Robotic-Assisted Major Pancreatic Resection and Reconstruction

Amer H. Zureikat, MD; Kevin T. Nguyen, MD, PhD; David L. Bartlett, MD; Herbert J. Zeh, MD; A. James Moser, MD

Hypothesis: Robotic-assisted pancreatic resection and reconstruction are safe and can reproduce perioperative results seen in open surgery.

Design: Single-institution retrospective review.

Setting: Tertiary care center.

Patients: Patients undergoing completed robotic-assisted pancreatic resection and reconstruction at the University of Pittsburgh Medical Center, Pittsburgh, Pennsylvania, between October 3, 2008, and February 26, 2010.

Main Outcome Measures: Primary pathology, operative time, operative blood loss, perioperative blood transfusions, pancreatic fistula, 90-day morbidity and mortality, and readmission rate.

Results: Thirty patients with a median age of 70 years (range, 32-85 years) underwent completed robotic-assisted pancreatic resection and reconstruction. Procedures were robotic-assisted non-pylorus-preserving pancreaticoduodenectomy (n = 24), robotic-assisted central pancreatectomy (n = 4), and the robotic-assisted Frey procedure (n = 2). The median operative time was 512 minutes (range, 327-848 minutes). The median blood loss was 320 mL (range, 50-1000 mL), with a median length of hospital stay of 9 days (range, 4-87 days). The final diagnoses included periampullary adenocarcinoma (n = 7), pancreatic ductal adenocarcinoma (n = 6), pancreatic neuroendocrine tumor (n = 5), intraductal papillary mucinous neoplasm (n = 4), mucinous cystic neoplasm (n = 3), serous cystic adenoma (n = 2), chronic pancreatitis (n = 2), and solid pseudopapillary neoplasm (n = 1). There was 1 postoperative death. The overall pancreatic fistula rate was 27% (n = 8). The clinically significant pancreatic fistula rate (International Study Group on Pancreatic Fistula grades B and C) was 10% (n = 3). Clavien grade III and IV complications occurred in 7 patients (23%), while Clavien grade I and II complications occurred in 8 patients (27%).

Conclusions: Robotic-assisted complex pancreatic surgery can be performed safely in a high-volume pancreatic tertiary care center with perioperative outcomes comparable to those of open surgery. Advances in robotic technology and increasing experience may improve long operative times.


Complex pancreatic resection remains the final frontier for minimally invasive surgery because of the twin technical challenges of controlling hemorrhage from major vessels and reconstructing the biliary and pancreatic ducts with acceptable morbidity. Despite recent data suggesting that complex pancreatic operations can be performed laparoscopically at high-volume centers, the use of traditional laparoscopic instruments has required that critical technical principles of open pancreatic surgery be modified to overcome the limitations of current technology. Examples include limited range of instrument motion, poor surgeon ergonomics, reliance on 2-dimensional imaging, and reduced dexterity, which precludes facile sewing with fine suture. Robotic-assisted minimally invasive surgery addresses many of the shortcomings of traditional laparoscopy and may permit complex anatomic reconstruction to be performed with the same techniques as open surgery. Robotic-enhanced dexterity, binocular 3-dimensional imaging, 3-axis motion of surgical instruments, and improved ergonomics may allow difficult pancreatic resections to be accomplished with safety and efficacy equal to those of open surgery but with reduced time to recovery and potentially improved cancer-specific outcomes.

Although perioperative mortality has declined significantly following pancreaticoduodenectomy at high-volume centers, the pancreaticoenteric anastomosis re-
mains a major source of morbidity. Pancreatic fistula develops in as many as 22% of cases6,8 and causes morbidity ranging from wound complications and delayed gastric emptying to intra-abdominal sepsis, postpancreactomy hemorrhage, and death. Although pancreas-related factors and preexisting medical comorbidities are associated with an increased risk of pancreatic leak,10-13 the technical aspects of pancreatic anastomoses are a critical focus of efforts to reduce the rate and morbidity of postoperative leaks. Pancreatic anastomotic failure rates as low as 5% have been reported following meticulous attention to technical details, operative magnification, and preservation of the vascular supply to the pancreatic remnant.14

We hypothesized that robotic-assisted minimally invasive surgery can reproduce traditional open techniques for pancreatic reconstruction with equivalent postoperative morbidity and mortality. We reviewed the outcomes of our first 30 completed robotic-assisted complex pancreatic reconstructions.

**METHODS**

We instituted a safety monitoring program to scrutinize outcomes of robotic-assisted pancreatic surgery on a continuing basis. Robotic-assisted procedures were performed by a 2-attending surgical team (A.H.Z., K.T.N., D.L.B., H.J.Z., and A.J.M.) possessing a combination of advanced laparoscopic skills and extensive experience with open pancreatic surgery. Robotic-assisted pancreatic surgery was performed with the daVinci S Robotic Surgical System (Intuitive Surgical, Inc, Sunnyvale, California).

Our study is a retrospective analysis of the first 30 patients undergoing completed robotic-assisted pancreatic resection and reconstruction at the University of Pittsburgh Medical Center, Pittsburgh, Pennsylvania, between October 3, 2008, and February 26, 2010. Study procedures were approved by the University of Pittsburgh Institutional Review Board. We identified 3 types of pancreatic reconstruction: non-pylorus-preserving robotic-assisted pancreaticoduodenectomy (RAPD), robotic-assisted central pancreatectomy (RAPC) for nonmalignant lesions of the pancreatic neck and body, and the Frey procedure for chronic pancreatitis. Whereas laparoscopic mobilization and dissection were used with varying frequency during the resection phase, division of the pancreas, resection of the uncinate process, and reconstruction of all anastomoses were performed robotically. The pancreas was divided with hook electrocautery after the placement of 2-0 silk suture ligatures at the superior and inferior borders to assure hemostasis. Vascular control during the uncinate resection was accomplished with a combination of suture ligatures, hemoclips, and LigaSure (Covidien, Boulder, Colorado) as necessary. In RACP, the proximal pancreatic transection was accomplished with an endoscopic stapler reinforced by absorbable mesh (Seamguard; W. L. Gore and Associates, Inc, Flagstaff, Arizona). Intraductal papillary mucinous neoplasm (IPMN) was used selectively to identify microscopic pancreatic ducts when visual inspection alone was insufficient. Pancreatic duct reconstruction following RAPD and RACP was performed with a modified Blumgart technique15 in every case. The anastomosis consisted of interrupted horizontal mattress sutures of 2-0 silk between the pancreatic parenchyma and the seromuscular layer of the jejunum. The duct-to-mucosa anastomosis was created with interrupted 5-0 polydioxanone sutures. Pancreatic duct stents (5F or 7F Zimmon stents; Cook Medical Inc, Bloomington, Indiana) were inserted routinely to assure duct patency. Reconstruction following the Frey procedure was performed with running 4-0 polydioxanone suture. Two closed suction drains were placed anterior and posterior to the pancreatic anastomosis in every case. Amylase levels were checked after the reinstatement of oral intake in all patients prior to drain removal.

We reviewed all perioperative events that occurred within 90 days. Details of the pancreatic remnant and the pancreatic anastomosis were recorded and classified by International Study Group of Pancreatic Surgery16 criteria. All pancreatic fistulae, regardless of their clinical significance, were identified and classified by International Study Group on Pancreatic Fistula (ISGPF) criteria.17 Postoperative complications were graded according to the Clavien classification system.18,19 Grade I and II complications are those not causing organ damage and not requiring operative, endoscopic, or radiological intervention; grade III and IV complications are those requiring operative, endoscopic, or radiological intervention or causing organ failure; and a grade V complication denotes death.

**RESULTS**

Thirty patients underwent minimally invasive pancreatectomy and robotic-assisted reconstruction within 15 months. Procedures included 24 RAPDs, 4 RACPs, and 2 duodenum-preserving pancreatic head resections with lateral pancreaticojunostomy (Frey procedure). The leading indication for surgery was to resect suspected malignant neoplasms in 18 patients (60%) and premalignant lesions in 8 patients (27%). Final pathologic diagnoses are shown in Table 1.

The study population consisted of 10 men and 20 women with a median age of 70 years (range, 32-85 years) (Table 2). All patients were graded as either...
American Society of Anesthesiologists class III (17 patients [57%]) or American Society of Anesthesiologists class II (13 patients [43%]). The median body mass index (calculated as weight in kilograms divided by height in meters squared) was 26.7 (range, 19.2-36.7). Sixteen patients (53%) of patients had prior abdominal surgery. The median operative time for the completed procedures was 512 minutes (range, 327-848 minutes), including the time to drape and dock the robot (approximated to be 30-45 minutes per case) but excluding general room setup time. The median blood loss was 320 mL (range, 50-1000 mL). Six patients (20%) required perioperative blood transfusion within 72 hours of surgery. The median length of hospital stay was 9 days (range, 4-87 days).

Technical details of the pancreatic duct reconstruction are presented in Table 3 and Table 4. Factors required to classify the pancreatic remnant by International Study Group of Pancreatic Surgery criteria include duct diameter (type I-III), consistency of the gland (grade A [soft or normal]; grade B [firm, hard, or fibrotic]), and length of pancreatic remnant mobilization (1-3 cm) prior to anastomosis. Factors related to the anastomosis itself include the type of reconstruction (type I [pancreaticojejunostomy] vs type II [pancreaticogastrostomy]), technique of anastomosis (grade A [duct to mucosa] vs grade B [dunking]), and the use of adjuncts such as pancreatic duct stenting. With the exception of the Frey procedures, all pancreatic duct reconstructions used an end-to-side, duct-to-mucosa technique. The pancreatic remnant was mobilized 1 to 2 cm in all cases to facilitate reconstruction. The major-

Table 3. International Study Group of Pancreatic Surgery Classification of Pancreatic Remnant in 28 Patients

<table>
<thead>
<tr>
<th>ISGPS Classification</th>
<th>Pancreatic Remnants, No.</th>
<th>Pancreatic Texture</th>
<th>Duct Size, mm</th>
<th>Remnant Mobilization, cm</th>
<th>ISGPF Leak Grade, No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>IA-PM2</td>
<td>15</td>
<td>Soft</td>
<td>&lt;3</td>
<td>1-2</td>
<td>A=3, B=1, C=2</td>
</tr>
<tr>
<td>IIA-PM2</td>
<td>5</td>
<td>Soft</td>
<td>3-8</td>
<td>1-2</td>
<td></td>
</tr>
<tr>
<td>IIIB-PM1</td>
<td>1</td>
<td>Firm</td>
<td>3-8</td>
<td>&lt;1</td>
<td></td>
</tr>
<tr>
<td>IIIB-PM2</td>
<td>2</td>
<td>Firm</td>
<td>3-8</td>
<td>1-2</td>
<td></td>
</tr>
<tr>
<td>IIA-PM1</td>
<td>1</td>
<td>Soft</td>
<td>&gt;8</td>
<td>&lt;1</td>
<td>A=2</td>
</tr>
<tr>
<td>IIIB-PM1</td>
<td>4</td>
<td>Firm</td>
<td>&gt;8</td>
<td>&lt;1</td>
<td></td>
</tr>
</tbody>
</table>


a A classification of I indicates a duct size of less than 3 mm; II, a duct size of 3 to 8 mm; III, a duct size greater than 8 mm; PM1, pancreatic mobilization less than 1 cm; and PM2, pancreatic mobilization of 1 to 2 cm.

b A grade of A indicates soft or normal pancreas; a grade of B, firm, hard, or fibrotic pancreas.

Postoperative fistulas are described in Table 3 and Table 5. The overall pancreatic fistula rate was 27% (8 of 30 patients) as defined by strict ISGPF criteria: 5 of 24 patients (21%) in the RAPD group and 3 of 4 patients (75%) in the RACP group. Among the 5 patients who underwent RAPD and developed pancreatic fistulae, 3 fistulae were subclinical (grade A) and 2 were clinically significant (1 was grade B and 1 was grade C). Of the 3 pancreatic fistulae following RACP, 2 were subclinical (grade A) and 1 was clinically significant (grade C). No patients undergoing a Frey procedure developed a postoperative fistula or complication.

Postoperative complications out to 90 days are presented in Table 5. Clavien grade III and IV complications occurred in 7 patients (23% of the total study group): 6 (25%) in the RAPD cohort and 1 (25%) in the RACP group. Two patients underwent reoperation. The first patient developed hemorrhage from the gastroduodenal artery stump secondary to a pancreatic leak. The second developed overwhelming intra-abdominal sepsis due to a bile leak compounded by distal bowel obstruction due to an unrecognized Meckel diverticulum. The patient died on day 87 of multisystem organ failure and is the only death in the series (3%). The other 5 complications included sepsis secondary to a pancreatic leak (1 patient), bleeding from a gastroduodenal artery pseudoaneurysm in the setting of a pancreatic leak (1 patient), small-bowel obstruction and severe delayed gastric emptying presenting 3 weeks after discharge (1 patient), biloma requiring subsequent percutaneous drainage (1 patient), and abdominal abscess requiring interventional radiology drainage (1 patient). Grade I and II complications occurred in 8 patients (27%) and were limited to the RAPD group. These included delayed gastric emptying (4 patients), deep venous thromboembolism or pulmonary embolism (2 patients), and wound infection in the right-lower-quadrant utility incision (2 patients).
An evidence-based consensus regarding the risks and benefits of minimally invasive complex pancreatic surgery remains elusive. Laparoscopic pancreaticoduodenectomy has been met with skepticism owing to the enormous technical challenges and uncertain outcomes of the procedure. As a result, only a few series describing totally laparoscopic pancreaticoduodenectomy have been published since the first description by Gagner and Pomp in 1994.20,21 Recently, Kendrick and Cusati2 reported totally laparoscopic pancreaticoduodenectomy in 62 patients with encouraging perioperative morbidity and short-term oncologic outcomes. Their results may be difficult to generalize to other centers. The inherent drawbacks of laparoscopy, such as 2-dimensional visualization, poor ergonomics, and lack of dexterity, have required adaptations in established techniques of complex pancreatic surgery to circumvent the technical limitations of laparoscopic instruments. These compromises of surgical principle may have unintended consequences for all but the most gifted laparoscopic surgeons. Robotic-assisted surgery has the potential to overcome some of the inadequacies of laparoscopic instrumentation and provides improved ergonomics, visualization, precision, and dexterity as the result of 3-dimensional optics and computer-enhanced motion control. These advantages permit traditional principles of open surgery to be applied under minimally invasive conditions with numerous potential benefits such as reduced wound morbidity, shortened hospital stay, and shortened postoperative recuperation.

We report the outcomes of 30 robotic-assisted complex pancreatic resections with primary pancreaticoenteric anastomoses. We duplicated every technique of our traditional open method and uses 2 layers of interrupted Blumgart duct-to-mucosa technique,15 which is identical to our traditional open method and uses 2 layers of interrupted sutures with intracorporeal knot tying. Three-dimensional, magnified visualization of the pancreatic duct combined with 3-axis motion of the robotic instruments allowed precise placement of duct-to-mucosa sutures without tearing the pancreatic parenchyma. Although tactile feedback is lacking, visual feedback becomes an important substitute sensory tool for the robotic-assisted surgeon. Moreover, with the aid of practice and secretin, even the smallest pancreatic ducts could be identified with ×10 magnification and successfully sutured to the adjacent jejunum using an interrupted parachute-style technique to create a tension-free pancreaticoenteric anastomosis.

The site of pancreaticoenteric drainage and the best method for pancreatic duct reconstruction remain controversial. Pancreateojejunostomy in its various forms and orientations (duct to mucosa vs invagination; end to end vs end to side) has no demonstrated advantage when compared with pancreaticogastrostomy.22-24 Similarly, adjunctive techniques such as pancreatic duct stenting, secretory inhibitors like octreotide, or fibrin glue have not reduced the frequency of pancreatic leaks.25-29 Surgeon experience and volume, meticulous technique, and adequate tissue perfusion remain the accepted benchmarks to prevent pancreatic leaks. To standardize reporting of pancreatic anastomoses and permit objective comparisons between methods, the International Study Group of Pancreatic Surgery recently developed a classification system to describe the pancreatic remnant and the technical details of the pancreaticoenteric anastomosis.16 As shown in Table 3 and Table 4, we routinely placed internal pancreatic duct stents to prevent technical obstructions of the anastomosis: 5F stents for type I ducts (<3 mm) and 8F stents for type II ducts and most type III ducts (3-8 mm and >8 mm, respectively). We avoided excessive mobilization of the remnant (>2 cm) in an effort to prevent ischemia of the pancreatic anastomosis. However, significant pancreatic remnant mobilization (1-2 cm) was required in the presence of a soft gland, small to medium-sized pancreatic duct, or planned drainage into the stomach.

We graded pancreatic fistulae in our series according to strict ISGPF criteria.17 The leak rate of 21% (5 of 24 patients) after RAPD included all ISGPF grades of fistula and is consistent with outcomes in large open series.4,12,29 Although the leak rate following RACP was 75% (3 of 4 patients), all 3 leaks occurred in high-risk pancreatic remnants, and there was only 1 clinically significant (grade C) event. These 8 pancreatic fistulae occurred with pathologies conducive to leak (ie, soft pancreatic parenchyma): neuroendocrine tumor (2 patients), serous cystic adenoma (2 patients), intraductal papillary mucinous neoplasm (1 patient), mucinous cystic neoplasm (1 patient), and ampullary cancer (2 patients). Moreover, 6 of the 8 leaks occurred in type IA pancreatic remnants (soft, <3-mm ducts), consistent with known risk factors for pancreatic fistula.10,13 Because many

Table 5. Postoperative Morbidity and Mortality in 28 Patients

<table>
<thead>
<tr>
<th>Operation</th>
<th>Pancreatic Fistula</th>
<th>Grade B or C Fistula</th>
<th>Clavien Grade I or II Complicationa</th>
<th>Clavien Grade III or IV Complicationa</th>
<th>Clavien Grade V Complicationa</th>
</tr>
</thead>
<tbody>
<tr>
<td>RAPD (n=24)</td>
<td>5 (21)</td>
<td>2 (8)</td>
<td>8 (33)</td>
<td>6 (25)</td>
<td>1 (4)</td>
</tr>
<tr>
<td>RACP (n=4)</td>
<td>3 (75)</td>
<td>1 (25)</td>
<td>0</td>
<td>1 (25)</td>
<td>0</td>
</tr>
</tbody>
</table>

Abbreviations: RACP, robotic-assisted central pancreatectomy; RAPD, robotic-assisted pancreaticoduodenectomy.

* A Clavien grade I or II complication indicates no organ failure and not necessitating radiological, endoscopic, or operative intervention; a Clavien grade III or IV complication, organ failure and/or necessitating radiological, endoscopic, or operative intervention; and a Clavien grade V complication, death.
investigators report only clinically significant pancreatic fistulae after open surgery, the rate of ISGPF grade B and C leaks was expected to range between 7% and 15% in the RAPD cohort, while the observed rate was 2 of 24 patients (8%). These robotic data, in conjunction with 2 recent publications, suggest that visual magnification may limit the technical contribution to pancreatic leak among high-risk type IA pancreatic remnants. Wada and Traverso observed a low rate of pancreatic leak when using an operating microscope. Similarly, Strasberg et al also emphasized the need for magnification during reconstruction of small pancreatic ducts. The leak rate after RACP is consistent with prior reports exceeding 50% in the open pancreatic surgical literature. Conversely, no leaks occurred after the Frey procedure for chronic pancreatitis, and both patients were symptom-free on subsequent examination.

Our outcomes compare favorably with 2 recently published series of minimally invasive pancreaticoduodenectomy. In their RAPD cohort, Giulianotti et al reported an overall fistula rate of 31.6% by combining data for pancreatic duct sclerosis with pancreaticojejunostomy. Sclerosis of the pancreatic remnant was associated with a higher fistula rate than pancreaticojejunostomy (36.5% vs 21.0%, respectively). Although some argue that sclerosis of the main pancreatic duct has no effect on the rate of intra-abdominal complications or pancreatic fistulae, we consider interrupted duct-to-mucosa pancreaticoenteric drainage to be the standard of care for reconstructing the pancreatic remnant as would be done routinely following open resection. As a consequence, our operative times are significantly longer than those reported by Giulianotti and colleagues following RAPD as well as open resection.

Because the nomenclature for reporting postoperative complications of pancreatic surgery is not standardized, we used the Clavien system for its simplicity and reproducibility. Clavien grade I and II and grade III and IV complication rates are not entirely synonymous with minor and major terminology used in prior studies. Nonetheless, our rates of observed grade I and II and grade III and IV complications following RAPD are equivalent to results with open surgery. Our single postoperative death, coupled with a reoperation rate of 7% for the entire cohort, is not inferior to rates observed in larger open series. Moreover, the incidence of postpancreatectomy hemorrhage, which occurred in 2 patients (7%) following RAPD in the setting of soft glands, is similar to that published by Yekebas et al (5.7%). Our median estimated blood loss is comparable to reported outcomes of minimally invasive and open pancreatic resection.

Robotic-assisted pancreatic surgery continues to evolve, and newer technologies may reduce operative times by mimicking the time associated with docking the robot as well as loading and extracting needles from the abdomen. Although no specific complications (pneumonia or prolonged ventilator dependence) were attributed to long operative times in this cohort of patients, larger series of patients and shorter operative times may demonstrate the underlying benefits of robotic-assisted surgery more convincingly. These include shortened hospital stay, decreased wound and pulmonary complications, and shorter convalescence in the short term as well as reduced rates of incisional hernia and adhesive bowel obstruction in the long term. Our report is an interim analysis of an ongoing outcomes project for robotic-assisted pancreatic surgery and is limited by its relatively small size, retrospective design, and selection bias, which favors soft glands and normal pancreatic ducts. Patients with known malignant neoplasms had clear evidence of resectable disease. As a result, the pancreatic fistula rate reported here is negatively biased by the preponderance of type IA pancreatic remnants. The series is not consecutive as robotic-assisted pancreatic resection and reconstruction must be performed in an advantageous group of highly selected patients before the inclusion criteria can be expanded.

Robotic-assisted pancreatic resections and reconstructions can be performed safely with postoperative complication rates and fistula formation comparable to results observed with open techniques. The robotic platform allows the principles of open surgical resection and reconstruction to be applied in a minimally invasive context with the potential to reduce postoperative morbidity and shorten patient recovery as the technology becomes more developed. Operative times are long but may improve with advances in technique and surgeon experience.

Accepted for Publication: June 28, 2010. Published Online: November 15, 2010. doi:10.1001/archsurg.2010.246

Correspondence: A. James Moser, MD, Division of Surgical Oncology, University of Pittsburgh Medical Center Pancreatic Cancer Center, 497 Scaife Hall, 3550 Terrace St, Pittsburgh, PA 15261 (mosera@upmc.edu).

Author Contributions: Drs Zeh and Moser contributed equally to this work. Study concept and design: Zureikat, Nguyen, Bartlett, Zeh, and Moser. Acquisition of data: Zureikat and Moser. Analysis and interpretation of data: Zureikat, Zeh, and Moser. Drafting of the manuscript: Zureikat, Nguyen, Bartlett, and Moser. Critical revision of the manuscript for important intellectual content: Zureikat, Zeh, and Moser. Obtained funding: Zureikat. Administrative, technical, and material support: Zureikat and Nguyen. Study supervision: Zureikat, Bartlett, Zeh, and Moser.

Financial Disclosure: None reported.

REFERENCES

The Advent of Laparoscopic Pancreatic Surgery Using the Robot

Patients are increasingly asking for their pancreatic operation to be performed laparoscopically, an approach known for both its clinical benefits and its technical challenge. Studies like these affirm the safety and feasibility of this approach using the robot. Advertisements for robotic-assisted surgery now appear on local television, and on a national level the technology seems to be winning the hearts and minds of the many prospective patients. Data from other surgical procedures, including 9 randomized controlled trials of robotic-assisted surgery vs standard laparoscopy, have thus far demonstrated similar patient outcomes, except for 1 Korean study that showed a slightly shorter length of stay. However, public demand for new technology has traditionally outpaced the data to support its adoption.

Zureikat and colleagues nicely demonstrate how major pancreatic resections can yield good outcomes when performed robotically, conferring to patients the interpolated benefits of the minimally invasive approach. These advantages typically include less postoperative pain, lower morbidity, shorter hospital stays, and faster recovery. The advent of robotic surgery has also brought new opportunities for pancreatic surgeons, such as improved visualization, enhanced precision, and reduced procedural time. Moreover, advancements in robotic technology continue to evolve, with new platforms and instruments being developed to further enhance the benefits of robotic-assisted pancreatic surgery.

References