



Robotic-assisted versus laparoscopic left pancreatectomy at a high-volume, minimally invasive center

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Abstract

Introduction While minimally invasive left pancreatectomy has become more widespread and generally accepted over the last decade, opinions on modality of minimally invasive approach (robotic or laparoscopic) remain mixed with few institutions performing a significant portion of both operative approaches simultaneously.

Methods 247 minimally invasive left pancreatectomies were retrospectively identified in a prospectively maintained institutional REDCap™ database, 135 laparoscopic left pancreatectomy (LLP) and 108 robotic-assisted left pancreatectomy (RLP). Demographics, intraoperative variables, postoperative outcomes, and OR costs were compared between LLP and RLP with an additional subgroup analysis for procedures performed specifically for pancreatic adenocarcinoma (35 LLP and 23 RLP) focusing on pathologic outcomes and 2-year actuarial survival.

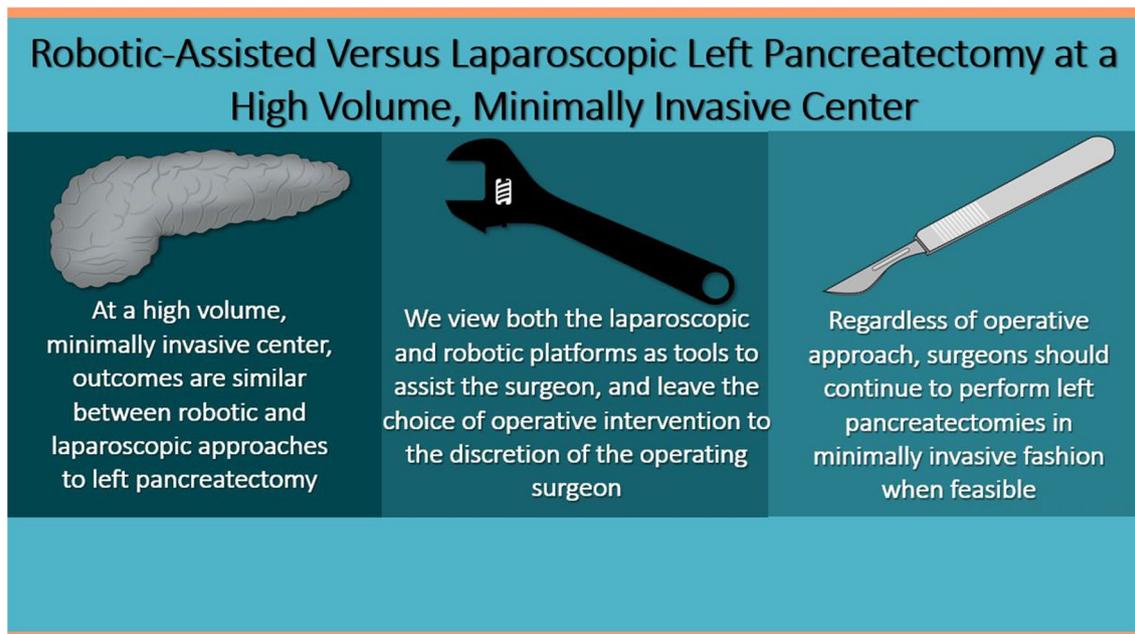
Results There were no significant differences in preoperative demographics or indications between LLP and RLP with 34% performed for chronic pancreatitis and 23% performed for pancreatic adenocarcinoma. While laparoscopic cases were faster ($p < 0.001$) robotic cases had a higher rate of splenic preservation ($p < 0.001$). Median length of stay was 5 days for RLP and LLP, and rate of clinically significant grade B/C pancreatic fistula was approximately 20% for both groups. Conversion rates to laparotomy were 4.3% and 1.8% for LLP and RLP approaches respectively. RLP had a higher rate of readmission ($p = 0.035$). Pathologic outcomes and 2-year actuarial survival were similar between LLP and RLP. LLP on average saved \$206.67 in OR costs over RLP.

Conclusions This study demonstrates that at a high-volume center with significant minimally invasive experience, both LLP and RLP can be equally effective when used at the discretion of the operating surgeon. We view the laparoscopic and robotic platforms as tools for the modern surgeon, and at our institution, given the technical success of both operative approaches, we will continue to encourage our surgeons to approach a difficult operation with their tool of choice.

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Graphical abstract



Keywords Laparoscopic pancreatectomy · Robotic pancreatectomy · Robotic-assisted pancreatectomy · Minimally invasive pancreatectomy · Distal pancreatectomy · Left pancreatectomy

Since the first reported laparoscopic left pancreatectomy in 1996, minimally invasive (MIS) pancreatectomies have been performed with increasing frequency for both benign and malignant disease of the pancreas; benefits over an open approach are often cited as reduced postoperative morbidity and shorter hospital length of stay [1, 2]. However, MIS approaches have experienced a much slower rate of adoption for pancreatic surgery compared to other fields within general surgery such as hernia repair colorectal surgery. Some considerations for the relatively slow uptake in laparoscopic left pancreatectomies include the technical difficulty and concern for oncologic outcomes versus the open approach [3]. As more institutions and surgeons begin to accept the laparoscopic approach, still other institutions are beginning to perform robotic-assisted left pancreatectomies with some transitioning to robotic-assisted procedures exclusively for an MIS approach for both benign and malignant disease [4–7]. The choice of a robotic-assisted or laparoscopic approach to MIS left pancreatectomy has remained a recent topic of debate both nationally and internationally [8, 9].

While prior studies have attempted to address the issue of robotic-assisted left pancreatectomy (RLP) versus laparoscopic left pancreatectomy (LLP) with mixed results, few studies have been performed to date at institutions performing a high volume of LLP and RLP simultaneously [10–12]. Studies

comparing large national and international databases include lower volume pancreatic centers as well as centers that continue to perform the majority of resections in an open fashion [13, 14]. Also, recent cost comparisons are typically either low volume or international studies which do not translate to healthcare and costs within the United States [15, 16].

While we will surely have limitations of our own (single institution, retrospective, etc.), we will attempt to address as many of the limitations of previous studies as possible. We will compare our baseline demographics, clinical outcomes, and costs for RLP and LLP at a high volume HPB specialty center where the majority of left pancreatectomies (> 70%) are performed in MIS fashion. Surgeons performing both LLP and RLP are highly experienced in their respective modality and past the initial learning curve for each approach. In addition, both modalities were used at the preference of the attending surgeon over the entire duration of the comparison and continue to be used with regularity at our institution.

Materials and methods

Study design

After obtaining appropriate institutional IRB approval, we retrospectively audited a prospectively collected RED-Cap™ database for all minimally invasive left pancreatectomies performed at our institution from January 2008 to June 2017. Inclusion criteria included patients whose primary procedure was listed as left pancreatectomy performed in MIS fashion ($n = 249$) within the Division of HPB Surgery. Excluded cases included one central pancreatectomy and one concurrent HIPEC ($n = 247$) that were incorrectly coded as left pancreatectomy for the primary procedure. There were no additional exclusion criteria. The MIS left pancreatectomies were separated by MIS modality to LLP ($n = 139$) and RLP ($n = 108$) with modality determined by intention to treat regardless of conversion status (e.g., if a robotic case was converted to a hand-assisted laparoscopy case and was subsequently converted to an open operation, it was analyzed in the RLP cohort).

Statistical analysis

Demographics, intraoperative outcomes, postoperative outcomes, and operating room costs were then compared between the two groups using a combination of Pearson's Chi-squared and Wilcoxon rank-sum tests for univariate and multivariable analyses as appropriate using STATA® statistical software. Conversions were defined as either conversion to an open procedure or conversion to hand-assisted laparoscopy. A subgroup analysis of patients undergoing LLP or RLP for pancreatic adenocarcinoma was then performed for previously mentioned outcomes in addition to pathological and survival analyses. Actuarial survival for patients with pancreatic adenocarcinoma was performed using a Kaplan–Meier estimate. Kaplan–Meier results were truncated when the number of patients at risk was less than one-third of the original cohort for each surgical modality. A p -value of less than 0.05 was considered the threshold for statistical significance.

Definitions

Pancreatic fistula was defined as clinically relevant grade B or C according to the 2016 updated International Study Group for Pancreatic Surgery (ISGPS) definitions for postoperative pancreatic fistula.¹⁷ Pancreatic fistulas were classified by manual review of the EMR by a single clinician to retrospectively apply updated definitions.

Specimens for adenocarcinoma were evaluated according to the Leeds Pathology Protocol (LEEPP) [17].

Operative approach and conversions

MIS approaches included laparoscopic left pancreatectomy (LLP) and robotic-assisted left pancreatectomy (RLP). While contraindications for minimally invasive left pancreatectomy varied among our attending surgeons, contraindications most often cited were known proximity or invasion of portosplenic confluence/cealic axis, multiple previous upper abdominal surgeries, and planned margin enhancement with irreversible electroporation (IRE). LLPs were approached either via pure laparoscopy or hand-assisted laparoscopy with conversions to an open procedure recorded. Conversions to hand-assisted laparoscopy from pure laparoscopy were not reliably discernible from operative reports. All RLPs were approached in pure robotic fashion after insertion of ports at bedside, and conversions to hand-assisted laparoscopy and open procedures were recorded separately. Reasons for conversion were collected by manual review of the EMR by a single clinician. Both techniques were approached using the radical antegrade modular pancreatosplenectomy (RAMPS) approach [18]. While the spleen was preserved in a fraction of both LLPs and RLPs, intention to attempt splenic preservation was not recorded. A postoperative drain was left in place following all left pancreatectomies, and JP amylase was recorded prior to discharge.

Of the four surgeons analyzed in this paper, for minimally invasive approaches two of our surgeons perform left pancreatectomies laparoscopically, and two of our surgeons prefer to perform left pancreatectomies with robotic-assistance. If operating room time was unavailable for robotic rooms, the latter group will perform left pancreatectomies laparoscopically. The choice of operative modality is at the discretion of the operating surgeon at our institution.

Cost analysis

Direct supply cost and direct case supply cost were collected from an institutional administrative OR billing database. Data were only available for a portion of our study period (2013–2017) and included 53 LLPs and 21 RLPs. Direct supply cost refers to the number of supplies used multiplied by the cost for the supplies (e.g., number of stapler loads used \times cost of stapler load). Direct case supply cost refers to the direct supply cost with the addition of direct labor costs (i.e., OR staffing).

Results

Results for all minimally invasive left pancreatectomies

After identifying MIS left pancreatectomies and excluding the two cases noted above, 139 LLPs and 108 RLPs comprised the two comparison cohorts. There were no significant differences in preoperative demographics or indication for surgery between the two comparison groups (Table 1). As a whole, the typical left pancreatectomy approached in minimally invasive fashion was 58 years old and female (51%) with a BMI of 29.2. 21% of patients were active smokers, 24% of patients were diabetic, and 70% of patients were ASA class III or IV. The most common indications for MIS left pancreatectomy at our institution were pancreatitis (34%), pancreatic adenocarcinoma (23%), neuroendocrine tumor (20%), MCN (10%), and IPMN (10%).

Two intraoperative variables varied significantly between LLP and RLP cohorts, total operative time and rate of splenic preservation. While LLPs were shorter on average (196 min versus 252 min, $p < 0.001$), RLPs were more likely to preserve the spleen (31.5% vs. 8.6%, $p < 0.001$). Notably, intention to attempt splenic preservation prior to splenectomy could not be reliably determined from operative reports; however, this finding has been reported previously as an advantage of the robotic-assisted approach [19]. Additional intraoperative variables including estimated blood loss, frequency of blood transfusion, and tumor size were similar between the two comparison groups (Table 2). 47.5% of LLPs were performed with hand assistance with six cases (4.3%) requiring a conversion to laparotomy. Eleven RLPs

(10.2%) required a conversion from a pure robotic-assisted approach to hand-assisted laparoscopy with 2 cases (1.85%) requiring conversion to laparotomy (Table 2). Conversions to hand-assisted laparoscopy from a pure robotic approach tended to occur earlier in the study period and most commonly occurred for inadequate visualization or difficulty discerning dissection planes due to dense adhesions. The eight conversions to laparotomy for both groups were performed for the following reasons: stapler misfire/jam (2), vascular invasion requiring open resection and reconstruction (2), dense fibrosis from preoperative XRT or chronic pancreatitis (2), inability to determine retroperitoneal margin (1), and inability to control splenic vein bleed (1).

Key postoperative outcomes were not significantly different between LLP and RLP with the exception of 30-day readmission. Readmissions were higher in the RLP cohort than the LLP cohort (25.0% vs. 14.4%, $p = 0.035$). Additional postoperative outcomes were not significantly different between the groups (Table 3). The median length of stay for all MIS LPs at our institution was 5 days (interquartile range 4–6 days) and rate of grade B/C pancreatic fistula was 19.8%. All cause 30-day mortality was 0.4%, and all cause 90-day mortality was 3.2% for minimally invasive left pancreatectomy. Only two of the postoperative 90-day mortalities were related to a technical postoperative complication (one pancreatic fistula and one colonic fistula). The one 30-day mortality occurred in a patient with incidental adenocarcinoma within a perisplenic abscess who was transitioned to hospice. Additional reasons for 90-day mortality included: progression of disease at other sites (2), pulmonary embolism and subsequent cardiopulmonary arrest (1), typhlitis and transition to comfort measures at an outside

Table 1 Preoperative demographics and indications for surgery

	Laparoscopic LP ($n = 139$)	Robotic LP ($n = 108$)	p value
Age (mean, SD)	59.5 year (15.5)	56.3 year (16.1)	0.120
BMI (mean, SD)	29.0 kg/m ² (8.5)	29.3 kg/m ² (6.5)	0.209
Female (n , %)	64 (46.0%)	62 (57.4%)	0.076
Race—White (n , %)	100 (71.9%)	80 (74.1%)	0.709
Race—Black (n , %)	29 (20.9%)	24 (22.2%)	0.796
Current smoker (n , %)	30 (22.7%)	19 (17.9%)	0.362
Diabetic (n , %)	31 (22.3%)	28 (25.9%)	0.508
ASA III or IV (n , %)	83 (72.2%)	63 (67.7%)	0.487
Adenocarcinoma (n , %)	35 (25.2%)	23 (21.3%)	0.475
MCN (n , %)	14 (10.1%)	10 (9.26%)	0.831
IPMN (n , %)	12 (8.6%)	12 (11.1%)	0.514
Neuroendocrine tumor (n , %)	31 (22.3%)	19 (17.6%)	0.361
Solid pseudopapillary tumor (n , %)	5 (3.6%)	4 (3.7%)	0.965
Pancreatitis (n , %)	44 (31.6%)	41 (38.0%)	0.301
Other indication (n , %)	31 (22.3%)	19 (17.6%)	0.361

Some patients underwent surgery for multiple indications (e.g., IPMN with chronic pancreatitis)

Table 2 (a) Intraoperative variables (b) further expansion of operative approach and intraoperative conversions

	Laparoscopic LP (<i>n</i> = 139)	Robotic LP (<i>n</i> = 108)	<i>p</i> -value
(a)			
Total operative time (mean, SD)	196 min (69.7)	252 min (85.1)	<0.001
Total operative time (median, IQR)	185 min (151–234)	240.5 min (188–292)	–
Estimated blood loss (mean, SD)	377 mL (508.1)	406 mL (624.7)	0.692
Estimated blood loss (median, IQR)	200 mL (100–500)	250 mL (100–500)	–
Patients requiring intraoperative blood transfusion (<i>n</i> , %)	13 (9.4%)	8 (7.4%)	0.587
Tumor size (mean, SD)	4.4 cm (2.7)	4.0 cm (2.8)	0.255
Spleen preserved (<i>n</i> , %)	12 (8.6%)	34 (31.5%)	<0.001
Conversion to laparotomy (<i>n</i> , %)	6 (4.32%)	2 (1.85%)	0.278
(b)			
Hand-assisted approach ^a (<i>n</i> , %)	66 (47.5%)	–	–
Converted to hand-assisted laparoscopy ^a (<i>n</i> , %)	–	11 (10.2%)	–
Converted to open/laparotomy (<i>n</i> , %)	6 (4.3%)	2 (1.85%)	0.278

Bold indicates statistical significance with a *p* value < 0.05

Operative approach based on intention to treat (e.g., robot-assisted converted to laparoscopic hand assist was considered robotic-assisted cohort)

^aUnable to determine planned versus unplanned hand-assisted laparoscopic procedures based on operative reports

Table 3 Postoperative outcomes

	Laparoscopic LP (<i>n</i> = 139)	Robotic LP (<i>n</i> = 108)	<i>p</i> -value
30-Day mortality (<i>n</i> , %)	1 (0.7%)	0 (0%)	0.377
90-Day mortality (<i>n</i> , %)	3 (2.2%)	5 (4.6%)	0.275
Length of stay (median, IQR)	5 days (4–6)	5 days (4–6)	0.908
30-Day readmission (<i>n</i> , %)	20 (14.4%)	27 (25%)	0.035
Pancreatic Fistula Grade B/C ^a (<i>n</i> , %)	28 (20.1%)	21 (19.4%)	0.891

Bold indicates statistical significance with a *p* value < 0.05

^aBased on 2016 ISGPS Pancreatic Fistula Classification Guidelines [20]

facility (1), and perforation of colon during IR replacement of jejunostomy tube at an outside facility (1).

Results for pancreatic adenocarcinoma only

58 patients were identified who underwent MIS LP for pancreatic adenocarcinoma (35 LLP and 23 RLP). RLP cases were again longer than LLP cases by 60 min on average ($p = 0.004$). Rate of pancreatic fistula was higher in RLP cases than LLP cases specifically for pancreatic adenocarcinoma (43.5% vs. 14.3%, $p = 0.013$). Additional demographics, intraoperative variables, and postoperative outcomes were not significantly different between the two operative approaches for pancreatic adenocarcinoma (Table 4).

Pathologic outcomes of MIS LP cases for pancreatic adenocarcinoma were similar between LLP and RLP approaches (Table 5). Average tumor size of all MIS cases was 4.4 cm with a median of 11.5 lymph nodes evaluated. 87.3% of patients had T3 lesions and 48% of patients were node positive. Rate of R0 resection was 73%. 2-year Kaplan–Meier survival estimates

of all-cause mortality was not significantly different between comparison cohorts for patients with pancreatic adenocarcinoma ($p = 0.488$) with actuarial survival of 74.3% and 72.7% at 1 year and 30.6% and 61.5% at 2 years for LLP and RLP approaches respectively (Fig. 1; Table 6).

Cost analysis

Costs were collected for only a portion of cases (2013–2017) comprising 53 LLPs and 21 RLPs. Direct supply cost was similar between LLP and RLP approaches; however, direct case supply cost was higher in the RLP approach ($p = 0.013$). On average, direct case supply cost was \$206.67 higher in the robotic cohort (Table 7).

Table 4 Demographics intraoperative variables, and postoperative outcomes for adenocarcinoma only

	Laparoscopic LP (n=35)	Robotic LP (n=23)	p value
Age (mean, SD)	66.7 year (9.1)	63.9 year (12.7)	0.504
BMI (mean, SD)	28.1 kg/m ² (10.0)	29.0 kg/m ² (6.2)	0.177
Female (n, %)	12 (34.3%)	11 (47.8%)	0.302
Race—White (n, %)	27 (77.1%)	16 (69.6%)	0.519
Race—Black (n, %)	6 (17.1%)	5 (21.7%)	0.662
Current smoker (n, %)	7 (21.9%)	6 (26.1%)	0.717
Diabetic (n, %)	31 (22.3%)	28 (25.9%)	0.508
ASA III or IV (n, %)	27 (90.0%)	13 (72.2%)	0.110
Total operative time (mean, SD)	203 min (60.6)	263 min (70.0)	0.004
Estimated blood loss (mean, SD)	390 mL (414)	321 mL (405)	0.470
Patients requiring intraoperative blood transfusion (n, %)	5 (14.3%)	0 (0%)	0.146
Conversion to laparotomy (n, %)	3 (8.6%)	2 (8.7%)	0.987
30-day mortality (n, %)	1 (2.9%)	0 (0%)	0.414
90-day mortality (n, %)	1 (2.9%)	2 (8.7%)	0.326
Length of stay (median, IQR)	5 days (4–8)	6 days (5–7)	0.796
30-day readmission (n, %)	5 (14.3%)	7 (30.4%)	0.137
Pancreatic Fistula Grade B/C ^a (n, %)	5 (14.3%)	10 (43.5%)	0.013
Adjuvant chemotherapy and/or XRT (n, %)	26 (74.3%)	15 (65.2%)	0.458

Bold indicates statistical significance with a *p* value < 0.05

^aBased on 2016 ISGPS Pancreatic Fistula Classification Guidelines [20]

Table 5 Pathologic outcomes for adenocarcinoma only

	Laparoscopic LP (n=35)	Robotic LP (n=23)	p value
Tumor size (mean, SD)	4.6 cm (22.9)	4.1 cm (16.4)	0.361
Lymph nodes evaluated (median, IQR)	11 (6–18)	14 (8–22)	0.143
Lymph nodes positive (mean, SD)	0.80 (1.05)	1.22 nodes (1.59)	0.450
Metastatic lymph node ratio (LNR) (mean LNR, SD)	0.085 (0.153)	0.112 (0.180)	0.702
Log odds of positive lymph nodes (LODDS) (mean LODDS, SD)	−0.969 (0.449)	−1.000 (0.542)	0.605
T3 (n, %)	30 (88.2%)	18 (85.7%)	0.785
T4 (n, %)	2 (5.9%)	1 (4.8%)	0.859
N1	16 (47.1%)	10 (50.0%)	0.835
R0 resection ^a (n, %)	23 (69.7%)	18 (78.2%)	0.476

^aResection status determined by Leeds Pathology Protocol (LEEPP) [17]

Discussion

From January 2008 to June 2017, 247 minimally invasive left pancreatectomies were performed laparoscopically or with robotic assistance at our institution comprising over 70% of all left pancreatectomies performed over the same period. Of these cases, 139 laparoscopic left pancreatectomies (LLP) and 108 robotic-assisted left pancreatectomies (RLP) were compared. While we found a small number of statistical advantages for both LLP and RLP, when viewed as a whole, baseline demographics, outcomes, and costs

were similar between the two groups. Intraoperatively, while the robotic approach was approximately 1 h longer than the laparoscopic approach, the robotic approach resulted in a higher rate of splenic preservation. Both groups displayed a low rate of conversion to laparotomy at 4.3% and 1.8% for LLP and RLP approaches respectively. No significant differences were noted in key postoperative outcomes with the exception of a higher rate of 30-day readmission in the RLP cohort, and median hospital length of stay was 5 days for both groups. Rate of grade B/C pancreatic fistula was 19.8% for all minimally invasive left pancreatectomies. No significant differences were

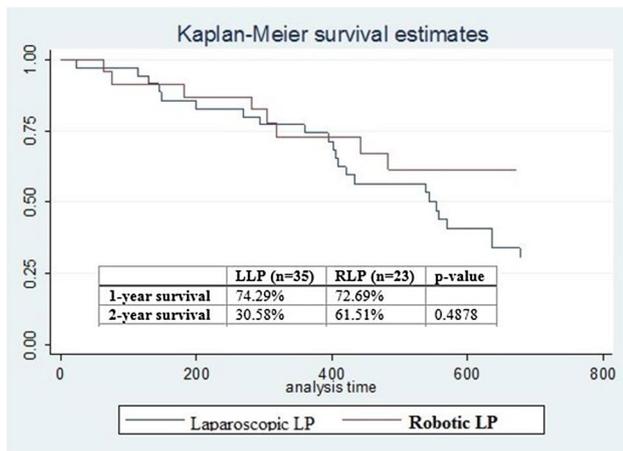


Fig. 1 Two-year Kaplan Meier survival analysis for adenocarcinoma

noted in pathologic outcomes or 2-year actuarial survival between LLP and RLP in cases performed for pancreatic adenocarcinoma. A limited cost comparison revealed an average of \$206.67 higher in direct case supply costs in the RLP cohort.

While this is not the largest single-center series comparing LLP and RLP, it is one of the few studies performed at a center that continues to use both laparoscopic and robotic-assisted approaches for the vast majority of left pancreatectomies. While the benefits of a minimally invasive approach to left pancreatectomy have been demonstrated in previous studies over the open approach when feasible, the majority of cases around the country continue to be performed in an open fashion as evidenced by recent large database comparisons. This study demonstrates the favorable results that can be achieved with either minimally invasive modality at a center that is well versed in each approach.

Examination of baseline characteristics of our comparison groups revealed that our patients tended to be overweight with a BMI of 29.2 kg/m². 21% were current smokers while 24% were diabetic. Compared to other high-volume pancreas surgery centers, a higher percentage of cases are performed for pancreatitis (34%) and slightly lower percentage of cases for pancreatic adenocarcinoma (23%). The significantly longer operative time for RLP must be balanced by the higher rate of splenic preservation in comparison to LLP. The outcomes of longer operative times and higher rates of splenic preservation have been previously described [9, 21]. While the difference in rate of splenic preservation may account for some of the difference in operative time, docking time and rate of hand-assistance in the laparoscopy group are additional factors that could explain the significant gap in operative time between modalities. Conversion rates to laparotomy for both approaches compare favorably with nearly all published series with an overall MIS left

pancreatectomy rate of conversion of 3.2% at our institution [22–24]. This rate has steadily declined during the study period as our surgeons continue to refine their minimally invasive approaches for LLP and RLP [25]. Postoperative outcomes including mortality, length of stay, and clinically significant pancreatic fistula rates were similar between LLP and RLP and well within established ranges in the literature. While the increased rate of readmission in RLP cannot be fully explained by our analysis, this phenomenon requires further investigation as previous studies have demonstrated similar results [9].

Subgroup analysis of patients undergoing MIS LP for pancreatic adenocarcinoma revealed similar overall results between RLP and LLP. While we found a significantly higher rate of clinically significant pancreatic fistulas in the RLP cohort, we believe this is a Type II error given the small sample size ($n=23$) and nearly equivalent rates of B/C pancreatic fistula between operative approaches in our overall analysis. Surprisingly, although we noted a higher incidence of pancreatic fistulas in the RLP subgroup analysis for pancreatic adenocarcinoma, we did not note an adverse effect on survival. Lymph node harvest and R0 resection rate were similar between LLP and RLP. Although rates of R0 resection are slightly lower than some published series, it is important to note that the LEEDS Pathology Protocol (LEEPP) is applied to all pancreatic adenocarcinoma specimens, resulting in a higher rate of R1 resection than analysis of neck margin alone [17].

Finally, our cost analysis, while limited, shows a statistically significant average of \$206.67 in direct case supply cost favoring LLP. While this value is statistically significant, it is likely not “financially significant” over the course of the entire hospital stay and treatment course.

Limitations

While we feel that this is a fair comparison of LLP and RLP at our institution, it certainly has its limitations. The inherent nature of a retrospective cohort study introduces the possibility of selection bias, although we did not identify any significant differences in preoperative demographics or indications for surgery between comparison groups. Additionally, when evaluating these outcomes, all procedures are performed at a high volume minimally invasive tertiary referral center with dedicated faculty experienced in both open and minimally invasive approaches to HPB disease processes and a dedicated hospital unit well versed in the treatment of HPB patients. We are fortunate to have the luxury of readily available consultants including interventional radiology and advanced GI to assist with preoperative evaluation and postoperative complications. These results and techniques may not be generalizable to lower volume pancreatic surgery centers as evidenced in previous studies

Table 6 STATA® output tables for Kaplan–Meier survival analyses for LLP and RLP for patients with adenocarcinoma

Time (days)	Total patients	Deaths during interval	Net patients lost	Survivor function	Standard error	95% Confidence interval
Laparoscopic						
23	35	1	0	0.9714	0.0282	0.8140–0.9959
114	34	1	0	0.9429	0.0392	0.7903–0.9854
130	33	1	0	0.9143	0.0473	0.7573–0.9715
145	32	1	0	0.8857	0.0538	0.7236–0.9555
149	31	1	0	0.8571	0.0591	0.6903–0.9379
199	30	1	0	0.8286	0.0637	0.6577–0.9191
269	29	1	0	0.8000	0.0676	0.6258–0.8992
294	28	1	0	0.7714	0.0710	0.5946–0.8758
360	27	1	0	0.7429	0.0739	0.5640–0.8570
381	26	0	1	0.7429	0.0739	0.5640–0.8570
395	25	1	0	0.7131	0.0767	0.5323–0.8342
402	24	1	0	0.6834	0.0790	0.5014–0.8107
405	23	1	0	0.6537	0.0810	0.4712–0.7865
409	22	1	0	0.6240	0.0826	0.4416–0.7618
421	21	1	0	0.5943	0.0838	0.4127–0.7364
434	20	1	0	0.5646	0.0847	0.3843–0.7105
456	19	0	1	0.5646	0.0847	0.3843–0.7105
538	18	1	0	0.5332	0.0856	0.3544–0.6830
544	17	1	0	0.5018	0.0861	0.3253–0.6549
554	16	1	0	0.4705	0.0863	0.2968–0.6262
558	15	1	0	0.4391	0.0860	0.2692–0.5960
571	14	1	0	0.4077	0.0854	0.2422–0.5669
606	13	0	1	0.4077	0.0854	0.2422–0.5669
636	12	1	0	0.3738	0.0848	0.2131–0.5345
637	11	1	0	0.3398	0.0836	0.1850–0.5013
678	10	1	0	0.3058	0.0819	0.1580–0.4673
755	9	0	1	0.3058	0.0819	0.1580–0.4673
Robotic						
64	23	1	0	0.9565	0.0425	0.7293–0.9938
75	22	1	0	0.9130	0.0588	0.6949–0.9775
182	21	1	0	0.8696	0.0702	0.6481–0.9560
265	20	0	1	0.8696	0.0702	0.6481–0.9560
282	19	1	0	0.8238	0.0801	0.5958–0.9300
296	18	0	1	0.8238	0.0801	0.5958–0.9300
305	17	1	0	0.7753	0.0888	0.507–0.9001
319	16	1	0	0.7269	0.0956	0.4889–0.8674
357	15	0	1	0.7269	0.0956	0.4889–0.8674
419	14	0	1	0.7269	0.0956	0.4889–0.8674
442	13	1	0	0.6710	0.1033	0.4274–0.8292
483	12	1	0	0.6151	0.1088	0.3709–0.7880
521	11	0	1	0.6151	0.1088	0.3709–0.7880
673	10	0	1	0.6151	0.1088	0.3709–0.7880
762	9	0	1	0.6151	0.1088	0.3709–0.7880
775	8	1	0	0.5382	0.1193	0.2867–0.7354

Table 7 Cost analysis between operative modalities

	Laparoscopic LP (n=53)	Robotic LP (n=21)	p value
Direct supply cost (median, IQR)	\$3500.20 (2964–4545)	\$3621.79 (3055–4308)	0.619
Direct supply cost ^a (mean, SD)	\$4164.62 (3136.02)	\$4091.92 (1601.76)	
Direct case supply cost (median, IQR)	\$3815.68 (3217–5053)	\$5122.65 (4216–6249)	0.013
Direct case supply cost ^b (mean, SD)	\$5279.54 (6615.49)	\$5486.21 (1964.76)	

Limited to data from 2013 to 2017 and all cases during the specified time period were not available

Bold indicates statistical significance with a p value <0.05

^aDirect supply cost = # of supply used × cost of supply

^bDirect case supply cost = direct supply cost + direct labor cost

[26]. While we present a cost comparison, it is admittedly limited both in period of evaluation (2013–2017) as well as a focus on operative room supply/labor costs alone which represent only a small percentage of costs/charges incurred during the entire course of treatment.

With two attendings performing the majority of LLPs and two attendings performing the majority of RLPs, some of the small differences that we do observe between operative modalities (e.g., higher rate of splenic preservation in RLPs), may represent differing opinions of attending operative approach and not necessarily a difference between the modalities themselves.

Conclusions and future directions

While benefits of minimally invasive left pancreatectomy have been demonstrated in multiple studies, the majority of institutions are still performing left pancreatectomies in an open fashion. While more recent debates have revolved around modality of minimally invasive approach, robotic or laparoscopic, this study demonstrates that at a high-volume center with significant minimally invasive experience, both LLP and RLP can be equally effective when used at the discretion of the operating surgeon. While contraindications will vary from institution to institution based on experience, we find that there are few relative contraindications at our institution to plan for a minimally invasive approach for left pancreatectomy (proximity of tumor to portosplenic confluence or celiac axis, multiple previous upper abdominal procedures, or planned margin enhancement with irreversible electroporation). While the cost of newer technologies will always remain a topic of debate in our current healthcare climate, further investigation with more transparent and global cost analyses are necessary to obtain an accurate picture of the effect of operative modality on hospital costs over the entire course of treatment. We view the laparoscopic and robotic platforms as tools for the modern surgeon, and at our institution, given the technical success of both operative approaches, we will continue to encourage our surgeons to approach a difficult operation with their tool of choice.

Compliance with ethical standards

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