Robot-Assisted Minimally Invasive Distal Pancreatectomy Is Superior to the Laparoscopic Technique

Mustapha Daouadi, MD, Amer H. Zureikat, MD,* Mazen S. Zenati, MD, MPH, PhD,† Haroon Choudry, MD,* Alan Tsung, MD,‡§ David L. Bartlett, MD,* Steven J. Hughes, MD,|| Ken K. Lee, MD,* A. James Moser, MD,* and Herbert J. Zeh, MD**

Background: Laparoscopic distal pancreatectomy (LDP) reduces postoperative morbidity, hospital stay, and recovery as compared with open distal pancreatectomy. Technical limitations of laparoscopic surgery may limit patient eligibility and require conversion to open or hand-assisted surgery to maintain patient safety. We hypothesized that robot-assisted distal pancreatectomy (RADP) was superior to LDP as a result of improved surgical manipulation and visualization, potentially expanding the indications for minimally invasive pancreatectomy.

Methods: We performed a retrospective analysis of all minimally invasive distal pancreatectomies at University of Pittsburgh Medical Center between January 2004 and February 2011. We compared the perioperative outcomes, 90-day morbidity and mortality of our first 30 RADPs to 94 consecutive historical control LDPs.

Results: Patients undergoing RADP and LDP demonstrated equivalent age, sex, race, American Society of Anesthesiologists' score, and tumor size. Postoperative length of hospital stay and rates of pancreatic fistula, blood transfusion, and readmission were not statistically different. Patients in the RADP group did not require conversion to open surgery unlike the LDP group (16%, $P < 0.05$) and had reduced risk of excessive blood loss. There were more pancreatic ductal adenocarcinomas approached robotically (43%) than laparoscopically (15%) ($P < 0.05$). Oncological outcomes in these cases were superior for the robotic-assisted group with higher rates of margin negative resection and improved lymph node yield for both benign and malignant lesions ($P < 0.0001$).

Conclusions: RADPs were equivalent to LDPs in nearly all measures of outcome and safety but significantly reduced the risk of conversion to open resection, despite a statistically greater probability of malignancy in the robotic cohort. We concluded that robotic assistance may broaden indications for minimally invasive pancreatectomy.

Keywords: laparoscopic distal pancreatectomy, minimally-invasive surgery, operative time, robotic-assisted distal pancreatectomy, retrospective study

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The number of surgical procedures being performed with robotic assistance tripled from 80,000 to 250,000 between 2007 and 2010.[1] Although robotic prostatectomy and radical hysterectomy are considered standard practice at many centers,[2,3] pancreatic surgery has been slow to implement minimal access techniques as compared with other surgical disciplines.[4] Barriers to implementation of minimally invasive pancreatic surgery include the retroperitoneal location of the pancreas, the proximity of large vascular structures, and the threat of inadequate margin clearance in malignant disease.

Recent data indicate that laparoscopic distal pancreatectomy (LDP) is both safe and feasible.[5,6] Compared with open distal pancreatectomy, LDP is associated with a shorter hospital stay, reduced analgesic requirements, less blood loss, and more rapid recovery.[7–10] Nevertheless, barriers to the widespread implementation of LDP include significant rates of conversion to hand-assisted or open procedures[11] to safely control the major vasculature. Robotic assistance may overcome these limitations of traditional laparoscopic surgery by providing magnified 3-dimensional visualization and improving the surgeon's dexterity and ability to manipulate instruments intracorporeally.

Although robot-assisted surgery may be superior to laparoscopic techniques when performing complex surgical tasks in an ex vivo model,[12] few data exist to validate the outcomes of robot-assisted distal pancreatectomy as compared with its laparoscopic counterpart.[13,14] We hypothesized that robot-enhanced surgical dexterity and visualization would lead to improved outcomes following robot-assisted distal pancreatectomy (RADP) as compared with LDP. To evaluate this, we performed a retrospective analysis of all minimally invasive distal pancreatectomies at our institution and compared the outcomes of RADP with historical LDP controls performed before the introduction of robotic technology.

MATERIALS AND METHODS

Design and Study Population

The University of Pittsburgh institutional review board abstracted data from a prospective pancreatic surgery database after approval. The RADP and LDP cohorts were separated in time to prevent selection bias following the introduction of the robot. The RADP cohort consisted of the first 30 cases performed at our institution between July 2008 and February 2011 using the DaVinci S or Si surgical system (Intuitive Surgical, Sunnyvale, CA). Twenty-two (73%) RADPs were performed by attending surgeon as the first assist, 6 (20%) fellows, and 2 (7%) residents as the first assist, respectively. The comparison group consisted of LDP controls performed before the robot became available (January 2004 and December 2007, n = 94), a time period during which more than 80% of all distal pancreatectomies were performed laparoscopically by a group of 7 surgeons. Our group had a collective experience of more than 100 LDPs before the first RADP, indicating that LDP had reached a state of mature implementation at our facility. The analysis of outcomes was performed on an intent-to-treat basis, with the outcomes of conversions to open surgery analyzed as consequences of the intended minimally invasive procedure. Laparoscopic procedures performed with hand assistance were excluded from analysis, as were those for trauma or metastasectomy.

Data Collection and Surgical Technique

Baseline demographics, preoperative characteristics, operative summaries, anesthesia logs, and discharge summaries were obtained

From the Division of GI Surgical *Oncology, General Surgery; and †Epidemiology; ‡Transplantation; §Hepatobiliary and Pancreatic Surgery, Department of Surgery, University of Pittsburgh Medical Center, Pittsburgh, PA; and ||Division of General Surgery, Department of Surgery, University of Florida, Gainesville, FL.

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Reprints: Herbert J. Zeh, MD, UPMC, Pancreatic Cancer Center, Division of Surgical Oncology, University of Pittsburgh, 5150 Center Avenue, Room 417, Pittsburgh, PA 15232. E-mail: zehxhx@upmc.edu. OR A. James Moser, MD, 330 Brookline Avenue, Shapiro 3Boston, MA 02215 E-mail ajmoser@bidmc.harvard.edu.

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from the electronic medical records. Data included perioperative outcomes such as estimated blood loss, red blood cell transfusions, conversion to open surgery, procedure duration (calculated as the time between skin incision and skin closure, which includes the time to dock the robot), intensive care unit admission, and length of hospital stay. The American Society of Anesthesiologists' score and body mass index were abstracted from the operative anesthesia record. Morbidity and readmission rates within 90 days and 30-day mortality rates were examined. Readmissions were defined as any hospitalization within our health system or any admissions to outside facilities, excluding a subacute or rehabilitation admission.

Definitions

A postoperative pancreatic fistula was defined as a drain output of any measurable volume of fluid on or after the third postoperative day, with amylase content greater than 3 times the serum amylase level. The grading system for a postoperative pancreatic fistula was based on the International Study Group of Pancreatic Fistula (grades A, B, and C).[15] Postoperative complications were categorized by the Clavien classification for intra-abdominal surgical complication.[16] The highest ranked complication was used to assess complication severity. Perioperative mortality was defined as death within 30 days or during the index hospitalization after surgery.

Statistical Analysis

Each variable's distributional characteristics were assessed for normality. Baseline characteristics and clinical outcomes were summarized as mean ± standard deviation or median [interquartile range], according to normalcy, (continuous variables) or as frequency and percent (categorical variables). A student *t* test was used to compare normally distributed variables between groups (robotic vs laparoscopic), whereas the Wilcoxon rank-sum test was used for nonnormally distributed variables. The χ^2 (or Fisher exact) test was used to compare categorical variables between groups, as appropriate. Multivariate logistic regression was performed with 90-day hospital readmission as the outcome. A 2-sided $P \leq 0.05$ was considered statistically significant. All statistical analyses were performed using STATA 10, (STATA Corporation, College Station, TX).

RESULTS

Patient Characteristics

A total of 124 patients, 30 RADPs and 94 LDPs, underwent minimally invasive distal pancreatectomy during the study period. More patients in the RADP cohort had undergone prior abdominal surgery (73% vs 51%, $P < 0.05$). Otherwise, the 2 cohorts were similar with respect to preoperative risk factors such as age, sex, American Society of Anesthesiologists' score, and body mass index (Table 1). No differences in the average tumor size as measured by preoperative computerized tomography scan or endoscopic ultrasound were observed between the groups.

The distribution of pathologic diagnoses among resected lesions in both cohorts is shown in Table 2. The most common indication for surgery in the LDP cohort was a benign lesion in 53 patients (56%) and malignancy in 41 (44%). The leading indication for LDP was a mucinous cystic neoplasm (n = 30) followed by neuroendocrine tumor (n = 21) and pancreatic adenocarcinoma (n = 14). The RADP cohort contained a relatively greater number of malignancies (22, 73%) and fewer (8, 27%) benign lesions ($P < 0.05$ vs LDP). Pancreatic adenocarcinoma was the most common indication in the RADP group (n = 13), followed by neuroendocrine tumor (n = 9).

TABLE 1. Outcomes Following Laparoscopic and Robot-Assisted Distal Pancreatectomy

Characteristics	Laparoscopic	Robot Assisted	*P*
N	94	30	
Age (yrs)	59 ± 16	59 ± 13	0.95
Female sex	61 (65%)	20 (67%)	0.86
Caucasian	91 (97%)	26 (87%)	0.058
BMI (kg/m^2)	29.0 ± 7.1	27.9 ± 5.1	0.434
ASA score			0.8
I/II	42 (45%)	11 (37%)	0.41
III/IV	51 (55%)	19 (63%)	0.41
Previous abdominal surgery	48 (51%)	22 (73%)	**<0.05**
Computerized tomography tumor size (cm)	2.9 ± 1.9	2.6 ± 1.4	0.45
Endoscopic ultrasound size (cm)	2.6 ± 1.6	2.7 ± 1.3	0.985

Values represent mean ± SD, or n (%). Boldface represents statistically significant value.

TABLE 2. Pathological Indications for Distal Pancreatectomy

Final Histology	Laparoscopic (n = 94)	Robot Assisted (n = 30)	*P*
Pancreatic ductal adenocarcinoma	14 (15%)	13 (43%)	**<0.05**
Mucinous cystic neoplasm	30 (31%)	4 (13%)	**<0.05**
Neuroendocrine tumor	21 (22%)	9 (27%)	0.46
Intraductal papillary mucinous neoplasm	11 (12%)	5 (17%)	0.534
Solid pseudopapillary neoplasm	6 (6.4%)	—	0.33
Other	12 (13%)*	1 (3)†	0.184

Boldface represents statistically significant values.

*Includes autoimmune pancreatitis (n = 2), chronic pancreatitis (*n* = 1), serous cystadenoma (n = 3), pseudocyst (n = 1), mucinous cystadenocarcinoma (n = 1), spindle cell lesion, (n = 1), benign epithelial cyst (n = 2), and oligocystic adenoma (n = 1).

†Includes lymphoepithelial cyst (*n* = 1).

Surgical Endpoints

Outcome parameters following distal pancreatectomy are shown in Table 3. Surprisingly, the time to complete RADP (including time to dock the robot) was significantly shorter than LDP (293 vs 371 minutes, $P < 0.01$). There were no differences observed in the rates of planned splenectomy between the groups. Median estimated blood loss and frequency of transfusion were also the same in the RADP (150 mL, interquartile range 100–300 mL) and LDP (150 mL, IQR 100–300 mL) cohorts. However, among patients in the top quartile of perioperative blood loss, estimated blood loss was significantly reduced in the robotic group (375 mL, IQR 300–550 mL) by comparison with the laparoscopic group (550 mL, interquartile range 400–650 mL $P < 0.05$), indicating improved control of major hemorrhage. Furthermore, conversions from minimally invasive to open distal pancreatectomy were eliminated in the robotic group (0%) as compared with the laparoscopic group (16%, $P < 0.05$). No other differences in postoperative morbidity or mortality following RADP and LDP were observed, including: rates of postoperative intensive care unit admission, length of hospital stay, 90-day cumulative morbidity, or hospital readmission. Similarly, there were no procedure-related differences in the Clavien score ($P = 0.68$) or the rate and severity of pancreatic fistulae ($P = 0.67$). In the LDP cohort, the pancreas was divided with a linear-cutting stapler in 81 cases (86%) and with the electrocautery followed by oversewing of the remnant in 13 (14%). During RADP, the pancreas was divided with a linear-cutting stapler in 23 cases (77%), with the remainder divided by electrocautery (4 cases, 13%) and then oversewn. The remaining 3 pancreatic remnants (10%) were divided with a stapler and also oversewn. The staple height varied with the thickness of the pancreas at the site of the intended transaction.

There were no deaths in the RADP group and a single death within 30 days after LDP ($P = 1.0$). Short-term oncological outcomes are shown in Tables 4 and 5. Thirty-four patients with pancreatic malignancies (83%) in the LDP group achieved margin-negative (R0) status after resection versus 21 (95%) in the RADP group. Among patients with pancreatic adenocarcinoma, however, 36% of those undergoing LDP (5/14) had microscopically positive pancreatic transection margins compared with zero (0 of 13, $P < 0.005$) in the robotic group, despite equivalent tumor sizes in the two groups.

We performed a subgroup analysis of the LDP cohort comparing patients with completed LDPs (79) to those requiring conversion to open distal pancreatectomy (15) to determine the effect of conversion on subsequent recovery from surgery (Table 5). There were no differences in the completed and converted groups with respect to age, sex, American Society of Anesthesiologists' score, or tumor size. The converted group experienced similar operative times, requirement for splenectomy, and rates of developing pancreatic fistula. However, the need to convert to open distal pancreatectomy was associated with a significantly higher frequency of pancreatic adenocarcinoma ($P < 0.01$), estimated blood loss [425 mL (IQR 300–700 mL) vs 150 mL (interquartile range 100–300 mL), $P < 0.001$], and length of postoperative hospital stay (8 vs 6 days, $P < 0.01$). Not

TABLE 3. Perioperative Outcomes Following Laparoscopic and Robot-Assisted Distal Pancreatectomy

Outcome Parameter	LDP (N = 94)	RADP (N = 30)	*P*
Procedure duration (mean ± SD) (min)	372± 141	293 ± 93	<**0.01**
Planned splenectomy	77 (82)	28 (93%)	0.157
Estimated blood loss (mL)	150 (100, 300)	150 (100, 300)	0.688
Frequency of blood transfusion (%)	12 (13)	3 (10%)	1.00
Average units transfused	2.25 ± 1.36	2.33 ± 0.58	0.921
Median estimated blood loss (mL) in upper quartile (>75th percentile for blood loss)	550 (400, 650)	375 (300, 550)	<**0.05**
Converted to open	15 (16)	0 (0%)	<**0.05**
Postoperative admission to intensive care unit	31 (33)	7 (23)	0.370
Pancreatic fistula	39 (41)	14 (46)	0.676
International Study Group of Pancreatic Fistula grade A	23 (24)	6 (20)	NS
International Study Group of Pancreatic Fistula grade B	11 (12)	4 (13)	NS
International Study Group of Pancreatic Fistula grade C	5 (5)	4 (13)	NS
90-day morbidity			0.658
Minor (Clavien 1/2)†	47 (50)	14 (46)	
Major (Clavien 3/4)†	13 (14)	6 (20)	
Length of stay (d)	7.1 ± 4.0	6.1 ± 1.7	0.183
90-day readmission	22 (23)	11 (37)	0.162
30-day mortality	1 (1.1)	0 (0%)	1.0

Normally distributed values are expressed as mean ± SD or n (%); otherwise: median (25th, 75th percentile) as IQR. Boldface represents statistically significant values.

†Clavien classification of surgical complications.[16]

TABLE 4. Pathological Outcomes Following Distal Pancreatectomy for Pancreatic Ductal Adenocarcinoma

Characteristic	LDP	RADP	*P*
Frequency, n (%)	14 (19)	13 (43)	<**0.005**
Tumor size (cm)	3.4 ± 1.6	3.1 ± 1.2	0.604
R1 margin status (%)	5 (36)	0 (0)	<**0.05**
Nodal harvest, median (IQR)	9 (7, 11)	19 (17, 24)	<**0.01**

Normally distributed values are expressed as mean ± SD or n (%); otherwise: median (25th, 75th percentile) as interquartile range (IQR). Boldface represents statistically significant values.

TABLE 5. Effects of Conversion During LDP on Perioperative Outcome

Characteristics	Converted LDP (N = 15)	Completed LDP (N = 79)	*P*
Age (yrs)	54 (46, 69)	62 (51, 71)	0.206
Sex (F)	9 (60)	76 (65.82)	0.770
Body mass index	28 (27.4, 33)	27 (24.5, 32.9)	0.474
American Society of Anesthesiologists (III/IV)	8 (53)	43 (55)	1.00
Operating room duration	345 (268, 593)	341 (259, 452)	0.557
Splenectomy	15 (100)	62 (79)	0.065
Estimated blood loss	425 (300, 700)	150 (100, 300)	**<0.001**
Frequency of blood transfusion	4 (27)	8 (10)	0.096
Pancreatic ductal adenocarcinoma	6 (40.0)	8 (10.13)	**<0.01**
Tumor size (cm)	4 (3.5, 4.5)	3 (2, 4)	0.3
R0 Margin status (pancreatic adenocarcinoma only)	3 (50.0)	4 (50.0)	1
Lymph nodes harvested (pancreatic adenocarcinoma)	9 (7, 11)	17 (10, 19)	0.845
Intensive care unit admission (d)	8 (53.33)	23 (29.11)	0.079
Pancreatic fistula	7 (46.67)	32 (41.03)	0.778
Length hospital stay (d)	8 (6, 10)	6 (5, 7)	**<0.01**

Normally distributed values are expressed as mean ± SD or n (%); otherwise: median (25th, 75th percentile) as interquartile rangeIQR. Boldface represents statistically significant values.

surprisingly, there was a trend toward increased risk of blood transfusion (27% vs 10%, $P = 0.096$) and need for intensive care unit admission (53% vs 29%, $P = 0.079$) in converted patients compared with completed LDP.

Multivariate logistic regression analysis was performed to identify predictors of readmission following minimally invasive distal pancreatectomy. Blood transfusion [odds ratio 6.1, 95% confidence interval, 1.6–22.7, $P = 0.007$] and pancreatic fistula (odds ratio 2.5, 95% confidence interval 0.89–6.97, $P = 0.08$) were the only significant risk factors for readmission identified after LDP. In the RADP cohort, the only predictor of readmission was pancreatic fistula with an odds ratio of 12.3 (95% confidence interval 1.89–79.36, $P = 0.09$).

DISCUSSION

Minimal access techniques reduce the physiological impact of surgery for lesions of the distal pancreas, permitting shorter hospital stays and improved recovery compared to traditional open procedures.[9] However, the minimally invasive approach is not currently available to all patients. Laparoscopic surgery has several technical constraints: limited range of motion, 2-dimensional visualization, and difficulty controlling large blood vessels.[17] These factors may impair the surgeon's dexterity[18] and compromise the technical aspects of safely resecting the distal pancreas, especially for malignancies. We hypothesized that robot-assisted surgical manipulation and visualization during minimally invasive distal pancreatectomy would generate superior outcomes compared with the laparoscopic approach. To test this, we compared retrospective outcomes of RADP with LDP and observed comparable outcomes with respect to length of stay, perioperative morbidity, and pancreatic fistula. However, the robotic approach demonstrated 3 significant advantages in our analysis, including (1) reduced risk of conversion to open pancreatectomy with its attendant effects of length of stay and risk of intensive care unit admission, (2) decreased probability of significant blood loss, and (3) improved oncological outcomes in pancreatic ductal carcinoma.

We observed a clinically meaningful difference in the conversion rates between the 2 minimally invasive approaches (RADP 0 vs LDP 16%). There are several potential explanations for this observation. First, our conversion rate for LDP may be higher than expected. However, our 16% conversion rate for the laparoscopic approach is consistent with values reported in the literature. In a large retrospective series, Jayaraman et al[19] reported a 30% conversion rate to open resection during LDP, with significantly higher complication rates among patients requiring conversion. Recent meta-analyses demonstrated that the rate of conversion from laparoscopy to a hand-assisted procedure was 37% and that from a minimally invasive to open procedure ranged from 9.2% to 11%.[11,20] The most common reasons for conversion include elevated body mass index, intraoperative bleeding, tumor proximity to major vascular structures, malignancy, and the experience of the surgeon. Second, there may be a significant selection bias toward easier cases for the newer robotic technique. Although selection bias is a factor in all retrospective studies, our study design minimized this bias by limiting the LDP control cohort to a period of time at our institution when robotic surgery was not possible. In fact, the LDP and subsequent RADP cohorts were equivalent in key demographic and preoperative characteristics. Furthermore, the LDP approach has been largely abandoned at our institution since the adoption of RADP, effectively eliminating any selection bias. In fact, the RADP cohort contained a significantly greater proportion of patients with pancreatic ductal adenocarcinomas and patients who had undergone previous abdominal surgery, suggesting a reverse selection bias in favor of more difficult anatomy. Fifty percent of the conversions in the LDP cohort were for PDA and resulted in a 35% margin-positive rate, suggesting that the laparoscopic approach was inferior for this disease. Conversely, none of the patients undergoing RADP for pancreatic adenocarcinoma required conversion to open resection and the R0 resection margin rate was 100% compared with 35% for the laparoscopic technique. The difference in conversion rate might also be explained by the experience of the surgical team. All of the robotic procedures were performed by 3 highly experienced pancreatic surgeons, whereas, 4 additional surgeons also performed LDP at our institution. However, the conversion rate for LDP among the 3 surgeons who adopted the robotic platform was not statistically different from that of the other surgeons (data not shown). In fact, 13 (87%) of 15 LDP cases that were converted to open resection were converted by our high-volume surgeons. Thus, the conversion rate for our highest-volume surgeons dropped significantly with the adoption of the robotic approach. In addition, the RADP cohort included our institutional learning curve, whereas the LDP cases were performed after significant institutional experience had already been obtained. Lastly, we cannot exclude the impact of a 2-attending surgical team on the resulting decrease in conversion rate and operative times. The potential safety and efficiency implications of improved 2-surgeon outcomes of highly technical procedures such as robotic distal pancreatectomy, are beyond the scope of this article. Future analysis will allow us how to address the potential advantage of a 2 "experienced pilot" approach to complex surgery, utilizing advanced techniques. These observations have potentially serious ramifications for current centers for medicare and medicaid services reimbursement policies regarding assistant surgeons. Together these data do not suggest a significant selection bias that can explain the dramatic difference in conversion rate. It is our opinion that the significantly lower conversion rate is a result of the improved dexterity, which allows improved ability to isolate and control the splenic artery and splenoportal veins with the robotic approach.

Blood transfusion increases the potential for postoperative complications including infection, systemic inflammatory response syndrome, multiple organ failure, and death. Retrospective analysis of the effect of perioperative blood transfusion on long-term survival in patients undergoing surgery for colon and pancreatic cancer demonstrates that transfusion significantly degrades 5-year survival.[21,22] Although there was no statistically significant difference in blood loss between the RADP and LDP cohorts, the risk of excessive blood loss among patients in the highest quartile was significantly reduced in the robotic group. In addition, logistic regression analysis demonstrated that blood transfusion was a significant predictor of readmission after LDP, but not RADP, with an odds ratio of 6. It is possible that greater experience with the robotic approach will demonstrate statistically meaningful advantages over LDP in terms of transfusion rates and readmission.

Lymph node status is a predictor of long-term survival.[23,24] Using the SEER database, Slidell et al[25] concluded that N0 patients with pancreatic adenocarcinoma who had fewer than 12 lymph nodes harvested were potentially understaged. More than half of the patients in SEER had less than 12 nodes evaluated. When we examined the lymph nodes harvested by each approach in the setting of pancreatic adenocarcinoma, we saw an advantage to the robotic approach. Although these results were promising, this series is not intended to validate specific surgical oncology outcomes.

Somewhat surprisingly, our findings show that RAPD was associated with shorter mean operative times (293 vs 371 minutes, $P < 0.01$). This is despite the time needed to dock the robot. This may be due to the increased dexterity and range of motion offered by the robotic approach. The technically challenging steps of pancreas and spleen mobilization and vascular control are likely factors prolonging the surgery time of the traditional laparoscopic approach.

This analysis has several important limitations. First, as a retrospective study, it is subject to the inherent bias of this study design. For example, the total number of RADP procedures reported herein is small, limiting the analysis to mostly univariate comparisons, with only limited adjustment for potential cofounders. Second, the lack of long-term follow-up (>2 years) makes it impossible for us to comment on the oncological outcomes between these 2 approaches. We have recently compared the long-term outcomes between open distal pancreatectomy and LDP and found them to be equivalent (article in preparation); it is not likely that the robotic approach will impose significant oncological hurdles compared with LDP.

In conclusion, our results suggest that RADP demonstrates equivalent safety compared with LDP. More patients undergoing RADP had successful completion of a minimally invasive distal pancreatectomy. The improved visualization and dexterity of RADP may offer benefits over LDP, leading to a greater proportion of patients for whom minimally invasive distal pancreatectomy might become feasible. It will be important to confirm these findings in larger multi-institutional studies.

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