

Minimally Invasive Approaches to Pancreatic Surgery



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KEYWORDS

- Pancreatic adenocarcinoma • Whipple • Distal pancreatectomy • Minimally invasive • Open

KEY POINTS

- Open and minimally invasive approaches to pancreatic surgery for benign and malignant lesions have been shown to be equivalent in regards to their safety profiles in multiple large single institution series.
- Emerging multicenter data indicate that outcomes including morbidity/mortality, fistula occurrence, and overall survival are equivalent between the two distinct operative techniques.
- Laparoscopic and robotic surgical techniques have gained increasing acceptance over the last few years especially in the setting of pancreatic malignancy and may be associated with decreased patient hospital stays and comparable oncologic outcomes.

INTRODUCTION

Minimally invasive techniques have the potential to revolutionize the surgical management of pancreatic disease in the setting of benign and malignant processes. Both laparoscopic and robot-assisted approaches to pancreatic surgery have made open procedures, traditionally wrought with high morbidity, safer and more feasible.¹ There still remains no consensus regarding the oncologic efficacy of minimally invasive surgery for pancreatic cancer even though median survival after open resection remains 16 to 19 months with 5-year overall survival averaging 22% to 25%.² Recent advances in minimally invasive surgery seem to reduce the perioperative morbidity of

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pancreaticoduodenectomy for benign tumors while maintaining a perioperative safety profile equivalent to open approaches. The laparoscopic pancreaticoduodenectomy (LPD) was initially met with skepticism because of long operative times, but has now been established as safe and feasible when performed by select high-volume surgeons at experienced centers.³ The robotic pancreaticoduodenectomy (RPD), first performed in 2007, is now being increasingly used because of the perceived benefits of stereotactic vision, magnification, platform stability, and favorable ergonomics.⁴ Our institution is a strong advocate for minimally invasive approaches to pancreatic surgery and has demonstrated equivalent outcomes between open, laparoscopic, and robotic approaches and favors the robotic technique for benign and malignant processes of the pancreas. The urgency and potential benefits of minimally invasive surgery for patients with pancreatic cancer are highlighted by two recent observations: findings from the National Cancer Database show that 71.4% of patients with clinical stage 1 pancreatic adenocarcinoma currently choose no therapy for their disease and experience shorter survival compared with patients treated with pancreatectomy ($P < .001$) suggesting a nihilism and fear about pancreatic surgery; and nearly half of patients undergoing open pancreaticoduodenectomy (OPD) have complications preventing administration of proven adjuvant chemotherapy.⁵ Wu and colleagues⁶ have demonstrated the impact of postoperative complications on the administration of adjuvant therapy following pancreaticoduodenectomy for adenocarcinoma. In their retrospective review of 1144 patients who underwent pancreaticoduodenectomy between 1995 and 2011, they noted an overall complication rate of 49.1%, and overall, 54% of the patients received adjuvant chemotherapy. Presence of a postoperative complication led to a definite delay in time to adjuvant therapy and reduced the likelihood of receiving multimodality therapy.

This article presents a review of two minimally invasive techniques for distal pancreatectomy (DP) and pancreaticoduodenectomy, focusing on metrics of technique, safety, morbidity, and oncologic outcomes and potential benefits.

LAPAROSCOPIC DISTAL PANCREATECTOMY

Indications for Minimally Invasive Distal Pancreatectomy

The minimally invasive approach to the DP (MIDP) is now considered by many to be the preferred method of resection for benign and malignant tumors of the distal pancreas. Several studies have been performed, collectively supporting that LDP and RDP can be performed with superior results to the open approach in patients with benign and malignant disease.^{1,3,4} Specifically, the minimally invasive approach results in shorter hospital stay, reduced blood loss (EBL), and decreased complication rates.^{4,7,8} Similar oncologic resections can be accomplished in terms of lymph node dissection and resection margins, although larger reports of long-term survival are still lacking. Current absolute contraindications to LDP or RDP include prohibitive medical comorbidities and poor patient functional status. Relative contraindications include locally advanced malignancies, vascular invasion, and prior major abdominal operations.⁸ Involvement of the celiac trunk is not an absolute contraindication to minimally invasive approach.

Technique of Laparoscopic Distal Pancreatectomy

The patient is placed in supine position, and the peritoneum is accessed either via a Veress needle approach or optical separator technique, which are both inserted in the left subcostal area to induce pneumoperitoneum. The second trocar is then inserted in the right supraumbilical region (12 mm). The remaining trocars are then

placed in the left paraxiphoid region (5 mm), right subcostal area (5 mm), and left supraumbilical region (12 mm). Dissection begins with division of the gastrocolic ligament to enter the lesser sac. The splenic flexure of the colon is then mobilized inferiorly, and the anterior surface of the pancreas is inspected. The transverse mesocolon is then dissected off the inferior border of the pancreas, and the pancreas is dissected out of the retroperitoneum at the site of transection, creating a subpancreatic tunnel. Early identification of the splenic vessels and dissection of the vein and artery off the superoposterior aspect of the pancreas allows safer pancreatic transection. Once the vessels have been mobilized, the pancreatic parenchyma is divided using a linear stapler or harmonic scalpel, which is followed by division of the splenic vessels using a stapling device or clips. The spleen is then mobilized by sectioning the suspending ligaments, and the specimen is then placed in a large bag and brought through an access incision.⁹

Outcomes of Laparoscopic Distal Pancreatectomy

Two methodologic problems complicate prospective studies of surgical technique for distal pancreatic cancer: only 20.8% of pancreatic ductal adenocarcinomas (PDA) arise in the distal pancreas; and the 1640 distal pancreatic resections performed annually in the United States are distributed among 1743 hospitals according to 1998 to 2003 data in the Nationwide Inpatient Sample, an average annual case volume of one per hospital. As a result, most comparative effectiveness research has been retrospective and confined to single institution data.¹⁰ Published outcomes after minimally invasive pancreatic resection demonstrate technical equivalence to open DP with reduced intraoperative blood loss and shortened hospital stay. There are only three published studies comparing open and laparoscopic DP (ODP and LDP) in patients with PDA. A single study of 23 patients undergoing LDP for PDC at nine centers has demonstrated median survival identical to open at 16 months by means of a 3:1 matched comparison with historical open DP control subjects.¹¹

Our institution performed a retrospective case series comparing clinicopathologic and long-term oncologic outcomes after MIDP and ODP for pancreatic ductal carcinoma in 62 consecutive patients at a single institution. Intention-to-treat analysis demonstrated no evidence for inferiority of MIDP compared with ODP in terms of postoperative outcomes or long-term survival.¹² Another recent study by Nakamura and colleagues¹³ comparing LDP and ODP using propensity score-matching indicated the superiority of the laparoscopic approach over the open technique in regards to perioperative outcomes, including higher rate of preservation of spleen and splenic vessels ($P < .001$), lower rates of intraoperative transfusion ($P = .020$), clinical-grade pancreatic fistula ($P < .001$), and morbidity ($P < .001$). The laparoscopic cohort also had a shorter hospital stay ($P = .001$), but a longer operative time ($P < .001$).

ROBOT-ASSISTED DISTAL PANCREATECTOMY

Technique of Robot-Assisted Distal Pancreatectomy

MIDP has several advantages to its open counterpart with regards to blood loss, operative time, hospital length of stay, and complications particularly for benign disease. Furthermore, emerging data suggest that the robotic technique is a superior minimally invasive platform. Since 2009, our institution has performed hundreds of RDPs and has been able to demonstrate specific technical advantages provided by the robot-assisted approach, which are particularly important in the setting of pancreatic adenocarcinoma where adherence to oncologic principles are key to successful resections.¹⁴

After the peritoneum is accessed in a similar fashion to that obtained in the laparoscopic approach, additional trocars are placed, and the robot is docked. Again, the lesser sac is entered by division of the gastrocolic ligament and the colonic splenic flexure is mobilized inferiorly. Focus is then paid on division of the pancreatic neck. Stereotactic vision and the robotic camera angle allow safe and quick isolation of the pancreatic neck over the superior mesenteric vein (SMV)–splenic vein confluence.¹⁴ The splenic artery is isolated at its takeoff from the celiac trunk, and divided with a vascular stapler (Figs. 1 and 2).¹⁴

A lymphadenectomy is then carried out starting from the left side of the superior mesenteric artery (SMA) laterally, taking the posterior pancreatic fascia en bloc, and a comprehensive celiac lymphadenectomy is completed. With large tumors involving the fourth portion of the duodenum or colon, the robot allows meticulous en bloc resections with reconstructions performed in a similar fashion to the open technique.¹⁴

Outcomes of Robot-Assisted Distal Pancreatectomy

At the University of Pittsburgh, we compared our prospectively gathered data from the first 30 cases of RDP (performed between 2008 and 2011) with a historical control group of 94 laparoscopic cases (2004–2007, before the robot became available, and well after the group had established maturity with LDP).¹⁵ Patients undergoing RDP and LDP demonstrated equivalent age, gender, ethnicity, ASA (American Society of Anesthesiologists) score, and tumor size. No conversions to open surgery occurred in the RDP group compared with 16% in the LDP group ($P < .05$). This was despite that more PDA were approached robotically than laparoscopically (43% vs 15%; $P < .05$).¹⁵ A more recent updated series of 100 RDPs by our institution demonstrated a persistently low conversion rate of (2%). This may be secondary to the ability of the surgeon at the console to control large vessels and manage unexpected bleeding via intracorporeal suturing more readily with the robot than using laparoscopy. In this experience, RDP outcomes were optimized after 40 cases.¹⁶

Additionally, the robot platform has been shown to allow improved ability over laparoscopy to perform splenic preservation. In our institutional experience, we have demonstrated enhanced ability to preserve the spleen given increased maneuverability of the robotic arms to carefully dissect out the splenic vessels.¹⁷ In the difficult scenario where the splenic artery is embedded within the superior pancreatic parenchyma, robotic visualization, magnification, and improved dexterity of the instruments allow for rapid and efficient isolation and division of this vessel thereby avoiding a conversion.¹⁵

The oncologic outcomes between the minimally invasive approach and the open technique for DP have been shown to be equivalent. Use of the robot seems to offer

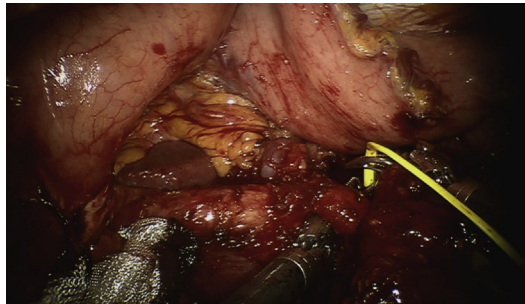


Fig. 1. The splenic artery is isolated and vessel looped before stapling.

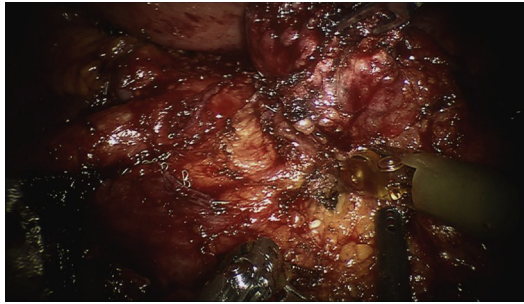


Fig. 2. Completed medial to lateral pancreatic body/tail mobilization.

an increased advantage over laparoscopy, based on the authors' experience. Our institutional experience demonstrated that despite a higher percentage of adenocarcinoma in the robotic group (43% vs 15%; $P < .05$) and a similar median tumor size of approximately 3 cm, RDP was associated with improved R0 resection rates (100% vs 64%; $P < .05$), and median lymph node count (19 vs 9; $P < .01$) when compared with laparoscopy.¹⁵ Although single institution outcomes may not be generalizable, we believe this observation reflects the ability to better recapitulate open oncologic principles with the robotic approach. A more comprehensive lymphadenectomy is completed given enhanced magnification and maneuverability of the robot.

Lastly, it has been shown that patients having undergone RDP as opposed to LDP or ODP have shorter hospital stays given decreased wound complications and increased rates of splenic preservation.¹⁵ As further experience with the robot-assisted approach is gained, additional advantages may be realized ([Table 1](#)).

LAPAROSCOPIC PANCREATODUODENECTOMY

Anatomic Considerations When Considering Approach/Indications for Minimally Invasive Approach

Determining the resectability of pancreatic adenocarcinoma of the head of the pancreas depends primarily on the involvement of the mesenteric vessels. Preoperative assessment of the presence of metastatic disease or superior mesenteric arterial or venous involvement in the tumor process is critical in determining whether a patient is a candidate for an open versus minimally invasive approach to the pancreaticoduodenectomy, or whether they are a candidate for surgical resection at all. Based on consensus guidelines, resectable tumors are those that have no distant metastasis; have no radiographic evidence of abutment or distortion of the SMV and portal vein (PV); and have clear fat planes surrounding the celiac axis, hepatic artery, and SMA.¹⁸ Patients with tumor abutment of the SMV/PV, gastroduodenal artery abutment or encasement up to the hepatic artery, or abutment of the SMA less than 180° are considered to be borderline resectable and benefit from neoadjuvant treatment.¹⁸

Minimally invasive approaches, including laparoscopic and robotic techniques, do not allow for palpation of the tumor intraoperatively, which often precludes determination of resectability. Therefore, the use of the triple-phase computed tomography to determine operative resectability is key before proceeding with surgical resection. The close relationship of these large vessels to tumors in the head of the pancreas frequently results in abutment or invasion often requiring vascular resection, which has not been often performed using a minimally invasive approach, but has been described.

Table 1
Select series of minimally invasive surgery distal pancreatectomy

Author, Year	Technique	N (Total)/N (Malignant)	EBL (mL)	Operative Time (min)	Fistula Rate (Grade C)	Mortality Rate	Oncologic Outcomes (R0 Rate, LN)
Fernandez Cruz et al, ³⁴⁻⁴¹ 2007	Laparoscopic	82/13	370	222	7%	0%	77%, 14.5
Kooby et al, ¹¹ 2008	Laparoscopic	142/54	357	230	26%	0%	93%, NR
Jayarman, ⁹ 2010	Laparoscopic	107/16	150	193	16%	NR	97%, 6
Kang et al, ⁴² 2011	Robot	20/18	372	348	NR	0%	NR, NR
Zureikat et al, ¹⁸ 2013	Robot	83/60	150	256	36%	0%	97%, 16

Abbreviations: LN, lymph node; NR, not reported.

Recent literature has revealed oncologic equivalency between open and minimally invasive pancreaticoduodenectomy.^{18,19} Most high-volume pancreatic centers are now performing laparoscopic and/or robotic surgery for benign and malignant processes. Song and colleagues²⁰ demonstrated in a case-control fashion comparable oncologic outcomes between patients undergoing open and laparoscopic pylorus-preserving pancreaticoduodenectomy. Similarly, Croome and colleagues²¹ demonstrated better operative outcomes and improved oncologic efficacy using the laparoscopic approach compared with the traditional open technique to the Whipple for PDA. An increasing number of pancreatic resections are being performed using minimally invasive approaches, but it remains to be determined if the benefits of this technique outweigh its longer operative times and higher costs. Minimally invasive pancreaticoduodenectomy is a feasible procedure in selected patients who are cared for in select centers by experts in pancreatic surgery.²² Patients who are candidates for an OPD are not precluded from a minimally invasive approach based on age, body mass index, or comorbidities. However, prior major abdominal surgery or evidence of vascular involvement most likely requiring vascular reconstruction were previously considered relative contraindications to using a minimally invasive approach to pancreatic resection.

Technique of Laparoscopic Pancreaticoduodenectomy

LPD has been described by Zureikat and colleagues²³ and involves complete laparoscopic mobilization of the pancreas and duodenum. The patient is placed supine on a standard operating room table. After gaining access to the abdomen using an optical-separator device in the left upper quadrant, a total of seven ports are placed in a crescent shape around the xiphoid process. A right lower quadrant incision with muscle-sparing technique is used to extract the specimen. On access to the abdomen, the peritoneal cavity is systematically explored to evaluate for metastatic disease. The laparoscopic procedure mirrors that of the open with a few minor modifications. The authors prefer to dissect the inferior border of the pancreas and SMV before the Kocher maneuver. The hepatic flexure is then mobilized and the duodenum fully kocherized. The porta hepatitis is dissected in a similar fashion used for open surgery. A tunnel is created between the PV and pancreatic neck and the pancreas is divided using bipolar electrocautery.²³ An antrectomy is typically performed rather than pylorus preservation procedure based on surgeon preference.

Reconstruction begins with an end-to-side duct to mucosa pancreaticojejunostomy using two-layered running absorbable monofilament. A running 4–0 absorbable monofilament suture is used for the hepaticojejunostomy. A stapled technique is used for the gastrojejunostomy. Two drains are left around the pancreaticojejunostomy before closure.²³

Outcomes of Laparoscopic Pancreaticoduodenectomy

The LPD is a technically challenging operation. The initial report of Gagner and Pomp²⁴ of 10 LPDs in 1997 did not favor use of the laparoscopic technique over the open approach because of the high conversion rate (40%) and lack of any perceived benefits. Subsequently, several reports have emerged attempting to further characterize the safety and oncologic efficacy of the LPD, and some have directly compared it with the OPD. Senthilnathan and colleagues²⁵ described one of the largest initial series of 150 LPDs (130 of which were for adenocarcinomas). This report demonstrated the advantages and feasibility of the minimally invasive approach when performed by highly skilled surgeons. Mean operative time for the entire cohort was 310 minutes (range, 276–344) with a mean EBL of 110 mL (range, 88–132), and one conversion to OPD.

Average hospital stay was 8 days (range, 5.4–10.6) and overall postoperative morbidity was 29.7%. Reoperation was required in five cases (3.84%; two with hemorrhage, one with jejunal loop obstruction, and two with grade C pancreatic fistula). Grade B and C postoperative pancreatic fistula rate was 8.46%. Resected margins were positive in 9.23% of cases, and the mean number of retrieved lymph nodes was 18. The overall 5-year actuarial survival was 29.42%, and the median survival was 33 months.²⁵

Kim and colleagues²⁶ describe another large series of laparoscopic pylorus preserving PD with 100 cases performed between 2007 and 2011 for patients with benign and malignant periampullary lesions. A median operative time of 7.9 hours with mean hospital stay of 14 days was reported for the entire cohort. Overall morbidity rate was 25%, with a 6% pancreatic fistula rate (International Study Group for Pancreatic Fistula grade B or C), all of which were treated conservatively. Postoperative hemorrhage occurred in five patients, only one of whom required reoperation, and DGE (Delayed gastric emptying) occurred in two patients.²⁶

In another series of 62 LPDs (45 patients with malignant disease) by Kendrick and Cusati,²⁷ operative metrics were impressive with a median operative time of 368 minutes and median EBL of 240 mL. Outcomes for the patients with cancer were not detailed separately. Mean length of hospital stay was 7 days and overall morbidity rate was 42%, which included DGE in nine patients and pancreatic fistula in 18% of the patients. Reoperation was required in three (5%) patients for control of sepsis secondary to a pancreatic leak (one), control of hemorrhage following percutaneous drain placement (one), and revision of a biliary leak (one). The reported 30-day operative mortality was 1.6%.²⁷

Another comparative review performed by Kendrick and colleagues²⁸ compared 31 patients undergoing LPD with major vascular resection with 58 patients undergoing the open approach. Mean operative blood loss was significantly less in the laparoscopic (842 mL) compared with the open group (1452 mL) ($P < .001$), as was median hospital stay, 6 (4–118) versus 9 (6–73) days, respectively ($P = .006$). There was no significant difference in the total number of complications (laparoscopic, 35%; open, 48%) or severe complications (laparoscopic, 6.4%; open, 3.4%) in the two groups. In-hospital mortality and 30-day mortality were also not statistically different between the laparoscopic and open groups, 3.2% and 3.4%, respectively. This review demonstrated that the minimally invasive approach to pancreatic resection with major vascular resection is not only feasible and safe but can also result in equivalent oncologic and operative outcomes to the traditional open technique, and although vascular reconstruction used to be considered a contraindication to the minimally invasive approach, it no longer is considered as such.²⁸

Kendrick and colleagues²¹ focused on the oncologic effectiveness of the MIDP in another review directly comparing 108 patients who underwent LPD with 214 patients who underwent OPD for PDA. They found a significantly higher proportion of patients in the OPD group (12%) who had a delay of greater than 90 days or who did not receive adjuvant chemotherapy at all compared with that in the TLPD (total laparoscopic pancreaticoduodenectomy) group (5%; $P = .04$). There was no significant difference in overall survival between the two groups, but a significantly longer progression-free survival was seen in the TLPD group than in the OPD group ($P = .03$). This study reveals a possible oncologic advantage to the laparoscopic approach over the open technique.²¹

The previously mentioned studies clearly indicate that these initial LPD outcomes are comparable with historic open control subjects, with equivalent operative time, morbidity, and mortality. Blood loss is consistently better than open series, and

oncologic outcomes have also been shown to be equivalent between the two approaches (Table 2).

ROBOT-ASSISTED PANCREATICODUODENECTOMY

Technique

The reported advantages of minimally invasive pancreaticoduodenectomy include better visualization, faster recovery time, and decreased length of hospital stay. In cases of robotic approaches, some of the proposed advantages include increased dexterity and a superior ergonomic position for the operating surgeon.

As described by Zeh and coworkers²⁹ and Zureikat and colleagues, the robot is now docked very early in the robot-assisted approach to the pancreaticoduodenectomy. The first step is achieved robotically and includes mobilization of the right colon and Kocherization of the duodenum along with mobilization of its third and fourth portions. A near total Cattell-Brasch maneuver is performed to expose the SMV at the root of the small bowel mesentery. An extended Kocher maneuver is completed to pull the jejunum into the right upper quadrant via division of the ligament of Treitz. The jejunum is transected around 10 cm distal to the ligament of Treitz using a linear stapler then marked with a suture around 50 cm distally and tacked to the stomach. The second step involves division of the gastrocolic omentum and entrance into the lesser sac, followed by dissection of the posterior stomach from the anterior surface of the pancreas. The right gastric artery is ligated close to the stomach and the right gastroepiploic artery is then ligated at the corresponding greater curvature side. The stomach is divided with a linear stapler at this time and an automated liver retractor is inserted to facilitate exposure.

Dissection is then carried out at the level of the superior border of the pancreas using the robotic hook to identify the common hepatic artery. The right gastric artery is again divided, now at its origin, and the gastroduodenal artery is transected. Cholecystectomy is performed and the lymph nodes are dissected along the lateral border of the common bile duct taking care to identify any aberrant right hepatic artery. The common bile duct is identified and divided followed by thorough portal dissection. The right gastroepiploic vein is identified and followed to its origin to locate the SMV and middle colic vein. The gastroepiploic vein is doubly clipped or tied and divided. The SMV is dissected off the inferior border of the pancreas and a tunnel is created over the PV. The angle afforded by the robotic camera ensures safe visualization of the tunnel. After completion of the tunnel, the neck of the pancreas is divided with electrocautery, reserving sharp robotic scissor transection for the PD. The pancreas is then mobilized from the lateral border of the SMV-PV working caudad to cephalad. The first jejunal branch is divided with a vascular stapler. The SMV-PV is reflected medially and the SMA is identified. Dissection proceeds along the SMA by clearing all the tissue around the anterior, right side, and posterior surface of the SMA.^{29,30}

Reconstruction is started with a two-layered end-to-side duct to mucosa pancreaticojejunostomy in a modified Blumgart fashion. The choledochojejunostomy is then performed in a running fashion. An antecolic Hoffmeister end-to-side gastrojejunostomy is hand-sewn in two layers.^{29,30}

Outcomes of Robot-Assisted Pancreaticoduodenectomy

Despite substantial literature supporting advantages to the minimally invasive approach for the DP, evidence supporting similar benefits for the minimally invasive pancreaticoduodenectomy is still lacking. Both LPD and RPD outcomes are similar, and are not inferior to OPD in carefully selected patients. Additionally, both minimally

Table 2
Select series of minimally invasive surgery pancreaticoduodenectomy

Author, Year	Technique	N (Total)/N (Malignant)	EBL (mL)	Operative Time (min)	Fistula Rate (Grade C)	Mortality Rate	Oncologic Outcomes (R0 Rate, LN)
Guilianotti et al, ⁴ 2010	Robot	60/45	394	421	31.6%	3%	90%, 18
Kim et al, ²⁶ 2013	Laparoscopic	100/12	—	474	6%	—	100%, 13
Kendrick, ²¹ 2014	Laparoscopic	108/108	492.4	379.4	11%	1%	77.8%, 21.4
Palanivelu, ²⁵ 2015	Laparoscopic	150/130	110	310	8.5%	0%	90.8%, 18
Zureikat, ³¹ (last 120 cases) 2015	Robot	200/166	250	417	6.9%	3.3%	91.4%, 26

Abbreviation: LN, lymph node.

invasive platforms seem to be advantageous to OPD with respect to blood loss. Other potential advantages need to be explored in larger control matched series.

Several case control studies evaluating outcomes of RPDs have been performed and have shown that estimated blood loss and length of stay is significantly better in the RPD with no increase in operative mortality compared with the open cohort. None of the studies to date have demonstrated an improvement in overall morbidity, fistula rate, or operative times. However, it should be noted that the largest of these case control studies is 44 robotic cases; thus, all published comparisons between open and robotic PDs suffer from low numbers that compare early robotic experiences with mature open ones. The learning curve for OPD is estimated to be around 60 to 70 cases and according to Boone and colleagues³¹ it is likely that the RAPD learning curve is similar.

Our institution has now performed more than 300 RPDs to date. In an analysis of the first 132 RPD, improvements in operative times, open conversion and EBL, morbidity, and pancreatic fistula rates have been observed. Although the operative time is often the main criticism of RPD, there has been a decline in this key point. The last 100 RPD at our institution have been performed with median time 340 minutes. A recent RPD analysis from the University of Pittsburgh confirmed that outcomes are optimized after an initial steep learning curve of approximately 80 cases. In-depth analysis of this learning curve revealed that blood loss and conversions were optimized after 20 cases (600 vs 250, $P < .05$, and 35% vs 3%, $P < .05$ respectively), incidence of pancreatic fistula after 40 cases (27% vs 14%; $P < .05$), and operative time after 80 cases (582 minutes vs 417 minutes; $P < .05$).³¹ Complication rates, length of stay, and readmissions also improved but the sample size was underpowered to detect a significant difference. In the last 100 cases, we found a fistula rate of 6%, a 90-day mortality rate of 3%, and a median length of stay of 8 days. Importantly, a two-attending approach was used throughout the learning curve period to ensure patient safety and procedural efficacy.³¹ These data suggest that meaningful comparative effectiveness studies of minimally invasive and open PD should take into consideration the impact of the learning curve before any outcomes are assessed.

Clavien grade 3 and 4 complications (requiring radiologic, endoscopic, or anesthetic intervention and/or causing end organ damage) have decreased from 30.7% in the first 80 to 13.7 % ($P = .035$). This compares favorably with published reports of OPD that estimate major morbidity using the Clavien system to be between 30% and 40%. This improved morbidity profile has not translated into shorter length of stay (median RPD hospital stay in the authors series = 10 days), but this may be largely a reflection of a cautious approach in our assessment of this early technology. Overall International Study Group on Pancreatic Fistula leak rate was 17% (grade C = 3.7%), comparing favorably with the most recent large analysis by Denbo and colleagues^{32,33} of more than 2700 OPDs (18% overall leak rate, grade C $\leq 5\%$).

The conversion rate and blood loss metrics have also improved with increased experience. The conversion rate and EBL have decreased from 35% and 600 mL in the first 20 cases to 3% and 250 mL in the subsequent cohort ($P = .0001$ and 0.002 , respectively). The conversion rate compares favorably with most LPD series, and the EBL is well below most OPD reports.³¹

Our institution's early optimization of the RPD was performed without the assistance of simulators and bioartificial organs. Over the past year, University of Pittsburgh Medical Center has implemented a robotic curriculum in the training of its surgical oncology fellows using a step-wise approach to advanced robot training. The past six fellows all completed RPDs on the pancreaticobiliary service, with no decrease

to the attending team's median operative time. This illustrates the benefit of an established robotic curriculum in surgical training.

Minimally invasive approaches to major gastrointestinal surgery have been shown to be as effective as the traditional open approach. Laparoscopic surgery offers patients distinct benefits but is not without its disadvantages to surgeons in terms of maneuverability and visualization. Robotic telemanipulation systems were introduced with the objective of providing a solution to the problems in this field of surgery. Pancreatic surgery, in particular, may be aided significantly by minimal access surgery given the high morbidity associated with traditional open pancreatic procedures. Our institutional experience demonstrates that minimally invasive pancreas resections are safe, feasible, and associated with equivalent outcomes to historical series of OPD. Moreover, our experience suggests that the robot-assisted approach may offer benefit over open and laparoscopic approaches. Currently, multicenter comparative effectiveness trials are hindered by the low number of centers with enough experience with these approaches to allow for either randomization or propensity scoring. However, as the minimally invasive approach continues to be widely adopted by specialized centers, these further investigations will be possible.

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