Published in final edited form as:
J Gastrointest Surg. 2012 December ; 16(12): 2233–2238. doi:10.1007/s11605-012-2040-1.

Minimally-Invasive Liver Resection: Robotic Versus Laparoscopic Left Lateral Sectionectomy

Vignesh Packiam[1], **David L. Bartlett**[2], **Samer Tohme**[1], **Srinevas Reddy**[1], **J. Wallis Marsh**[1], **David A. Geller**[1], and **Allan Tsung**[1,*]

[1]Division of Hepatobiliary and Pancreatic Surgery, University of Pittsburgh Medical Center, Pittsburgh, PA

[2]Division of Surgical Oncology, Department of Surgery, University of Pittsburgh Medical Center, Pittsburgh, PA

Abstract

Background—The purpose of this study was to compare the clinical and economic outcomes of robotic versus laparoscopic left lateral sectionectomy (LLS).

Methods—A retrospective analysis was made comparing robotic (n=11) and laparoscopic (n=18) LLS performed at the University of Pittsburgh Medical Center between January 2009 and July 2011. Demographic data, operative, and post-operative outcomes were collected.

Results—Demographic and tumor characteristics of robotic and laparoscopic LLS were similar. There were also no significant differences in operative outcomes including estimated blood loss and operating room time. Patients undergoing robotic LLS had more admissions to the ICU (46% vs. 6%), increased rate of minor complications (27% vs. 0%), and longer lengths of stay (4 vs. 3 days). There were no significant differences in major complication rates or 90-day mortality. The cost of robotic and laparoscopic LLS were not significantly different when only considering direct costs ($5,130 vs $4,408, $p=0.401$). However, robotic LLS costs were significantly greater when including indirect costs, which were estimated to be $1,423 per robotic case ($6 553 vs. $4 408, $p=0.021$).

Discussion—Robotic LLS yields slightly inferior clinical outcomes and increased cost compared to the laparoscopic approach.

Keywords

robotic liver; laparoscopic liver; hepatic resection; robotic surgery

Introduction

Laparoscopic liver surgery has steadily grown to become an accepted minimally invasive option for patients with selected hepatobiliary lesions [1–3]. The size of reported laparoscopic resections has grown from wedge biopsies and small peripheral resections [4, 5], to anatomic and even extended left and right hepatectomies [6–8]. The applicability of the laparoscopic approach was further extended to malignant lesions, especially following several publications showing equivalent oncologic outcomes [9–14].

*Corresponding author: Allan Tsung M.D., Division of Hepatobiliary and Pancreatic Surgery, UPMC Liver Cancer Center, Montefiore Hospital, 3459 Fifth Ave., 7 South, Pittsburgh, PA 15213, (tel) 412-692-2001, (facsimile) 412-692-2002, tsunga@upmc.edu.

Numerous case controlled studies have shown improvements in operative and postoperative outcomes when comparing laparoscopic to conventional open liver resection, especially with respect to decreased estimated blood loss (EBL) and length of stay (LOS) [10, 15, 16]. This reduction in LOS has been shown to be associated with cost benefits [17]. However, several limitations of laparoscopic surgery hinder its applicability to more complex operations [18]. Some of the limitations which can potentially be addressed by robotic assistance include limited degrees of motion, amplification of tremor, and loss of 3 dimensional vision. The majority of laparoscopic surgery is limited to wedge resections or left lateral sectionectomy (LLS) [10]. Modifications to the pure laparoscopic technique such as hand assistance or the "hybrid" approach have allowed for expanded applicability of laparoscopic liver resections for larger resections [17, 19]. However, benefits of pure laparoscopic liver resection, such as reduction in LOS, are neutralized when a hand-assistance port is used [20].

Robotic liver resection has been increasingly used to overcome the limitations of laparoscopic surgery [18]. This is based on maintenance of three-dimensional vision, the availability of seven degrees of freedom, and decreased physiologic tremor [21]. These theoretical benefits have accounted for a boom in the number of robotic liver resections being performed [18]. Although several series of robotic liver resections have been published [22, 23], to date there is little evidence comparing the clinical outcomes of laparoscopic and robotic surgery. Potential cost implications of robotic surgery have also not yet been considered for robotic liver resection, although this will play a role in the widespread adoption of this modality.

LLS is an attractive choice for comparison between resection modalities due to its standardized approach [24]. When comparing laparoscopic versus open LLS, recent studies have found clinical[25, 26] and economic benefits [20]. As a result, minimally invasive surgery has been proposed to be the gold standard for LLS[27, 28]. While our institution has accumulated many years of experience and expertise with laparoscopic liver resection, this study captures our early adoption phase of robotic liver resection. The clinical benefits and potential economic impact of using this new modality for liver surgery is unclear. Thus, the purpose of this study was to compare the clinical and economic outcomes of robotic and laparoscopic LLS.

Material and Methods

Between January 2009 and July 2011, 29 patients underwent minimally invasive LLS at the University of Pittsburgh Medical Center (UPMC) Liver Cancer Center in Pittsburgh, Pennsylvania. Data was analyzed retrospectively from an Institutional Review Board-approved hepatic cancer registry. Patients were divided into groups based on type of resection; 11 and 18 patients received robotic and laparoscopic LLS, respectively. All cases in the laparoscopic resection group were performed with a "pure" laparoscopic approach, without hand-assistance or a hybrid incision. All robotic cases were performed using a dual console da Vinci robot with four arms. Parenchymal transaction is performed primarily with staples in the laparoscopic approach and crush/clamp technique with robotic bipolar device and clips for the robotic approach. LLS was offered based on lesion characteristics and assessment of overall clinical status, while the type of surgical approach for each LLS was determined based on surgeon preference. Treatment recommendations were made for all patients with malignancies at a weekly multidisciplinary liver tumor conference. LLS was chosen for analysis in the study since it is a highly standardized minimally invasive resection. The minimally invasive approach is the surgical modality of choice for patients with lesions in the left lateral segment at UPMC. The determination to offer laparoscopic versus robotic LLS was made based on surgeon preference.

Clinical factors examined included demographic, operative, and post-operative outcomes. EBL was determined from anesthesia records. Operating room (OR) time was defined as the time from skin incision to wound closure. There were no adjustments made for lysis of adhesions. Post-operative ICU admission rates were determined from discharge summaries at our institution. Post-operative complications were graded according to the Clavien-Dindo Classification scale [29]. Major complications were defined as an event requiring surgical, endoscopic, or radiological intervention (Clavien Classification grade ≥ 3).

Direct costs of OR surgical supplies were obtained for all patients receiving minimally invasive LLS. These OR supplies were further subdivided to include laparoscopic instruments associated with both laparoscopic and robotic surgery, robotic instruments, clips, staples, and other miscellaneous OR supplies. Miscellaneous expenses included the remaining supply costs that are largely shared by open surgery. Physician charges were not included in this analysis. Indirect costs that included purchase and maintenance of the robotic system were also estimated and analyzed.

Data analysis was performed using PASW Statistics 19 for Windows (version 19.0; SPSS Inc., Chicago, IL). Groups were compared using the χ^2 test for independence for categorical variables, Analysis of Variance for continuous parametric variables, and the Mann-Whitney U test for continuous non-parametric variables. Categorical variables are presented as whole numbers and percentages. Continuous parametric variables are presented as means with standard deviation. Continuous non-parametric variables are presented as medians with interquartile range. For all statistical measures, $p<0.05$ were considered significant.

Results

A total of 29 patients with hepatic lesions underwent minimally invasive resections; 11 and 18 received robotic and laparoscopic, respectively. Malignant indications for resection included metastatic colorectal cancer (n=7), hepatocellular carcinoma (n=6), and metastatic melanoma (n=1). Benign lesions resected included focal nodular hyperplasia (n=8), adenoma (n=3), hemangioma (n=3), and biliary cystadenoma (n=1).

The demographic and tumor characteristics of patients receiving robotic and laparoscopic LLS are summarized in Table 1. There was no significant difference between both groups with respect to age, body-mass index (BMI), gender, number of lesions, size of the largest lesion, and percentage of malignant lesions.

The operative and post-operative characteristics of patients receiving robotic versus laparoscopic LLS are summarized in Table 2. Estimated blood loss, transfusion rate, operative time, and conversion to open rate were all similar between both groups. Patients undergoing robotic LLS had increased intensive care unit (ICU) admission rates, minor complication rates, and LOS. All 3 minor complications were Clavien Class 1, and included atelectasis, wound infection, and diarrhea two days after discharge that required readmission. None of these complications were treated in the ICU. There were no major complications or 90-days mortality in either group.

Direct costs of OR surgical supplies are summarized in Table 3. The total surgical supply costs were not significantly different between the robotic and laparoscopic groups ($5 130 vs. 4 $4 408, *p=0.401*). All laparoscopic and robotic instruments composed 79% and 84% of the total supply costs for the average robotic and laparoscopic surgery, respectively. The average robotic supply cost of $1 413 included the price of 6 robotic instruments, all of which can be used for a total of 10 cases. Thus, the average robotic instrument cost accounts for the sum of the prices of these instruments divided by 10. The total price of the 6 instruments used was $2 000, $2 900, $2 200, $2 400, $3 200, $1 400, for hook cautery, PK

Gyrus, Prograsp, Needle Drivers, Scissors, and a Clip Applicator, respectively. Staple costs were not significantly different between groups, although there were generally more staple loads used per laparoscopic surgery. While the cost of clips were significantly different between groups, they accounted for <2% of total costs.

The purchase and maintenance of the robot were not included in the direct costs for OR surgical supplies. These additional expenses were estimated based on data for the dual console model that was used for all the patients receiving robotic LLS at our institution. This model has a 10 year lifespan, a purchase cost of $2 200 000, annual maintenance cost of $150 000, and is utilized for an average of 260 total cases per year, which yields an indirect cost of $1 423 per robotic case. Since indirect costs for laparoscopic surgery were more difficult to quantify, and often shared with robotic surgery, they were not estimated. Therefore, adding indirect costs for robotic surgery to direct costs, the total surgical supply costs of robotic and laparoscopic surgery were significantly different ($6 553 vs. $4 408, $p=0.021$).

Discussion

Over the past decade, there has been a cautious acceptance for using laparoscopic techniques in hepatobiliary surgery [1, 30]. Controlled studies showed that the general benefits of minimally invasive techniques specifically applied for liver resection, including decreased post-operative pain, reduced complications, reduced LOS, and equivalent oncologic results [10, 31–33], resulting in widespread agreement among hepatobiliary surgeons that laparoscopic liver resection is safe and feasible for selected lesions in selected patients [3, 34, 35]. Some have proposed that the availability and increasing expertise in laparoscopic hepatic resection may change the management of solid benign tumors in that laparoscopic resection may in fact replace the need for exhaustive diagnostic tests designed to ascertain the nature of the lesion [36]. However, in our study the majority of patients undergoing resection for benign disease were performed by surgeons who favor resections only for symptomatic lesions.

There has been growing evidence that laparoscopic techniques have difficulty with complex and large hepatic resections [1], which has led to increasing use of hand-assisted and hybrid techniques, which supplement the “pure” laparoscopic method [35]. There are hints that these methods may cancel some of the benefits of minimally invasive methods, predominantly with LOS and cost [20]. The relatively slow learning curve for learning laparoscopic liver resection also impedes rapid improvement of outcomes after initial adoption of this technology, except in the highest volume centers [37].

The exploding popularity of robotics in the field of surgery can broadly be attributed to several reasons: overcoming some of the operative limitations of laparoscopic surgery, conferring the post-operative benefits of minimally invasive surgery, and gaining positive financial advantages with increased marketability for the surgical procedure. Some of these benefits, especially operative, are beginning to be shown for liver surgery [18, 38]. However, it is important to actually assess post-operative outcomes for benefits as well [39]. LLS is a procedure well suited for comparison of operative techniques, and has been the surgical procedure of choice to compare laparoscopy to conventional open surgery in several publications [20, 24–26]. It was therefore chosen as the resection type in this study to compare the clinical and economic outcomes of robotic and laparoscopic LLS.

Considering operative outcomes, we found no significant differences between the robotic and laparoscopic LLS groups. While there was an initial concern for increased conversion to open rates with robotic surgery, there were no instances of this in our early experience.

Interestingly, operative times were also similar between groups even with the additional time required for docking the robotic system. However, our study did demonstrate several significant differences concerning post-operative outcomes. While there were no major complications in either group, there were significantly more minor complications in the robotic group (27%) compared to in the laparoscopic group (0%). This high percentage is likely attributable to the small sample size of the robotic LLS group. In addition, there was a significantly higher ICU admission rate in the robotic (46%) versus laparoscopic group (6%). We attribute this to our cautious post-operative management during the initial adoption phases of our robotic liver program by having all patients receiving robotic surgery go the ICU. However, this practice was discontinued after about a year of experience with robotic liver resections, resulting in no postoperative ICU admission for the second half of the robotic series. The initially cautious postoperative management also resulted in delaying discharge for patients undergoing robotic liver resection, which may have also contributed to the longer LOS by an average of 1 day compared to the laparoscopic series. Furthermore, the mean LOS of the second half of patients in the robotic series was 3 days, which is similar to the LOS of the laparoscopic series.

Costs of OR surgical supplies were used to assess the economic impact of robotic surgery for several reasons. There was a large variance of overall cost among cases in each group. However, there was homogeneity of OR supply costs between cases within each resection modality that made it amenable for comparison. Furthermore, direct and indirect costs of OR supplies are a primary concern for centers that are deciding on the utilization of robotics for liver surgery. While the post-operative benefits of robotic surgery have been quantified in many other surgical fields [40–43], analysis of OR supply costs in this study offers insights specific to hepatobiliary surgery.

There is no previous data that assesses the cost of robotic instruments in liver surgery. While there are 6 robotic instruments utilized per case at our institution, previous studies that have considered robotic instrument costs for other specialties utilized between 4 and 7 robotic instruments [43–45]. These generally cost between $2 000 and $3 000, and since each instrument can be used 10 times, this yields a net additional cost of $1 000 to $1 500 per case [46]. It is also important to consider how much additional expense is attributed to laparoscopic instruments. Summing both laparoscopic and robotic instruments in both groups, there is only a $302 greater total instrument cost with robotic surgery due to the additional expenses of laparoscopic instruments such as the Harmonic© or the LigaSure© that are only used in laparoscopic LLS. Also although some laparoscopic LLS surgeries utilize a large amount of staples, on average there is only $162 more spent on staples per laparoscopic LLS surgery. There were generally 6–7 rounds of staples fired per laparoscopic case, and 2–3 per robotic case. This may change over time as fewer staples are used in robotic resections, and this offers an opportunity for cost savings using the robotic method.

One limitation of this cost assessment is that it does not consider the overall cost of the inpatient stay, which was limited by the large variation of cost data in the small sample of patients in the robotic group. Future studies with larger study groups can address this. Other cost factors which are difficult to analyze and thus were not included in our analysis were that there were generally two surgery attendings present during the robotic cases, while there was one surgery attending with a resident assisting during the laparoscopic cases. There were also more circulating technicians during the robotic cases. Additionally, although indirect costs for robotic surgery could be roughly approximated, there were no estimations made for laparoscopic surgery. Despite the fact that most equipment used for laparoscopic surgery can be shared with robotic surgery, there are some indirect fees such as the purchase and maintenance of multiple monitors that are unique to laparoscopic surgery. Finally, the calculations used to estimate indirect costs in this analysis are cannot be generalized to other institutions due to variability in type of robotic model used, cost of maintenance, and overall institutional case-volume. Even if using the same robotic systems with similar amortization, low volume centers would have significantly higher robotic premiums per case. However, the framework offered for assessment of cost shows that the direct and indirect supply costs for robotic surgery do not vastly exceed those for laparoscopic surgery.

In summary, this study demonstrates that robotic LLS is safe and feasible compared to the “gold standard” for LLS: the laparoscopic approach. This is based on similar operative and post-operative outcomes. While there appeared to be some inferior post-operative outcomes for robotic LLS, these were not noteworthy, as explained earlier in the discussion. Some outcomes, such as increased ICU admission and a longer LOS, were improved after changes in postoperative management for the second half of our robotic series. The average cost of surgical supplies between resection modalities shows that there are similar expenses when simply considering direct costs. However, there is a substantially greater economic impact when considering the indirect costs of installation and maintenance of a robotic system. We have decided to report our results early in our experience since we have not found much benefit from robotic LLS compared laparoscopic LLS. Based on these results, we have transitioned most of the LLS procedures back to a laparoscopic approach. However, other factors such as patient preference to undergo robotic surgery and robotic availability also influence decision making in selection of resection modality. Although our series for patients undergoing minimally invasive LLS do not yet show clear benefits for the robotic surgery, our initial experience suggests that the robotic approach allows for more major hepatectomies to be increasingly performed in a minimally invasive fashion. Larger comparative studies are required to further address the clinical and economic impact of this relatively new surgical modality for liver surgery.

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Table 1

Robotic Vs. Laparoscopic LLS: Demographic and Pre-Operative Parameters

	Robotic	**Laparoscopic**	***p-value***
Number of Patients	11	18	
Age (mean years, SD)	57 ± 16	52 ± 17	*0.485*
BMI (mean kg/m^2, SD)	31 ± 7	29 ± 7	*0.498*
Male (%)	3 (27)	4 (22)	*0.758*
Number of lesions*	1 (1–1)	1 (1–1)	*0.684*
Largest tumor size* (cm)	5.5 (2.4–6.5)	4.4 (2.6–7.1)	*0.867*
Malignant (%)	6 (55)	8 (45)	*0.597*

*reported as median (Interquartile Range)

Table 2

Robotic Vs. Laparoscopic LLS: Operative and Post-Operative Outcomes

	Robotic	Laparoscopic	*p-value*
EBL * (mL)	30 (30–50)	30 (30–30)	*0.309*
Transfusion Rate (%)	0 (0)	0 (0)	-
OR time * (mins)	175 (156–253)	188 (156–222)	*0.982*
Conversion to Open Rate (%)	0 (0)	0 (0)	-
Minor Complication Rate (%)	3 (27)	0 (0)	***0.019***
Major Complication Rate § (%)	0 (0)	0 (0)	-
Post-operative ICU Admission Rate (%)	5 (46)	1 (6)	***0.010***
LOS * (days)	4 (3–5)	3 (2–3)	***0.031***
90 days Mortality (%)	0 (0)	0 (0)	-

EBL=Estimated Blood Loss, LOS=Length of Stay

§ Major Complications have Clavien Classification ≥ 3

* reported as median (Interquartile Range)

Table 3

Robotic Vs. Laparoscopic LLS: Direct Cost of Operating Room Supplies*

	Robotic	**Laparoscopic**	***p-value***
Total Operating Room Supplies	$5 130	$4 408	*0.401*
Laparoscopic Instruments	$2 601 (51%)	$3 712 (84%)	*0.498*
Robotic Instruments	$1 413 (28%)	$0 (0%)	-
Staples	$828 (16%)	$990 (22%)	*0.578*
Clips	$16 (<1%)	$65 (1.5%)	***0.022***
Miscellaneous	$272 (5%)	$181 (4%)	*0.079*

*reported as US$ (percentage of total OR Supply Cost)