for these segments.^{4,5} The posterosuperior location of segments 1, 4A, 7, and 8 makes these lesions

relatively difficult to access with the currently available laparoscopic instruments and was therefore deemed relatively unfit for the minimally invasive approach.

Alternative approaches to facilitate minimally invasive liver resections involving the posterosuperior segments include the laparoscopic hand-assisted transabdominal technique, the laparoscopic transthoracic approach, and the robotic transabdominal approach;^{3,6–10} however, these modified techniques possess their own challenges and potential complications. The hand-assisted transabdominal technique requires an extra incision and is still limited by the compromised visualization. A transthoracic approach potentially increases the risk of seeding of the malignancy to the chest, pleural effusion, and pneumonia. Moreover, a chest tube has to be placed afterwards.

The robotic system offers potential solutions through its more sophisticated features. It provides articulating instruments and a magnified, three-dimensional (3D) view of the operative field, as well as motion scaling and tremor filtering, thereby increasing surgical dexterity. On the contrary, the disadvantages include higher costs of the robot and lack of haptic feedback.^{11,12}

The role of robotic liver resection is undefined. Moreover, little has been published on robotic minor resections of the posterosuperior segments.^{13,14} Parenchymal-sparing resection of the posterosuperior segments often requires a curvilinear transection plane, which can be hard to accomplish with conventional laparoscopy in that difficult location. The authors believe that the robot is particularly well-suited for resections of these segments because of the increased dexterity of the robotic instruments. We hypothesized that robotic minor liver resection of the posterosuperior segments results in shorter hospital stay, with similar perioperative outcomes compared with open resection. We compared surgical parameters and postoperative outcomes between patients undergoing robotic and open minor liver resections of segments 1, 4A, 7, and 8. Data from four expert centers worldwide were retrospectively collected, and groups were compared before and after propensity score matching, to evaluate differences on length of stay as the primary outcome.

METHODS

Design and Patients

This was a multinational, retrospective cohort study. All adult patients who had a minor robotic liver resection or minor open liver resection including at least one segment or wedge from a posterosuperior segment (1, 4A, 7 and 8) were included.

Robotic liver resections performed between 1 January 2009 and 31 December 2016 were collected from three robotic liver surgeons (YF, GC and JH) at four different institutions: City of Hope National Medical Center (YF), Memorial Sloan Kettering Cancer Center (YF), Yonsei University Severance Hospital (GC), and University Medical Center Utrecht (JH). Data on open liver resections performed by various surgeons were collected from three institutions during the same time period (City of Hope National Medical Center, University Medical Center Utrecht, and Yonsei University Severance Hospital) [Fig. 1].

Patients were excluded if they underwent an additional procedure simultaneously with the liver resection, or if the procedure was a donor hepatectomy or an associating liver partition and portal vein ligation for staged hepatectomy (ALPPS) procedure. Concomitant cholecystectomies, liver biopsies, and en bloc resection of the diaphragm, retroperitoneum, or adrenal gland were not excluded.

We adhered to the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) Statement.¹⁵

Definitions

Minor liver resection was defined as resection of three or fewer segments. A wedge resection was counted as a half segment.¹⁶ Liver segments were identified using Couinaud's classification.¹⁷ Segments 1, 4A, 7, and 8 were classified as posterosuperior segments. Operative time was defined as the time from first incision until wound closure. Postoperative complications were scored using Clavien–Dindo's scale for grading postoperative complications;¹⁸ a complication of grade III or higher was considered a major complication. Postoperative parameters were scored up to 90 days after surgery. Conversion was defined as any other laparotomy made than for specimen retrieval. If there were no tumor cells present in the resection plane and within 1 mm of the resection plane, the resection was considered oncologic (R0), however when tumor cells were present in the transection plane or within 1 mm from the resection plane, resection margins were considered microscopically (R1) or macroscopically positive (R2). If multiple tumors were removed, we used the closest margin to determine the R status. Standardized mean differences (SMDs) were defined as the mean difference (mean control group – mean intervention group) divided by the standard deviation of the control group. The participating centers were subdivided into regions: East (Yonsei University Severance Hospital) and West (City of Hope Medical Center, Memorial Sloan Kettering Cancer Center, and University Medical Center Utrecht).

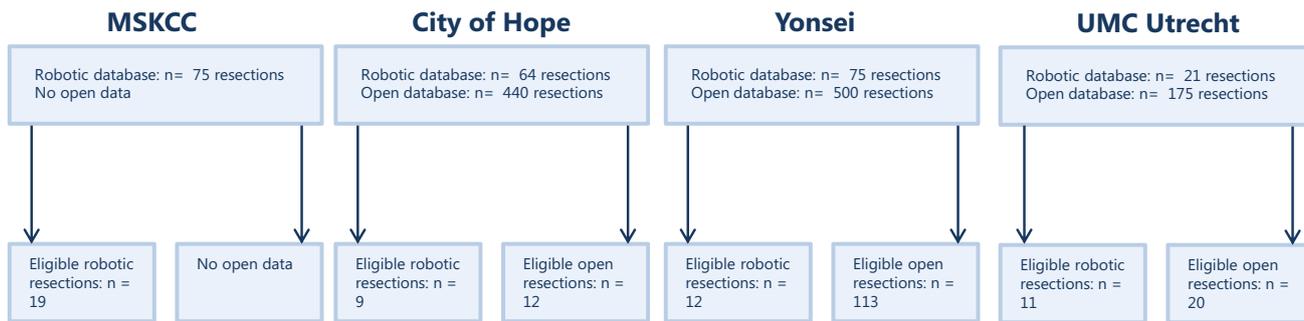


FIG. 1 Included patients per hospital. *MSKCC* Memorial Sloan Kettering Cancer Center, *UMC* University Medical Center

Data Collection

Data were collected from existing databases and extracted from patient charts. Baseline characteristics collected consisted of age, sex, body mass index (BMI; kg/m²), American Society of Anesthesiologists (ASA) physical status, previous abdominal surgery, and whether the patient received chemotherapy preoperatively. Surgical parameters collected were segments resected, operative time, intraoperative drain placement, blood loss, and conversion. Pathology parameters consisted of histopathology diagnosis, largest tumor size, number of tumors, and margin status. Postoperative outcomes collected were complications, intensive care unit admission, length of hospital stay, surgery-related readmissions, and 30- and 90-day mortality.

Statistical Analysis

Patients were divided into two groups based on the surgery approach: robotic versus open liver resection. These two groups were compared for baseline characteristics, as well as primary and secondary outcomes. The primary outcome was length of stay, while secondary outcomes included operative time, blood loss, intraoperative drain placement, major complications, intensive care unit (ICU) admissions, readmissions, margin status, number of tumors, largest tumor size, and 90-day mortality.

Data with a skewed distribution were reported as median with interquartile range (IQR). Continuous data were compared using a Mann–Whitney *U* test, while categorical variables were compared using a Chi-square test or Fisher’s exact test, where appropriate. The analyses were performed as intention to treat.

Propensity Score Matching

In addition, groups were compared after propensity score matching. Robotic patients were matched to open patients, using a propensity score in a 1:1 ratio, based on

BMI, ASA score, previous abdominal surgery, preoperative chemotherapy, age, sex, and region. Propensity scores for undergoing robotic liver resection were calculated using a non-parsimonious multivariable logistic regression model. A patient who had undergone robotic liver resection was matched to the nearest neighbor who had undergone open resection in a random fashion without replacement with a caliper of 0.05.^{19,20} Baseline characteristic imbalances were compared before and after matching using SMDs. We aimed to minimize group imbalances and obtain an absolute SMD smaller than 0.10, with a maximum absolute difference of 0.25 allowed.^{20,21} Matched continuous data were compared using the unpaired two-sided *t* test or Mann–Whitney *U* test, where appropriate, and categorical variables were compared using a Chi-square test or Fisher’s exact test, where appropriate. Data were analyzed using STATA/MP version 14.2 (StataCorp LLC, College Station, TX, USA). A two-tailed *p*-value < 0.05 was considered statistically significant.

Zero-Truncated Negative Binominal Regression Analysis

In addition, we performed a zero-truncated negative binominal regression analysis for length of stay, using the unmatched database.²² For the multivariate analysis, a mixed-level zero-truncated negative binomial regression to account for clustering of data by region was used. Subsequently, holding all baseline parameters at mean, we predicted length of stay for patients undergoing robotic resection versus patients undergoing open resection.

Ethical Approval

The Institutional Review Board of the City of Hope National Medical Center approved the study, with a waiver for patient informed consent.

RESULTS

A total of 196 patients were included in our study; 51 patients (26%) had robotic liver resections and 145 patients (74%) had open liver resections. After matching, 31 robotic resections were compared with 31 open resections. Resection types are summarized in Table 1.

Baseline Demographics and Tumor Characteristics

Baseline characteristics and tumor demographics are summarized in Table 2. In the unmatched cohort, the majority of open cases were performed in the East. On the contrary, most of the robotic resections were performed in the West. The open resections were mostly performed for hepatocellular carcinomas, whereas the robotic resections were mainly performed for colorectal liver metastases. After matching, the imbalances between the two groups were fairly reduced, with all SMDs under 0.25.

Perioperative Parameters

Postoperative outcomes are summarized in Table 3. In the matched cohorts, the patients undergoing robotic liver resection displayed a shorter hospital stay compared with patients undergoing open resection (4 days vs. 8 days, respectively; $p < 0.001$), with similar readmission rates. No patients in the robotic group were transferred to the intensive care unit postoperatively, versus 8 patients (26%) in the open group ($p = 0.005$). In the robotic group, 14 patients (45%) received a drain intraoperatively, versus 25

patients (81%) in the open group ($p = 0.008$). Upon assessment of final pathology, the largest tumor dimension was slightly different (robotic: median 25 mm [IQR 16–30], versus 30 mm [IQR 21–41] for the open group). The number of tumors did not differ between the two approaches (robotic: median 1 [IQR 1–2], versus open: 1 [IQR 1–2]).

Zero-Truncated Negative Binominal Regression Analysis

To further explore the results found in the propensity score-matched analysis, we performed a regression analysis, with length of stay as the outcome variable. Results from the univariate and multivariate analyses are summarized in Table 4. After adjusting for all variables expected to influence the outcome in a hierarchical multivariate model, the robotic approach was still significantly associated with a shorter length of stay than the open approach (zero-truncated negative binomial regression coefficient -0.668 , 95% confidence interval CI -0.859 , -0.477 ; $p < 0.001$).

Subsequently, keeping all baseline parameters at the mean, the predicted length of stay for patients undergoing robotic resection was 5 days (95% CI 4.01, 6.42), versus 10 days (95% CI 9.77, 10.57) for undergoing open resection.

TABLE 1 Resection types for the matched and unmatched cohorts

	Wedge resection (n)	Segmental resection (n)	Wedge resection (n)	Segmental resection (n)
	Robotic liver resection [n = 51]		Open liver resection [n = 145]	
<i>Unmatched cohorts</i>				
Segment 1	–	–	–	7
Segment 4A	–	–	5	5
Segment 7	8	4	7	7
Segment 8	7	5	7	23
Combination ^a	27		84	
	Robotic liver resection [n = 31]		Open liver resection [n = 31]	
<i>Matched cohorts</i>				
Segment 1	–	–	–	1
Segment 4A	–	–	1	–
Segment 7	3	3	2	2
Segment 8	3	2	1	4
Combination ^a	20		20	

^aCombination of wedge resections/segmental resections of the posterosuperior segments or in combination with wedge resections/segmental resections from other segments

TABLE 2 Patient demographics and tumor characteristics

Characteristic	Unmatched			Matched		
	RL [<i>n</i> = 51]	OL [<i>n</i> = 145]	SMD	RL [<i>n</i> = 31]	OL [<i>n</i> = 31]	SMD
Age, years [median (IQR)]	59 (49–65)	59 (53–67)	0.24	59 (52–66)	57 (52–63)	– 0.18
Male sex	34 (67)	100 (69)	0.05	20 (65)	17 (55)	– 0.19
BMI, kg/m ² [median (IQR)]	25 (22–28)	24 (22–26)	– 0.52	25 (22–27)	24 (22–26)	– 0.18
ASA score						
ASA I/II	28 (55)	130 (90)	1.14	20 (65)	19 (61)	– 0.07
ASA III/IV	23 (45)	15 (10)	– 1.14	11 (35)	12 (39)	0.07
Previous abdominal surgery	32 (63)	54 (37)	– 0.53	17 (55)	17 (55)	0.0
Chemotherapy preoperatively	23 (45)	49 (34)	– 0.24	14 (45)	12 (39)	– 0.13
Region						
West	39 (76)	32 (22)	– 1.31	20 (65)	19 (61)	– 0.07
East	12 (24)	113 (78)	1.31	11 (35)	12 (39)	0.07
Histopathology						
Colorectal liver metastases	23 (45)	34 (23)	– 0.51	13 (42)	11 (35)	– 0.13
Hepatocellular carcinoma	12 (24)	96 (66)	0.90	11 (35)	14 (45)	0.19
Benign	6 (12)	1 (1)	– 1.33	2 (6)	1 (3)	– 0.18
Cholangiocarcinoma	0 (0)	3 (2)	0.14	0 (0)	0 (0)	NA
Other metastasis	9 (18)	8 (6)	– 0.53	4 (13)	5 (16)	0.09
Combined HCC/CCC	1 (2)	3 (2)	0.01	1 (3)	0 (0)	NA
Malignancy	45 (88)	144 (99)	1.33	29 (94)	30 (97)	0.18
Lesion origin						
Metastatic	32 (63)	42 (29)	– 0.74	17 (55)	16 (52)	– 0.06
Primary	13 (25)	102 (70)	0.98	12 (39)	14 (45)	0.13
Benign	6 (12)	1 (1)	– 1.33	2 (6)	1 (3)	– 0.18

Data are expressed as *n* (%) unless otherwise specified

ASA American Society of Anesthesiologists, BMI body mass index, CCC cholangiocarcinoma, HCC hepatocellular carcinoma, IQR interquartile range, OL open liver resection, RL robotic liver resection, SMD standardized mean difference, NA not available

DISCUSSION

This multinational, multi-institutional propensity score-matched study demonstrates that robotic minor liver resections of the posterosuperior segments have superior short-term outcomes compared with the open approach. The robotic approach was associated with a shorter length of stay, with no differences in major complication rates and with the ability to achieve negative margins. These findings demonstrate that a robotic approach to minor liver resections of the posterosuperior segments is safe and feasible and may cut the duration of hospital stay by half.

The benefits of conventional laparoscopy over open resections in liver surgery have been shown.^{2,3} Unfortunately, laparoscopic resections of the posterosuperior segments are considered difficult to perform.²³ In several studies on conventional laparoscopic liver resection, resections of the posterosuperior segments are identified as independent predictors for conversion.^{24,25} In addition,

laparoscopic resections of the posterosuperior segments were found to have a significantly longer operative time and higher blood loss when compared with laparoscopic resections of the anterolateral segments.⁶

In contrast to conventional laparoscopy, robotic surgery seems to be eminently suited for these resections. The articulating robotic instruments allow the surgeon to operate with more freedom of motion than the human hand.¹¹ These wristed instruments enable curved transection planes, which are needed in parenchymal-sparing resections of the posterosuperior segments. Previously published case series of robotic liver resections included a small proportion of patients who underwent posterosuperior segments. These demonstrate acceptable outcomes in terms of conversion rate, operative time, and morbidity (reviewed in Nota et al.¹⁴). One study has been published comparing open and robotic segment 6 and 7 liver resections.²⁶ Differences found in this study included longer operative time and longer inflow occlusion time for the

TABLE 3 Perioperative parameters and surgical outcomes

Characteristic	Unmatched			Matched		
	RL [<i>n</i> = 51]	OL [<i>n</i> = 145]	<i>p</i> -Value	RL [<i>n</i> = 31]	OL [<i>n</i> = 31]	<i>p</i> -Value
Operative time, min [median (IQR)]	198 (141–381)	255 (201–309)	0.073	222 (164–505)	231 (190–301)	0.668
Estimated blood loss, mL [median (IQR)]	180 (100–400)	300 (170–700)	0.001	200 (100–400)	300 (125–750)	0.121
Received drain intraoperatively	17 (33)	136 (94)	< 0.001	14 (45)	25 (81)	0.008
Conversion	4 (8)	NA	NA	2 (6)	NA	NA
Major complication, CD grade III or higher	3 (6)	10 (7)	> 0.99	1 (3)	3 (10)	0.612
Major complication, bile leak	0 (0)	3 (2)	0.569	0 (0)	1 (3)	> 0.99
ICU admission	0 (0)	11 (8)	0.070	0 (0)	8 (26)	0.005
R1 resection	8 (16)	18 (12)	0.632	4 (13)	7 (23)	0.504
No. of tumors [median (IQR)]	1 (1–1)	1 (1–1)	0.949	1 (1–2)	1 (1–2)	0.304
Largest tumor size, mm [median (IQR)]	25 (16–31)	25 (20–32)	0.316	25 (16–30)	30 (21–41)	0.032
Length of stay, days [median (IQR)]	4 (3–6)	10 (8–13)	< 0.001	4 (3–7)	8 (6–10)	< 0.001
Readmission	4 (8)	6 (4)	0.271	3 (10)	2 (6)	> 0.99
90-day mortality	0 (0)	0 (0)	NA	0 (0)	0 (0)	NA

Data are expressed as *n* (%) unless otherwise specified

CD Clavien–Dindo, ICU intensive care unit, IQR interquartile range, OL open liver resection, RL robotic liver resection, NA not available

robotic cases, while length of stay did not differ significantly. However, this study suffered from a small sample size and non-specific eligibility criteria.

The strength of the present study lies in the multi-institutional, multinational character, hereby increasing generalizability of the results. In addition, two different statistical approaches were applied to test the hypothesis and confirm results. The study also made a striking finding on the markedly reduced length of stay, which is a surrogate marker for pain control, mobility, and oral intake in patients' recovery, indicating faster recovery after robotic surgery. Remarkably, several patients included in this study who received robotic minor liver resection had a 1-day hospital stay. Although not measured in this study, there are several explanations for the fact that patients are sent home earlier after robotic liver resection. The absence of a large incision minimizes incisional pain. This results in an improvement of breathing effort and hence a lower risk of pleural effusion and pneumonia, and less need for postoperative oxygen supplementation.

The main limitation of this study lies in the possibility of inherent selection bias due to the retrospective nature of the study. To limit this bias, we kept strict inclusion criteria and aimed to create well-balanced groups using propensity score matching. Although propensity score matching is a well-established method to balance comparative groups, it cannot correct for unmeasured confounders. We performed regression analysis to further confirm the results found in the propensity score-matched analysis. Another limitation to take into account is the fact that certain parameters were

not available. Data on preoperative tumor size, proximity of the tumor to vessels, or preoperative Child–Pugh scores were not available, hence could not be incorporated in the regression model to calculate propensity scores. In addition, open cases were only collected from three of four hospitals, thereby potentially introducing bias. However, although raw data on the open resections from this fourth center were not available, the mean length of stay was 7 days for open resections in this center. Thus, this is not very likely to have influenced the results.

There are two main barriers to the adoption of robotic liver resection of posterosuperior segments. First, the robotic operations in this study require a high level of training, dexterity and skill, which is acquired after a significant length of experience in robotic liver resections. The study's surgeries were performed by highly skilled hepatobiliary surgeons. Further studies are needed to investigate the learning curve of robotic liver resection for the next generation of surgeons adopting this technique. Moreover, an international registry of procedures, standardization of techniques, as well as teaching and education within an international focus group for robotic hepatopancreatobiliary surgery will further aid implementation of these techniques. Second, the costs associated with robotic surgery are currently high. Therefore, robotic hepatectomy should only be embarked upon in institutions with firmly established liver surgery practice and robotic programs covering a wide spectrum of procedures. Interestingly, several companies are expected to bring new surgical robots to the market in the coming years.²⁷ Hence,

TABLE 4 Univariate and multivariate regression analyses of length of stay

Characteristic	Univariate analysis			Hierarchical multivariate analysis ^a		
	Coefficient	95% CI	p-Value	Coefficient	95% CI	p-Value
Age (continuous)	0.009	0.001, 0.016	0.030	0.008	0.008, 0.008	< 0.001
Sex, male	Reference					
Sex, female	- 0.146	- 0.314, 0.022	0.089			
BMI (continuous)	- 0.016	- 0.040, 0.007	0.174			
ASA score, I and II	Reference			Reference		
ASA score, III and IV	- 0.540	- 0.741, - 0.338	< 0.001	- 0.015	- 0.359, 0.330	0.934
Previous abdominal surgery, no	Reference			Reference		
Previous abdominal surgery, yes	- 0.600	- 0.739, - 0.462	< 0.001	- 0.189	- 0.491, 0.114	0.221
Chemotherapy preoperatively, no	Reference			Reference		
Chemotherapy preoperatively, yes	- 0.403	- 0.560, - 0.247	< 0.001	- 0.013	- 0.334, 0.308	0.937
Region, East	Reference					
Region, West	- 0.750	- 0.894, - 0.607	< 0.001			
<i>Histopathology</i>						
CRLM	Reference			Reference		
HCC	0.683	0.536, 0.830	< 0.001	0.174	0.169, 0.180	< 0.001
Benign	- 0.456	- 0.915, 0.004	0.052	0	^b	
CCC	1.100	0.679, 1.521	< 0.001	0.428	0.288, 0.568	< 0.001
Other metastasis	- 0.142	- 0.420, 0.135	0.315	- 0.063	- 0.064, - 0.062	< 0.001
Combined HCC/CCC	0.415	- 0.020, 0.850	0.061	0	^b	
<i>Lesion origin</i>						
Primary	Reference			Reference		
Metastatic	- 0.720	- 0.856, - 0.584	< 0.001	- 0.206	- 0.246, - 0.167	< 0.001
Benign	- 1.145	- 1.598, - 0.693	< 0.001	- 0.241	- 0.343, - 0.139	< 0.001
Approach, open	Reference			Reference		
Approach, robotic	- 0.930	- 1.101, - 0.759	< 0.001	- 0.668	- 0.859, - 0.477	< 0.001

ASA American Society of Anesthesiologists, BMI body mass index, CRLM colorectal liver metastases, CCC cholangiocarcinoma, CI confidence interval, HCC hepatocellular carcinoma

^aData clustered by region

^bOmitted because of collinearity

competitive pricing will most likely bring down costs. Moreover, a reduced hospital stay, as shown in our study, should also decrease costs.

CONCLUSION

A robotic approach to minor liver resections of the posterosuperior segments displays several benefits, including a shorter length of stay, than an open approach in selected patients at expert centers. The use of robotic technology possibly extends indications for minimally invasive liver resection.

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REFERENCES

1. Jin S, Fu Q, Wuyun G, et al. Management of post-hepatectomy complications. *World J Gastroenterol*. 2013;19(44):7983–91.
2. Ciria R, Cherqui D, Geller DA, et al. Comparative Short-term Benefits of Laparoscopic Liver Resection: 9000 Cases and Climbing. *Ann Surg*. 2016; 263(4):761–77.
3. Fretland AA, Dagenborg VJ, Bjorneliv GMW, et al. Laparoscopic versus open resection for colorectal liver metastases: the OSLO-COMET randomized controlled trial. *Ann Surg*. 2018; 267(2):199–207.
4. Buell JF, Cherqui D, Geller DA, et al. The international position on laparoscopic liver surgery: the Louisville statement, 2008. *Ann Surg*. 2009; 250(5):825–30.
5. Wakabayashi G, Cherqui D, Geller DA, et al. Recommendations for laparoscopic liver resection: a report from the second international consensus conference held in Morioka. *Ann Surg*. 2015; 261(4):619–29.
6. Ishizawa T, Gumbs AA, Kokudo N, et al. Laparoscopic segmentectomy of the liver: from segment I to VIII. *Ann Surg*. 2012; 256(6):959–64.
7. Herman P, Krüger JAP, Perini MV, et al. Laparoscopic hepatic posterior sectionectomy: a hand-assisted approach. *Ann Surg Oncol*. 2013; 20(4):1266.
8. Ogiso S, Conrad C, Araki K, et al. Laparoscopic transabdominal with transdiaphragmatic access improves resection of difficult posterosuperior liver lesions. *Ann Surg*. 2015; 262(2):358–65.
9. Okuno M, Goumard C, Mizuno T, et al. Operative and short-term oncologic outcomes of laparoscopic versus open liver resection for colorectal liver metastases located in the posterosuperior liver: a propensity score matching analysis. *Surg Endosc*. 2018; 32(4):1776–86.
10. Nota C, Molenaar IQ, van Hillegersberg R, et al. Robotic liver resection including the posterosuperior segments: initial experience. *J Surg Res*. 2016; 206(1):133–8.
11. Leung U, Fong Y. Robotic liver surgery. *Hepatobiliary Surg Nutr*. 2014; 3(5):288–94.
12. Barbash GI, Glied SA. New technology and health care costs: the case of robot-assisted surgery. *N Engl J Med*. 2010; 363(8):701–4.
13. Melstrom LG, Warner SG, Woo Y, et al. Selecting incision-dominant cases for robotic liver resection: towards outpatient hepatectomy with rapid recovery. *Hepatobiliary Surg Nutr*. 2018;7(2):77–84.
14. Nota CL, Rinkes IHB, Molenaar IQ, et al. Robot-assisted laparoscopic liver resection: a systematic review and pooled analysis of minor and major hepatectomies. *HPB (Oxford)*. 2016; 18(2):113–20.
15. von Elm E, Altman DG, Egger M, et al. The strengthening of reporting of observational studies in epidemiology (STROBE) statement: guidelines for reporting observational studies. *Int J Surg*. 2014; 12(12):1495–9.
16. Reddy SK, Barbas AS, Turley RS, et al. A standard definition of major hepatectomy: resection of four or more liver segments. *HPB (Oxford)* 2011; 13(7):494–502.
17. Couinaud C. Liver lobes and segments: notes on the anatomical architecture and surgery of the liver. *Presse Med*. 1954; 62(33):709–12 (in French).
18. Dindo D, Demartines N, Clavien PA. Classification of surgical complications: a new proposal with evaluation in a cohort of 6336 patients and results of a survey. *Ann Surg*. 2004; 240(2):205–13.
19. Garrido MM, Kelley AS, Paris J, et al. Methods for constructing and assessing propensity scores. *Health Serv Res*. 2014; 49(5):1701–20.
20. Austin PC. An introduction to propensity score methods for reducing the effects of confounding in observational studies. *Multivar Behav Res*. 2011; 46(3):399–424.
21. Cluver L, Boyes M, Orkin M, et al. Child-focused state cash transfers and adolescent risk of HIV infection in South Africa: a propensity-score-matched case-control study. *Lancet Glob Health*. 2013; 1(6):e362–70.
22. Cameron AC, Trivedi PK. Regression analysis of count data. Cambridge: Cambridge University Press; 1998.
23. Cho JY, Han HS, Yoon YS, et al. Feasibility of laparoscopic liver resection for tumors located in the posterosuperior segments of the liver, with a special reference to overcoming current limitations on tumor location. *Surgery*. 2008; 144(1):32–8.
24. Troisi RI, Montalti R, Van Limmen JG, et al. Risk factors and management of conversions to an open approach in laparoscopic liver resection: analysis of 265 consecutive cases. *HPB (Oxford)*. 2014; 16(1):75–82.
25. Halls MC, Cipriani F, Berardi G, et al. Conversion for unfavorable intraoperative events results in significantly worse outcomes during laparoscopic liver resection: lessons learned from a multicenter review of 2861 cases. *Ann Surg*. 2017. <https://doi.org/10.1097/SLA.0000000000002332>.
26. Patrìti A, Cipriani F, Ratti F, et al. Robot-assisted versus open liver resection in the right posterior section. *JSLs*. 2014; 18(3):e2014.00040. <https://doi.org/10.4293/JSLs.2014.00040>.
27. Peters B, Armijo P, Krause C, Choudhury S, Oleynikov D. Review of emerging surgical robotic technology. *Surg Endosc*. 2018;32:1636–55.