Pancreatic Surgery: A Multidisciplinary Assessment of the Value of Intraoperative US[1]

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Purpose: To assess the value of intraoperative ultrasonography (US) for different types of pancreatic surgery.

Materials and Methods: An institutional review board–approved, HIPAA-compliant retrospective review with waiver of informed consent was performed to evaluate all cases of pancreatic surgery with intraoperative US or laparoscopic US that occurred at a single institution during a 10-year period. Surgical notes, radiologic images, and clinical data for each surgical procedure and subsequent clinical course were reviewed by pancreatic surgeons and radiologists. Presumptive diagnosis, type of surgical procedure performed, and final pathologic data were recorded. A relative value score was established by consensus and assigned to each case with a grade of 0–3, which indicated the value of the intraoperative or laparoscopic US. The type of operation and pathologic data were compared in each of the value score groups. Categoric variables were compared by using either χ^2 or Fisher exact test.

Results: One hundred ninety-three intraoperative or laparoscopic US procedures were performed in 189 patients. Of the patients, there were 102 men and 87 women. The mean age was 57.8 years (range, 18–86 years). Intraoperative or laparoscopic US value scores were as follows: value score 0, 3.6%; value score 1, 11.9%; value score 2, 31.1%; and value score 3, 53.4%. The most common contribution that resulted in a high score (value score 3) was facilitation of technical performance of the surgery ($n = 60$). High value score was significantly associated with performance of pancreatitis-related surgery ($P < .001$). The surgical indication that most commonly resulted in a low value score of 0 or 1 was staging of pancreatic cancers. All cases that received a score of 0 occurred in the laparoscopic adenocarcinoma surgical setting (staging or pancreatic biopsy).

Conclusion: Intraoperative or laparoscopic US can be a valuable procedure in multiple types of surgical procedures that involve the pancreas and shows clear patterns of value in the different types of surgery.

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Intraoperative ultrasonography (US) allows high-resolution depiction of anatomic detail during the course of a procedure. Since its development in the early 1980s, intraoperative US and laparoscopic US have proved to be particularly useful in hepatobiliary and pancreatic surgical procedures (1). In the realm of pancreatic surgery, intraoperative or laparoscopic US has been used to identify nonpalpable lesions (2), guide surgical procedures (3), and stage pancreatic malignancy (1,4). Because of technical developments over the course of 30 years, the range of applications of intraoperative US has expanded to include minimally invasive laparoscopic techniques. As a result, intraoperative or laparoscopic US may be used in a wide variety of surgical procedures, and the specific aims may vary widely. To our knowledge, the relative value of intraoperative or laparoscopic US across multiple applications to pancreatic surgery has not been studied. At our institution, we have over 2 decades of experience with intraoperative and laparoscopic US as part of a variety of pancreatic surgical procedures. The aim of our study was to retrospectively review these surgical and radiologic data in conjunction with the surgeons who performed the operations to assess the value of intraoperative or laparoscopic US for different types of pancreatic surgery.

Advances in Knowledge

- Intraoperative or laparoscopic US during pancreatic surgery added value by providing additional information, which sometimes resulted in a change of the surgical plan.
- Intraoperative or laparoscopic US was particularly useful in the facilitation of technical performance of surgery.
- The value of intraoperative or laparoscopic US in adenocarcinoma surgery was variable, but it tended to receive lower value scores than when it was used during other types of surgery.
- Intraoperative or laparoscopic US was more useful for nonadenocarcinoma tumors than for pancreatic adenocarcinoma and was particularly helpful for facilitation of the technical performance of distal pancreatectomies or enucleations because it demonstrated relationships to the pancreatic duct and critical vasculature.

Materials and Methods

This study was approved by our institutional review board and is compliant with the Health Insurance Portability and Accountability Act. A waiver of informed consent was approved by the institutional review board because of the retrospective nature of the study. Cases were identified by examining surgical records and by searching the picture archiving and communication system (Centricity PACS; GE Healthcare, Barrington, Ill). The study group included all cases of intraoperative or laparoscopic US that were performed as part of a pancreas-related surgical procedure during the 10-year period between January 2001 and December 2010 at a single institution. Limited information was available on the overall rate of pancreatic surgery during this time period, and those data were used to assess the rate of intraoperative or laparoscopic US use in these procedures. A total of 1148 pancreatic or pancreas-related operations were performed during the study period; the 193 cases in our study group reflected a usage of 16.8%. There were 197 laparoscopic staging procedures performed, and 68 (34.5%) cases involved intraoperative US; there were 106 pseudocyst drainages and 30 cases that involved intraoperative or laparoscopic US (28.3%). Of the 56 Puestow procedures that were performed, 20 were performed with intraoperative or laparoscopic US (35.7%). There were 638 open operations for pancreatic tumors (benign and malignant), and 71 cases involved intraoperative or laparoscopic US (29 adenocarcinomas, 37 other tumors, five resections for pancreatitis), which reflected 11% of the cases. A total of four pancreatic stents were retrieved at surgery, and two of these were retrieved by using intraoperative or laparoscopic US. The remaining 147 cases in this group were types of procedures that were not included in our study group (eg, duodenal tumor resections or biliary procedures).

Surgeries that involved the pancreas but were performed by nonpancreatic surgeons were excluded because the surgeons were unavailable to review the impact of the intraoperative or laparoscopic US on the surgery. A total of 203 intraoperative or laparoscopic US studies were performed in 199 patients as part of a primarily pancreatic surgical procedure during the study period. Ten cases were excluded because the procedures were performed by nonpancreatic surgeons who were unavailable to review the impact of the intraoperative or

Implications for Patient Care

- Intraoperative or laparoscopic US can add value by contributing to the technical performance of an operation and by providing additional diagnostic information.
- The role of intraoperative or laparoscopic US for adenocarcinoma-related procedures should be reviewed on a case-by-case basis, because the value of intraoperative or laparoscopic US was variable and tended to show lower value scores.

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Conflicts of interest are listed at the end of this article.

laparoscopic US on the surgery. The 10 excluded cases were pseudocyst drainage (n = 1), pancreatic tumor resection (n = 8), and use of intraoperative or laparoscopic US to evaluate superior mesenteric vein thrombus in a pancreatic transplant (n = 1). The study group was made up of the remaining 193 cases.

Preoperative Imaging Examinations

Preoperative imaging studies were available for review in all cases. Thirty-seven of 193 cases incorporated preoperative magnetic resonance (MR) imaging examinations, 36 of which were performed at the authors' institution by using a standard liver mass or MR cholangiopancreatography protocol that included three-dimensional T1-weighted gradient-echo acquisitions obtained dynamically before and after the intravenous administration of a bolus of 0.1 mmol per kilogram of body weight of gadolinium chelate (Magnevist; Bayer Health Care, Wayne, NJ). One of the MR imaging examinations was performed at an outside institution. Of the 193 preoperative imaging studies, 169 were computed tomography (CT) scans. Of the CT scans, 136 were performed at the authors' institution by using a dedicated multiphasic pancreatic CT angiography protocol, which included helically acquired multidetector CT (16- or 64-detector) images that were obtained through the abdomen before and after the intravenous administration of a nonionic low- or iso-osmolar contrast agent (ioversol, Optiray 350, Covidien, Hazelwood, Mo; iodixanol, Visipaque, GE Healthcare, Amersham Health). Thirty-two contrast material–enhanced CT examinations were performed with a nonpancreatic protocol. One CT examination was performed at an outside institution and included contrast-enhanced imaging of the abdomen in multiple phases. One patientunderwent CT without intravenous contrast material at the request of the referring physician, but this patient then underwent contrast-enhanced MR cholangiopancreatography. Preoperative CT and MR imaging studies were interpreted by academic radiologists with subspecialty fellowship training in abdominal imaging.

US Technique

Intraoperative and laparoscopic US examinations of the pancreas and liver were performed according to previously described methods throughout the study period (5–7). One of two dedicated US machines was used (Philips 5000, Philips Healthcare, Andover, Mass; Leopard, BK Medical, Peabody, Mass). All intraoperative US examinations were performed by a radiologist, and the surgeon was present in the operating room. Intraoperative US examinations were performed by one of four radiologists, all of whom are fellowship-trained attending radiologists in an academic institution with 3–37 years of experience. A sonographer was present to assist with operation of the unsterilized US imager. On rare occasions where additional scanning was required because of a complex case, the radiologist would return to the surgical suite for repeat imaging sessions as necessary.

Typical intraoperative US examinations lasted approximately 10–15 minutes, with an additional 10 minutes to observe operating room protocol. A variety of transducers were used for intraoperative US. The pancreas was imaged by either a T-shaped curvilinear array with frequency range of 4–8 MHz or by one of the several end-fire linear-array transducers that were available with frequency ranges of 5–10 MHz or 7–15 MHz. Laparoscopic or intraoperative US was performed by using side-fire linear- or curved-array laparoscopic transducers with a frequency range of 5–10 MHz. Specific imaging protocol varied according to the surgical indication. When possible, the entire pancreas was scanned by overlapping sweeps in the transverse and sagittal planes. If surgical exposure of the pancreas had been performed prior to imaging, the transducer was placed directly on the surface of the gland by using either the moisture of the gland itself or additional instilled saline, if necessary, as an acoustic coupling agent. If the pancreas was not surgically exposed, transhepatic or transgastric approaches were used, and the left lobe of the liver or compressed stomach was used as an acoustic window. The liver was scanned during open surgery by using overlapping transverse and/or sagittal sweeps with a T-shaped curvilinear-array transducer (frequency range, 4–8 MHz), the low profile of which allowed for navigation of the subdiaphragmatic space. Laparoscopic US of the liver consisted of overlapping transverse or sagittal sweeps with a linear or curvilinear array (frequency range, 5–10 MHz).

Multidisciplinary Review and Value Scores

A retrospective multidisciplinary review of each case was performed for value scores of intraoperative or laparoscopic US cases, with concurrent review by radiologists and surgeons. There were at least two surgeons present for the review of each case (C.M.V., M.P.C.) and the operating surgeon. At least two radiologists were present for the review of every case (R.A.K., B.S., M.R.M.S., J.M.N.M., with 37, 10, 3, and 1 years of experience in abdominal imaging, respectively). For each review, the date of surgery, type of procedure, and surgical route (ie, laparoscopic or open) were documented. The indication for the procedure and the final pathologic diagnosis (in cases where specimens were obtained) were recorded. Preoperative, intraoperative, and relevant follow-up images were reviewed by the radiologists while the surgeons reviewed the surgical notes for each patient.

Review of surgical data.—Retrospective reviews of each case were completed by one of two pancreatic surgeons who performed the majority of the pancreatic surgeries during the study period (193 of 203 cases). Both reviewers are experienced academic pancreatic surgeons with subspecialty training in advanced pancreatic surgery (C.M.V. and M.P.C., with 21 and 10 years of experience in pancreatic surgery, respectively). From review of surgical notes and additional clinical notes obtained from the medical record and from personal knowledge of the surgical encounter, we made one of the following determinations regarding the surgical effect of intraoperative or

Figure 1

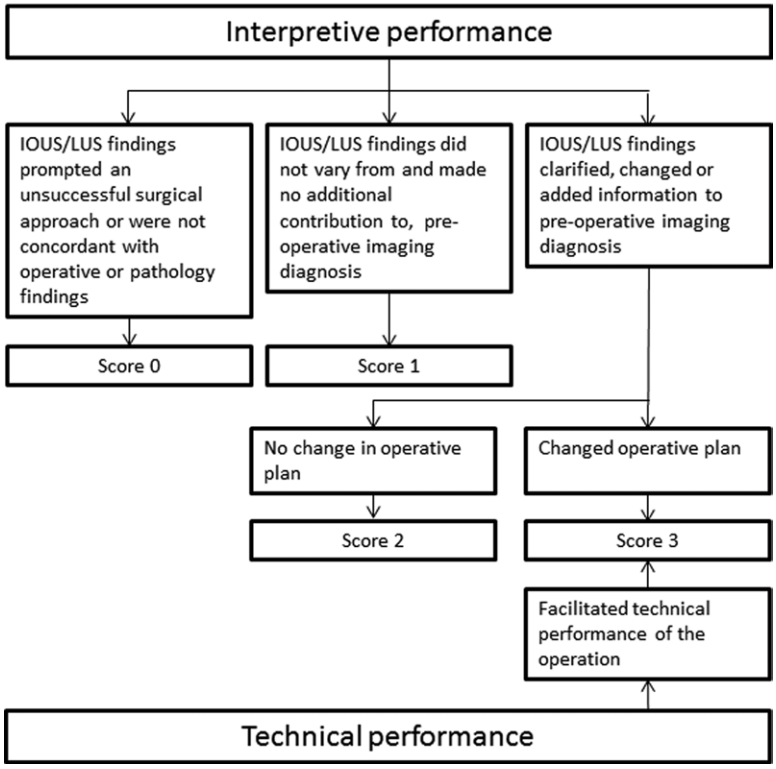


Figure 1: Decision algorithm. *IUS* = intraoperative US, *LUS* = laparoscopic US.

laparoscopic US: No change in surgical plan occurred after use of intraoperative or laparoscopic US; change in surgical plan was made owing to use of intraoperative or laparoscopic US; use of intraoperative or laparoscopic US resulted in a negative impact on the planned surgery (ie, it prompted an unsuccessful surgical approach, such as a surgery that was attempted but could not be completed as planned, or it was not concordant with surgical or pathologic findings); use of intraoperative or laparoscopic US facilitated the technical performance of the surgery. This latter term was developed to include cases in which intraoperative or laparoscopic US did not directly add any additional information, but instead was valuable because it provided real-time guidance for the surgical procedure, such as in Puestow procedures that use intraoperative or laparoscopic US–guided needle cannulation of the pancreatic duct with subsequent surgical dissection down to the needle. These designations were applied to a scoring algorithm to determine the value score (Fig 1).

Review of radiologic data.—Retrospective reviews of preoperative and intraoperative or laparoscopic US imaging data were performed for each case. Reviews of radiologic data were performed by one or more of four academic radiologists with subspecialty training in abdominal imaging (R.A.K., B.S., M.R.M.S., J.M.N.). For each patient, intraoperative or laparoscopic US examinations were reviewed and compared with preoperative imaging examinations, and concordance or discrepancy between these examinations was designated into one of the following categories: Intraoperative or laparoscopic US findings that did not vary from or made no additional contribution to preoperative imaging findings; intraoperative or laparoscopic US that clarified indeterminate preoperative imaging findings; intraoperative or laparoscopic US that provided additional or discrepant findings compared with preoperative imaging. Discrepancies between intraoperative or laparoscopic US and preoperative imaging findings were adjudicated through review of pathologic and/or clinical data by a consensus of radiologists and surgeons. Any instances in which discrepant or additional findings of intraoperative or laparoscopic US examinations that were discordant with pathologic data or with findings at surgery were categorized as intraoperative or laparoscopic US findings that prompted an unsuccessful surgical approach or were not concordant with surgical or pathologic findings. These designations were then applied to a scoring algorithm to determine the value score (Fig 1).

Score Method

After concurrent surgical and radiologic review as described, each case was consensually assigned a value score from 0 to 3 by using the score algorithm depicted in Figure 1.

Statistical Analysis

Descriptive statistics were generated for demographic data (age, sex), value scores, and types of surgery. Categoric variables were compared by using either the χ^2 test or Fisher exact test. Data were analyzed by using statistical software (SPSS 18, IBM, Armonk, NY; Minitab 16 Windows, Minitab, State College, Pa.). To determine whether there were particular types of surgery that were more likely to be associated with a high score, cases with a value score of 3 were compared with those with a score of 0, 1, or 2. This was then cross-tabulated with the type of surgical procedure performed. To determine whether there were particular surgical procedures where intraoperative or laparoscopic US was likely to be of lower value, the value scores were categorized into cases that had a score of 0 or 1 and compared with cases that had a score of 2 or 3. This was then cross-tabulated with the type of surgical procedure performed. To determine whether this change in utilization was associated with any change in distribution of value scores, we compared scores from before 2008 with those from after 2009.

Results

The study group included 193 cases of intraoperative or laparoscopic US performed in 189 patients as part of a primarily pancreatic surgical procedure. In four cases, two intraoperative or laparoscopic US procedures were performed in the same patient. One patient had multiple pseudocyst drainages, one patient had both a pseudocyst drainage and an intraductal papillary mucinous neoplasia resection, and two patients had laparoscopic US of a possible mass and subsequent open tumor resection with intraoperative US on the mass that was identified in the initial laparoscopic procedure. Of the 189 patients, 102 (54.0%) were men and 87 (46.0%) were women. The mean age was 57.8 years ± 13.3 (standard deviation). Of the 193 cases, 118 (61%) were open procedures and 75 (39%) were laparoscopic procedures.

In our group there were 30 (15.5%) pseudocyst drainage procedures, 20 (10.4%) Puestow procedures, 68 (35.2%) laparoscopic staging procedures with a presumptive diagnosis of pancreatic adenocarcinoma, 29 (15%) open surgical procedures for pancreatic adenocarcinoma, and 37 (19.2%) surgical procedures performed for pancreatic masses other than adenocarcinoma. These procedures included 27 neuroendocrine tumors, three intraductal papillary neoplasms, two mucinous cystic neoplasms, two serous cystadenomas, one solid pseudopapillary tumor, one mass that was subsequently found to be a splenule, and one neurogenic tumor (paraganglionoma), all of which were pathologically proven. There were nine (4.7%) other procedures that could not be classified into the other categories. These included two cases in which pancreatic stents were retrieved, five pancreatic resections for pancreatitis, one case of an aspirated cystic mass (subsequent resection confirmed intraductal papillary mucinous neoplasia), and one surgery performed for treatment of a common channel choledochal cyst.

Summary of Value Scores

A summary of the assigned value scores is provided in Table 1.

Table 1

Summary of Value Scores

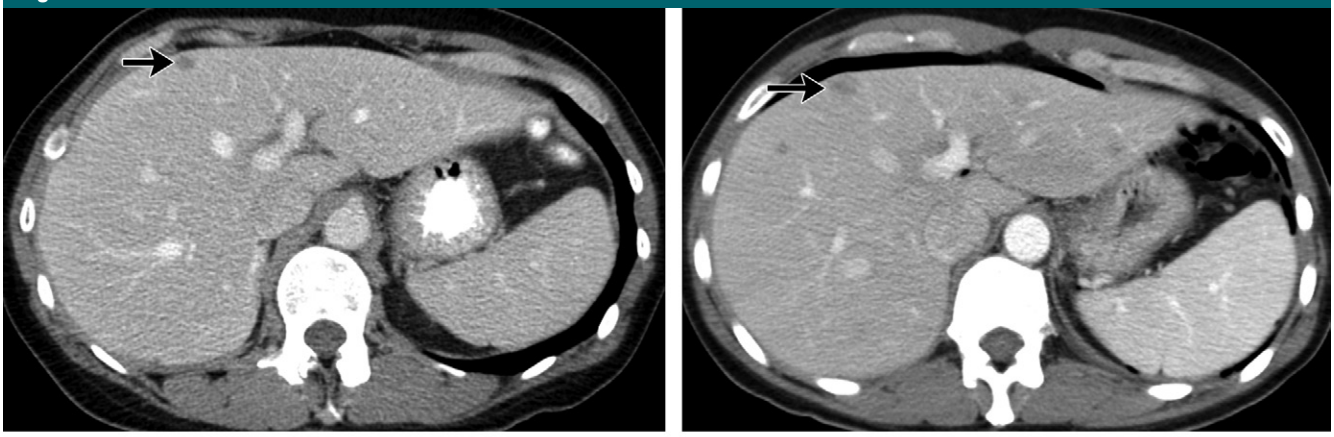
Value Score	Type of Surgery	No. of Cases
0 ($n = 7$)	Laparoscopic adenocarcinoma surgery	7
1 ($n = 23$)	Laparoscopic adenocarcinoma surgery	18
	Open adenocarcinoma surgery	4
	Other	1
2 ($n = 60$)	Pseudocyst	8
	Laparoscopic adenocarcinoma surgery	25
	Open adenocarcinoma surgery	9
	Other pancreatic mass	15
	Other	3
3 ($n = 103$)	Pseudocyst	22
	Puestow	20
	Laparoscopic adenocarcinoma surgery	18
	Open adenocarcinoma surgery	16
	Other pancreatic mass	22
	Other	5

Value Score 0.—Seven cases (3.6%) were assigned a value score of 0 (findings prompted an unsuccessful surgical approach or were not concordant with surgical or pathologic findings). All cases that received a score of 0 occurred in the setting of a laparoscopic adenocarcinoma surgery (staging or pancreatic biopsy). These represented seven (10.3%) of the 68 intraoperative or laparoscopic US examinations performed in this setting. The most common reason for the assignment of a value score of 0 was a discrepancy between determination of resectability at intraoperative or laparoscopic US examination and at surgery. In five cases, the intraoperative or laparoscopic US examination (performed to determine resectability of a pancreatic mass) led us to initially classify the mass in question as likely to be resectable, but it was discovered at surgery that the mass was unresectable. Preoperative CT angiography had indicated potential resectability in four cases by showing possible vascular involvement with abutment of the involved vessel for less than 180°; in the fifth case, no preoperative imaging had been performed because of the patient's severe allergy to contrast agents and chronic kidney disease. An additional instance of value score of 0 was a case in which laparoscopic US was used to evaluate equivocal liver lesions based on preoperative imaging. No lesions were identified. However, when the operation was converted to an open procedure, adhesions were found to obscure a small surface liver lesion. In the final case where the value score was 0, intraoperative or laparoscopic US was used to evaluate equivocal liver lesions that were thought to be hemangiomas based on US examination. However, follow-up imaging demonstrated interval growth, and subsequent biopsy confirmed the presence of metastatic adenocarcinoma (Fig 2).

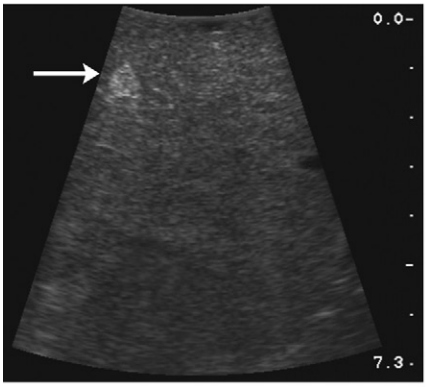
Value Score 1.—Value scores of 1 were most frequently assigned during laparoscopic adenocarcinoma surgery (78.3% [18 of 23]; staging or pancreatic biopsy). In each of these cases, it was anticipated that intraoperative or laparoscopic US was going to be used for laparoscopic staging of pancreatic adenocarcinoma, but intraoperative or laparoscopic US provided no additional information when compared with the preoperative imaging.

Value Score 2.—What follows are examples of imaging findings at intraoperative or laparoscopic US that resulted

Figure 2



a. c.



b.

Figure 2: Severe acute pancreatitis of unknown origin in a 46-year-old woman. The patient was brought to the operating room to evaluate the pancreas and liver lesions. Intraoperative US (not shown) did not demonstrate a pancreatic lesion. Subsequent biopsy demonstrated poorly differentiated adenocarcinoma of unknown primary. Preoperative contrast-enhanced CT (not shown) demonstrated fullness of the pancreas. **(a)** Axial preoperative contrast-enhanced CT image shows multiple indeterminate hypoattenuating liver lesions, including an 8-mm segment IVb lesion (arrow). **(b)** Transverse intraoperative US image of segment IVb shows echogenic hepatic lesion consistent with hemangioma (arrow). Additional hepatic lesions showed similar appearance at intraoperative US. Therefore no biopsy was performed. **(c)** Axial contrast-enhanced multidetector CT image from follow-up examination performed 1 month later shows interval growth of the segment IVb lesion (arrow). New hypoattenuated lesions (not shown) had also developed.

in a value score of 2: Intraoperative or laparoscopic US provided reassuring findings for hepatic lesions that were equivocal at preoperative imaging (six hemangiomas, four cysts or hamartomas, three cases of focal fatty sparing, two cases with no lesion identified); intraoperative or laparoscopic US confirmed or excluded the presence of a pancreatic mass that was equivocal on preoperative imaging; intraoperative or laparoscopic US confirmed the resectability of a tumor (Fig 3).

Value Score 3.—A value score of 3 was most commonly assigned for facilitation of the technical performance of surgery by intraoperative or laparoscopic US (60 of 103 [58.2%]). Examples of facilitation of technical performance include cases in which intraoperative or laparoscopic US imaging was used to select a safe landing site for pseudocyst drainage (Fig 4)

Figure 3

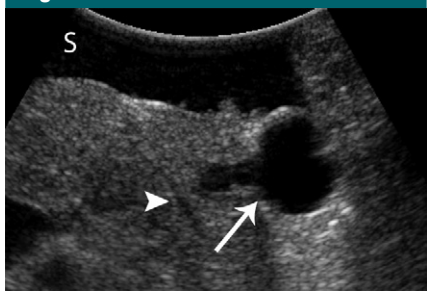


Figure 3: US image in a 36-year-old woman who was brought to the operating room for planned distal pancreatectomy for a multilobulated cystic mass in the tail of the pancreas. Intraoperative US confirmed the presence of the mass, clarified preoperative imaging findings, demonstrated the relationship between the mass (arrow) and the pancreatic duct (arrowhead) and confirmed the extent of distal pancreatectomy that was required. Sterile saline *(S)* was infused into the abdomen to facilitate US. Pathologic examination revealed this was serous cystadenoma. Value score of 2.

Figure 4

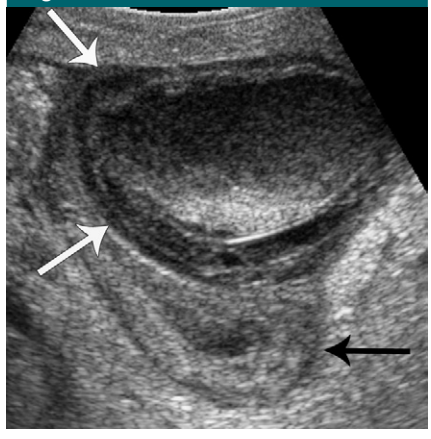


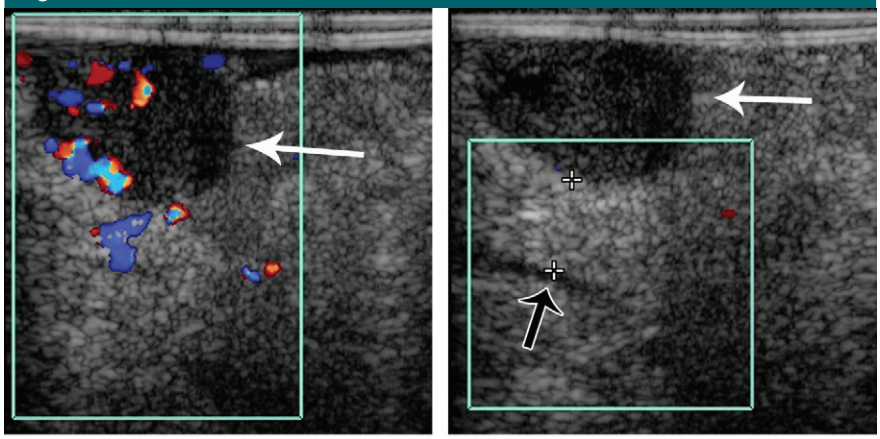
Figure 4: US image in a 76-year-old man with chronic pancreatitis and multiple prior surgeries who underwent laparotomy for drainage of multiple pseudocysts. On entering the abdomen, the surgeon encountered extensive adhesions and a prior Roux-en-Y anastomosis, and US imaging was used to demonstrate the relationship between one of the pseudocysts (white arrows) and the Roux loop (black arrow) and identify a safe location to access the cyst. Value score of 3.

Figure 5

a. b.

Figure 5: Intraoperative US images in a 47-year-old man with chronic pancreatitis and a biliary stricture who was brought to surgery for biliary bypass and Puestow procedure. When the pancreas was adequately exposed, intraoperative US was used to cannulate the pancreatic duct. **(a)** Pancreatic body shows heterogeneous pancreatic echotexture that is consistent with chronic pancreatitis, with needle (arrow) placed in the pancreatic duct. **(b)** The operating surgeon was able to confidently dissect a wedge of tissue (arrow) and expose the pancreatic duct without damage to the splenic vein. Sterile saline *(S)* was used to facilitate US imaging. Value score of 3.

Figure 6



a. b.

Figure 6: Intraoperative US images in a 68-year-old woman with a known endocrine tumor who underwent enucleation of the mass. **(a)** US confirmed presence of the vascular mass (arrow). **(b)** There was a 5-mm margin of normal pancreatic tissue that separated the mass (white arrow) from the pancreatic duct (black arrow), which was sufficient to allow safe enucleation. Value score of 3.

or to identify and cannulate the pancreatic duct for a Puestow procedure (Fig 5). Additional examples of facilitation of technical performance of surgery include the use of intraoperative or laparoscopic US to demonstrate and refine the relationship of a neuroendocrine tumor to the pancreatic duct (Fig 6) and to localize pancreatic duct stents. In the latter case, stents that had migrated entirely into the pancreatic duct and could not be retrieved at endoscopy were localized to identify the optimal site for surgical incision to limit the extent of the distal pancreatectomy that was needed (Fig 7).

Examples of interpretive intraoperative or laparoscopic US findings (discrepant or additive to preoperative diagnosis) that altered the surgical plan

Figure 7

Figure 7: US in a 51-year-old woman who had a recent episode of gallstone pancreatitis. A pancreatic stent was placed during a therapeutic endoscopic retrograde cholangiopancreatography at another institution. However, the stent migrated into the pancreatic duct and could not be retrieved at endoscopy. Intraoperative US was used to demonstrate the position of the stent (arrow) to determine the amount of pancreatic tissue that needed to be excised to ensure removal of the stent. Value score of 3.

include a pancreatic lesion that was equivocal at preoperative imaging was confirmed at intraoperative or laparoscopic US examination (Fig 8). In this case, intraoperative or laparoscopic US examination was helpful because it localized the lesion for resection and confirmed its complete resection by using specimen US imaging. In a case of pseudocyst drainage, intraoperative or laparoscopic US demonstrated unexpectedly large varices that surrounded a pseudocyst, which resulted in a change of the surgical plan to a transgastric approach (Fig 9). An additional case was that of a patient with presumed changes of chronic pancreatitis who, on the basis of preoperative imaging results, was found to have an obstructive mass at the time of surgery (Fig 10) .

Type of Surgery and Value Score

There were more low value scores (score 0 or 1) in the laparoscopic group compared with those in the open group ($P < .001$) (Table 2). There was a statistically significant difference in value scores across different types of surgery

($P < .001$). The total number of each score received, clustered by surgery type, is shown in Table 2. Intraoperative or laparoscopic US used in the setting of laparoscopic adenocarcinoma surgery (staging or pancreatic biopsy) was highly represented in the lower value score groups and represented 78.3% of value score–1 cases and 41.7% of value score–2 cases. However, the majority (43 of 68 [63%]) of intraoperative or laparoscopic US that were used in the setting of a laparoscopic adenocarcinoma surgery (staging or pancreatic biopsy) received a score of 2 or 3, and 26% (18 of 68) intraoperative or laparoscopic US in laparoscopic adenocarcinoma surgery (staging or pancreatic biopsy) received the highest value score of 3. The group with the highest value scores (value score 3) showed a diverse contribution from each of the types of surgical procedures.

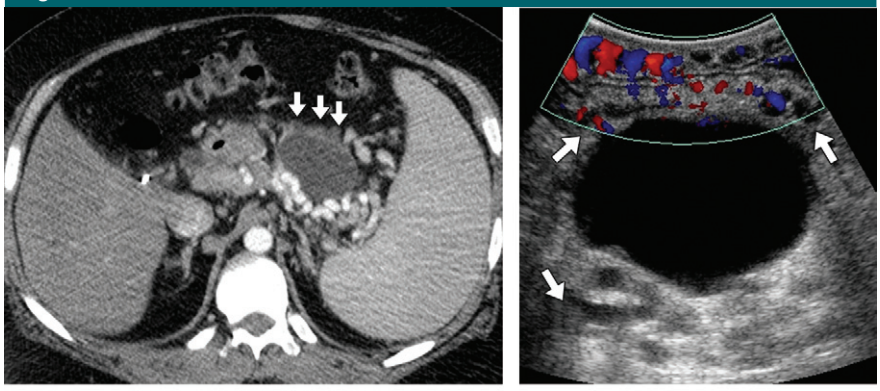
Value score of 0 or 1.—There were 30 cases that received a score of 0 or 1, and 163 cases received a score of 2 or 3. There were more low scores in laparoscopic adenocarcinoma surgery (staging or pancreatic biopsy) than expected (25 versus 11). This was statistically significant ($P < .001$).

Value score of 3.—There were 103 cases that received a value score of 3, and the remaining 90 cases received scores of 0, 1, or 2. There was a significantly higher proportion of Puestow and pseudocyst drainage procedures and, to a lesser extent, other pancreatic tumor resections compared with other surgical types in the group that received the highest value score ($P < .001$).

Final Pathologic Results

In cases where a pancreatic mass was resected, the final pathologic results were compared with the value score that was assigned to the procedure (Table 2). Cystic neoplasms of the pancreas were included in a single group and consisted of intraductal papillary mucinous neoplasm ($n = 3$), mucinous cystic neoplasm ($n = 2$), serous cystadenoma ($n = 2$), and serous pseudopapillary tumor ($n = 1$). While a range of value scores were observed in cases of pancreatic

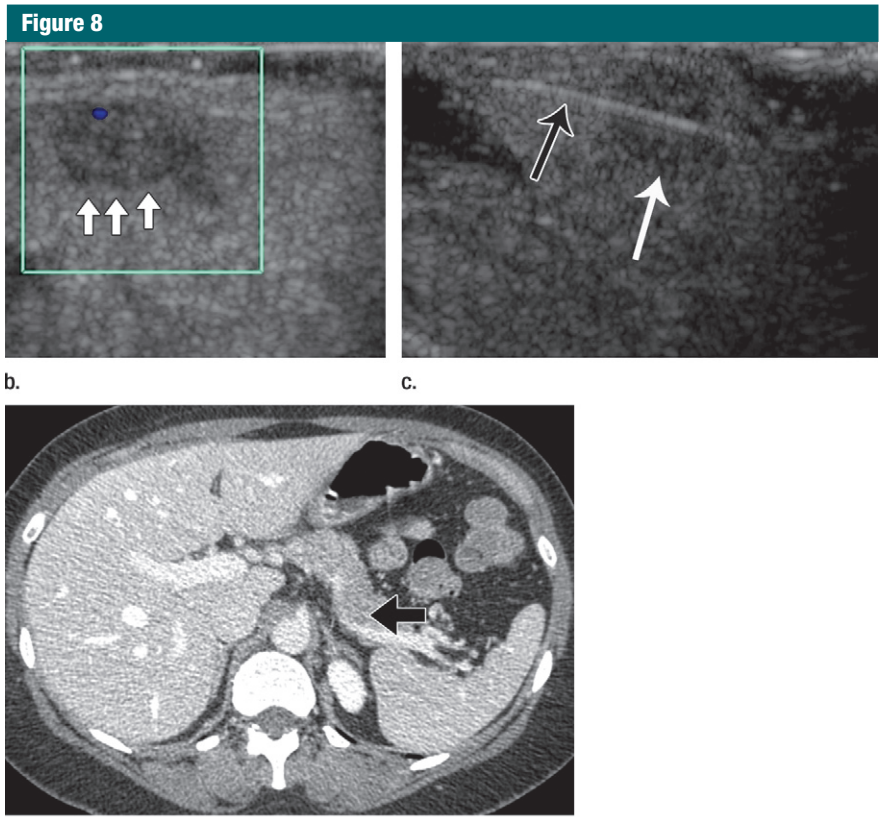
Figure 9



a. b.

Figure 9: Images in a 37-year-old man with chronic pancreatitis and a symptomatic pseudocyst and splenomegaly who underwent a laparotomy for planned splenectomy and pseudocyst drainage. **(a)** Preoperative CT angiogram shows varices adjacent to the pseudocyst, as well as a probable safe approach anteriorly (arrows). **(b)** Intraoperative US images shows numerous large varices surrounding the pseudocyst (arrows), which rendered the lesion unsafe to drain directly, as planned; instead, a transgastric approach was used. Value score of 3.

Figure 8



b. c.

a.

Figure 8: Images in a 50-year-old woman with a strong family history of pancreatic cancer. Intraoperative US was used to localize the lesion and determine the extent of distal pancreatectomy required. **(a)** CT image shows equivocal hypoenhanced lesion (arrow) that was not amenable to laparoscopic biopsy. **(b)** No mass could be palpated at laparotomy, but US image confirms presence of 6-mm lesion (arrows). **(c)** After excision, ex vivo US was used to assist placement of needle (black arrow) through the lesion (white arrow) to allow the pathologist to obtain a frozen section, which demonstrated pancreatic intraepithelial neoplasia. Value score of 3.

Figure 10

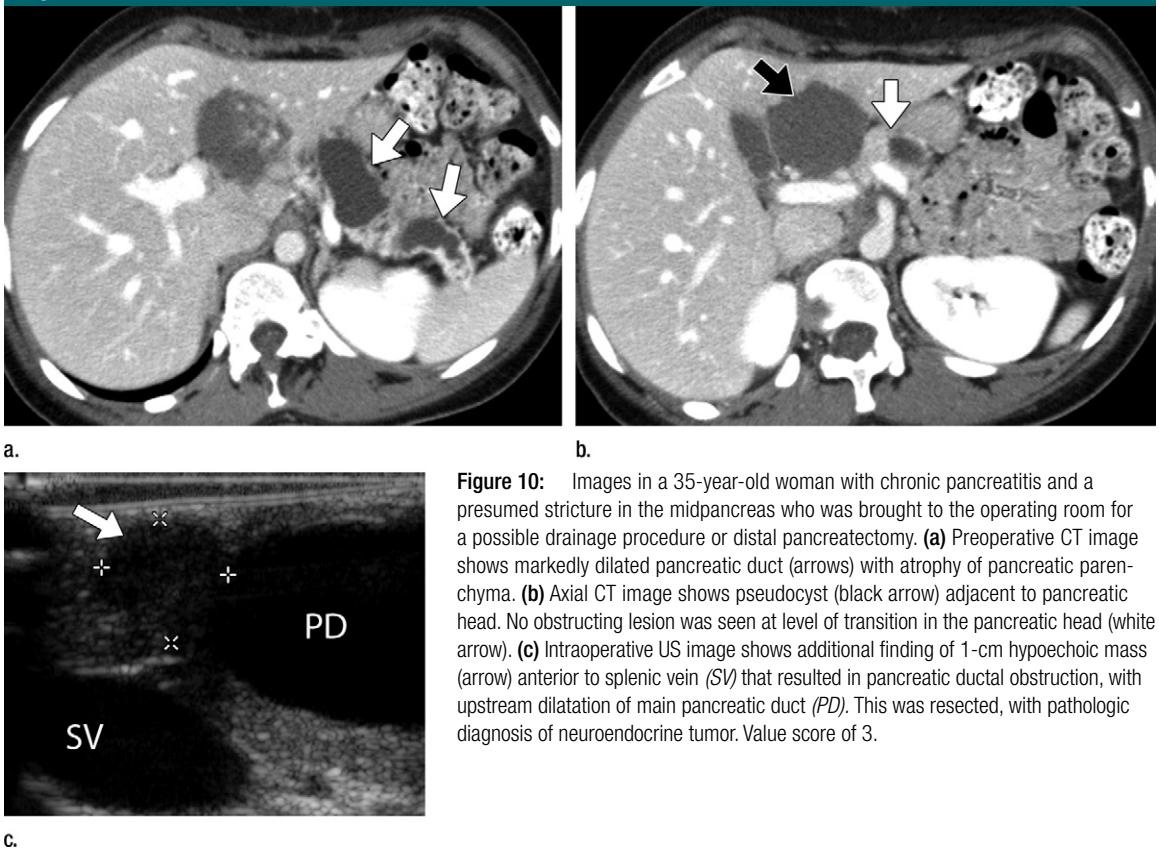


Figure 10: Images in a 35-year-old woman with chronic pancreatitis and a presumed stricture in the midpancreas who was brought to the operating room for a possible drainage procedure or distal pancreatectomy. **(a)** Preoperative CT image shows markedly dilated pancreatic duct (arrows) with atrophy of pancreatic parenchyma. **(b)** Axial CT image shows pseudocyst (black arrow) adjacent to pancreatic head. No obstructing lesion was seen at level of transition in the pancreatic head (white arrow). **(c)** Intraoperative US image shows additional finding of 1-cm hypoechoic mass (arrow) anterior to splenic vein *(SV)* that resulted in pancreatic ductal obstruction, with upstream dilatation of main pancreatic duct *(PD)*. This was resected, with pathologic diagnosis of neuroendocrine tumor. Value score of 3.

adenocarcinoma, value scores of 0 and 1 were limited to cases with this pathologic diagnosis.

Trends over Time

The usage rate of intraoperative or laparoscopic US over time demonstrated an apparent trend; there was a gradual increase in utilization of intraoperative or laparoscopic US from 2000 to 2005, and there was a subsequent decrease that reached a plateau from 2008 to 2009 (Table 2). Although there were more cases than expected in the higher scored categories and proportionally fewer cases in the lower scored categories after 2009, this was not statistically significant ($P = .239$). The rate of each type of surgery before 2008 compared with the rate after 2008 showed a statistically significant difference ($P < .001$), with a decrease in the usage rate of laparoscopic US for laparoscopic adenocarcinoma surgery (staging or pancreatic biopsy) in the post-2008 time period compared with the pre-2008 period.

Discussion

The technical aspects of performing intraoperative US on the pancreas have been previously described (5,7,8). The purpose of our study was to assess the value of this technique during different types of pancreatic surgery. The experience accrued in 10 years of practice at our institution provided an opportunity to evaluate the role of this technique in the setting of an academic facility. While the determination of whether intraoperative or laparoscopic US would be beneficial in a specific clinical situation is a matter of individual judgment and experience, our findings demonstrated clear patterns of value in the different types of surgery.

Both Puestow and pseudocyst drainage procedures and, to a slightly lesser extent, the resection of nonadenocarcinoma pancreatic masses rated highly in this assessment of the value of intraoperative or laparoscopic US. This was in agreement with our concurrent finding that facilitation of technical performance of surgery was the most common reason for a high value score assessment. In both Puestow and pseudocyst drainage procedures, intraoperative or laparoscopic US can directly facilitate the technical performance of surgery. The Puestow procedure is a lateral pancreaticojejunostomy that facilitates drainage of the pancreatic secretions and was first performed in the 1950s (9). Because patients with chronic pancreatitis often have scars, fibrosis, and distortion of the anatomic planes, it can be time consuming and difficult to obtain adequate surgical exposure (3). In these patients, intraoperative US may

Table 2

Breakdown of Value Scores

Parameters	Value Score 0	Value Score 1	Value Score 2	Value Score 3
Laparoscopic	7 (9.3)	18 (24)	28 (37.3)	22 (29.3)
Open	0	5 (4.2)	32 (27.1)	81 (68.7)
Type of surgery				
Pseudocyst	0	0	8 (26.7)	22 (73.3)
Puestow	0	0	0	20 (100)
Laparoscopic adenocarcinoma surgery	7 (10.3)	18 (26.5)	25 (36.7)	18 (26.5)
Open adenocarcinoma surgery	0	4 (13.8)	9 (31)	16 (55.2)
Other pancreatic mass	0	0	15 (40.5)	22 (59.5)
Other surgery	0	1 (11.1)	3 (33.3)	5 (55.6)
Pathologic diagnosis				
Adenocarcinoma	7 (13.5)	18 (34.6)	12 (23.1)	15 (28.8)
Endocrine neoplasms	0	0	10 (40)	15 (60)
Cystic neoplasms	0	0	4 (50)	4 (50)
Trends over time				
Pre-2008	6 (4)	21 (14.1)	48 (32.2)	74 (49.7)
Post-2008	1 (2.3)	2 (4.6)	13 (29.5)	28 (63.6)

Note.—Numbers in parentheses are percentages.

help identify the pancreatic duct and allow for easier and safer surgical exposure, or intraoperative or laparoscopic US may be used to perform US-guided needle cannulation of the duct. Intraoperative or laparoscopic US may also be used to identify intraductal calculi (10) or strictures or to localize adjacent vascular structures (11) for further guidance of surgical intervention. Similarly, during pseudocyst drainage procedures, intraoperative or laparoscopic US can be useful to guide puncture, localize small pseudocysts, or identify pseudoaneurysms or varices (2,12) that may make cyst drainage hazardous. The finding that intraoperative or laparoscopic US was particularly helpful in resection of pancreatic masses other than adenocarcinoma agrees with both the technical performance and interpretive contributions of intraoperative or laparoscopic US; in these cases, intraoperative or laparoscopic US can both help localize impalpable tumors and assist in planning a partial pancreatic resection by mapping relationships of tumors and adjacent critical structures.

Neuroendocrine tumors are a special case. Insulinomas are the most common type of neuroendocrine tumor, and they represent 60% of cases (13). These masses can be difficult to localize at preoperative imaging because they are often smaller than 1 cm and may be multifocal as a part of the multiple endocrine neoplasia type 1 syndrome (14). In these cases, intraoperative or laparoscopic US serves a dual role by aiding in the search for additional lesions and by helping localize the primary lesion to allow a limited resection, which includes enucleation or wedge resection, and thereby spares as much normal pancreatic tissue as possible.

The picture is less clear for adenocarcinoma surgery. While some authors (4) advocate laparoscopic staging as part of the standard preoperative workup for pancreatic malignancy, others (15) have questioned its value. It is likely that assessment of resectability of pancreatic carcinoma with modern high-resolution multiphase CT and/or MR imaging studies would yield diagnostic laparoscopy that is too low to justify its routine use (16,17). Laparoscopic surgery has a role for assessment of peritoneal deposits, but laparoscopic US has limited usefulness (18). In our series of cases, we found that intraoperative US that was used in the setting of laparoscopic adenocarcinoma surgery (staging or pancreatic biopsy) was associated with lower value scores. Furthermore, all of the cases in which intraoperative or laparoscopic US were considered detrimental to the surgery (ie, they contributed to the choice of an unsuccessful surgical approach or were ultimately not consistent with findings at the pathologic level or at surgery) occurred in the setting of a laparoscopic adenocarcinoma surgery (staging or pancreatic biopsy). In this setting, our finding of decreased utilization of intraoperative US in diagnostic laparoscopy over time may represent a "learning curve" effect, in which a less-helpful imaging study was used less frequently. We noted that, despite the findings in this series, 26% of intraoperative or laparoscopic US examinations that were performed in the setting of a laparoscopic procedure for adenocarcinoma (staging or pancreatic biopsy) received the highest value score of 3, and 63% of intraoperative or laparoscopic US examinations that were performed for laparoscopic staging or biopsy received scores of 2 or 3. Therefore, the decision of whether to use US in the setting of these procedures should be made according to the clinical setting in conjunction with the radiologist and surgeon.

Our study had limitations. Because this was a retrospective study, it was not possible to rigorously evaluate the criteria that were used by the surgeons to decide which cases would require intraoperative or laparoscopic US. The decision to use intraoperative or laparoscopic US was not regimented, it was at the discretion of the surgeon. For the enucleation of neuroendocrine tumors or distal pancreatectomies, they regularly relied on intraoperative or laparoscopic US for localization of the tumor. In cases of pancreatitis, in which a drainage procedure was anticipated, intraoperative or laparoscopic US would frequently be scheduled. However, intraoperative or laparoscopic US would be cancelled if the ducts were palpable or visible intraoperatively. The use of intraoperative US for adenocarcinoma surgery was variable and was determined on a case-by-case basis. We hope that the data presented in our study will help to guide future prospective research in

the utilization and value of intraoperative or laparoscopic US.

As a retrospective review, recall bias cannot be avoided. This was somewhat mitigated by the detailed surgical notes that were available for each procedure. Our study was also limited by the inherently subjective process of the application of a value score to clinical cases. For this reason, scores were assigned by using a stepwise algorithm that incorporated clearly defined radiologic and surgical criteria, and reviews were performed by consensus in an attempt to minimize individual subjectivity that is associated with grading the value of each case. In addition, the assessment of usage patterns of intraoperative or laparoscopic US over time was performed here in an attempt to demonstrate a nonsubjective trend that could correlate with the observations from the value analysis. There were limited data available on pancreatic surgery that was performed without intraoperative or laparoscopic US, and only a limited analysis could be performed; therefore, no true control group was available. Finally, differences in the US machines may have somewhat confounded the findings; however, our study was not designed to assess the differences in the sensitivities of the US machines used.

In conclusion, intraoperative or laparoscopic US may be a valuable procedure in many types of surgical procedures that involve the pancreas, and the procedure showed clear patterns of value in different types of surgery. Lower value scores were observed for laparoscopic US performed in the setting of a laparoscopic adenocarcinoma surgery (staging or pancreatic biopsy), a finding that may be helpful to surgeons and radiologists who are considering which patients may most benefit from the use of intraoperative US. Intraoperative or laparoscopic US was found to be particularly valuable in pancreatitis-related procedures (Puestow procedures and pseudocyst drainages), and in nonadenocarcinoma pancreatic tumor resections. In an era where demands on the time and resources of both radiologists and surgeons have increased, knowledge of these trends may help to create meaningful collaborations in the surgical suite.

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References

1. D'Onofrio M, Vecchiato F, Faccioli N, Falconi M, Pozzi Mucelli R. Ultrasonography of the pancreas. 7. Intraoperative imaging. Abdom Imaging 2007;32(2):200–206.
2. Sigel B, Machi J, Ramos JR, Duarte B, Donahue PE. The role of imaging ultrasound during pancreatic surgery. Ann Surg 1984; 200(4):486–493.
3. Mayo-Smith WW, Iannitti DA, Dupuy DE. Intraoperative sonographically guided wire cannulation of the pancreatic duct for patients undergoing a Puestow procedure. AJR Am J Roentgenol 2000;175(6):1639–1640.
4. Doucas H, Sutton CD, Zimmerman A, Dennison AR, Berry DP. Assessment of pancreatic malignancy with laparoscopy and intraoperative ultrasound. Surg Endosc 2007; 21(7):1147–1152.
5. Sun MR, Brennan DD, Kruskal JB, Kane RA. Intraoperative ultrasonography of the pancreas. RadioGraphics 2010;30(7):1935–1953.
6. Kruskal JB, Kane RA. Intraoperative US of the liver: techniques and clinical applications. RadioGraphics 2006;26(4):1067–1084.
7. Ganguli S, Kruskal JB, Brennan DD, Kane RA. Intraoperative laparoscopic ultrasound. Radiol Clin North Am 2006;44(6):925–935.
8. Kruskal JB, Kane RA. Intraoperative ultrasonography of the pancreas: techniques and clinical applications. Surg Technol Int 1997; 6:49–57.
9. McHale A, Buechter KJ, Cohn I Jr, O'Leary JP. Surgical management of chronic pain from chronic pancreatitis. Am Surg 1997; 63(12):1119–1122; discussion 1122–1123.
10. Printz H, Klotter HJ, Nies C, et al. Intraoperative ultrasonography in surgery for chronic pancreatitis. Int J Pancreatol 1992; 12(3):233–237.
11. Luck AJ, Maddern GJ. Intraoperative abdominal ultrasonography. Br J Surg 1999;86(1): 5–16.
12. Kubota K, Noie T, Sano K, Abe H, Bandai Y, Makuuchi M. Impact of intraoperative ultrasonography on surgery for cystic lesions of the pancreas. World J Surg 1997;21(1):72–76; discussion 77.
13. King CM, Reznek RH, Dacie JE, Wass JA. Imaging islet cell tumours. Clin Radiol 1994; 49(5):295–303.
14. Alexakis N, Neoptolemos JP. Pancreatic neuroendocrine tumours. Best Pract Res Clin Gastroenterol 2008;22(1):183–205.
15. White R, Winston C, Gonen M, et al. Current utility of staging laparoscopy for pancreatic and peripancreatic neoplasms. J Am Coll Surg 2008;206(3):445–450.
16. Thomson BN, Parks RW, Redhead DN, et al. Refining the role of laparoscopy and laparoscopic ultrasound in the staging of presumed pancreatic head and ampullary tumours. Br J Cancer 2006;94(2):213–217.
17. Maire F, Sauvanet A, Trivin F, et al. Staging of pancreatic head adenocarcinoma with spiral CT and endoscopic ultrasonography: an indirect evaluation of the usefulness of laparoscopy. Pancreatology 2004;4(5):436–440.
18. Barabino M, Santambrogio R, Pisani Ceretti A, Scalzone R, Montorsi M, Opocher E. Is there still a role for laparoscopy combined with laparoscopic ultrasonography in the staging of pancreatic cancer? Surg Endosc 2011; 25(1):160–165.