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Robotic Liver Resection: A Case-Matched Comparison

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Abstract

Background—In recent years, increasingly sophisticated tools have allowed for more complex robotic surgery. Robotic hepatectomy, however, is still in its infancy. Our goals were to examine the adoption of robotic hepatectomy and to compare outcomes between open and robotic liver resections.

Methods—The robotic hepatectomy experience of 64 patients was compared to a modern case-matched series of 64 open hepatectomy patients at the same center. Matching was according to benign/malignant diagnosis and number of segments resected. Patient data were obtained retrospectively. The main outcomes and measures were operative time, estimated blood loss, conversion rate (robotic to open), Pringle maneuver use, single non-anatomic wedge resection rate, resection margin size, complication rates (infectious, hepatic, pulmonary, cardiac), hospital stay length, ICU stay length, readmission rate, and 90-day mortality rate.

Results—Sixty-four robotic hepatectomies were performed in 2010–2014. Forty-one percent were segmental and 34% were wedge resections. There was a 6% conversion rate, a 3% 90-day mortality rate, and an 11% morbidity rate. Compared to 64 matched patients who underwent open hepatectomy (2004–2012), there was a shorter median OR time (p=0.02), lower median estimated blood loss (p<0.001), and shorter median hospital stay (p<0.001). Eleven of the robotic cases were isolated resections of tumors in segments 2, 7, and 8..

Conclusions—Robotic hepatectomy is safe and effective. Increasing experience in more centers will allow definition of which hepatectomies can be performed robotically, and will enable optimization of outcomes and prospective examination of the economic cost of each approach.

Keywords

cancer; liver malignancy; liver resection; minimally invasive surgery; surgical outcome

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Introduction

Historically, high morbidity and mortality rates were associated with liver resections.[1] Efforts to reduce these rates via minimally invasive surgery (MIS) have been slow to take hold due to the combination of advanced MIS skills and knowledge of liver surgery that is needed. The robotic surgery platform may help to increase the adoption of MIS liver surgery. Laparoscopic liver surgery series have demonstrated that the laparoscopic approach is associated with a decreased length of hospital stay, decreased estimated blood loss, earlier return to daily activities, and lower morbidity rate when compared to open surgery.[2, 3] Over 3,000 laparoscopic liver resections have been reported in the literature. This robust worldwide clinical research experience has lent strong support to favorable conclusions about the safety and oncologic equality of laparoscopic liver resections in well selected patients when compared to open resections.[4] There are, however, few reports on robotic liver surgery series.

The potential advantages of robotic liver resections are related to the wristed instruments, 3-D visualization, and improved ergonomics. It is unclear how these potential advantages translate to improved outcomes. In addition, the safety and oncologic efficacy of the robotic approach has still not been established to the same level as that of laparoscopic liver surgery. In this series we matched open and robotic liver resection patients according to a benign or malignant diagnosis and the number of segments resected. The safety and oncologic outcomes were compared between open and robotic resections.

Materials and Methods

Robotic liver resections were performed in 65 patients between 2002 and 2014. Four of six hepatopancreatobiliary surgeons performed the robotic surgeries. Patient demographics, operative details, pathology reports, and outcomes data were obtained retrospectively from a prospectively maintained liver surgery database at Memorial Sloan Kettering Cancer Center (MSKCC). IRB approval was obtained to perform this analysis. Complications were graded using the MSKCC scoring system (Grade 1 – 5).[5] The extent of the liver resection was classified according to the International Hepato-Pancreato-Biliary Association's system.[6] Major hepatectomy was thus defined as a resection of 3 or more segments. Margins were defined as positive (<1 mm), close (1–10 mm), and negative (>10 mm). Margin evaluation excluded patients with benign tumors, excisional biopsies, re-resections for incidental gallbladder cancer, and complete pathological response following systemic chemotherapy.

Patients were evaluated by each surgeon for suitability of the robotic approach according to tumor location, liver quality, and overall clinical status. Selection criteria for robotic resection were minimal. Inclusion criteria were a mass resectable with a procedure no more extensive than a hemihepatectomy. Patient characteristics, such as BMI, were not a factor in patient selection. The only contraindications to robotic resection were invasion of the inferior vena cava (IVC) or base of hepatic vein close to the IVC, invasion of the main right or left portal vein, and need for vascular or biliary reconstruction. The approach for benign and malignant tumors was similar.

The da Vinci Si Surgical System was used. Patients were secured to a tilt table with a footboard that allowed a 30-degree reverse-Trendelenburg position. A 12-mm balloon trocar was used to place a camera and three 8-mm ports were used for the instrument arms. Liver parenchyma was divided with a combination of hook cautery, the Harmonic scalpel or Vessel Sealer, and the bipolar PK Dissecting Forceps. The scrub nurse was positioned by the patient's right leg, and the assistant surgeon or surgical physician assistant was positioned by the patient's left leg. For robotic cases a "drop-in" ultrasound (US) was used and for open cases a "t-probe" US was used.

The sixty-four patients (32 male : 32 female) who underwent robotic hepatectomies (2010–2014) were matched to 64 patients (29 male : 35 female) who underwent open hepatectomies (2004–2012) according to malignant or benign status and the number of segments resected (1, 2, 3, or 4). Single-segment and wedge resections were considered equivalent due to the similarly low morbidity rates for both of these resection types. Additional categories for matching were not possible given the number of robotic patients. Comparisons of the characteristics of robotic hepatectomies with the characteristics of open hepatectomies were performed using McNemar's test for categorical variables and paired t-test for continuous variables. P-values < 0.05 are considered significant. All analysis was done using R version 3.1.1 (cran.r-project.org).

Results

Sixty-four patients underwent robotic liver resection from 2010 to 2014. Two of the authors performed 61 (94%) of the robotic cases. Due to a recent upsurge of interest in this technique, 63 of these 64 resections were performed between 2012 and 2014. Patient, tumor, and surgery characteristics are presented as median and range for continuous variables and as frequency and percent for categorical variables. Surgeon volume ranged from 1 to 48 robotic liver resections. The median age of patients was 64 years (range 40–91) (Table 1). The median ASA (American Society of Anesthesiologists) score was 3 (range 2–4). The majority of patients who underwent robotic liver resection had been diagnosed with metastatic cancer (n=35, 55%). The second most common indication was benign pathology (n=13, 20%). The third most common indication for resection was primary liver cancer (n=12, 19%), and the fourth was gallbladder cancer (n=3, 5%). Following resection, seven of the 13 benign tumors were determined to be premalignant, such as hepatic adenomas and gallbladder polyps requiring hepatic resection. Thus, 88% (57/65) of resected lesions were malignant or premalignant. Twenty-four (38%) of the robotic hepatectomy patients were treated with neoadjuvant chemotherapy. The quality of the underlying liver was similar between the two groups with 23 patients in the robotic group and 25 in the open group with steatosis. There were 7 patients in the robotic group and 5 in the open group that had hepatitis.

The 64 robotic hepatectomy patients were matched with 64 open hepatectomy patients (2004–2012) according to malignant or benign indication and the number of segments resected (1, 2, 3, or 4). The robotic resections had a significantly shorter operative time (median 163 min; range 56–480) than the open resections (median 210 min; range 6.5–535; p=0.017) (Table 2). The estimated blood loss was also significantly lower in the robotic group (median 100 mL; range 10–1700) than in the open group (median 300 mL; range 0–2700; p<0.001). Four (6%) of the 64 robotic resections were converted to open. Reasons for conversion included difficulty exposing vascular anatomy, a stapler malfunction and resultant hemorrhage, discovery of additional hepatic tumors, and inability to visualize the tumor and resection planes. Pringle maneuver was used less frequently in the robotic group (9% vs. 75%, p<0.001). There was a similar rate of single segment wedge or segmentectomy resections between the groups [robotic 48 (75%) and open 51 (80.0%); Table 3].

There was no difference in the pathology of the resected specimens between the two groups. The median number of tumors was 1 (range 1–3) in the robotic group and 1 (range 1–4) in the open group (p=0.1). The median size of the largest tumor resected was 2.5 cm (range 0.3–14.5 cm) in the robotic group and 2.7 cm (range 0–16.5 cm) in the open group. The resection margins of the malignant tumors were similar using both techniques. Positive margins (<1 mm) occurred in 1.6% of robotic resections and 14% of open resections (p=0.4). Close margins were similar (45% in the robotic group and 52% in the open group). Margins >10 mm were found in 16% of robotic resections and 17% of open resections.

Complication rates were similar between the robotic (10.9%) and open groups (14.1%, p=0.8, Table 4). Major complication rates were also similar between the two groups (5% robotic group vs. 6% open group, p=1.0). Specific complication rates, such as infectious, hepatic, pulmonary, and cardiac, were all similar between the groups. Readmission rates within 30 days of surgery were also similar (6% robotic group vs. 13% open group, p=0.3). The median length of stay was significantly shorter for the robotic group (4 days, range 1–25) than the open group (7 days, range 3–24; p<0.001). Duration of intensive care unit stays was similar between the two groups (median of 0 days). The 90-day mortality rate was 3% (n = 2) for robotic and 1.6% (n = 1) for open hepatectomies (p=1.0).

Discussion

Adoption of MIS of the liver has lagged behind MIS of the other regions included in general surgery. This is due not only to the complexity of the operation and the technical expertise required, but also to concerns about the capability for adherence to safe and oncologically appropriate resections. The robotic platform offers several theoretical advantages over laparoscopic surgery, specifically, 3-D visualization and wristed instruments. At the same time, there are potential disadvantages to the use of robotics with liver surgery: the primary surgeon is not at the bedside, there is a loss of haptic feedback, and the cost can be prohibitive. We chose to compare our series of 65 patients that underwent robotic liver resection to a matched group of patients that underwent open liver resection. We did not compare the robotic cohort to a laparoscopic cohort, as the two MIS approaches are philosophically similar. Our goal was to demonstrate that the robotic platform is a reasonable alternative when compared to the open approach.

Our comparison demonstrated that the safety profile of the two groups was equivalent. Rates of both major complications and infectious complications for the two approaches were similar. In the one patient whose urgent conversion to open hepatectomy was due to a stapler misfire and resultant hemorrhage, the bleeding was controlled with robotic compression while an open incision was made. There were no robotic cases that demonstrated adverse outcomes due to the primary surgeon's position away from the patient's bedside. The commonly reported advantages of laparoscopic resections, when compared to open resections, include less blood loss, shorter length of hospital stay, and a quicker return to work.[7, 8] Our analysis confirmed the reports of less blood loss and shorter length of stay, in comparison with open liver resections.

Other series have also demonstrated the safety of major and minor robotic liver resections. Guilianotti described outcomes of two series of patients with a 4% conversion rate for right hepatectomies and only 150mL (range 100–2000) median blood loss for minor resections..[9].[10] Less than 10% of our robotic cases were major resections, which is a reflection of our patient population that is dominated by patients with metastatic colorectal cancer who need small parenchymal-preserving resections, and careful patient selection. Thus, our conclusions primarily are relevant for minor resections.

It is difficult to accurately describe a learning curve with the number of cases reported in our series. Other series have demonstrated that early in a surgeon's robotic experience operations can have an extended duration. Choi et al, for example, described a single surgeon's experience with robotic liver resection in 30 consecutive patients.[11] The average "operating time" for all 30 patients was 507 minutes, and the average for right hepatectomy patients (n=6) was 724 minutes. Tsung et al in their series of 57 patients found that median "room time" dropped significantly from 466 minutes to 314.5 minutes (p=0.001), and median "OR time" dropped significantly from 381 minutes to 232 minutes (p=0.001), in a comparison of their early patients (n=13) with later patients (n=44).[12] These decreases were accompanied by a drop in EBL from 300 mL to 100 mL (p=0.008). In contrast, the robotic surgery approach in our series had a meaningfully shorter median OR time of 163 min.

In our series, the pathologic outcomes, including margin status, of robotic liver resections were equivalent to those of open resections. In addition, there were a high number of non-anatomic wedge resections in the robotic group, suggesting that parenchymal preservation was upheld when using this technique. Performance of a larger resection than necessary to facilitate a minimally invasive approach is demonstrated by one series from Korea.[11] In our series, however, a tumor in segment 7, was removed via a segment 7 wedge resection or segmentectomy, as opposed to a posterior sector resection or even a right hepatectomy. Robotic liver surgery still has some limitations. Currently, one method of parenchymal transection uses a robotic non-wristed Harmonic scalpel. This device negates the advantage gained with wristed robotic instruments. The other method uses the robotic Vessel Sealer. This instrument is bulky and difficult to use in small resections. There is room for the development of improved robotic instrumentation for parenchymal transection. Despite the limitations of these devices, in our series the Pringle was used in only 9% of robotic cases, compared to 75% (P<0.001) of open cases. This difference is, however, likely due to surgeon's choice, rather than need for a Pringle.

Several comparisons of laparoscopic and robotic liver resections have been published (Table 5). Small numbers, ranging from 9 to 57 robotic resections, limit all of these reports. It is unclear whether use of wristed instruments, otherwise considered advantageous, can lead to measurable improvements when combined with robotic liver resection. The portal dissection, for example, is subjectively simpler, as is extrahepatic ligation of the right portal vein. There are no data that show this improvement in technique leads to a meaningful change in outcomes of robotic liver resections.

We agree with prior authors that the robotic approach allows for resection of the more difficult segments 2, 7, and 8 lesions.[10, 13] In fact, the Louisville consensus statement on laparoscopic liver surgery recommended that the best indications for laparoscopic resection were lesions in segments 2 through 6, not segments 7 and 8.[2] In the current series, 12 of the cases involved isolated segment 2, 7, or 8 and three were posterior sectorectomies.

Our analysis was limited by the small numbers of robotic resections and complications. In addition, accurate cost data were not available to determine the cost effectiveness of each approach. We have demonstrated in a matched retrospective comparison that the robotic and open approaches appear to be similar in two vital areas: safety and oncologic outcomes. Given these two findings, additional advantages to the robotic platform may be demonstrated as the robotic experience grows. It is clear that open or minimally invasive approaches are appropriate as long as the surgeon is comfortable with whichever method of resection they choose.

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Table 1

Demographics

	Robotic (n=64)	Open (n = 64)	p-value
Age (years), median (range)	64 (40 – 91)	63 (29 – 85)	0.50
Male Sex	32 (50%)	29 (45%)	0.72
ASA score, median (range)	3 (2 – 4)	3 (2 – 4)	0.43
Comorbidities			
Htn	27 (42%)	0 (0%)	< 0.001
DM	6 (9.4%)	0 (0%)	0.04
CAD	3 (4.6%)	0 (0%)	0.25
Hepatitis	7 (10.9%)	5 (7.8%)	0.77
COPD	3 (4.7%)	0 (0%)	0.25
Smoking history			
Never	41 (64.1%)	39 (60.9%)	0.77
Former	17 (26.6%)	20 (31.3%)	
Current	6 (9.4%)	5 (7.8%)	
BMI, median (range)	26.7 (17.3 – 45.1)	28 (17.0 – 48)	0.15
Malignant pathology			
Primary liver cancer	12 (18.8%)	11 (17.2%)	0.97
Metastatic liver cancer	35 (54.7%)	36 (56.3%)	
Gallbladder cancer	3 (4.7%)	4 (6.3%)	
Neoadjuvant chemo	24 (37.5%)	25 (39.1%)	0.71
Prior liver resection	5 (7.8%)	6 (9.4%)	1.00

ASA, American Society of Anesthesiologists; Htn, hypertension; DM, diabetes mellitus; CAD, coronary artery disease; COPD, chronic obstructive pulmonary disease; BMI, body mass index; chemo, chemotherapy

Table 2

Intraoperative variables

	Robotic	Open	p-value
OR time (min), median (range)	163 (56 – 480)	210 (6.5 – 535)	0.017
EBL (mL), median (range)	100 (10 – 1700)	300 (0 – 2700)	< 0.001
Intraoperative transfusion PRBC	1 (1.6%)	9 (14.1%)	0.03
Conversion to open	4 (6.3%)	--	NA
# of ports, median (range)	4 (3 – 5)	--	NA
Pringle used	6 (9.4%)	48 (75%)	< 0.001
Pringle time (min), median (range)	27 (17 – 40)	27 (3 – 70)	< 0.001
Synchronous organ resection	7 (10.9%)	13 (20%)	0.003

OR, operating room; EBL, estimated blood loss; PRBC, packed red blood cells

Table 3

Anatomic location of robotic and open hepatectomies

	Robotic	Open	p-value
Left hepatectomy	4 (6.3%)	4 (6.3%)	1.00
Right hepatectomy	2 (3.1%)	2 (3.1%)	NA
Single segment resections	48 (75%)	51 (79.7%)	
• *Wedge resection*	22	7	
• *Wedge resection location*			
○ Left lobe	5 (7.8%)	4 (6.3%)	1.00
○ Right lobe	20 (31.3%)	6 (9.4%)	NA
-Anterior sector	11 (17.2%)	4 (6.3%)	0.10
-Posterior sector	9 (14.1%)	2 (3.1%)	0.07
• *Segmental resection*	26	44	
caudate	0 (0%)	2 (3.2%)	0.48
II	1 (1.6%)	2 (3.2%)	1.00
III	5 (7.8%)	3 (4.7%)	0.68
IV	1 (1.6%)	4 (6.3%)	0.37
V	4 (6.3%)	11 (17.2%)	0.10
VI	5 (7.8%)	12 (18.8%)	0.12
VII	7 (10.9%)	6 (9.4%)	1.00
VIII	3 (4.7%)	4 (6.3%)	1.00
Left lateral sectorectomy	10 (15.6%)	10 (15.6%)	1.00
Right posterior sectorectomy	3 (4.7%)	5 (7.8%)	0.72
Gallbladder/wedge segment IVb/V	4 (6.3%)	3 (4.7%)	1.00

Table 4

Complications

	Robotic	Open	p-value
Any complications *	7 (10.9%)	9 (14.1%)	0.77
Any Major complications (grade ≥3) *	3 (4.7%)	4 (6.3%)	1.00
Any Infectious complications *	5 (7.8%)	1 (1.6%)	0.22
Wound infection	1	0	
Infected abdominal fluid collection	2	0	
Pneumonia	3	0	
Urinary tract infection	0	1	
GI complications *	1 (1.6%)	1 (1.6%)	
Ileus	1	1	
Hepatobiliary complications *	0	0	--
Liver failure	0	0	
Bile leak	0	0	
Pulmonary complications *	0	0	--
Cardiac complications *	0	0	--
Incisional hernia	0	0	--
Deep Vein Thrombosis	1(1.6%)	0	
Readmission within 30 days	4 (6.3%)	8 (12.5%)	0.34

GI, gastrointestinal

* Patient can have more than one complication

Table 5

Comparisons of robotic vs. laparoscopic liver resections

Authors	Laparoscopic	Robotic	Clinically relevant differences
Spampinato[14]	25	25	1)*Pringle*: 32% lap vs. 0% robot (p=0.004)
Troisi[13]	223	40	1)*Parenchymal preservation*: 55% robot vs. 34% lap (p=0.01) 2)*Conversion*: 20% robot vs. 8% lap (p=0.034)
Berber[15]	23	9	No differences
Tranchart[16]	28	28	1)*Superior and posterior segments resections*: 50% robot vs. 11% lap (p=0.003)
Tsung[12]	114	57	1)*OR time*: 253 min robot vs. 199 min lap (p<0.05) 1)*EBL minor resections*: 285 mL robot vs. 50 mL lap (p=0.011)

lap, laparoscopic; robot, robotic; OR, operating room; EBL, estimated blood loss