Published in final edited form as:
J Hepatobiliary Pancreat Sci. 2013 February ; 20(2): 151–156. doi:10.1007/s00534-012-0560-4.

Robotic Surgery – Improved Tool for Major Liver Resections?

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Abstract

Minimally-invasive liver surgery has recently undergone an explosion in the reported worldwide experience. Given its comparable outcomes to its open counterpart, high volume centers are utilizing minimal access liver surgery more frequently under well-defined criteria. The recent introduction of robotic-assisted surgery has further revolutionized the field of minimally invasive surgery and has expanded the reach of feasibility. Robot-assisted surgery was developed to help overcome the disadvantages of conventional laparoscopic surgery. As a result, there has been an increase in the reporting of advanced robot-assisted liver resections. A literature review was performed to identify the current manuscripts describing robotic liver surgery. Nine case series were identified, yielding 144 unique patient characteristics. Outcomes indicate that robot-assisted liver resection is feasible and safe for both minor and major liver resections in regards to EBL, LOS, and complications. Early data also suggests that robot liver surgery is efficacious in regards to short-term oncologic outcomes. Future studies will be needed to better evaluate advantages and disadvantages to laparoscopic liver resections.

Keywords

Robotic liver resection; laparoscopic liver resection; robotic hepatectomy; robotic surgery; liver surgery

INTRODUCTION

Minimally-invasive surgery has evolved dramatically since the first laparoscopic cholecystectomy was reported by Mühe in 1985.(1) Thanks in part to the acquisition of advanced laparoscopic skills and improved instrumentation, nearly all fields of surgery have seen the open counterpart achieved through minimal access surgery. As a result, reduction of hospital stay, improvement in cosmetic results, and decreased postoperative pain has been demonstrated in nearly all the surgical specialties when compared with conventional open operations. (2–5)

Laparoscopic liver surgery was first reported in 1992(6). Over the next 15 years, several case series reporting results of biopsises and small wedge resections, as well as resections of the left lateral section or anterior hepatic segments (segments 4b, 5,6) were reported with results consistent with the previously published benefits of minimally invasive surgery. Following the Cherqui et al report of a prospective cohort of 30 patients(7), numerous

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reports have been published further supporting the feasibility and adequacy of laparoscopic liver resection.(8) Recently, reports of anatomic laparoscopic liver resections – left and right hepatectomies, left lateral sectionectomy, and even extended left and right hepatectomy, have demonstrated the feasibility of such advanced resections.(9–11)

In an effort to standardize and summarize the current world position on laparoscopic liver surgery, a consensus conference was convened in 2008.(12) World experts agreed that laparoscopic liver surgery is a safe and effective approach to the management of surgical liver disease in the hands of trained surgeons with experience in hepatobiliary and laparoscopic surgery. Furthermore, the members of the consensus consortium agreed on the following as guidelines: 1. The best indications for laparoscopic liver resection are in patients with solitary lesions, 5 cm or less, located in the peripheral liver segments (segments 2–6); 2. The laparoscopic approach to the left lateral sectionectomy should be considered the standard of care; 3. Although most types of liver resection can be performed laparoscopically, including major liver resections, these should be reserved to experienced surgeons already facile with more complex laparoscopic resections.

Robot-assisted technology was developed to address the limitations of conventional laparoscopy. The robotic articulating laparoscopic instruments recreate the seven degrees of freedom of the human hand, thus providing the dexterity and precise movements that are lacking in laparoscopic instruments. The 3-dimensional view and magnification of the operative field enhances visual perception while complex algorithms minimize physiologic tremor.(13) These features allow the surgeon to perform delicate tissue dissection and precise intracorporeal suturing. Theoretical advantages of robotic surgery allow for resections of lesions adjacent to major vessels, near the liver hilum, and with generally more complex anatomy.(14) As a result, robotic surgery has expanded the scope of surgical procedures that can be performed through minimally invasive techniques. (15–17) It is still important to note that robot-assisted technology should be viewed as an advanced tool to improve the minimally invasive approach for complex procedures.

At present, the application of robot-assisted laparoscopic surgery in liver surgery remains largely unanswered. What follows is a review of the current state of the literature concerning robot assisted liver resection.

METHODS

A literature search was performed using PUBMED for cited publications in English using key phrases “robotic liver surgery”, “robotic hepatic surgery”, “robotic liver resection”, “robotic hepatic resection”, and “robotic liver”. Using these key terms, over 70 publications were identified, which included reviews and descriptions of robotic surgery overall. Following a screen of all results, a total 25 publications relevant to robotic liver surgery were found, 9 of which contained unique patient data for patients undergoing robotic liver resections only for benign and malignant lesions.

To date, no prospective trials comparing open vs. robot-assisted or laparoscopic vs. robot-assisted has been reported. As such, the current body of literature will be collectively reviewed in order to present the contemporary view of short term outcomes, including operative time, estimated blood loss, length of stay and morbidity and mortality. Reports including patients undergoing combined resections were excluded from the comparative review. Table I represents the 9 publications identified.

RESULTS

Robotic Liver Surgery – Cohort Analysis

Following review of the reported literature, 9 case reports/series were identified which contained the unique patient cohort utilized for analysis. Overall, 70% of lesions resected were reported as malignant, with hepatocellular carcinoma the most frequently recorded (Table 2). Colorectal metastases accounted for the next largest group, representing 20% of the cases reported. Other HPB metastases, including 5 cases of cholangiocarcinoma, 4 cases of gallbladder cancer, and 1 hepatoblastoma, represented the next largest group. The most common benign lesions were hemagiomas, representing 10% of the robot-assisted liver resections performed for benign disease. Focal nodular hyperplasia (6%), followed by adenoma (5%) was the next most common benign lesions reported.

Table 3 demonstrates the frequency and type of robot-assisted resection. Left lateral sectionectomy was the most common resection, reported in 37 (26%) cases. Right hepatectomy and left hepatectomy accounted for 19% and 11%, respectively. Furthermore, reports of both extended right hepatectomy (2%) and extended left hepatectomy (1%) with biliary reconstruction were included.

Operative Time

All nine cases series reviewed reported robotic operative times and are summarized in Table 4. Given the heterogeneous types of resections performed, it is difficult to analyze and adequately draw comparisons. Moreover, methods for reporting OR times were not clearly defined. As a result, further conclusions cannot made regarding trends to decreased OR times with increased experience, as previously demonstrated throughout the laparoscopic liver resection literature.(8) Of the reports analyzed, OR times were reported with a range of 90 minutes to 720 minutes. In regards to major resections (> 3 segments), Giulianotti *et al* reported median OR times of 313 minutes (range 220–480) for the 27 major resections analyzed. These results were comparable to Ji *et al* who reported mean OR times of 338 minutes (range 150–720), in which the majority of their resections were considered major. When considering minor resections (≤ 3 segments), Giulianotti reported median OR times of 198 minutes (range 90–459). The timing for minor resections remained relatively consistent across studies analyzed, with Chan *et al* reporting OR times of 200 minutes (range 90–307) and Tomulescu *et al* reporting OR times of 137 minutes (range 120–180).

When retrospectively compared, Berber *et al* found no significant difference in OR times between robotic resections (259 ±28 minutes) and laparoscopic resections (234 ± 16 minutes) when comparing 9 robotic cases and 11 laparoscopic cases. However, Ji *et al* noted a difference when comparing robot-assisted (338 min) to laparoscopic (130 min) to open (205 min). This comparison was based on 13 robot-assisted cases, 20 laparoscopic cases, and 32 open cases.

Overall, there did not appear to be a decrease in OR time in the largest series of patients. Nonetheless, the heterogeneity of reporting and “learning curve” likely contribute to this phenomenon. When comparing the early results of robot-assisted liver surgery to the aggregate worldwide laparoscopic experience(8), operative time rangers were slightly wider (90 minutes to 720 minutes vs. 99 minutes to 331 minutes). As increased experience is accrued, these differences will likely lessen as instrumentation and surgical team experience continues to improve.

Estimated Blood Loss (EBL)

Intraoperative blood loss was reported in 8 of the studies analyzed (Table 4). Blood loss ranged from 5 mL to 2000 mL. When initially evaluating EBL as a surrogate marker for experience, there again appears to be no correlation. The authors of the larger case series did not report decreased EBL as experience increased. However, Giulianotti *et al* demonstrated several differences when comparing both resection type and associated pathology. When analyzing their data, major resections had a median EBL of 300 mL (range 100–2000) with a transfusion rate of 22%. This was compared to a minor resection EBL of 150 mL (range 20–1800) with a transfusion rate of 21%. Furthermore, a higher EBL was associated with liver resections in cirrhotic patients. There was an EBL of 400 mL (range 100–1800) with 6 patients requiring transfusions. Comparatively, Ji *et al* reported a median EBL of 280 mL in a cohort of resections that consisted of a majority of major liver resections. As previously, in a retrospective comparative analysis, Berber *et al* found no significant difference in EBL when comparing robot-assisted (136±61 mL) to laparoscopic (155±54 mL) when comparing 9 robot-assisted liver resections to 23 laparoscopic liver resections. Overall, the results of the robot-assisted cohort did not differ significantly when compared to the reported laparoscopic literature, where EBL ranged from 50 to 659 mL. As previously demonstrated by Topal *et al*(18), EBL was significantly reduced in patients undergoing laparoscopic liver resection when compared to open resection. Although no definitive data has yet to be reported, it is most likely that the robot- assisted approach will have a similar EBL profile to laparoscopy.

Length of Stay

Length of stay was reported in 7 of the publications reviewed. LOS ranged from 3–26 days. When comparing the two largest cohorts, LOS was comparable with 5.5 days (range 3–11) (14) and 7 days (range 2–26)(19). Guilianotti *et al* represents a unique perspective as two patient cohorts from two different countries. Their group reported a median hospital stay of 7 days for the entire series, but median hospital stay of 7 days (range 4–15) in the Italian cohort and 5 days (range 2–8) in the United States cohort. Furthermore, minor resections in Italy resulted in a median postoperative duration of 7 days (range 4–15) and major resections required 10 (range 5–23), while in the US group, the median hospital stay was 5 days (range 2–7) for minor resection and 6 days (range 4–8) for major resections. Previous authors have noted that, while the exact reasons are unknown, the variability of hospital stays may be due to a cultural and health system bias. As demonstrated in both the laparoscopic and robotic literature, the average LOS typically represent a shorter length of stay in the United States and longer length in Europe and Asia.

Complications and Conversions

The overall complication rate for the nine series analyzed was 14.6% (Table 5), which is comparable to the laparoscopic liver resection literature, which cites a complication rate of 10.5%.(8). The most common complication noted was bile leak, occurring in 6 patients included in the study. Out of the 6 that occurred, 4 resolved spontaneously and resolved with drains placed intra-operatively. Two bile leaks required percutaneous intervention postoperatively. Furthermore, none of the complications required re-operation. The review of the laparoscopic literature demonstrated an increased tendency of complications after liver resection for hepatocellular cancer (50%) compared to colorectal metastasis (11%), citing the underlying liver disease as the most likely culprit. The current body of literature for robot-assisted liver surgery did not differentiate the occurrence of complications as a function of the underlying pathology.

Overall, there were 6 conversions (Table 5). Five patients were converted to open surgery and one was converted to a hand-assisted approach. The reasons noted for conversion included: difficulty in controlling bleeding from the left hepatic vein during a left lobectomy of a cirrhotic liver(19), an injury to the hepatic venous branches during a wedge resection resulting in a hand-port conversion(14), and non-specified bleeding(20). The three remaining conversions were due to maintaining the oncologic principles in safe removal of the liver tumor.(19) There were no reported deaths.

Oncologic Outcomes

Based on a metaanalysis of laparoscopic versus open liver resection, (21) there was comparable overall and disease-free survival when comparing laparoscopic to open liver resection. Moreover, operative blood loss and hospital length of stay was significantly less in the laparoscopic group, even when matched for extent of resection and presence of malignancy. Currently, given its novelty, there is no long-term data regarding oncologic outcomes for robot-assisted liver surgery. Lai *et al*. reported that 9 of their ten patients underwent operations for malignant tumors. Six patients had R0 resections while 3 patients had R1 resections. The authors further explain that two of the three patients with R1 resections had bilobar colorectal liver metastases, and hemihepatectomies were combined with RFA to manage the bilobar disease. In their cohort of 6 with R0 resection, only one patient had local recurrence.

The remaining publications that reported resection margins for malignant disease reported negative margins.(19, 20, 22, 23) Berber *et al* reported a mean resection margin of 11+8 mm for robotic resection and 14 + 10 mm for laparoscopic resection. Giulianotti reported 18mm (range 1–70) for all malignant lesions, further breaking down based on tumor type. The overall recurrence rate that was reported in the literature was 15%, as reported by only 4 publications. (19, 20, 22, 23) None of the publications reported port site recurrences.

DISCUSSION

Despite the explosion of reports of the feasibility and safety of laparoscopic surgery, the indications for liver resection should remain unchanged. As articulated by the Louisville Consensus(12), minimally invasive liver resection surgery requires expertise in open hepatic resection surgery, minimally invasive surgery, and laparoscopic ultrasonography. Robotic-assisted laparoscopic liver surgery has received increased attention as a result of advancement in technology. With the refinement of technology, easier set-up, better image quality, and smaller robotic systems, there has been recent interest in utilizing the robot for complex hepatobiliary procedures. By combining the efficacy of open surgery with a minimally invasive approach, the surgical robotic system allows for technical refinements of laparoscopic hepatectomy.

The current state of literature for robotic-assisted liver resection remains limited. Robot-assisted liver resection appears to be comparable to its laparoscopic and open counterpart in many regards, including operating room time, estimated blood loss, length of stay and complications. Many questions remained unanswered, most notably, its efficacy in regards to long term oncologic outcomes. Nonetheless, analysis of the current available short-term data demonstrates noninferiority to its laparoscopic and open equivalents. It is certain that future well-organized studies will be necessary to adequately evaluate short and long term outcomes.

CONCLUSION

The current state of literature demonstrates that robot-assisted liver surgery is a feasible and safe tool. Minimally invasive liver surgery is best performed by individuals trained in open liver surgery who are facile with minimally invasive techniques. The robot platform helps to overcome the inherent limitations of laparoscopy, thus expanding the role of minimally

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invasive surgery for complex hepatobiliary procedures. While it is evident that robot-assisted liver surgery is feasible, the overall efficacy in regards to patient outcomes remains largely unanswered. Future studies will help elucidate this question.

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Table 1

Publications with reported robotic liver resection

Authors	Year	Country	Study Type	# Pts	Malignant	Benign
Lai *et al*(24)	2011	China	Case series	10	9	1
Giulianotti *et al*(25)	2011	USA/Italy	Case series	70	42	28
Chan *et al*(14)	2011	China	Case series	27	21	6
Ji *et al*(23)	2011	China	Comparative	13	8	5
Wakabayashi *et al*(26)	2011	Japan	Case series	4	3	1
Berber *et al*(20)	2010	USA	Comparative	9	9	0
Giulianotti *et al*(27)	2010	USA	Case report	1	1	0
Tomulescu *et al*(28)	2009	Romania	Case series	7	7	0
Choi *et al*(22)	2008	Korea	Case series	3	2	1

Table 2

Resected Lesion Type

Benign Lesions (%)	Malignant Lesions (%)
Hemangioma – 10%	Hepatocellular Cancer - 27%
Focal Nodular Hyperplasia – 6%	Colorectal Mets – 20%
Adenoma – 5%	Primary HPB – 8%
Recurrent pyogenic abscess – 3%	Other Mets – 8%
Hepaolithiasis – 1%	Not Documented – 7%
Not Documented – 4%	

Primary HPB included – 5 cases of cholangiocarcinoma, 4 cases of gallbladder cancer, and 1 case of hepatoblastoma

Table 3

Types of Robotic Resections

Total Cases	144	
Left Lateral Sectionectomy	37	26%
Segmentectomy	34	24%
Right hepatectomy	28	19%
Left hepatectomy	16	11%
Wedge resection	15	10%
Bisegmentectomy	10	7%
Extended right hepatectomy	3	2%
Extended left hepatectomy	1	1%

Table 4

Primary Outcome Measures

Publication	# of pts	OR Time (min)	EBL (mL)	Length of Stay (days)	Transfusion
Lai *et al*(24)	10	347 ±85.9	407 ±286.8	6.7±3.5	1
Giulianotti *et al*(25)	70	270 (90–660)	262 (20–2000)	7 (2–26)	15
Chan *et al*(14)	27	200 (90–307)	50(5–1000)	5.5(3–11)	-
Ji *et al*(23)	13	338(150–720)	280	6.7	0
Wakabayashi *et al*(26)	4	272	Negligible	-	-
Berber *et al*(20)	9	259 ±28	136 ±61	-	-
Giulianotti *et al*(27)	1	540	800	11	1
Tomulescu *et al*(28)	7	137 (120–180)	-	11(4–19)	-
Choi *et al*(22)	3	463	367	3	1

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Table 5

Reported Complications and Conversions (N=144)

Deaths	0	
Complications	21	14.6%
Liver-Related Complications		
Bile Leak	6	4%
Transient Liver Failure	2	1.4%
Ascites	1	0.7%
Surgical-Related Complications		
Pleural Effusion	3	2%
Wound infection	1	0.7%
Ileus	1	0.7%
Urinary Bladder Injury	1	0.7%
Thoracic Empyema	1	0.7%
Intra-abdominal Collection	1	0.7%
General Complications		
Transient Ischemic Attack	2	1.4%
Deep Vein Thrombosis	2	1.4%
Conversions	6	4.2%
Open	5	3.5%
Hand Port	1	0.7%