The failure of the pancreaticojejunal anastomosis remains an important and potentially lethal postoperative complication after pancreaticoduodenectomy. During the pancreaticojejuno- nostomy, creation of compressive and shear forces during suture placement and knot tying may cause deformation of and cutting through the fragile pancreatic parenchyma. We sought to understand the mechanics of needle-pancreas interaction and make adjustments to our pancreaticojejunoanastomosis technique so that the creation of shear and compressive stress could be minimized. We provide a detailed description, a mathematical model, and analysis of the outcomes of our new technical modifications.

Methods

We reviewed hepatobiliopancreatic surgical procedures performed from January 1, 2001, through December 31, 2013, by a single hepatobiliopancreatic fellowship-trained surgeon (P.F.S.). We reviewed the medical records of the patients who underwent pancreaticoduodenectomy and retrieved pertinent clinical information. Preoperative data collected included the patient’s age and sex. Intraoperative findings included pancreatic texture (firm or soft) and pancreatic duct size. Postoperative data included pathological diagnosis, length of hospital stay, and pancreatic anastomotic failure as defined by the International Study Group on Pancreatic Fistula Study Group Consensus.19 Institutional review board approval was obtained per protocol and informed consent was waived.

Operative Procedure

The jejunal limb is brought in a retrocolic fashion to the right of the middle colic vessels. The pancreaticojejunoanastomosis is performed on the outer row using interrupted, double-armed, 3-0 coated polyglactin 910 U-sutures (Vicryl; Ethicon, Inc) with a small half-circle needle (SH needle; Ethicon, Inc). The needle is straightened by 2 needle holders to facilitate its placement through the pancreas and to minimize creation of shearing and compressive forces. Sutures are placed downward through the full-thickness pancreatic parenchyma from the anterior to the posterior aspect, including the pancreatic capsule, then through the seromuscular layer of the jejunum, followed by placement of the needle upward through a full-thickness pancreas, including the gland capsule from the posterior to the anterior aspect (Figure 1A). These sutures are placed approximately 5 to 10 mm apart, and the number may vary depending on the size and consistency of the gland. A 5F pediatric feeding tube (Covidien) is placed in the pancreatic duct to facilitate identification and to prevent an inadvertent placement of these stitches through the main pancreatic duct. The double-armed suture needles are left in place, and the sutures are kept

Figure 1

A). These sutures are placed approxi- mately 5 to 10 mm apart, and the number may vary depending on the size and consistency of the gland. A 5F pediatric feeding tube (Covidien) is placed in the pancreatic duct to facilitate identification and to prevent an inadvertent placement of these stitches through the main pancreatic duct. The double-armed suture needles are left in place, and the sutures are kept
loose until the duct-to-mucosa anastomosis has been performed. A small enterotomy is created in the jejunum just opposite the pancreatic duct orifice. The duct-to-mucosa anastomosis is created by using 5-0 or 6-0 polydioxanone sutures, with at least 1 in each corner and more if the duct is larger, placing the posterior sutures first followed by the anterior sutures (Figure 2). After all sutures are placed, the pancreas and the jejunum are approximated by parachuting the gland and the jejunum together along the 3-0 polyglactin 910 and 5-0 polydioxanone sutures. The duct-to-mucosa sutures are tied such that the knots are on the outside (Figure 2).

Each needle of the double-armed 3-0 polyglactin 910 sutures of the outer row is then placed through the seromuscular layer of the anterior aspect of the jejunum in Lembert fashion and tied down. If performed correctly, the seromuscular edge of the jejunum should be imbricated onto the pancreatic capsule on the anterior and posterior surfaces (Figure 3A). Octreotide acetate is not routinely used intraoperatively or in the postoperative period.

Rationale of the Technique
The rationale of our main technical modifications includes (1) use of double-armed sutures for the outer row of U-sutures, (2) straightening the needles on these sutures before placing them through the pancreatic tissue, and (3) not tying the outer-row sutures on the anterior aspect of the pancreas before placing each double-armed suture needle through the seromuscular layer of the jejunum. As with all deformable bodies, the tendency of the pancreatic tissue to shear and deform during surgery is a complex phenomenon that depends on the mechanical properties of the tissue. The rigidity and compressivity are among the major determinants of pancreatic mechanics. These determinants depend on patient- and disease-related factors and do not change during the surgical procedure. Although the rigidity and compressivity are independent of the surgical process, they give an idea of the extent of tissue deformation caused by the stress from needle placement. Increasing the radius of the needle and straightening the angle at which the force is applied will decrease the force needed to pass the needle through
the gland (Supplement [eAppendix]). In other words, straightening the needle will make placement of the suture much easier for the surgeon and less traumatic to the tissue (Figure 1B and C). The rationale of using double-armed sutures is based on the possibility of redistributing the shear stress created during knot tying from the pancreas to the bowel (Figure 3A).

Placing each double-armed suture needle through the jejunum and tying the sutures on the anterior aspect of the bowel allows for redirection of the shear forces created in the pancreatic tissue to the bowel wall (Figure 3B). This technical step cannot be accomplished with a single-needle technique because the suture strands missing a needle cannot be placed through the bowel wall, which would prevent the surgeon from being able to redistribute the respective shear forces from the pancreas to the jejunum (Figure 3C). For the same reason, we do not tie outer-row sutures on the anterior aspect of the pancreas before placing each double-armed suture needle through the seromuscular layer of the jejunum. The rationale is that tying sutures on the anterior surface of the pancreas would change the direction of the shear forces from the bowel back to the pancreas (Figure 3D).

Results

During the respective study period, 203 hepatobiliopancreatic procedures were performed. Of these, 44 (21.7%) were pancreaticoduodenectomies performed as classic, non–pylorus-preserving procedures using our modified Blumgart technique. Patients included 25 men (57%) and 19 women (43%) with a median age of 69 (range, 50-86) years. The mean length of postoperative hospital stay was 10 (range, 6-28) days. Pancreatic texture was soft in 28 cases (64%) and firm in 16 (36%). Median pancreatic duct size was 3 (range, 2-15) mm. Indications for surgery included pancreatic adenocarcinoma, ampullary cancer, distal common bile duct cancer, duodenal villous adenoma with dysplasia, duodenal cancer, mucinous cystic neoplasm, and intraductal pancreatic mucinous neoplasm.

Two cases of grade B fistula (leak) (5%) were associated with soft pancreatic gland texture and small pancreatic ducts. Both leaks resolved with conservative treatment and percutaneous drainage.

Discussion

A noticeable decline in the postoperative mortality rate after partial pancreatic resection has occurred during the last several decades.20-22 Several factors have been recognized to contribute to this phenomenon, including a better understanding of the biology of pancreatic neoplasms, advances in the cross-sectional imaging, and improvements in operative technique and perioperative patient care.15-21,25 However, despite the sensible success in decreasing mortality, the rate of postoperative complications after partial pancreatic resection remains relatively high, even in high-volume surgical centers.26-28

Of all potential complications of partial pancreatic resection, PJF has received the most attention. Multiple studies27-31 have been published, and many factors contributing to PJF have been recognized. The gland texture, the duct size, and the blood supply to the pancreatic remnant are among the most reported potential risk factors for PJF. Since the original description of pancreaticoduodenectomy in 1935 by Whipple et al,32 multiple techniques with numerous variations, primarily technical, have been developed.2-9,11,33,34 However, a particular technical challenge that surgeons commonly face when performing pancreaticojjunostomy is the creation of shear and compressive forces that cause cutting through and deformation of the fragile pancreatic parenchyma during suture placement and knot tying.

Although our proposed modifications would probably not be ideal for all cases, the outcome analysis showed no PJF associated with firm gland texture and favorable results with soft gland texture. One possible explanation is that straightening the needles on the double-armed sutures for the outer row can significantly decrease the shear and compressive stress during suture placement. This result could be especially relevant in soft glands with low tissue density that are prone to larger compressive distortions (Supplement [eAppendix]). We do not tie outer-row sutures on the anterior aspect of the pancreas, which allows us to redistribute the stress from the pancreas to the bowel. Sandwiching the pancreas between the jejunum without tying sutures on the anterior aspect of the pancreas provides mild hemostatic compression well enough to control small-vessel hemorrhage without negatively affecting the blood flow to the healing anastomosis.

Conclusions

Although physical experimentation during surgery is limited by patient safety issues, the mathematical analysis of our
Figure 3. Schematic of Tying Outer-Row Sutures

A, The double-armed sutures tied on the jejunum. B, The shear (horizontal) component ($F_h$) of the force ($F_s$) created during double-armed suture tying redirected from the pancreas to the bowel wall. $F_v$ indicates the nonshear (vertical) component. C, Single-needle suture technique not allowing for complete redistribution of shear component ($F_v$) to the forces ($F_s$) from the pancreas to the bowel. D, Tying sutures on the anterior surface of the pancreas before placing them through the jejunum changes the direction of the force vectors from vertical ($F_v$) to horizontal ($F_h$) and results in redistributing the shear forces ($F_s$) from the bowel back to the pancreas. Calculations are given in the Supplement (eAppendix).

technical modifications showed potential outcome advantage, which was supported by a relatively low rate of pancreatic leaks. Future studies of the outcomes of our technical modification will be conducted to evaluate its reliability.
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Study concept and design: All authors.
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