New Tools for Laparoscopic Division of the Pancreas

A Comparative Animal Study

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Abstract: We tested the hypothesis that the pancreas can be safely divided laparoscopically using non-suture devices. Twelve pigs were randomized into 4 groups: 1) laparoscopic distal pancreatectomy (LDP) using an ultrasonic scalpel; 2) LDP using an ultrasonic scalpel with pancreatic stump suture reinforcement; 3) LDP using a 35-mm laparoscopic linear vascular stapler; 4) LDP using a prototype 35-mm radio-frequency laparoscopic linear vascular stapler. There were no serious complications related to distal pancreatectomy. All groups gained weight by postoperative day (POD) 14. Serum amylase, glucose, electrolytes and total bilirubin levels were measured preoperatively and on POD 1, 3, 7, and 14, and peripancreatic peritoneal fluid amylase levels were measured on POD 7 and 14; all remained normal in all groups. Fewer adhesions to the pancreatic stump were found in the ultrasonic scalpel groups as compared with the stapler groups. Ultrasonic dissection may be the superior means of laparoscopic transection of the pancreas.

Key Words: laparoscopic distal pancreatectomy, ultrasonic scalpel, laparoscopic linear stapler, radio-frequency stapler, pancreatectomy, laparoscopy

(*Surg Laparosc Endosc Percutan Tech* 2004;14:53–60)

The videoendoscopic surgical approach is now used regularly to approach diseases of the lung, stomach, colon, spleen, adrenal glands, kidneys, and abdominal wall. The advantages of minimally invasive surgery for appropriate conditions are now well accepted. Decreased postoperative pain, shorter hospital stays, more rapid return to preoperative activity, decreased postoperative ileus, preserved immune function, and superior cosmesis are among the benefits of the laparoscopic approach.[1–7] Improvements in the optics of laparoscopes and cameras, ergonomic and dexterous enhancement and miniaturization of laparoscopic instruments, and incorporation of videoendoscopic training into surgical residencies have all contributed to the use of laparoscopy in surgical cases of ever increasing complexity.

In addition to improvements in instrumentation, advances in the understanding of the splenic blood supply[8] have allowed surgeons to perform laparoscopic distal pancreatectomy, with or without spleen salvage, successfully in humans.[8–23] However, postoperative pancreatic fistula formation occurs in up to 50% of these patients,[12] and this complication can lead to prolonged hospitalization and greater costs. Clearly, improvements in the surgical technique of laparoscopic distal pancreatectomy are needed to reduce the incidence of pancreatic fistula.

Newer dissecting and cauterizing technology has led to the development of new tools which diminish the heat transferred to surrounding tissue, allowing faster and more precise surgery. The Harmonic Scalpel (Ethicon Endo-Surgery, Cincinnati, OH, USA) is an advanced coagulation device that uses ultrasonic energy to coapt tissue planes and seal blood vessels and ductal structures. Ultrasonic scalpels are relatively easy to use for dissection and cauterization, can be used to seal vessels up to 3 mm in diameter, and are readily available in a laparoscopic configuration. Laparoscopic stapling devices rely on the mechanical pressure of multiple rows of metal or composite staples to coapt and seal. Staplers are somewhat more cumbersome to use than ultrasonic coagulation devices, but they can be used to transect vascular and ductal structures of greater diameter. Because no coagulation energy is delivered in standard stapling devices, associated with their use is a small but clinically significant risk of capillary bleeding and a theoretical risk of leaking from small ductal structures. To address this limitation, a novel radio-frequency laparoscopic linear vascular stapler has been developed (Ethicon Endo-Surgery, Cincin-

Received for publication May 5, 2003; accepted December 15, 2003.

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This study was supported by a grant from Ethicon Endo-Surgery, Cincinnati, Ohio

A preliminary abstract written prior to completion of this manuscript is in press for *Current Surgery.*

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nati, OH, USA) that applies radio-frequency energy to coagulate tissue along staple lines before the staples are delivered.[24]

The principal objective of this study was to evaluate different methods of laparoscopic pancreatic transection on the basis of ease of use and incidence of intraoperative and postoperative complications including the formation of pancreatic fistulae. The secondary objective was to describe the histologic characteristics of pancreatic tissue healing following transection with current and novel laparoscopic devices. Laparoscopic devices such as ultrasonic scalpels and radiofrequency staplers were tested in the dissection and cauterization of pancreatic tissue by performing laparoscopic distal pancreatectomy in an animal model.

MATERIALS AND METHODS

Twelve female Yorkshire pigs were randomized into 4 groups based on the method of pancreatic transection with each animal undergoing laparoscopic distal pancreatectomy (LDP) from the mid-body of the pancreas, sparing the splenic vasculature. Group 1 underwent LDP using only an ultrasonic scalpel (Harmonic Scalpel, Ethicon Endo-Surgery, Cincinnati, OH, USA); group 2 underwent LDP using an ultrasonic scalpel followed by suture reinforcement of the pancreatic stump with interrupted 4–0 silk; group 3 underwent LDP using a 35-mm laparoscopic linear vascular stapler (Ethicon Endo-Surgery, Cincinnati, OH, USA); and group 4 underwent LDP using a prototype 35-mm radio-frequency laparoscopic linear vascular stapler (Ethicon Endo-Surgery, Cincinnati, OH, USA).

Preoperative Care

Pigs weighing 35 to 45 pounds were fasted overnight; anesthetized with ketamine, pentobarbital, and fentanyl; paralyzed with pancuronium; and intubated and mechanically ventilated. Body temperature was kept between 37 and 37.5°C with a heating pad. Oxygen saturation and heart rate were monitored using a pulse oxymeter placed on the ear. Indwelling external jugular vein catheters were placed under direct vision and exteriorized in the back of the neck for intraoperative vascular access and for postoperative blood draws. Lactated Ringer's solution was infused at a rate of 10 mL/kg per hour, and prophylactic doses of cefazolin and cefoxitin were administered 20 minutes prior to abdominal incision.

Surgical Technique

All surgical procedures were performed under aseptic conditions. A Veress needle was inserted above the umbilicus and a CO_2 pneumoperitoneum of 14 mm Hg to 15 mm Hg was established (insufflator by Olympus, Melville, NY, USA). Three 10-mm trocars (one umbilical camera port and one instrument port in each of the right lower and left upper quadrants) and two 5-mm trocars (one in each of the right upper and left lower quadrants) were used in all cases. The stomach was decompressed with an orogastric tube and then retracted anteriorly with an atraumatic grasping forceps. The initial dissection was performed with the 5-mm ultrasonic dissector in all groups. The lesser sac was entered through the omentum. A plane between the superior border of the third and fourth portions of the duodenum and the inferior edge of the body and the tail of the pancreas was developed. The pancreas was further dissected free from surrounding tissue until the superior mesenteric vein (SMV) was exposed. A window between the body of the pancreas and the SMV was then created using blunt dissection. The pancreas was then transected in the mid-body according to animal group assignment.

All animals in groups 3 and 4 required one stapler reload to transect the pancreas completely. However, meticulous attention was paid to the location of the main pancreatic duct within the pancreas, and care was taken to assure that the entire main duct was transected and/or coagulated with a single "firing" of either the ultrasonic scalpel or stapling device. In the group receiving suture reinforcement of the pancreatic stump (group 2), the main pancreatic duct was identified visually and then ligated using a figure-of-eight stitch. The dissection of the distal pancreas from the duodenum, portal vein, splenic vessels and other retroperitoneal attachments was performed using the ultrasonic dissector. The excised distal pancreas was removed through one of the 10-mm ports. The operative field was irrigated with antibiotic saline and meticulous hemostasis was assured. A davol-type suction drain was placed in the pancreatic bed, exteriorized through the LLQ wound, and tunnelized subcutaneously to the lumbar area. All wounds were closed in standard fashion. The animals were allowed to awaken from anesthesia and were extubated when clinically indicated.

Postoperative Care

All animals received bupinephrine (0.1 mg IV) for postoperative analgesia and cefazolin (500 mg IV) and cefoxitin (500 mg IV) for antimicrobial prophylaxis every 12 hours until postoperative day (POD) 3. Pigs were given water ad libitum postoperatively and were advanced to regular diet on POD 4. Body weight was measured preoperatively and on POD 1, 3, 7, and 14. Peripancreatic drain output was monitored closely each day. Complete blood-cell (CBC) counts, serum glucose, serum electrolytes (Na^+, K^+, Ca^{2+}, Cl^-), serum amylase, and total bilirubin levels were obtained preoperatively and on POD 1, 3, 7, and 14. Peripancreatic fluid amylase levels were measured from the drain on POD 7 and at laparotomy on POD 14. The indwelling internal jugular vein catheter was removed on POD 7.

On POD 14, all pigs were again anesthetized, intubated, and ventilated as previously described. Exploratory laparotomies were performed and the peritoneal cavity was carefully examined for the presence of adhesions, undrained fluid collections, and other pathology. The remaining pancreas (stump, head, and uncinate process) was carefully dissected, removed, and placed in 10% buffered neutral formalin for subsequent

histopathologic analysis. The surgical edge and approximately two centimeters away from the site were examined after being embedded in paraffin. Sections were cut at 5 μm and stained with hematoxylin and eosin. Once the pancreatic tissue was removed, the pigs were euthanized. All aspects of this experiment were performed as part of an animal research protocol (SW98M247) reviewed and approved by the Institutional Animal Care and Use Committee (IACUC), The Johns Hopkins University School of Medicine.

RESULTS

All procedures were performed successfully and there were no intraoperative nor postoperative complications related to jugular vein catheters, peritoneal drains, or distal pancreatectomy other than elevated peritoneal fluid amylase levels in two pigs. The range of operative time was 95 to 105 minutes. All animals tolerated regular diet on POD 4. All pigs appeared healthy during the duration of the postoperative period of the study. Animals were weighed immediately before laparoscopic distal pancreatectomy and on postoperative day (POD) 1, 3, 7, and 14 (Table 1). The average weight of all pigs before the procedure was 37.2 pounds. Each of the four groups of pigs had gained 8% to 18% (mean = 13.4%) of preoperative body weight by POD 14.

Complete blood-cell (CBC) count data was collected immediately before laparoscopic distal pancreatectomy and on POD 1, 3, 7, and 14 (Table 2). Hematocrit and white blood-cell (WBC) and neutrophil counts remained within the normal range on POD 3 for three of the four groups; only the group that underwent pancreatic transection with the ultrasonic dissector followed by suture reinforcement of the pancreatic stump was found to have elevated WBC and neutrophil counts. All CBC parameters were normal for all groups on POD 7 and 14.

Mean blood serum glucose, electrolyte (Na^+, K^+, Ca^{2+}, Cl^-), and total bilirubin levels were measured preoperatively and on POD 1, 3, 7, and 14. Electrolyte levels were normal in all groups at all time points (Table 3). Serum glucose levels were never elevated in any group (Table 3). Because elevations in serum amylase level can indicate pancreatitis or intra-abdominal pancreatic fistula formation, blood amylase levels were measured preoperatively and at regular intervals after laparoscopic distal pancreatectomy (Fig. 1). Serum amylase levels peaked on POD 1, but remained within the normal range in all groups at all time points.

Because the presence of significant peripancreatic fluid amylase can be the earliest indication of intra-abdominal pancreatic fistula formation, drain output was carefully monitored and peripancreatic fluid amylase levels were determined on POD 7 and 14. Animals produced minimal amounts of fluid from the peripancreatic drains within the first 72 hours postoperatively (3 mL to 5 mL of serosanguineous fluid). Approximately 1 mL of clear peritoneal fluid was obtained from the peripancreatic drain of each pig on POD 7. Peritoneal fluid was also obtained from the peripancreatic region at the time of laparotomy on POD 14. Figure 2 shows average peripancreatic fluid amylase levels in the pigs 7 and 14 days following laparoscopic distal pancreatectomy. Levels from all groups were somewhat higher on POD 7 than on POD 14, and levels on POD 7 from the two stapler groups were elevated compared with levels from the two ultrasonic dissector groups. While average peripancreatic fluid amylase levels remained within the normal range of serum amylase levels for all groups at all time points, the peritoneal fluid-to-serum amylase ratio was calculated for each pig on both POD 7 and 14. This ratio was less than 1.5 for all pigs on POD 14, but on POD 7, two pigs had greatly elevated ratios: one pig from the stapler group had a ratio of 4.76 (fluid = 7850, serum = 1650) and one pig from the radio-frequency stapler group had a ratio of 6.44 (fluid = 7010, serum = 1089). These 2 cases of pancreatic fistulae result in pancreatic leak rates of 0% (0/3) for each of the two ultrasonic scalpel groups and 33% (one out of three) for each of the stapler groups.

All pigs underwent exploratory laparotomy on POD 14. Significantly more adhesions attaching the stomach and transverse colon to the pancreatic stump developed in the two stapler groups as compared with the ultrasonic dissector groups. No pancreatic fistulae, pseudocysts, or abscesses were identified in any of the animals by POD 14 (the two pancreatic fistulae had sealed by this time).

TABLE 1. Body Weight

Pancreatic Transection Method	Pre-op	POD 14	Increase
Ultrasonic scalpel	36.67 ± 0.44	39.50 ± 1.04	8%
Ultrasonic scalpel + Suture	36.33 ± 2.46	42.83 ± 2.59	18%
Stapler	36.67 ± 0.33	41.17 ± 0.73	12%
Radio-frequency stapler	39.17 ± 3.61	45.25 ± 1.75	16%

Animals were weighed immediately before (pre-op) laparoscopic distal pancreatectomy and on postoperative days (POD) 1, 3, 7, and 14 (data not shown for POD 1, 3, 7). All pigs had gained weight 2 weeks following laparoscopic distal pancreatectomy regardless of the method of pancreatic transection. Data are mean ± SEM expressed in lbs.

Histopathologic Analysis of the Pancreatic Stump

A careful dissection and excision of the remaining pancreas was performed in all animals on POD 14. Samples of pancreatic tissue from all animals were processed for histopathological analysis. Sections were performed at the level of the surgical edge of the stump for evaluation of the main duct, pancreatic tissue, and surgical scar (Fig. 3). The histologic pattern of healing following transection with an ultrasonic scalpel

TABLE 2. Complete Blood-Cell Count

CBC Parameter		Ultrasonic Scalpel		Ultrasonic Scalpel + Suture		Stapler		Radio-frequency Stapler	
	Normal Values	Pre-op	POD 3	Pre-op	POD 3	Pre-op	POD 3	Pre-op	POD 3
HCT (%)	32–50	47 ± 1	45 ± 4	42 ± 4	48 ± 3	44 ± 2	50 ± 2	46 ± 2	48 ± 0
WBC (k/μL)	6–17	14.1 ± 1.8	14.1 ± 4.8	16.6 ± 1.7	19.4 ± 4.2	15.0 ± 3.2	15.7 ± 1.1	16.5 ± 2.2	16.9 ± 1.3
Neutrophils (k/μL)	2.0–6.9	3.4 ± 0.6	5.6 ± 1.5	4.3 ± 1.1	7.3 ± 2.9	6.2 ± 3.0	4.4 ± 0.1	4.2 ± 1.0	4.4 ± 0.6

Complete blood-cell counts (CBCs) for pigs immediately before (pre-op) laparoscopic distal pancreatectomy and on the third postoperative day (POD 3). Hematocrit (HCT) and white blood-cell (WBC) and neutrophil counts remained within the normal range on POD 3 for three of the four groups; only the group that underwent pancreatic transection with an ultrasonic scalpel plus suture reinforcement of the pancreatic stump with 4-0 silk was found to have elevated WBC and neutrophil counts. All parameters were normal for all groups on POD 7 and 14 (data not shown). Blood samples were obtained through an indwelling catheter in the right external jugular vein exteriorized in the back of the neck. Data were determined using an automated cell counter, and normal values are those for normal Yorkshire pigs of similar age and weight measured on our institution's machine. Data are mean ± SEM. HCT is expressed as the percentage of red blood cells in whole blood by volume. WBC and neutrophil counts are expressed in thousands of cells per μL of whole blood (k/μL).

was one of necrosis at the surgical margin with fibroplasia adjacent to normal pancreas. Reinforcement of the pancreatic stump with 4–0 silk produced an intense pyogranulomatous inflammatory reaction to the suture. Stapler transection of the pancreas produced a pattern of peristaple serpentine necrosis resulting from the intermittent crushing of tissue along the staple line. The addition of radio-frequency energy to the staples resulted in no discernable histologic differences. Overall, a more prolific microscopic inflammatory reaction was found surrounding the area of pancreatic transection in the ultrasonic scalpel groups as compared with the stapler groups. The main pancreatic duct showed mild ectasia near the site of transection in all groups, but in no group was there necrosis or other significant pathology identified in the main duct distant from the surgical margin.

DISCUSSION

In the current study we performed laparoscopic distal pancreatectomy in pigs using four different methods of pancreatic transection: 1) ultrasonic scalpel; 2) ultrasonic scalpel plus pancreatic stump suture reinforcement; 3) 35-mm laparoscopic linear vascular stapler; and 4) prototype 35-mm radio-frequency laparoscopic linear vascular stapler. The relative low profile of the ultrasonic scalpel made it somewhat easier to use than the staplers, but all methods of pancreatic division were successful. Serum chemistry levels remained normal in all groups following surgery, and only in the group that received suture reinforcement of the pancreatic stump was an abnormality in complete blood-cell parameters found (slightly elevated WBC and neutrophil counts on POD 3).

Peripancreatic fluid collected on POD 7 and 14 was analyzed for the presence of amylase in an effort to identify intra-abdominal pancreatic fistula formation. Average peripancreatic fluid amylase levels remained within the normal range for all four groups at both time points, but, amylase levels from all groups were relatively higher on POD 7 than on POD 14, and levels on POD 7 from the two stapler groups were elevated compared with the two ultrasonic scalpel groups. While it is

TABLE 3. Serum Chemistry

	Normal Values		Ultrasonic Scalpel		Ultrasonic Scalpel + Suture		Stapler		Radio-frequency Stapler	
	Glu	Ca^{2+}	Glu	Ca^{2+}	Glu	Ca^{2+}	Glu	Ca^{2+}	Glu	Ca^{2+}
POD 0			126	8.4	108	8.8	121	9.1	103	9.2
POD 1			76	9.2	76	8.3	99	9.2	72	9.7
POD 3	80–150	7.0–11.6	66	9.1	75	8.9	137	9.2	131	9.2
POD 7			81	9.1	96	9.3	111	9.1	69	8.7
POD 14			89	8.7	94	9.1	95	9.7	82	9.4

Mean blood serum chemistry levels in pigs before and after laparoscopic distal pancreatectomy using different pancreatic transection methods. Ca^{2+}, Na^{+}, K^{+}, and Cl^{-} levels were normal in all groups at all time points (Na^{+}, K^{+}, and Cl^{-} data not shown). Serum glucose (Glu) levels were never elevated in any group. Levels were determined using an automated blood chemistry machine, and normal values are those for normal Yorkshire pigs of similar age and weight measured on our institution's machine. Data are expressed in mg/dL. POD = postoperative day.

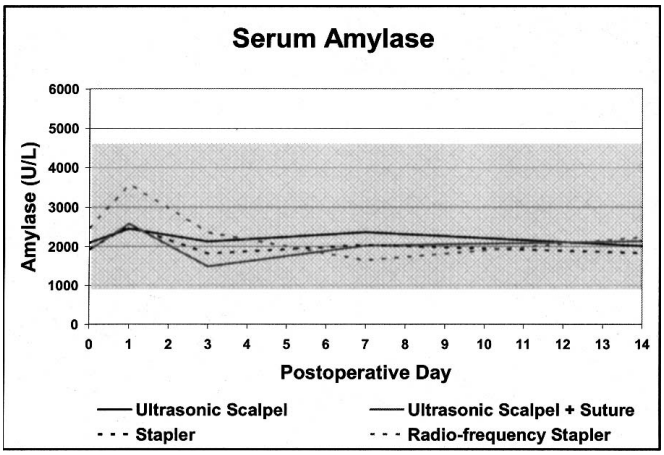

FIGURE 1. Mean serum amylase levels in pigs before and after laparoscopic distal pancreatectomy using different pancreatic transection methods. Serum amylase levels remained normal in all groups at all time points. Shaded area represents the normal range in serum amylase for normal Yorkshire pigs of similar age and weight. U/L = international units per liter.

not surprising to find peripancreatic peritoneal fluid amylase levels somewhat higher one week following pancreatic surgery as compared with two weeks following pancreatic surgery, the greater elevation of peritoneal fluid amylase levels in the two stapler groups on POD 7 warrants discussion.

Careful review of the amylase data from individual pigs reveals that peritoneal fluid amylase level elevations in the two stapler groups occurred as a consequence of elevated peritoneal fluid amylase levels in two pigs, one from each of the two stapler groups. The peritoneal fluid-to-serum amylase ratios were 4.76 in one pig from the stapler group and 6.44 in one pig from the radio-frequency stapler group. All other animals in the study had peritoneal fluid-to-serum amylase ratios less than 1.5 on POD 7 and 14. The high peritoneal fluid-to-serum amylase ratios in these two pigs are indicative of leakage of pancreatic ductal fluid into the peritoneal cavity. Twelve laparoscopic distal pancreatectomies does not represent a large enough sample size to permit detection of a statistically significant difference between two pancreatic leaks in one combined group (stapler plus radio-frequency stapler) and no leaks in the other combined group (ultrasonic scalpel plus ultrasonic scalpel with suture reinforcement). Furthermore, both fistulae had resolved by the end of our study (POD 14) and neither of these animals became ill. However, the finding does raise some concerns about the ability of staplers to effectively seal pancreatic ducts. Our findings at the time of laparotomy 2 weeks following laparoscopic distal pancreatectomy corroborate this finding. Significantly more adhesions from the stomach and transverse colon to the pancreatic stump were found in both stapler groups as compared with the ultrasonic scalpel groups. As one might expect, the animals with the densest adhesions were those with apparent pancreatic ductal leaks (ie, the two pigs with elevated peritoneal fluid-to-serum amylase ratios).

Histopathologic analysis of pancreatic tissue taken at the level of the surgical edge of the stump following completion pancreatectomy on POD 14 revealed a fairly typical pattern of healing following surgical resection: necrosis at the surgical margin with fibroplastic reaction flanking the remaining normal tissue. Because of silk's immunostimulatory properties, reinforcement of the pancreatic stump with 4–0 silk produced an intense pyogranulomatous inflammatory reaction to the suture. This inflammatory reaction may have contributed to the elevated average WBC count found in this group. Sections from the ultrasonic scalpel groups were noted to have more inflammatory cells present as compared with the stapler groups. However, because the staples had to be physically removed prior to histologic processing, it is possible that an equivalent amount of reactive tissue from the stapler groups was removed with the staples. The use of heat-generating tissue coagulation devices on or near ductal or other vital structures always raises concerns about the potential for lateral thermal injury. For this reason, careful attention was paid to the histologic appearance of the remnant pancreatic duct following transection with ultrasonic or radio-frequency coagulation

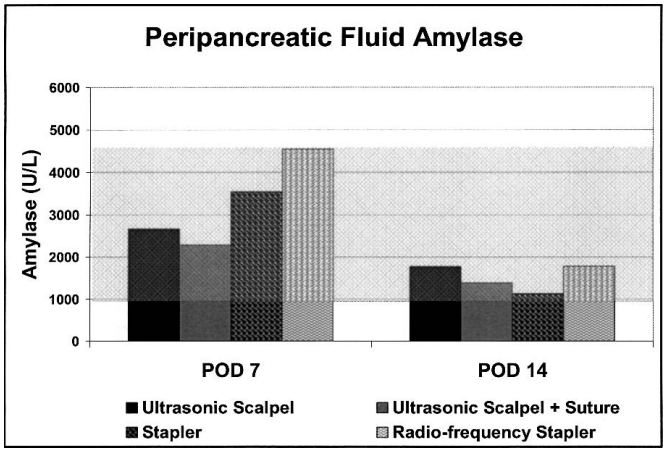

FIGURE 2. Mean pig amylase levels in fluid collected from peripancreatic drains 7 days following laparoscopic distal pancreatectomy using different pancreatic transection methods and 14 days postoperatively during exploratory laparotomy. Average peripancreatic fluid amylase levels remained within the normal range in all groups at both time points, however, levels from all groups were somewhat higher on POD 7 than on POD 14, and levels on POD 7 from the two stapler groups were elevated compared with levels from the two ultrasonic dissector groups. The peritoneal fluid-to-serum amylase ratio was elevated in one pig from each of the two stapler groups indicating minor subclinical pancreatic leaks. Shaded area represents the normal range in serum amylase for normal Yorkshire pigs of similar age and weight. U/L = international units per liter. POD = postoperative day.

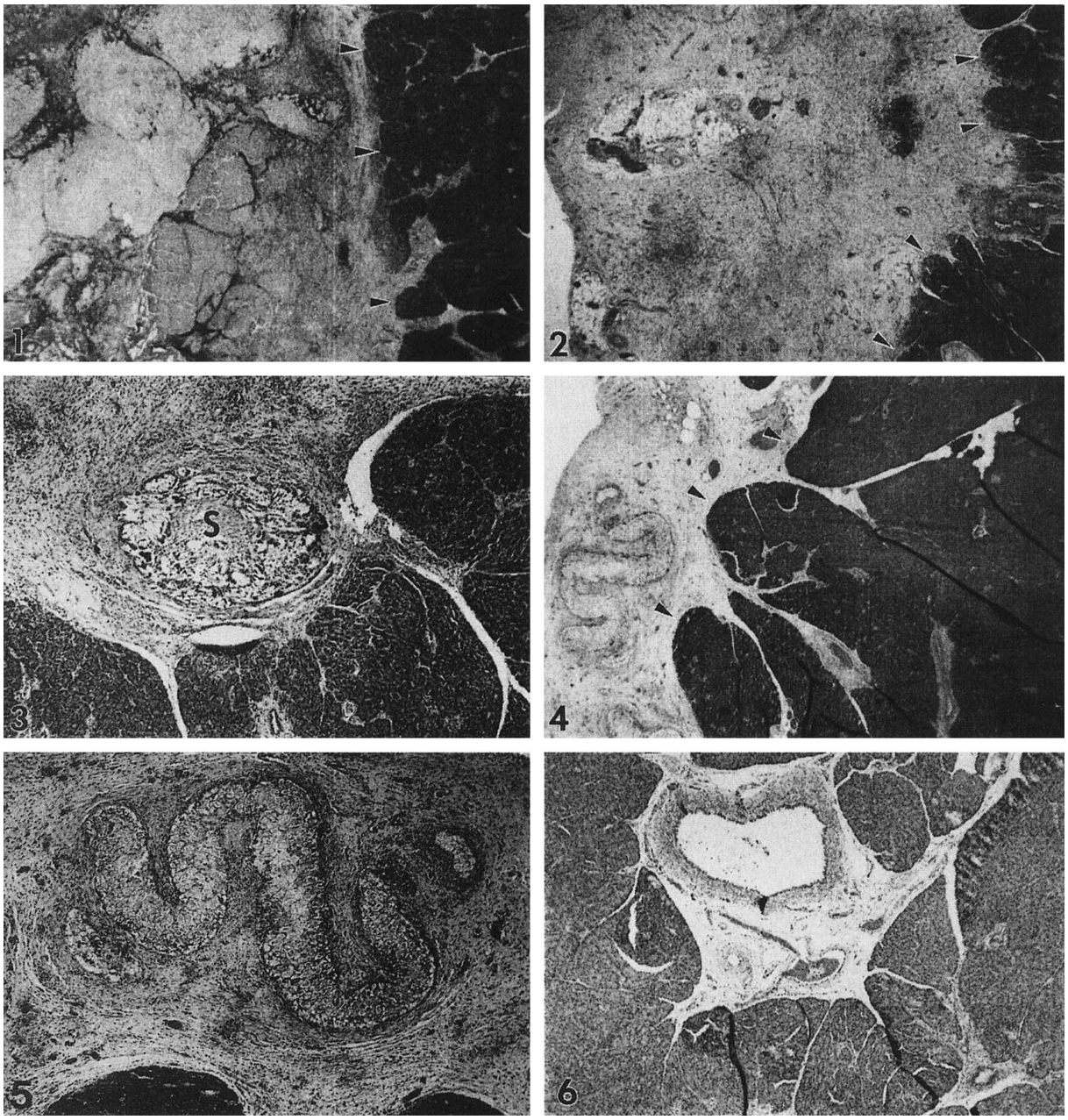

FIGURE 3. Photomicrography using hematoxylin and eosin staining of pancreatic stump tissue harvested 14 days following laparoscopic distal pancreatectomy in pigs using different pancreatic transection methods. Photo 1 (16X mag.) shows a large area of necrosis at the surgical margin with fibroplasia adjacent to normal pancreas (arrows) observed following pancreatic transection with an ultrasonic scalpel. Pancreatic transection with an ultrasonic scalpel followed by suture reinforcement of the pancreatic stump using 4-0 silk (photo 2, 16X; photo 3, 40X) produced a similar pattern of surgical margin necrosis and fibrosis adjacent to normal pancreas (arrows) with the addition of an intense pyogranulomatous inflammatory reaction to the suture (S). Photos 4 (16X) and 5 (40X) are representative of the pattern of general surgical margin necrosis (arrows indicate normal pancreas) and peristaple serpentine necrosis observed following staple transection of the pancreas with or without radio-frequency energy. The main pancreatic duct showed mild ectasia near the site of transection in all groups, but in no group was there necrosis or other significant pathology identified in the pain duct distant from the surgical margin (photo 6, 16X).

devices. All groups (including the stapler group that received no form of coagulation energy) showed mild ectasia near the site of transection, but the normal appearance of ducts distal to the site of transection in all groups testifies to the relative safety of the ultrasonic scalpel and radio-frequency stapler with regard to collateral damage from the lateral dispersement of energy.

In 1994, Soper et al reported the first study of laparoscopic distal pancreatectomy in an animal model in which five pancreatic transections were successfully performed using laparoscopic vascular staplers.[25] Though no pancreatic fistulae were reported in this study, peripancreatic drains were not used, and thus minor subclinical leaks (like the two in our series) would not have been identified. The first successful laparoscopic distal pancreatectomy in a human was reported in 1996 by Sussman et al.[9] Since this time a number of cases and small series have been reported.[10–23] Currently, the largest reported series is by Park et al in which laparoscopic distal pancreatectomy was attempted in 25 patients with an 8% rate of conversion to a hand-assisted procedure, a 4% pancreatic leak rate, a mean length of stay of 4 days, and no mortality.[22] While a wide range of surgical technique for laparoscopic distal pancreatectomy is reported in the literature (eg, spleen-preserving versus spleen-sacrificing, etc.), a common thread among all but one of the reported cases is the use of stapling devices to transect the parenchyma and main duct of the pancreas. Matsumoto et al described a single laparoscopic resection of a pancreatic mucinous cystadenoma by proximal mass suture ligation of the gland followed by distal transection using ultrasonic coagulating shears.[13] However, this group also individually ligated the main pancreatic duct with clips, revealing their lack of confidence in the ability of the ultrasonic coagulator alone to seal the main pancreatic duct.

Other than the early feasibility study in pigs[25] and a basic science experiment demonstrating improved postoperative intestinal transit time and serum cytokine levels following laparoscopic as compared with open distal pancreatectomy in dogs,[26] no reports describing experimental laparoscopic distal pancreatectomy exist. Our experiment is the first to compare different methods of laparoscopic pancreatic transection, and the only study demonstrating successful ligation of the main pancreatic duct using only an ultrasonic scalpel. Finally, we report the first use of a novel radio-frequency laparoscopic stapler in pancreatic surgery. Additional laboratory and clinical investigation is clearly needed to advance the field of laparoscopic pancreatic surgery.

Future research aimed at identifying the ideal method of laparoscopic pancreatic transection should attempt to address the limitations of our study. Swine generally provide an excellent model for human laparoscopic abdominal procedures. However, anatomic differences between pigs and humans limit this model's applicability for pancreatic surgery. First, the tail of the pancreas is far more intraperitoneal in the pig than in the human, making performance of laparoscopic distal pancreatectomy significantly less challenging in the pig. Second, because of the exorbitant cost and inherently cumbersome nature of full-grown adult Yorkshire pigs, most researchers use younger pigs (less than two or three years of age) in their swine surgical models. Just as human children have leaner pancreases than adults, "weaner" and "feeder" swine have leaner pancreases than full-grown "sows." Because our model employed the use of young feeder pigs, our subjects had very little intra- and peri-pancreatic fat. This made identification of the main pancreatic duct relatively easy in our study, leading to consistent sealing and transection of the main duct in a single "bite." The majority of pancreatic surgeons do not find themselves operating on such ideal patients. It is possible that these differences contributed to the relatively low incidence of pancreatic fistula formation in our study (17% overall). Finally, future studies should include controlled evaluation of other new laparoscopic tissue coagulation and transection devices such as Valleylab's LigaSure device (Boulder, CO, USA).

In conclusion, our study suggests that use of an ultrasonic dissector alone is safe and effective for pancreatic transection, and that no apparent benefit is gained when the coagulated pancreatic stump and main duct are reinforced with suture closure. Stapler division of the pancreas is also safe and effective but results in significantly greater postoperative adhesion formation—likely the result of subclinical and, in some cases, clinically identifiable pancreatic fistula formation. Neither benefit nor detriment was found to be associated with the addition of radio-frequency energy to the staple line. Ultrasonic scalpel coagulation devices may be the superior means of laparoscopic transection of the pancreas.

ACKNOWLEDGMENTS

This study was supported by a grant from Ethicon Endo-Surgery, Cincinnati, OH.

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