Imaging after Pancreatic Surgery: Expected Findings and Postoperative Complications

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See the invited commentary by Winslow in this issue.

Pancreatic surgery is considered one of the most technically challenging surgical procedures, despite the evolution of modern techniques. Neoplasms remain the most common indication for pancreatic surgery, although inflammatory conditions may also prompt surgical evaluation. The choice of surgical procedure depends on the type and location of the pathologic finding because different parts of the pancreas have separate vascular supplies that may be shared by adjacent organs. The surgical approach could be conventional or minimally invasive (laparoscopic, endoscopic, or robotic assisted). Because of the anatomic complexity of the pancreatic bed, perioperative complications may be frequently encountered and commonly involve the pancreatic-biliary, vascular, lymphatic, or bowel systems, irrespective of the surgical technique used. Imaging plays an important role in the assessment of suspected postoperative complications, with CT considered the primary imaging modality, while MRI, digital subtraction angiography, and molecular imaging are considered ancillary diagnostic tools. Accurate diagnosis of postoperative complications requires a solid understanding of pancreatic anatomy, surgical indications, normal postoperative appearance, and expected postsurgical changes. The practicing radiologist should be familiar with the most common perioperative complications, such as anastomotic leak, abscess, and hemorrhage, and be able to differentiate these entities from normal anticipated postoperative changes such as seroma, edema and fat stranding at the surgical site, and perivascular soft-tissue thickening. In addition to evaluation of the primary operative fossa, imaging plays a fundamental role in assessment of the adjacent organ systems secondarily affected after pancreatic surgery, such as vascular, biliary, and enteric complications.

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Introduction

Pancreatic surgical procedures are performed for a wide range of indications. The most common indication is malignancy, primarily pancreatic ductal adenocarcinoma (1). Other indications include pancreatic neuroendocrine tumors, cystic pancreatic neoplasms, pancreatic metastases, chronic pancreatitis not responding to medical management, and complications of acute pancreatitis (2–4). The technique for pancreatic resection varies depending on the location of the pancreatic pathologic entity, as different parts of the pancreas have separate vascular supply, which is also shared by adjacent structures. Pancreatic surgeries can be performed with an open approach or minimally invasive (laparoscopic or robotic-assisted) techniques (5). Endoscopic surgical procedures may be used to manage complications associated with acute pancreatitis (4,6).

Understanding the anatomy of the pancreas, recognizing indications for pancreatic surgery, being familiar with postoperative changes in anatomy, and identifying expected postsurgical changes are crucial for detecting postsurgical complications. Despite variations in pancreatic surgical techniques, these procedures commonly manifest similar complications such as pancreaticobiliary, bowel, and vascular complications, among others. Proper utilization of suitable imaging modalities is vital in the diagnosis of postoperative complications and in directing their treatment.

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Abbreviations: CBD = common bile duct, ERCP = endoscopic retrograde cholangiopancreatography, MPD = main pancreatic duct, MRCP = MR cholangiopancreatography, SMA = superior mesenteric artery, SMV = superior mesenteric vein

TEACHING POINTS

- Complications often occur at the sites of surgical anastomoses, and knowledge of the surgical approach is critical for identifying the location and type of complication with imaging.
- Leakage of pancreatic juice can trigger the autodigestion of nearby structures, resulting in complications such as vascular erosion, hemorrhage, pseudoaneurysms, and fistulous communications with adjacent structures. Additionally, it is known to be associated with delayed gastric emptying, ileus, and infections, including abdominal abscesses and wound infections.
- Unexplained abdominal pain, features of pancreatic exocrine insufficiency, and attacks of acute pancreatitis in the late postoperative period associated with imaging findings of progressive pancreatic ductal dilatation and abrupt narrowing at the anastomotic site should raise concern for stricture formation.
- Risk factors for anastomotic leak include preoperative radiation therapy, small size of the bile duct, and anastomosis of the CBD rather than the common hepatic duct to the jejunal loop. Pancreatic leak can also lead to bile leaks.
- Early-onset hemorrhage is due to surgical factors including inadequate hemostasis, slipped ligature, or fresh bleeding at a surgical site. It can occur due to arterial or venous injury or bleeding along the anastomotic site or resected parenchymal surface. Late-onset hemorrhage can occur up to several days or weeks after surgery and generally has a pathologic cause.

This article reviews the normal anatomy and embryology of the pancreas, indications for pancreatic surgeries, various types of pancreatic surgeries and their normal postoperative appearances, expected postsurgical findings, complications of pancreatic surgical procedures, and the role of imaging in their assessment.

Pancreatic Anatomy and Embryology

The pancreas is a foregut-derived retroperitoneal structure situated in the anterior pararenal space. It develops in the 4th week of embryogenesis from separate dorsal and ventral pancreatic buds (7,8) (Fig S1). Anatomically, the pancreas is divided into the head, neck, body, and tail. The C-loop of the duodenum surrounds the head of the pancreas. The neck lies anterior to the portal venous confluence and the proximal superior mesenteric vein (SMV). The splenic vein courses posterior to the body and tail of the pancreas. Anteriorly, the pancreas is bordered by the stomach and the lesser sac (9).

Blood Supply and Lymphatic Drainage

The pancreas mainly receives its blood supply from the celiac trunk and in part from the superior mesenteric artery (SMA). Typically the pancreatic head gets its arterial supply through the superior pancreaticoduodenal branches of the gastroduodenal artery and the inferior pancreaticoduodenal branches of the SMA. The body and tail receive their arterial supply predominantly from the dorsal pancreatic artery, which commonly arises from the splenic artery but may occasionally arise from the proximal proper hepatic artery or the celiac trunk. Additional small pancreatic branches from adjacent arteries, most of which arise from the splenic artery, also supply the body and tail (10,11).

The venous drainage of the pancreatic head passes through four pancreaticoduodenal veins. The posterior superior pancreaticoduodenal vein drains via the main portal vein. The anterior superior, anterior inferior, and posterior inferior pancreaticoduodenal veins drain via the SMV. The body and tail drain via tributaries predominantly into the splenic vein (10,11). Pancreatic lymphatic drainage mainly follows the arterial supply of the pancreas. The head drains into the pyloric nodes, and the body and tail drain into the pancreaticosplenic nodes. These lymph nodes drain into the celiac and superior mesenteric nodes (12).

Table 1: Types of Pancreatic Surgeries according to Clinical Indications or Diagnosis

Pancreatic neoplasms
Pancreaticoduodenectomy
Central pancreatectomy
Distal pancreatectomy
Total pancreatectomy
Surgical enucleation
Chronic pancreatitis
Drainage procedures:
Puestow procedure, pancreaticoduodenectomy, beger procedure
Resective procedures:
Total pancreatectomy, Frey procedure
Acute pancreatitis
Necrosectomy
Cystogastrostomy
Cystoduodenostomy
Cystojejunostomy

Pancreatic Surgeries and Interventions

Various management options including medical, interventional, and surgical are used to treat pancreatic neoplasms, chronic pancreatitis, and specific complications of acute pancreatitis (2–4). Some of these approaches are summarized in Table 1.

Surgical Approaches for Pancreatic Neoplasms

The surgical techniques used for resection of pancreatic neoplasms vary depending on the location of the tumor and can differ depending on whether the tumor is benign or malignant (Tables 1, 2). Surgical procedures include pancreaticoduodenectomy, distal pancreatectomy, total pancreatectomy, or, less commonly, central pancreatectomy (Fig 1). Surgical enucleation may also be performed for benign pancreatic neoplasms, neoplasms with malignant potential (eg, well-differentiated pancreatic neuroendocrine tumors), or cystic

Table 2: Indications, Techniques, and Practical Pearls for Different Surgeries Used in Management of Pancreatic Neoplasms

Procedure	Indications	Surgical Technique and Practical Pearls
Pancreaticoduodenectomy (for pancreatic head lesions)	Malignant lesions: PDAC, NET, IPMN, metastasis Premalignant diseases: IPMN, MCN Benign conditions: benign tumors	Standard approach (Whipple procedure): Resection of the pancreatic head, duodenum, proximal jejunum, gastric antrum, common bile duct (CBD), and gallbladder Followed by pancreaticojejunostomy, hepaticojejunostomy, and gastrojejunostomy (Fig 1A) Modified approach (pylorus-preserving pancreaticoduodenectomy): Spares the gastric antrum and pylorus
Distal pancreatectomy (for pancreatic body and tail lesions)	Similar indications to those for pancreaticoduodenectomy SPN	Involves resection of the body and tail of the pancreas to the left of the superior mesenteric artery and vein, with or without splenectomy (Fig 1B) Splenectomy is commonly performed when the indication is pancreatic malignancy to ensure negative resection margin Spleen-preserving distal pancreatectomy can be performed with benign tumors and small NETs not extending to the splenic hilum Preserving the spleen decreases risk for infection and sepsis Appleby procedure: Performed for locally advanced PDAC Involves resections of celiac axis
Central (middle) pancreatectomy (for central pancreatic lesions)	Applicable conditions: benign or low-grade malignant pancreatic tumors; small size (less than 5 cm), near the pancreatic neck	Resection of the central portion of the pancreas, leaving the head and tail intact (Fig 1C): Typically, the proximal stump is closed, and the distal stump drains through a Roux-en-Y pancreaticojejunostomy (Fig 1C) or a pancreaticogastrostomy Less commonly, Roux-en-Y anastomosis between the proximal and distal pancreatic stumps and the jejunum can be performed Advantage: preservation of pancreatic function and spleen Disadvantage: increased risk of pancreatic fistula (two suture lines)
Total pancreatectomy	Main duct IPMN, multifocal/diffuse PDAC, multifocal NET, and multiple metastatic lesions isolated to pancreas, such as RCC metastases	Entire pancreas, spleen, duodenum, gallbladder, and CBD are excised; spleen may be preserved when feasible (Fig 1D) Results in complete loss of the endocrine and exocrine functions

Note.—PDAC = pancreatic ductal adenocarcinoma, NET = neuroendocrine tumor, IPMN = intraductal papillary mucinous neoplasm, MCN = mucinous cystic neoplasm, SPN = solid pseudopapillary neoplasm, RCC = renal cell cancer.

neoplasms (2–4,11,13,14). The indications and details of the various surgical approaches are listed in Table 2 (15–22).

Vascular Reconstruction during Pancreatic Surgical Procedures

Assessment of resectability is most commonly based on the National Comprehensive Cancer Network (NCCN) guidelines (23–25). Vascular reconstruction may be performed for borderline resectable pancreatic tumors. The objective is to achieve a microscopically negative resection margin (R0) with no residual pancreatic tumor, an important independent factor impacting survival (26). Venous reconstruction of the involved portions of the portal vein and SMV is commonly performed (27). The reconstruction options for venous grafts include autologous veins, falciform ligament, parietal peritoneum, cryopreserved allografts, or prosthetic grafts (25).

Arterial resections are not routinely performed, as studies have shown that arterial reconstructions during pancreatic surgery have significantly higher morbidity and lower short-term and long-term survival (24,25,27). Resection of the SMA, common hepatic artery, or celiac axis is the main arterial resection performed in pancreatic malignancies (28). When arterial reconstructions are performed, they can involve a direct anastomosis, arterial transposition, or arterial bypass graft (29).

Surgeries for Chronic Pancreatitis Not Responding to Medical Management

Chronic pancreatitis has various clinical and imaging presentations. It may involve a long segment of the main pancreatic duct (MPD) with formation of strictures and/or stones. Focal chronic pancreatitis in the head of the pancreas may result in an inflammatory mass that can be mistaken for malignancy. In some cases, there may be isolated involvement of the pancreatic body or tail. The surgical approach selected for treatment is dependent on the type of pancreatic involvement and can be classified as a drainage, resection, or combined procedure (Tables 1, 3; Fig 2) (2,11,30).

Surgeries for Complications of Acute Pancreatitis

Following an episode of acute pancreatitis, a wide range of complications can develop involving different organs. Surgical management of pancreatic parenchymal complications aims mainly to treat complications of necrotizing pancreatitis, including

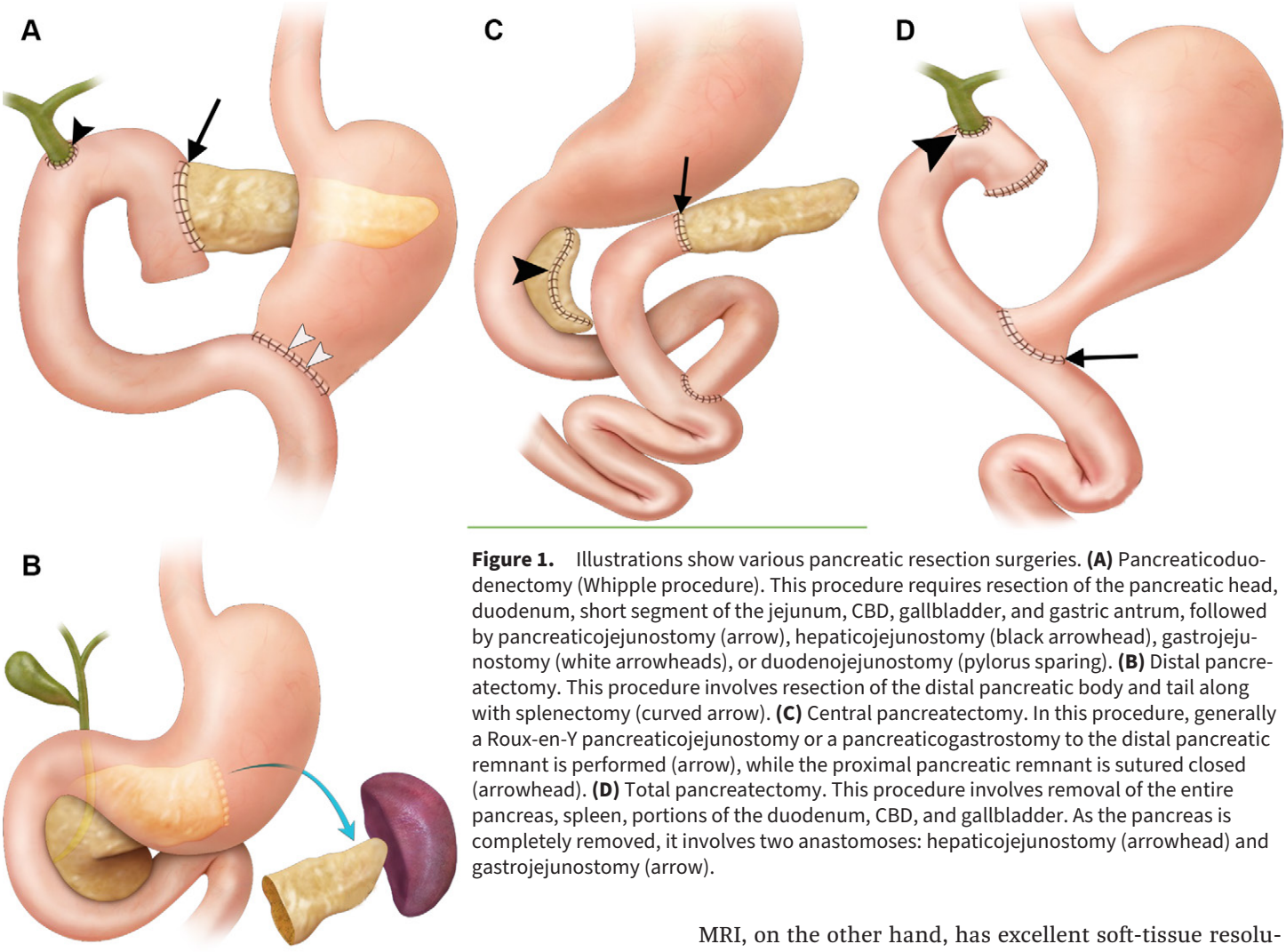


Figure 1. Illustrations show various pancreatic resection surgeries. **(A)** Pancreaticoduodenectomy (Whipple procedure). This procedure requires resection of the pancreatic head, duodenum, short segment of the jejunum, CBD, gallbladder, and gastric antrum, followed by pancreaticojejunostomy (arrow), hepaticojejunostomy (black arrowhead), gastrojejunostomy (white arrowheads), or duodenojejunostomy (pylorus sparing). **(B)** Distal pancreatectomy. This procedure involves resection of the distal pancreatic body and tail along with splenectomy (curved arrow). **(C)** Central pancreatectomy. In this procedure, generally a Roux-en-Y pancreaticojejunostomy or a pancreaticogastrostomy to the distal pancreatic remnant is performed (arrow), while the proximal pancreatic remnant is sutured closed (arrowhead). **(D)** Total pancreatectomy. This procedure involves removal of the entire pancreas, spleen, portions of the duodenum, CBD, and gallbladder. As the pancreas is completely removed, it involves two anastomoses: hepaticojejunostomy (arrowhead) and gastrojejunostomy (arrow).

acute necrotic collections and walled-off necrosis (Fig S4). A conservative approach is typically favored over surgical intervention. When intervention is necessary, minimally invasive techniques such as percutaneous or endoscopic drainage and necrosectomy are preferred over invasive options. It is preferable to perform the percutaneous procedures through a retroperitoneal approach. Surgical procedures may include cystogastrostomy and cystojejunostomy (Table 1) (4,6).

Imaging Evaluation of Postsurgical Complications

Various imaging modalities can be used to assess postoperative complications of pancreatectomy and pancreatic interventions. CT is the primary imaging modality used for postoperative pancreatic imaging due to its excellent spatial resolution, short imaging time, and accurate depiction of air and calcifications. Additionally, CT angiography aids in detecting vascular complications (31). The CT protocol for postoperative surveillance should be multiphase. It should include contrast-enhanced imaging during the arterial phase (pancreatic parenchymal phase) at 40–50 seconds and portal venous phase at 65–70 seconds, which is also in line with the recommended protocol for preoperative evaluation (32).

MRI, on the other hand, has excellent soft-tissue resolution and helps evaluate the pancreaticobiliary ductal anatomy, tumor recurrence, and indeterminate hepatic lesions seen at CT. MRI with hepatobiliary contrast material may help evaluate suspected biliary leak. MRI is limited by longer acquisition times, reliance on breath hold, lower spatial resolution, and suboptimal assessment of air and calcifications (32). Secretin-enhanced MR cholangiopancreatography (MRCP) can be performed to evaluate postoperative anatomy and possible stenosis of the MPD. It has good specificity in cases of leak. However, it should not be used to exclude leaks, due to the hazardous effect of the leaking pancreatic juice (33).

Digital subtraction angiography is often necessary for evaluation and management of vascular complications. Fluoroscopic evaluation may also be used to assess bowel motility, differentiate ileus from bowel obstruction, and evaluate the integrity of bowel anastomosis. US is a valuable tool in guiding drainage procedures, while a hepatobiliary iminodiacetic acid (HIDA) scan can help confirm the presence of biliary leak. PET/CT may be considered in cases of suspected recurrence with negative CT results (11,15,31,32,34).

Expected Postoperative Findings

Postsurgical changes can be subdivided into early and late postoperative findings. Early changes reflect the initial

Table 3: Indications and Techniques for Various Surgeries for Chronic Pancreatitis Refractory to Medical Management

Procedure	Indication	Surgical Technique
Modified Puestow (Partington-Rochelle or lateral pancreaticojejunostomy) procedure	Dilatation of the MPD without inflammatory mass or biliary obstruction in the pancreatic head	Longitudinal incision along the MPD followed by anastomosis of the MPD to a longitudinally opened Roux-en-Y loop of the jejunum (Figs 2A, S2)
Frey procedure	Chronic pancreatitis with enlargement of the pancreatic head	A duodenum-sparing surgery that involves coring of the pancreatic head Accompanied by a longitudinal incision along the length of the MPD that is anastomosed to a Roux-en-Y loop of the jejunum Small portions of pancreatic head are preserved to maintain the pancreatic parenchymal continuity and integrity of the CBD (Figs 2B, S3)
Beger procedure	Chronic pancreatitis with enlargement of the pancreatic head	A duodenum-sparing surgery that involves resection of the pancreatic head Duodenum, the intrapancreatic CBD, and inferior uncinate process are spared A Roux-en-Y loop of jejunum drains the proximal and distal pancreas (Fig 2C)
Berne procedure	Chronic pancreatitis with enlargement of the pancreatic head	A modification of the Beger procedure Coring of the pancreatic head is performed instead of resection Other steps are the same as those in the Beger procedure
Pancreaticoduodenectomy	Chronic pancreatitis with enlargement of the pancreatic head	Surgical technique described in Table 2 (Fig 1A)
Total pancreatectomy	Chronic pancreatitis refractory to medical management, with diffuse sclerosis or small duct disease (last resort)	Surgical technique described in Table 2 (Fig 1D) Islet autotransplantation may be performed in conjunction Has lower morbidity than that of pancreaticoduodenectomy Insulin independence in up to 20% of patients at 10 years after total pancreatectomy and islet autotransplantation Procedure usually not performed in alcoholic chronic pancreatitis due to lower islet yield and poor islet isolation

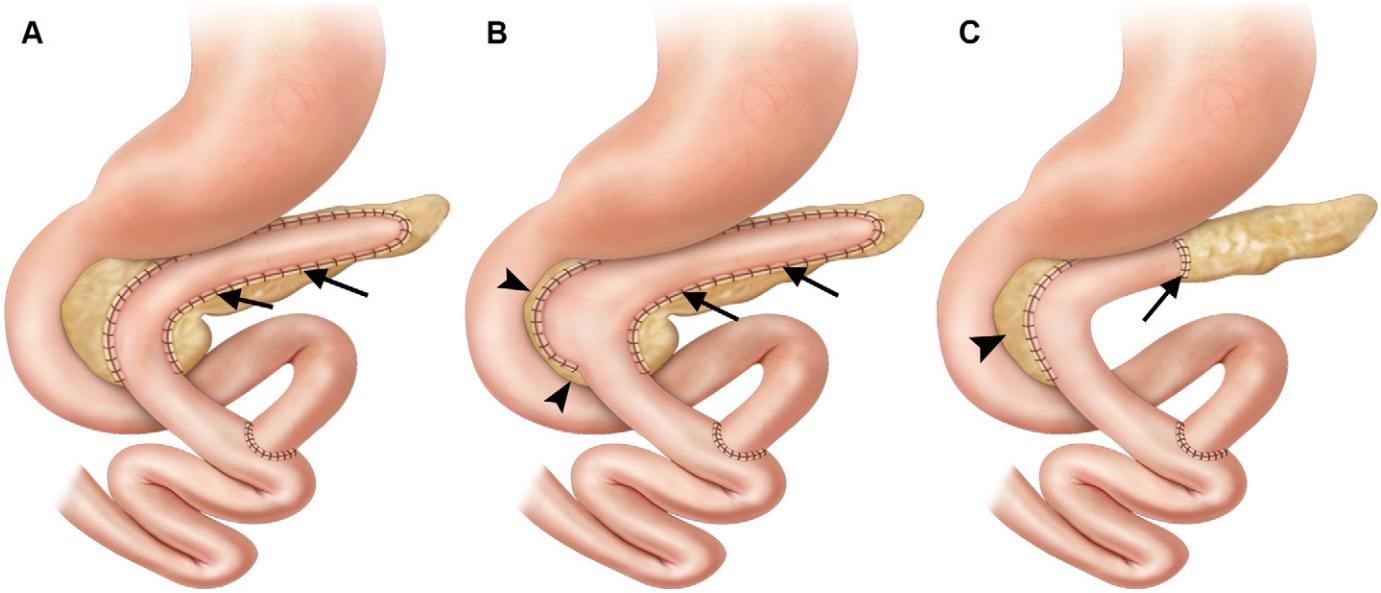


Figure 2. Illustrations show pancreatic ductal drainage procedures. **(A)** Lateral pancreaticojejunostomy (Puestow procedure), in which the MPD is opened along its long axis from the uncinate process to the tail followed by anastomosis of the MPD to a longitudinally opened Roux-en-Y loop of the jejunum (arrows). **(B)** The Frey procedure includes uncovering of the pancreatic head and opening the MPD. However, a rim of pancreatic head tissue (arrowheads) is left to keep the integrity of the biliary duct. This is followed by longitudinal opening of the pancreatic duct and pancreaticojejunostomy (arrows). **(C)** The Beger procedure involves removal of the pancreatic head while sparing the duodenum, intrapancreatic CBD, and inferior uncinate process (arrowhead), followed by pancreaticojejunostomy (arrow).

postoperative imaging features, observable within the first 3–6-month period after surgery (15,34). Late changes can manifest as persistence of previous imaging findings or emergence of new imaging findings beyond the expected time frame. It is essential to distinguish these changes from postoperative complications and/or tumor recurrence.

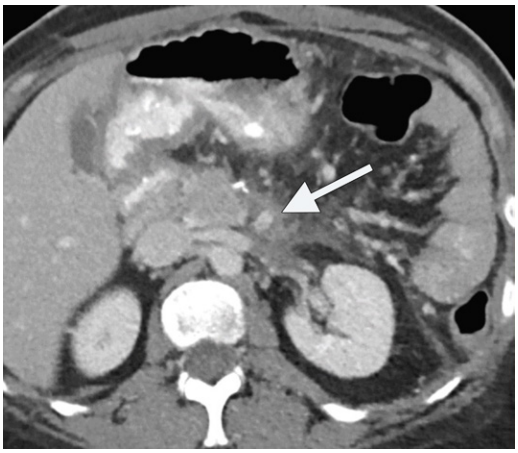


Figure 3. Soft-tissue thickening in a 53-year-old woman after distal pancreatectomy and splenectomy for pancreatic adenocarcinoma. Axial contrast-enhanced CT image of the abdomen shows postoperative fat stranding in the surgical bed and soft-tissue thickening surrounding the SMA (arrow).

Changes in the Early Postoperative Period

Postoperative Collections.—Small-volume transient uncomplicated fluid collections are commonly seen after surgery (34). In the immediate postoperative period, small pockets of air may also be present. Generally, the collections do not demonstrate rim enhancement and remain stable or decrease in size at serial imaging (15,34).

Surgical Site Edema and Fat Stranding.—Edema is common at the gastrojejunostomy, hepaticojejunostomy, and pancreaticojejunostomy anastomotic sites. Edema at the respective anastomotic sites may cause dilatation of the pancreatic duct or biliary system. Surgical anastomotic site edema and collapsed or crowded bowel loops can mimic local tumor recurrence (11,17,34).

Soft-Tissue Thickening Surrounding the Vasculature.—Perivascular cuffing (Fig 3) can manifest as thickening of soft tissue around the celiac trunk and/or superior mesenteric vasculature and may resemble a mass. A negative surgical resection margin makes the possibility of residual tumors less likely (15). Comparison with preoperative imaging findings can be useful, as residual disease following surgery is likely to be contiguous with the site of primary malignancy (11,35,36).

Prominent Regional Lymph Nodes.—Enlarged lymph nodes can manifest in the surgical bed in the postoperative period and can measure greater than 1 cm in diameter. These lymph nodes are rarely metastatic. They can be followed up at subsequent imaging to ensure stability or resolution (Fig 4) (31).

Pneumobilia, Medical Devices, and Surgical Materials.—Pneumobilia is secondary to the absence of a biliary sphincter. It is more common in the left biliary ductal system. Air in the pancreatic ductal system is less common (31). Surgical drains, clips, vascular grafts and stents, and feeding tubes may be present in the immediate postoperative period. A pancreatic duct stent is often used to decrease the risk of pancreatic leak after pancreaticojejunostomy (36).

Expected Findings in the Late Postoperative Period

Pancreatic Ductal Dilatation and Parenchymal Atrophy.—Pancreatic ductal dilatation can persist after surgery. However, progressively increasing dilatation should raise concern for local recurrence. Atrophy of the residual parenchyma after surgery is not uncommon, which may or may not be associated with dilatation of the MPD (15).

Postsurgical Scarring.—Soft-tissue thickening surrounding the mesenteric vasculature may persist into the late postoperative period. It can mimic tumor recurrence, and, therefore, comparison with prior examinations to assess subtle changes is prudent (Fig 5) (36). Radiation therapy, including adjuvant therapy, can also produce ill-defined soft-tissue thickening and stranding in the postoperative bed that can persist long after surgery and mimic tumor recurrence.

Prominent Regional Lymph Nodes.—Prominent regional lymph nodes can also manifest in the late postoperative period (Fig 4). However, an interval increased size of the lymph nodes compared with prior imaging examinations should raise suspicion for nodal metastases (15).

Postoperative Complications of Pancreatic Surgeries

Pancreatic operative procedures are among the most challenging gastrointestinal surgeries and have a high rate of postoperative complications (37). Often patients have other comorbidities that directly correlate with an increased risk of developing complications (38,39). There are several parameters used to classify surgical complications, including timing (early vs late) and severity (major vs minor) or based on the specific structures or organs affected. Morbidity and mortality rates can vary significantly among institutions, with high-volume centers generally experiencing lower rates (40,41).

Beugniez et al (42) in a root-cause analysis of 3195 patients reported a 90-day mortality rate of 4.4% (42). Harnoss et al (43) in a systematic review stated that the most common complications were delayed gastric emptying, pancreatic fistula, and postoperative hemorrhage, with a reported incidence of 22.8%, 21.9%, and 5.9%, respectively (43). Postoperative complications are classified according to the affected organs into pancreaticobiliary, vascular, bowel, and other complications in Table 4. It is not uncommon to find multiple complications in the same patient. Complications often occur at the sites of surgical anastomoses, and knowledge of the surgical approach is critical for identifying the location and type of complication with imaging.

Pancreaticobiliary Complications

Postoperative Pancreatic Leak.—Pancreatic leak following pancreatic surgery may sometimes be referred to as

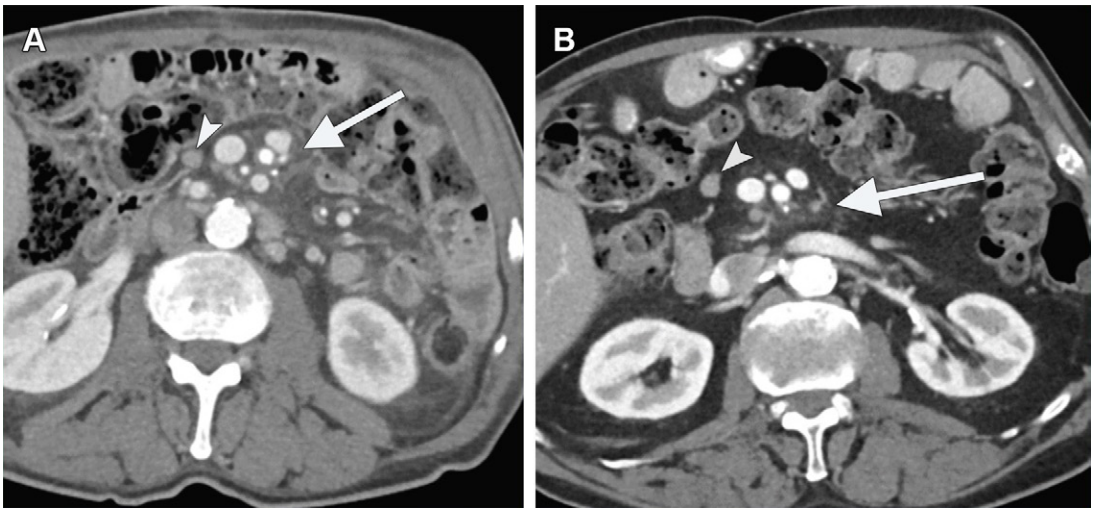


Figure 4. Prominent lymph nodes and edema in the surgical bed in a 55-year-old man after total pancreatectomy performed for adenocarcinoma of the neck and body of the pancreas. **(A)** Axial contrast-enhanced CT image of the abdomen shows ill-defined mesenteric edema (arrow) and a prominent peripancreatic lymph node (arrowhead). **(B)** Follow-up axial contrast-enhanced CT image of the abdomen obtained 6 months later shows a stable lymph node (arrowhead) and improvement of the mesenteric edema (arrow).

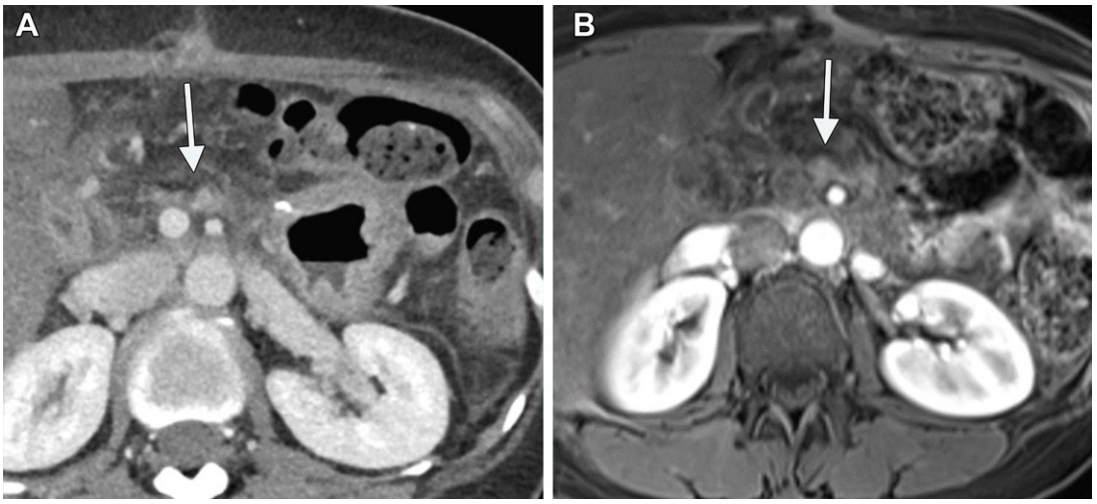


Figure 5. Postsurgical soft-tissue nodularity in a 46-year-old man who underwent total pancreatectomy 2 months earlier for adenocarcinoma of the neck of the pancreas. **(A)** Axial contrast-enhanced CT image of the abdomen shows soft-tissue nodularity anterior to the superior mesenteric vasculature (arrow). **(B)** Follow-up axial T1-weighted postcontrast MR image of the abdomen obtained 8 months after surgery shows no significant change in the interval, denoting the benign nature of these changes (arrow).

postoperative pancreatic fistula in the literature (39,44). This condition occurs when pancreatic juices leak into the abdominal cavity, either due to dehiscence of the pancreatic anastomotic site or from the raw pancreatic surface (Figs 6–12A) (34,45). It is widely regarded as the Achilles' heel of pancreatic surgery owing to its potential to cause significant morbidity and mortality (42,43). Leakage of pancreatic juice can trigger the autodigestion of nearby structures, resulting in complications such as vascular erosion, hemorrhage, pseudoaneurysms, and fistulous communications with adjacent structures (Fig 9). Additionally, it is known to be associated with delayed gastric emptying, ileus, and infections, including abdominal abscesses (Fig 8) and wound infections (Fig 9). In some cases, sepsis and multiorgan failure can also result from pancreatic leak (39,46,47).

The primary reason for development of the leak is the damaging effect of pancreatic enzymes on the anastomotic site (48). There are several predisposing factors that increase the risk of pancreatic leak, which can be categorized into pancreas-related, patient-related, and procedure-related factors. With respect to pancreas-related factors, a soft texture of the residual parenchyma and high pancreatic juice output are markers for good pancreatic function. However, such pancreatic tissue is more difficult to suture and more likely to leak compared with fibrosed pancreas. The volume of the residual pancreatic parenchyma and the size of the MPD (diameter <3 mm) are other contributing factors. Procedure-related factors also play a significant role and include type of resection, technique of anastomosis, and intraoperative blood loss. Patient-related factors include advanced age, male patients, malnourishment, jaundice, and higher body mass index (39,47).

Pancreatic leak is the most common cause of pathologic fluid collection after surgery (39). The rate of clinically significant leak after distal pancreatectomy ranges from 5% to 40% in various studies. It is generally higher than the incidence observed after pancreaticoduodenectomy, which is reported to be between 6% and 14%. However, the leak following distal pancreatectomy tends to be less severe in terms of clinical impact than those following pancreaticoduodenectomy (15,47). The diagnosis of leak is essentially based on clinical and laboratory parameters and covers a spectrum ranging from a mild self-limiting leak to a severe or fatal leak. The International Study Group for Pancreatic Fistula (ISGPF) defines *pancreatic leak* as any measurable output from the surgical drain where the drain amylase level is greater than

Table 4: Complications Related to Pancreatic Surgeries

Pancreaticobiliary complications
Pancreatic leak or postoperative pancreatic fistula
Acute pancreatitis
Pancreaticojejunostomy stricture
Biliary leak or biloma
Hepaticojejunostomy stricture
Fistulous communications of pancreatic contents (pancreatic-enteric or cutaneous fistulas)
Vascular complications
Hemorrhage
Pseudoaneurysms
Arteriovenous fistulas
Vascular thrombosis
Vascular stenosis
Organ ischemia
Bowel complications
Delayed gastric emptying
Afferent loop syndrome
Bowel injury
Anastomotic leak
Gastrojejunostomy stricture
Marginal ulcer
Other complications
Abscess
Local recurrence of metastatic disease

three times that of the serum. The ISGPF categorizes pancreatic fistula or leak into three subgroups (Fig 13) (45).

In patients with no drain placement or a drain output not suggestive of a leak, an alternative indicator of pancreatic leak includes fluid collection adjacent to the anastomotic site, which could be due to discontinuity at the anastomotic site or communication with the MPD. Associated air pockets or leakage of oral contrast material may also be present (11,15,31). Foci of fat within the postoperative collection or adjacent fat necrosis may also provide a clue for pancreatic leak (Figs 6B, 8C).

Pancreatic leaks should be differentiated from other postoperative fluid collections such as reactive ascites, seromas, or hematomas. These collections are commonly small-sized without significant regional inflammatory changes and will stay stable or decrease in size at follow-up examinations. Further differential considerations include postoperative hemorrhage or bleeding and other anastomotic leaks, such as leakage from the hepaticojejunostomy or gastrojejunostomy, which will not show increased amylase levels (Table 5). It is important to remember that pancreatic leak is much more common than leakage from other anastomotic sites and is three to four times more common than hemorrhage (39,43). In addition to the diagnosis (which may already be known to the clinician), the role of imaging is to identify associated complications, including vascular complications or abscess formation. The formation of intra-abdominal abscesses after pancreatic surgery is related to pancreatic leak in up to 50%–60% of cases (48).

Pancreaticojejunal anastomotic dehiscence refers to separation or breakdown of the connection between the pancreas and jejunum at the surgical site. This can lead to leakage of pancreatic secretions (15,31,49). Imaging plays a crucial role in detection and diagnosis of dehiscence, and findings include a visible separation between the pancreatic remnant and jejunum at CT, the presence of fluid collection at the suture line or in a peripancreatic location, and free air at the site of the anastomosis or within the abdominal cavity (Figs 10, 11) (15,31,50). In cases of distal pancreatectomy with fluid collections surrounding the anastomotic suture lines, radiologists should remain vigilant in examining the cut margin to rule out the possibility of dehiscence (Fig 12A) (51).

Although uncommon, pancreatic-jejunal anastomotic dehiscence is one of the most catastrophic complications, and prompt intervention is crucial. Treatment options include supportive measures, percutaneous drainage, and pancreaticojejunal stent placement as needed (52). In severe cases, surgical exploration and repair of the dehiscence can be performed. Rarely, completion pancreatectomy may be executed when other options are exhausted (53).

Postoperative Pancreatitis.—Pancreatitis can occur in the early or late postoperative period (Fig 14). During the early postoperative period, it is difficult to differentiate mild acute pancreatitis from postsurgical changes. Elevated amylase and lipase levels are also unreliable to diagnose acute pancreatitis during the early postoperative period (54). Severe acute pancreatitis will appear at CT or MRI with extensive peripancreatic inflammatory changes and fluid collections (Fig 14) (15,31). Postsurgical changes are commonly generalized rather than focal, while localized inflammatory changes around the pancreatic remnant should raise suspicion for acute pancreatitis (15). Patients with postoperative pancreatitis can develop a spectrum of complications similar to those of primary acute pancreatitis.

Pancreaticojejunostomy Stricture.—Pancreaticojejunostomy stricture is a long-term surgical complication seen in up to one-third of patients. The reported median time for development of a stricture after pancreaticoduodenectomy is 46 months (55). Development of pancreatic atrophy and pancreatic ductal dilatation, which occur commonly after pancreatic surgery, makes the diagnosis of a stricture difficult. Unexplained abdominal pain, features of pancreatic exocrine insufficiency, and attacks of acute pancreatitis in the late postoperative period associated with imaging findings of progressive pancreatic ductal dilatation and abrupt narrowing at the anastomotic site should raise concern for stricture formation (Fig 15) (31,34,55). A stricture needs to be differentiated from tumor recurrence at the anastomotic site, which can also cause obstructive pancreatic ductal dilatation (Fig 15) (31).

Serial follow-up cross-sectional imaging can help in making the diagnosis. T2- and diffusion-weighted MRI sequences may help assess recurrence at the anastomotic site, while MRCP helps in the assessment of ductal dilatation (Fig 15). Endoscopic retrograde cholangiopancreatography (ERCP) can help in diagnosis and management (Fig 15). Most cases are managed by balloon dilatation and stent placement in the pancreatic duct (Fig 15) (15).

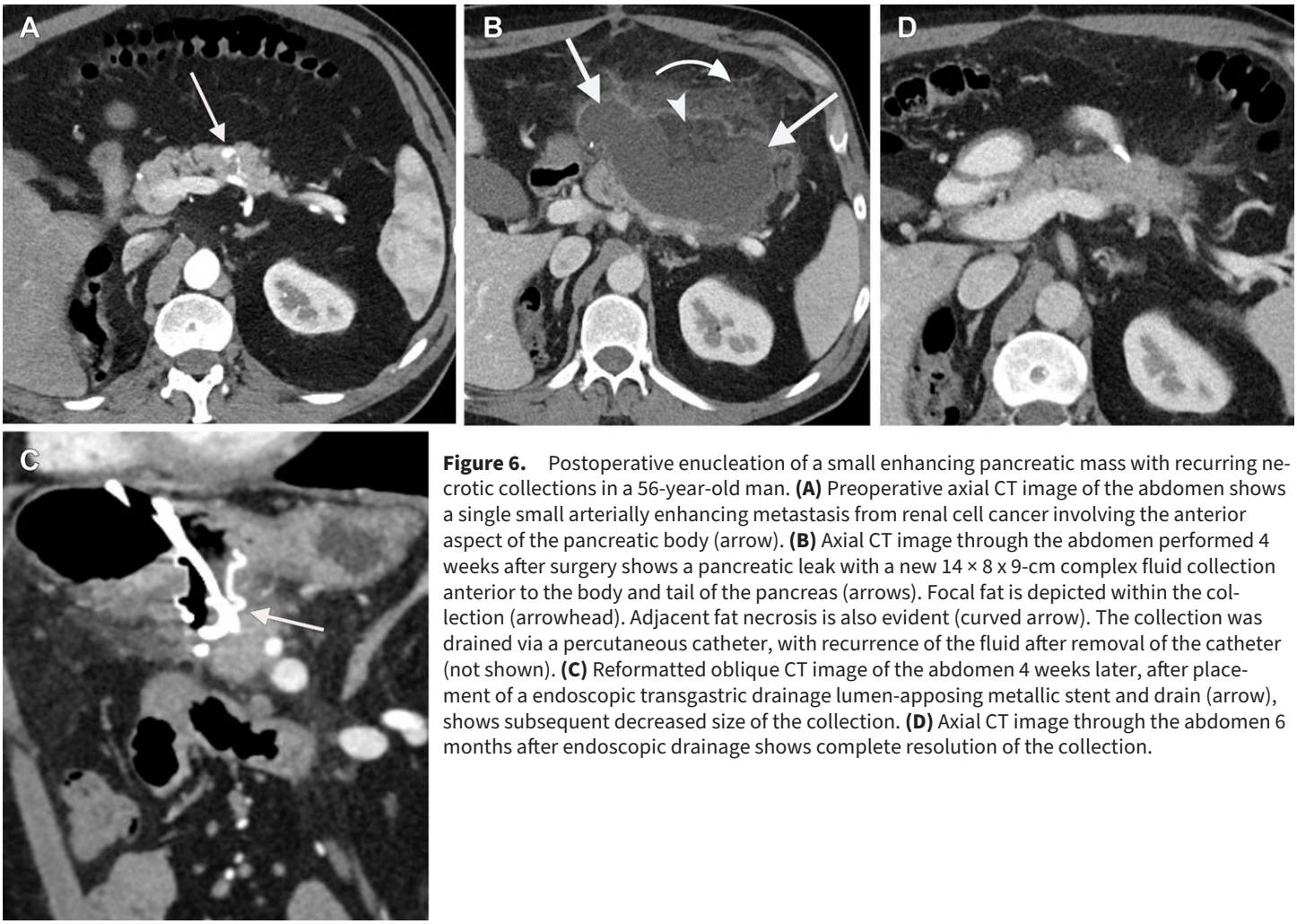


Figure 6. Postoperative enucleation of a small enhancing pancreatic mass with recurring necrotic collections in a 56-year-old man. **(A)** Preoperative axial CT image of the abdomen shows a single small arterially enhancing metastasis from renal cell cancer involving the anterior aspect of the pancreatic body (arrow). **(B)** Axial CT image through the abdomen performed 4 weeks after surgery shows a pancreatic leak with a new 14 × 8 x 9-cm complex fluid collection anterior to the body and tail of the pancreas (arrows). Focal fat is depicted within the collection (arrowhead). Adjacent fat necrosis is also evident (curved arrow). The collection was drained via a percutaneous catheter, with recurrence of the fluid after removal of the catheter (not shown). **(C)** Reformatted oblique CT image of the abdomen 4 weeks later, after placement of a endoscopic transgastric drainage lumen-apposing metallic stent and drain (arrow), shows subsequent decreased size of the collection. **(D)** Axial CT image through the abdomen 6 months after endoscopic drainage shows complete resolution of the collection.

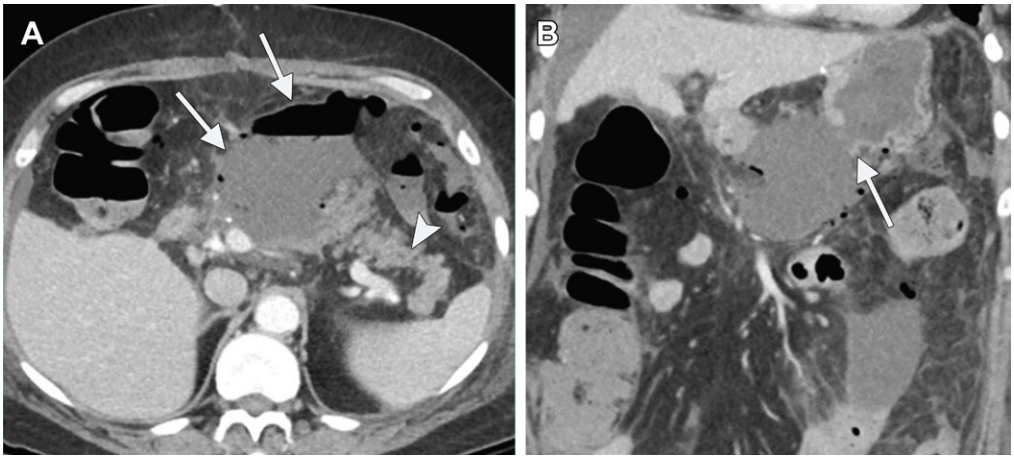


Figure 7. Anastomotic dehiscence at the pancreaticogastrostomy site in a 56-year-old man after central pancreatectomy was performed for an intraductal papillary mucinous neoplasm involving the pancreatic neck. **(A)** Axial contrast-enhanced CT image of the abdomen shows the distal portion of the pancreatic remnant (arrowhead). Note the large complex collection with air-fluid level between the proximal and distal pancreas remnants (arrows). **(B)** Coronal contrast-enhanced CT image of the abdomen shows a defect at the pancreaticogastrostomy site (arrow) consistent with anastomotic dehiscence and pancreatic leak.

Bile Leak.—Biliary fistula or bile leak can occur as a complication of pancreatic surgeries involving the head region and can be caused by anastomotic leakage or iatrogenic biliary injury, with a reported incidence of 8% after pancreaticoduodenectomy (56). The International Study Group of Liver Surgery (ISGLS) defines *bile leak* as elevated bilirubin concentration from the surgical drain, which is over three times the level of serum bilirubin, from the 3rd postoperative day (57). There is increased risk for postoperative morbidity with extended hospitalization, biliary peritonitis, abscess formation, and other infections in these patients. Risk factors for anastomotic leak include preoperative radiation therapy, small size of the bile duct, and anastomosis of the CBD rather than the common hepatic duct to the jejunal loop (36,56). Pancreatic leak can also lead to bile leaks (56). The diagnosis may be suspected clinically by raised bilirubin levels in the drain fluid.

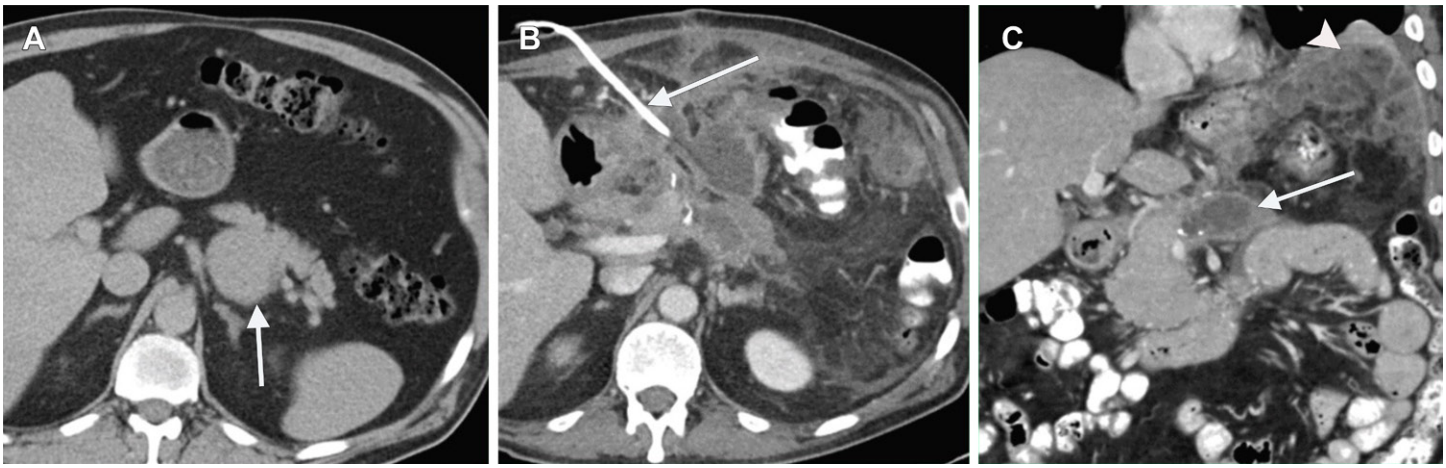


Figure 8. Pancreatic leak in a 57-year-old man after distal pancreatectomy. **(A)** Preoperative axial noncontrast CT image of the abdomen shows an isoattenuating exophytic lesion (arrow) arising from the undersurface of the body of the pancreas. The lesion proved to be a benign lymphoepithelial cyst. **(B, C)** Axial **(B)** and coronal **(C)** contrast-enhanced CT images of the abdomen were obtained due to continuous output from the drain for 20 days after surgery. The axial image **(B)** shows a large complex fluid collection in relation to the site of the distal pancreatectomy with a partially visualized drain (arrow). Additionally, there are inflammatory changes, fat necrosis, and small abscesses (arrowhead in **C**) in the left upper quadrant, better depicted on the coronal image.

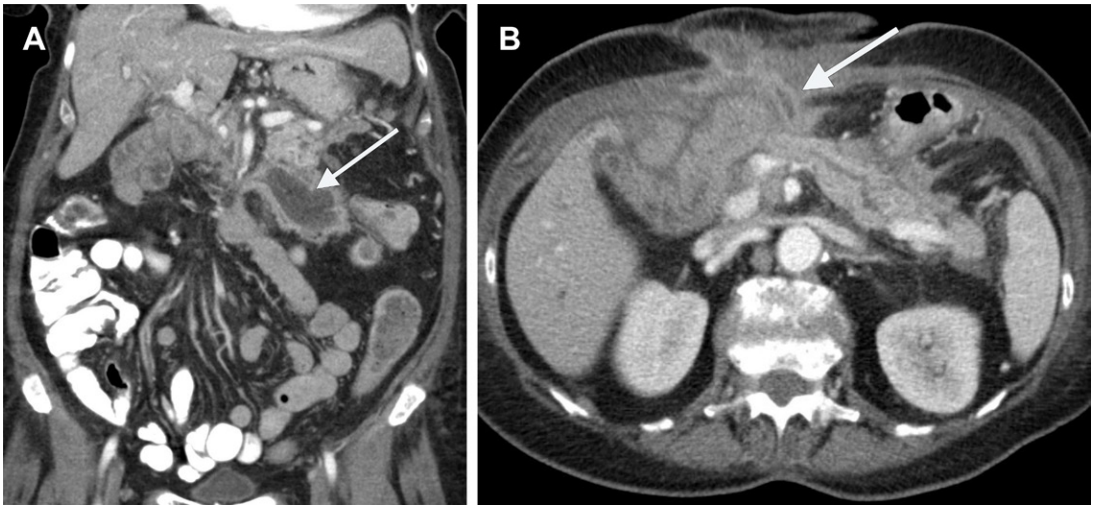


Figure 9. Pancreaticocutaneous fistula in a 71-year-old woman after a Whipple procedure for distal cholangiocarcinoma. The patient presented with a nonhealing midline wound. **(A)** Coronal contrast-enhanced CT image of the abdomen shows a collection adjacent to the pancreatic remnant (arrow). **(B)** Axial contrast-enhanced CT image of the abdomen shows a fistulous communication between the peripancreatic collection and the anterior abdominal wall collection (arrow).

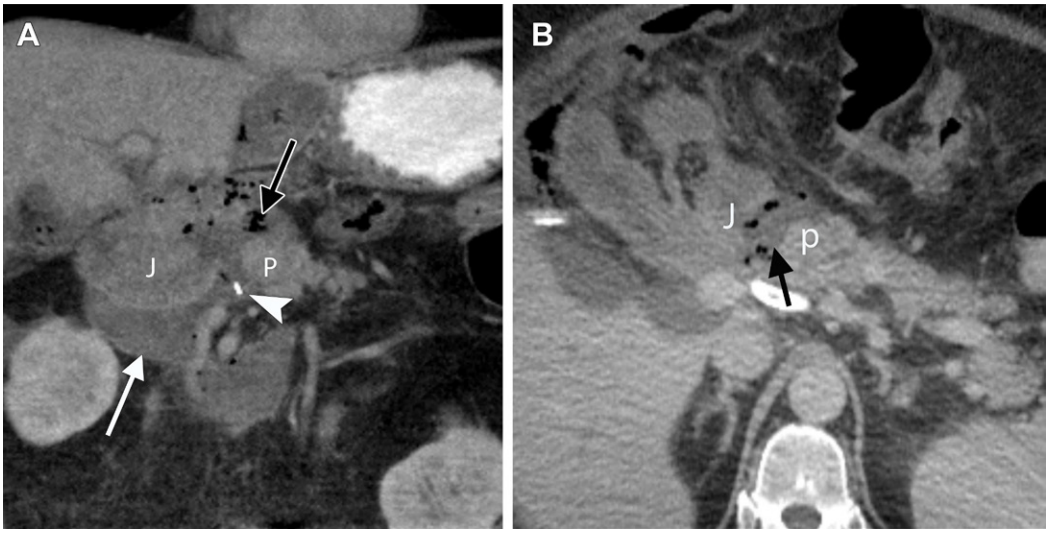


Figure 10. Leak secondary to dehiscence of the pancreaticojejunostomy anastomosis in a 72-year-old man after Whipple surgery for an intraductal papillary mucinous neoplasm. Coronal **(A)** and axial **(B)** contrast-enhanced CT images of the abdomen show a collection with foci of air within it (black arrow), interspersed between the pancreatic *(p)* and jejunal *(J)* portions of the pancreaticojejunostomy anastomosis with gaping consistent with anastomotic dehiscence. The fluid collection is seen tracking inferior to the anastomotic site (white arrow in **A**). A surgical suture (arrowhead in **A**) is also noted.

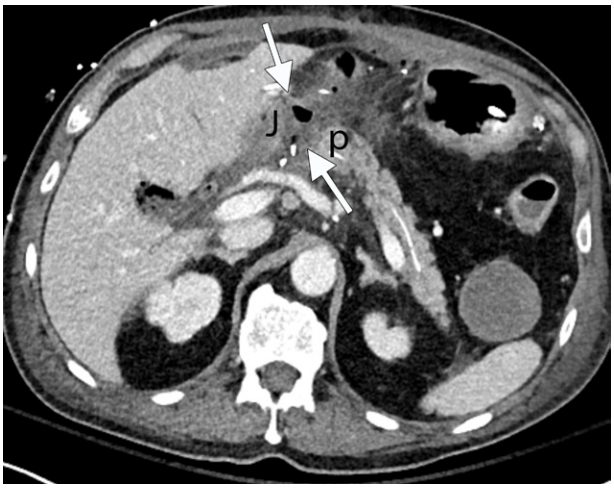


Figure 11. Anastomotic dehiscence in a 78-year-old man with distal bile duct cancer who underwent Whipple surgery 7 days earlier. The patient presented with leukocytosis and thickened tan output from the drain. Axial contrast-enhanced CT image of the abdomen shows the pancreatic *(p)* and jejunal *(J)* portions of the pancreaticojejunostomy anastomotic site. There is gaping of the anastomotic site, which is filled with a fluid collection and small extraluminal gas foci (arrows) suggestive of anastomotic dehiscence.

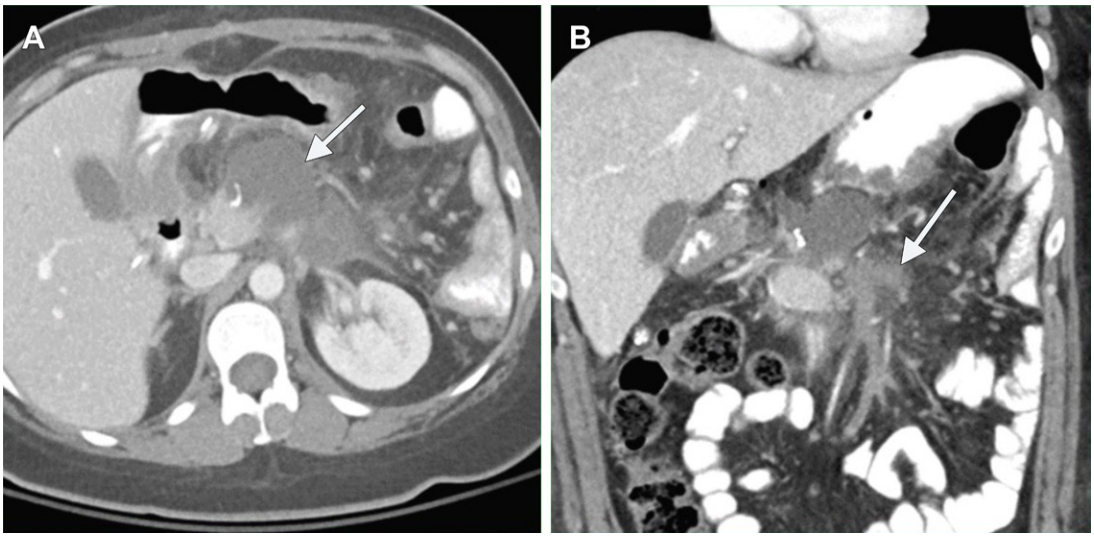


Figure 12. SMV thrombosis and operative bed collection in a 74-year-old man after distal pancreatectomy performed for mucinous cystic neoplasm. **(A)** Axial contrast-enhanced CT image of the abdomen shows a complex collection adjacent to the pancreatic remnant (arrow in **A**) consistent with leak from the distal pancreatectomy cut margin. **(B)** Coronal contrast-enhanced CT image of the abdomen shows thrombosis of the SMV and its tributaries (arrow).

CT images may show a fluid collection adjacent to the hepaticojejunostomy site, but it is difficult to differentiate from a pancreatic leak due to the proximity of both anastomoses (31). The findings can be confirmed at MRI by using hepatobiliary contrast material or with a hepatobiliary iminodiacetic (HIDA) scan. SPECT/CT can be used to differentiate a biloma from the normal accumulation of the radiotracer in the bowel (58).

Hepaticojejunostomy Stricture.—Hepaticojejunostomy is performed for biliary reconstruction after pancreaticoduodenectomy and total pancreatectomy. A hepaticojejunostomy stricture is a delayed surgical complication usually of benign cause after pancreatic surgical procedures (Fig 16). In a study conducted in patients who underwent pancreaticoduodenectomy, the reported incidence was 2.6%. There was no significant association between the size of the common bile duct (CBD) at the time of surgery and the later development of stricture or surgeries performed for benign versus malignant neoplasms (59). Patients may present with jaundice or laboratory evidence of biliary obstruction. The strictures can often be identified by following dilated intrahepatic ducts inferiorly toward the anastomotic site with the bowel at imaging (Fig 16). Due to biliary stasis, there is an increased incidence of developing infections including cholangitis and abscess formation (Fig 16). MRI with MRCP is useful in making the diagnosis and detecting associated complications. The stricture can be managed endoscopically with ERCP and through balloon dilation and stent placement (15,34).

Vascular Complications

Multiple vascular complications can occur after pancreatic surgery (Figs 12, 17–19, S7). These complications include hemorrhage, stenosis, thrombosis, graft occlusion, pseudoaneurysm formation, and organ ischemia and infarction. They are more common in patients undergoing vascular reconstructions, and risk increases with the complexity of the reconstruction

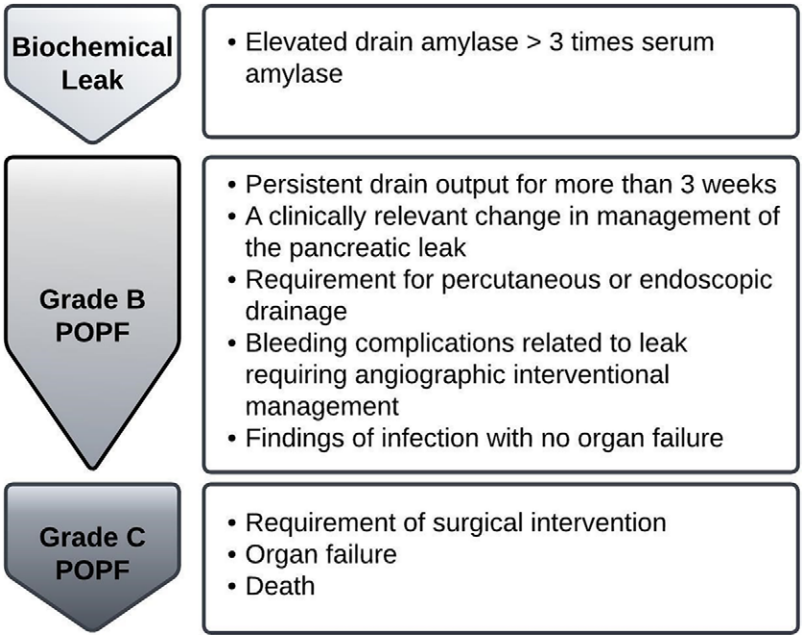


Figure 13. Chart shows International Study Group for Pancreatic Fistula (ISGPF) categories and grading system for pancreatic fistula and leak. *POPF* = postoperative pancreatic fistula.

Table 5: Types of Fluid Collections after Pancreatic Surgery

Type of Postsurgical Collection	Description and Imaging Pearls
Pancreatic leak	Most common pathologic collection Drain amylase is three times more than serum amylase Can lead to infection and abscess formation Secondary to the corrosive nature of pancreatic secretions, other complications can occur: anastomotic site dehiscence, vascular complications
Bile leak	Drain bilirubin concentration is more than three-fold that of serum bilirubin HIDA scan or hepatobiliary contrast-enhanced MRI helps confirm the diagnosis of biliary leak
Gastrojejunostomy leak	Gas-containing collection adjacent to the gastrojejunal anastomosis with contrast material leak if oral contrast material is administered Unlocalized leak results in peritonitis Localized leak causes abscess formation
Hemorrhage	Potentially lethal if not promptly identified and managed Secondary hemorrhage is more serious as it results from vascular erosion. CT images show high-attenuation collection within the operative bed ± active contrast material extravasation
Abscess	Results from secondary infection of any of the postoperative collections Characteristic rim enhancement might not be seen in early phases Confirmed by results of drain fluid analysis
Transient postsurgical collection	Small collections that remain stable or resolve over time

(15,25,28,29,36). Additionally, other postoperative complications and endovascular procedures can lead to the development of vascular complications (Fig 17).

Hemorrhage.—The International Study Group of Pancreatic Surgery (ISGPS) developed a classification system for post-pancreatic surgery hemorrhage (60). This system is based on three key parameters: the timing of onset (early vs late), the location of bleeding (intraluminal vs extraluminal), and the severity of the hemorrhage (mild vs severe). The ISGPS classification system further subdivides hemorrhage into three distinct grades. Specifically, grade A refers to mild early-onset hemorrhage within the first 24 hours after surgery, whereas grade B represents severe early-onset or any mild late-onset hemorrhage. Finally, grade C hemorrhage denotes severe late-onset hemorrhage (60). Early-onset hemorrhage is due to surgical factors including inadequate hemostasis, slipped ligature, or fresh bleeding at a surgical site. It can occur due to arterial or venous injury or bleeding along the anastomotic site or resected parenchymal surface. Late-onset hemorrhage can occur up to several days or weeks after the surgery and generally has a pathologic cause. Anastomotic leaks (most commonly pancreatic leak) and postsurgical infection or abscess can lead to vascular erosions causing delayed hemorrhage. Arterial pseudoaneurysms and bleeding anastomotic ulcers can also cause delayed hemorrhage.

Clinically, hemorrhage is suspected when there are signs of shock, an unexplained drop in hemoglobin concentration,

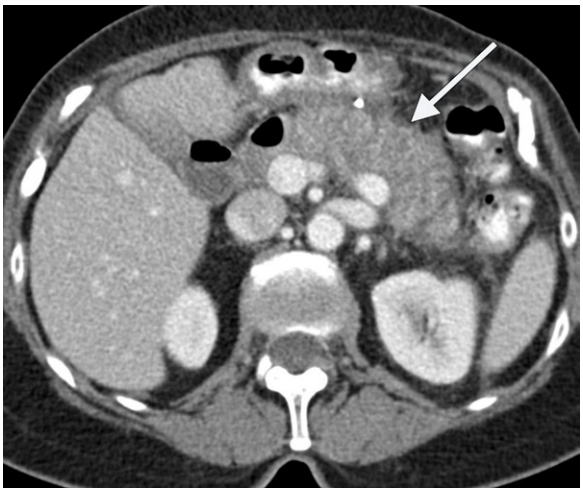


Figure 14. Pancreatic parenchymal changes consistent with acute pancreatitis in a 71-year-old woman after Whipple surgery for a pancreatic head neuroendocrine tumor. The patient presented with acute-onset abdominal and back pain. Axial contrast-enhanced CT image of the abdomen shows changes of the Whipple procedure with diffuse enlargement of the pancreatic remnant and peripancreatic inflammatory change (arrow), consistent with acute interstitial pancreatitis of the pancreatic remnant. There was elevation of serum lipase levels, corroborating the imaging evidence of pancreatitis.

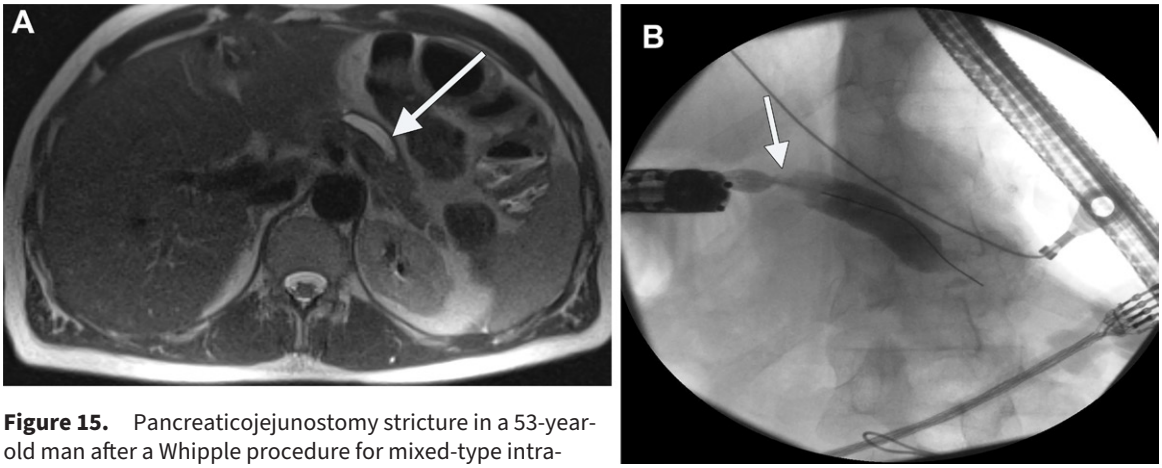


Figure 15. Pancreaticojejunostomy stricture in a 53-year-old man after a Whipple procedure for mixed-type intraductal papillary mucinous neoplasm. **(A)** Axial T2-weighted MR image of the abdomen obtained 6 months postoperatively shows a new diffuse dilatation of the MPD in the pancreatic remnant (arrow). There was no dilatation of the biliopancreatic limb. The findings are highly suggestive of anastomotic stricture. **(B)** ERCP image shows cannulation of the pancreaticojejunostomy and a marked narrowing at the anastomosis (arrow). A stent was placed across the stenosis (not shown). Brushing of the pancreatic duct and tissue biopsy of the stricture were performed at the time of ERCP, and histopathologic assessment showed no tumor recurrence.

bleeding from the surgical drain or nasogastric tube, hematemesis, or melena (39,60–62). Small amounts of bleeding (sentinel bleeding) from the surgical drain or enteric drainage tube may be evident in some cases before an episode of major hemorrhage. The gastroduodenal artery stump is the most common site of bleeding and pseudoaneurysm formation after pancreaticoduodenectomy (60,63).

Active bleeding (Fig S5) and pseudoaneurysms can be identified after intravenous contrast material injection and are ideally evaluated at CT angiography. With a sensitivity and specificity of 91% and 99%, respectively, arterial phase contrast-enhanced CT is highly effective in identifying the precise bleeding site (64). During the arterial phase, active extravasation may exhibit a jetlike or swirling appearance (Fig S5). Confirmation of the diagnosis can be achieved by observing contrast material pooling at the same site during the venous phase on dual-phase CT images (Figs 17, S5). Patients whose condition is unstable may directly undergo conventional angiography for both diagnosis and therapy (Fig 19) (15,36). A technetium 99m (^{99m}Tc)–labeled red blood cell (RBC) scan is highly sensitive in detecting small quantities of hemorrhage but has the drawback of poor localization of the bleeding site. Localization of the bleeding site at nuclear imaging has improved with the use of SPECT/CT (34).

Vascular Thrombosis, Stenosis, and Pseudoaneurysms.—The portal vein and the SMV are the most common sites of venous thrombosis after pancreatic surgery (65). Patients who undergo venous resections may be at increased risk of venous thrombosis after surgery, particularly with more complex reconstructions (Figs 12, 18) (36). The use of prosthetic grafts and a long operating time are known risk factors (34). Thrombosis can lead to ischemia of the affected organs, including the bowel and liver, and can lead to death (Figs 17, 18).

Dual-phase CT angiography is an ideal imaging modality for evaluation of vascular complications. Venous thrombosis is best seen in the portal venous phase (Figs 12, 18). Multiplanar coronal reformatted images are helpful in the assessment of portal and SMV thrombosis (Fig 12). The high spatial resolution of CT makes it ideal for evaluation of pseudoaneurysms and vascular

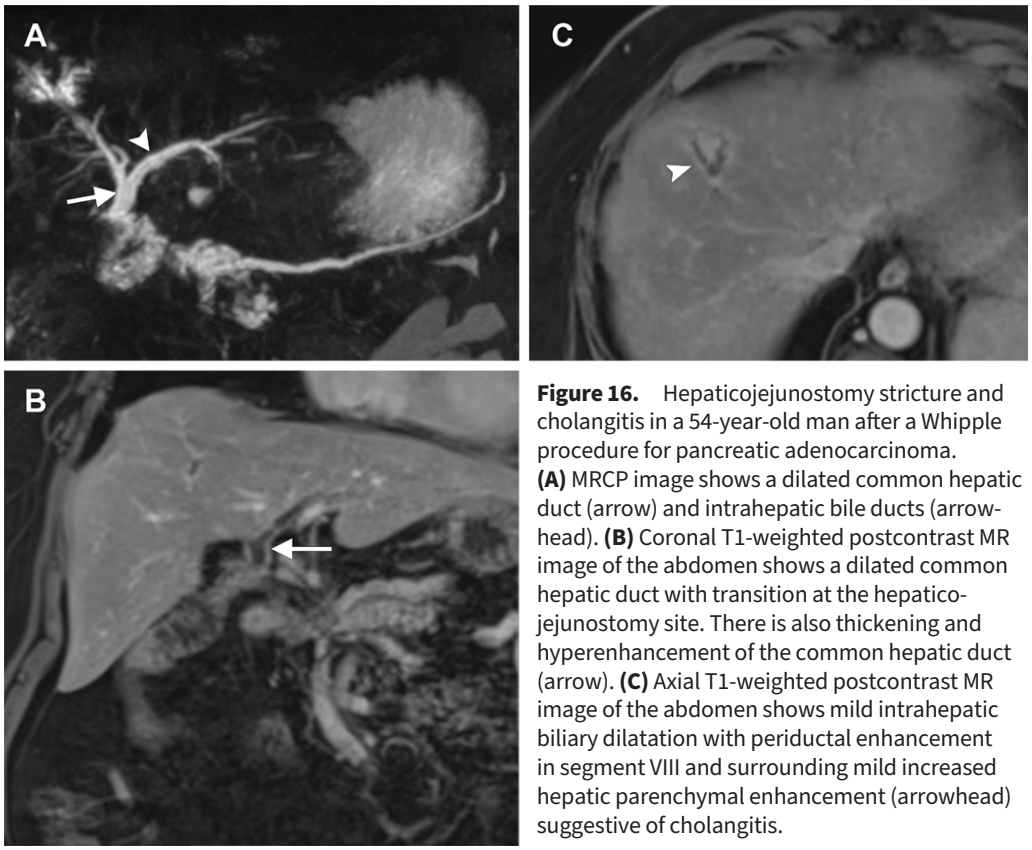


Figure 16. Hepaticojejunostomy stricture and cholangitis in a 54-year-old man after a Whipple procedure for pancreatic adenocarcinoma. **(A)** MRCP image shows a dilated common hepatic duct (arrow) and intrahepatic bile ducts (arrowhead). **(B)** Coronal T1-weighted postcontrast MR image of the abdomen shows a dilated common hepatic duct with transition at the hepaticojejunostomy site. There is also thickening and hyperenhancement of the common hepatic duct (arrow). **(C)** Axial T1-weighted postcontrast MR image of the abdomen shows mild intrahepatic biliary dilatation with periductal enhancement in segment VIII and surrounding mild increased hepatic parenchymal enhancement (arrowhead) suggestive of cholangitis.

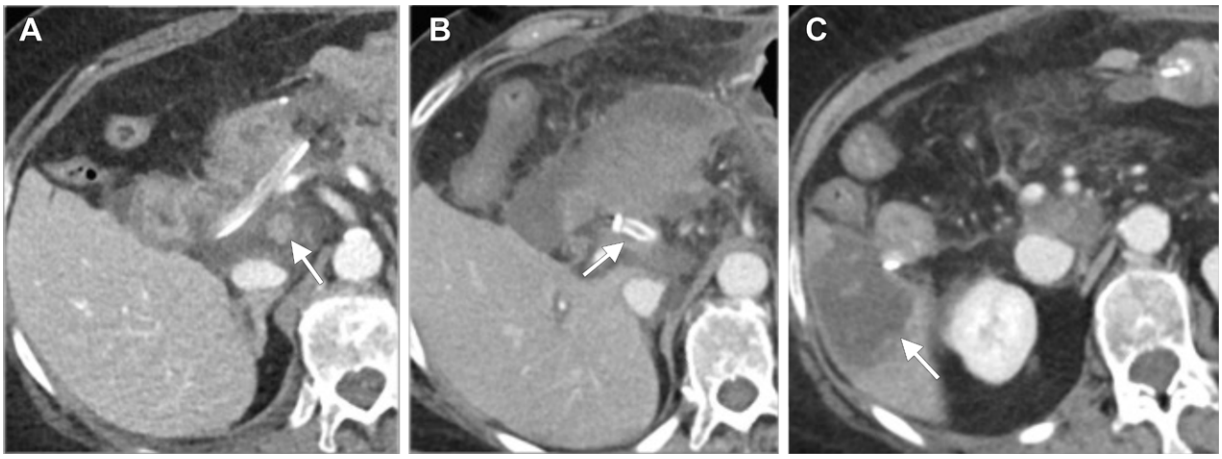


Figure 17. Active bleeding complicated by hepatic infarcts secondary to endovascular in-stent thrombosis in a 44-year-old woman after a Whipple procedure for a duodenal mass. The mass was confirmed to be a duodenal adenoma at pathologic analysis. **(A)** Axial postoperative contrast-enhanced CT image of the abdomen shows a complex collection in the surgical bed with active contrast material extravasation (arrow). A stent was placed in the common hepatic artery to isolate the gastroduodenal artery. **(B, C)** Axial contrast-enhanced CT images of the abdomen obtained after stent placement show thrombosis in the common hepatic artery stent (arrow in **B**) and right hepatic infarct (arrow in **C**). The distal hepatic arterial branches were not visualized.

stenosis. Doppler US may be performed in the initial evaluation of portal venous thrombosis. At MRI, acute thrombus demonstrates increased signal intensity with T1- and T2-weighted sequences. MRI with contrast material will also demonstrate a filling defect in cases of thrombosis. Systemic anticoagulation therapy is typically used in the treatment of acute portal vein or SMV thrombosis after pancreatic surgery to avoid propagation of the thrombosis and associated complications. Conventional angiography may be used for endovascular management of these complications (15,31,36).

Organ Ischemia and Infarction.—Hepatic infarction is a rare complication of pancreatic surgery since the liver has a dual blood supply. Factors leading to hepatic infarction include intraoperative hypotension, prolonged clamping of the vasculature, preexisting arterial disease, atherosclerosis, hepatic arterial

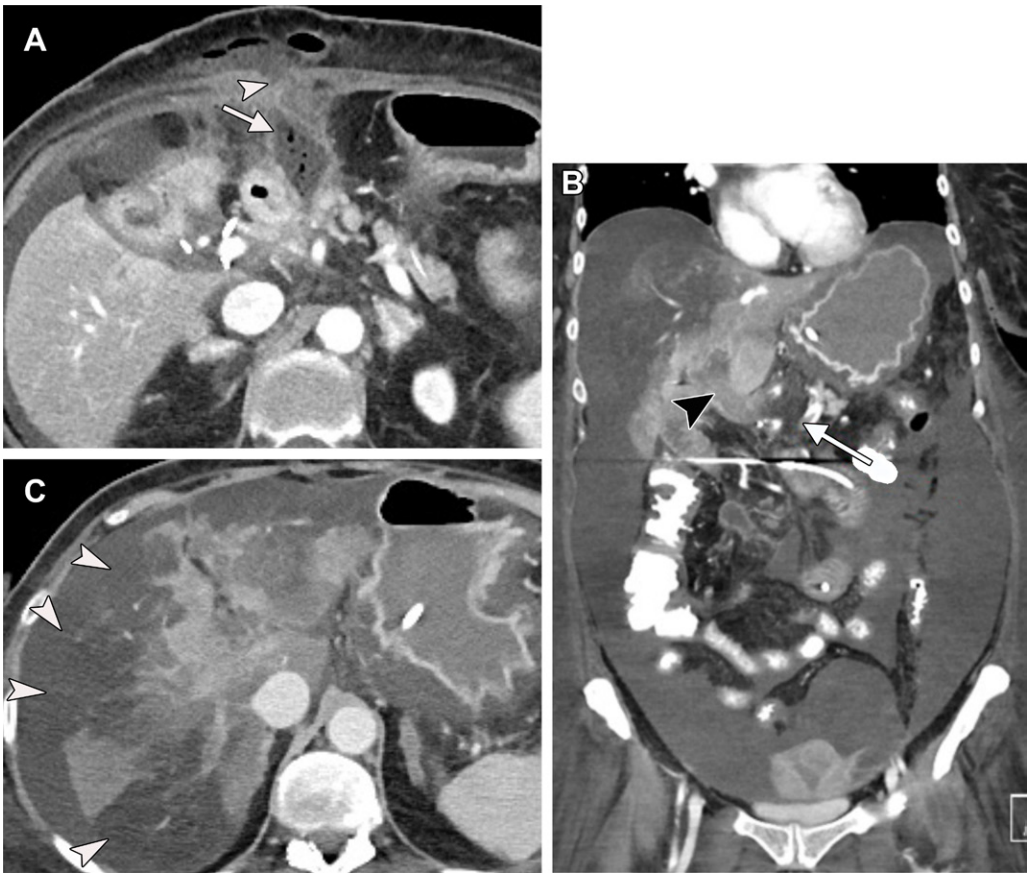


Figure 18. Development of portal vein thrombosis and hepatic infarction in a 73-year-old woman after a Whipple procedure for pancreatic adenocarcinoma. **(A)** Axial contrast-enhanced CT image of the abdomen shows an intra-abdominal collection (arrow). The collection is communicating with an abdominal wall collection through a possible wall defect (arrowhead), suggestive of a pancreatic-cutaneous fistula. **(B, C)** Coronal **(B)** and axial **(C)** contrast-enhanced CT images of the abdomen show nonopacification of the portal vein (arrowhead in **B**) and its branches, denoting extensive portal vein thrombosis. Note the nonocclusive thrombus in the splenic vein (arrow in **B**). Additionally, there is diffuse geographic hepatic hypoenhancement representing liver infarctions (arrowheads in **C**).

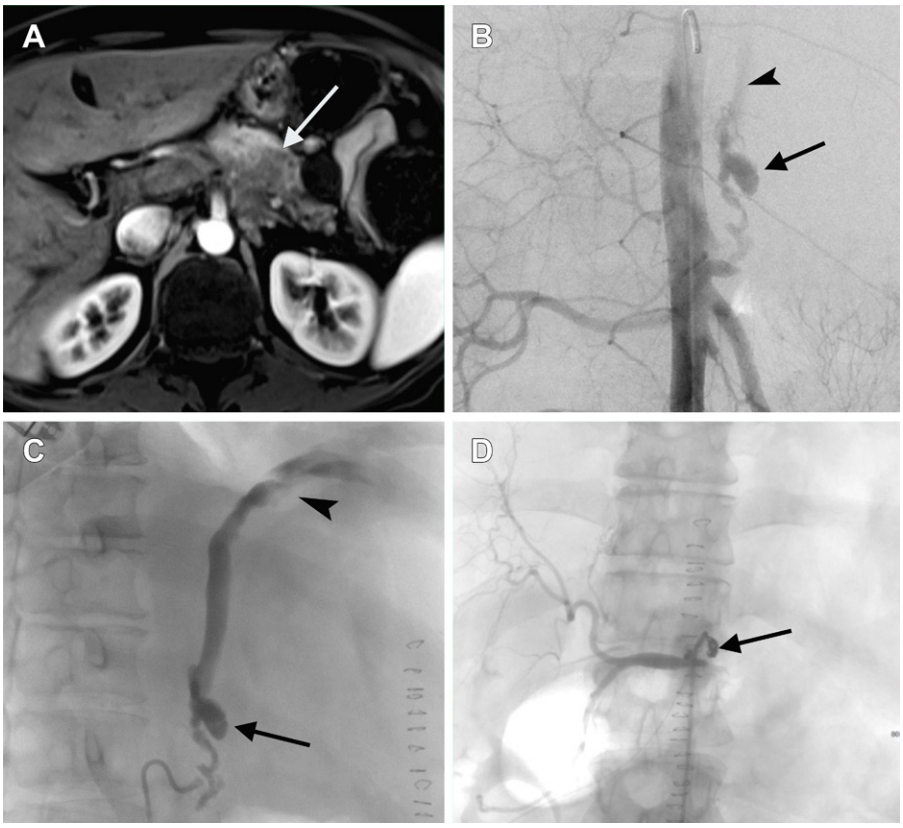


Figure 19. Active bleeding from the gastrohepatic trunk in a 42-year-old man after a distal pancreatectomy performed for pancreatic adenocarcinoma. **(A)** Preoperative axial contrast-enhanced T1-weighted MR image shows a pathologically proved adenocarcinoma of the body of the pancreas that infiltrates the left adrenal gland (arrow). Distal pancreatectomy was performed after neoadjuvant chemotherapy. The patient had a variant celiac arterial anatomy with a gastrohepatic trunk giving rise to the splenic, left gastric, and left hepatic arteries. Conventional angiography was performed secondary to hemodynamic instability and serosanguineous discharge from the drain. **(B)** Conventional angiogram of the abdominal aorta shows a pseudoaneurysm (arrow) and active contrast material extravasation from the gastrohepatic trunk (arrowhead). **(C)** Angiogram obtained after selective cannulation of the gastrohepatic trunk confirms the pseudoaneurysm (arrow) and the site of active bleeding (arrowhead). **(D)** Angiogram shows resolution of the bleed after gel foam and coil embolization (arrow).



Figure 20. Bowel perforation after pancreatic surgery in a 36-year-old-man with known pancreatic adenocarcinoma invading the duodenum with a possible duodenocolic fistula. He underwent pancreaticoduodenectomy, right hemicolectomy, and ileocolonic anastomosis. The patient presented with acute abdominal pain a few days after surgery. Axial contrast-enhanced CT image of the abdomen shows dehiscence of the bowel wall at the ileocolonic anastomotic site (arrow) with moderate pneumoperitoneum (arrowheads).

or portal venous thrombosis, and vascular injuries, which are more common with variant arterial anatomy (15,31,34). Hepatic infarction is a known complication of the Appleby procedure because the gastroduodenal artery supplies the liver via collateral flow from the SMA through the pancreaticoduodenal artery (17). The biliary tree is exclusively supplied by the arterial system, and an arterial occlusion can cause ischemic cholangitis, biliary strictures, or bilomas without causing hepatic parenchymal infarction (66). On CT and MR images, hepatic infarcts appear as peripheral wedge-shaped areas of hypoenhancement without mass effect (Figs 17, 18) (31,34).

Bowel ischemia can also occur secondary to arterial or portal venous occlusion. In addition to the direct sign of vascular occlusion, other possible findings include bowel wall thickening, hemorrhage as evidenced by hyperattenuating bowel wall on unenhanced CT images, nonenhancement of the bowel wall, pneumatosis intestinalis, and portal venous gas (67). Ischemic gastropathy is a complication of an Appleby procedure and can manifest with refractory gastric ulcers, which may be complicated by bleeding or perforation (17). Beger and Frey procedures involve resection of the pancreatic head and may lead to ischemia of the CBD or duodenum owing to the possible disruption of their blood supply (11).

Bowel Complications

Postpancreatic surgery bowel complications include delayed gastric emptying, gastrojejunostomy leak or stricture, ischemia or perforation (Figs 20, S6), ileus, bowel adhesions or obstruction (Fig S7), and marginal ulcers. Some of these bowel complications are unique to pancreatic surgical procedures involving creation of gastrojejunostomy, such as pancreaticoduodenectomy and total pancreatectomy.

Delayed Gastric Emptying.—Delayed gastric emptying is the most common bowel complication after pancreatic surgery. It is characterized by the inability of the patient to have a normal diet after pancreatic surgery by the end of the first postoperative week requiring prolonged nasogastric intubation (68). It is often associated with other postsurgical complications such as pancreatic leak, abscess, or hemorrhage (34). Although the diagnosis is not based on imaging features, features that may be present at cross-sectional imaging include a dilated stomach containing large food residue. Nuclear medicine and barium studies can demonstrate the dilated stomach and delayed gastric transit (15,34).

Gastrojejunostomy Leak or Bowel Injury.—An anastomotic leak at the gastrojejunostomy site is uncommon. Early diagnosis is important as it carries high risk of morbidity and mortality. It can lead to abscess formation when localized and may also lead to peritonitis. CT may help identify an air-containing collection abutting the dehisience or perforation site (Fig 20). A leak might be demonstrated with detection of extraluminal oral contrast material at CT or fluoroscopy (15,36). As with any other abdominal surgery, an iatrogenic bowel injury can occur during pancreatic surgery.

Gastrojejunostomy Stricture and Marginal Ulcer.—Gastrojejunostomy stricture and marginal ulcer are similar to those complications that occur after other gastrojejunal surgical anastomoses. Gastrojejunostomy site narrowing in the early postoperative period may be related to surgical site edema. Stricture formation in the late postoperative period may be related to ischemia or scarring. Symptoms include postprandial abdominal pain, bloating, and vomiting. Fluoroscopy is helpful for confirming the diagnosis of stricture (69,70). Marginal ulcers are formed in the jejunum at or just distal to the anastomotic site due to exposure to acidic gastric contents. Although the diagnosis is made at endoscopy, CT performed for abdominal pain may demonstrate edema and fat stranding at the gastrojejunostomy site or complications like perforation or bleeding (71). In rare cases, a secondary gastric adenocarcinoma may develop at the gastrojejunal anastomosis (72).

Afferent Limb Syndrome.—The afferent limb is the section of the small bowel located before the gastrojejunal anastomosis where biliopancreatic secretions are drained. When this loop becomes obstructed, it leads to a condition known as afferent limb syndrome (Fig 21), a type of closed-loop obstruction usually requiring surgery to prevent further complications. The causes of afferent limb syndrome may include tumor recurrence, postoperative edema, adhesions, and stricture formation (34). CT images can show dilated small bowel proximal to the gastrojejunostomy site, while the bowel loops distal to the anastomotic site will be collapsed (Fig 21).

Other Complications

Abscess.—Intra-abdominal collections that develop after pancreatic surgery can get infected and form abscesses. These can occur in and/or away from the operative bed (Fig 8).

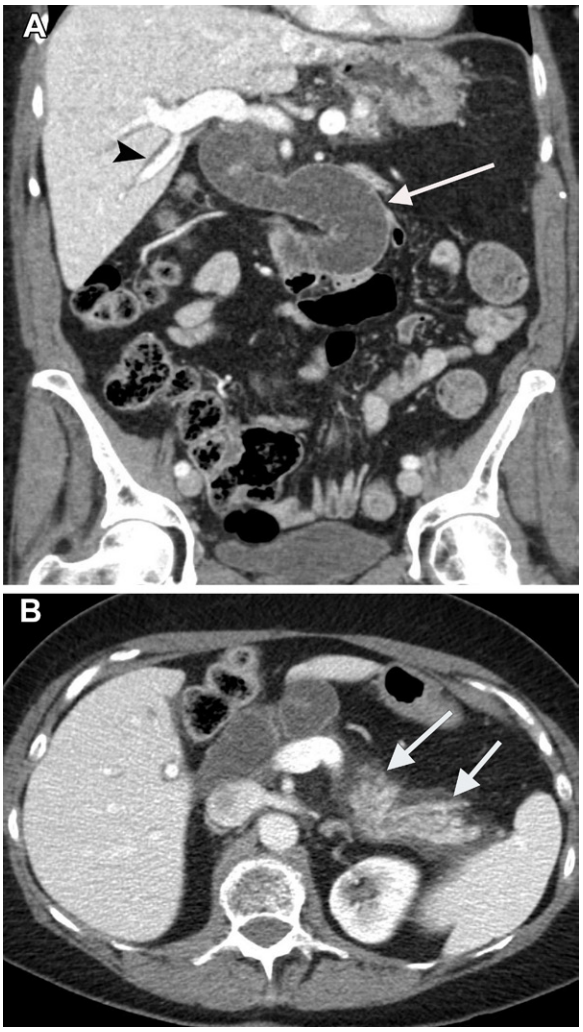


Figure 21. Afferent limb syndrome in a 62-year-old woman after a Whipple procedure for pancreatic cancer. The patient presented with nausea and vomiting and had elevated liver function levels. **(A)** Coronal contrast-enhanced CT image of the abdomen shows dilatation of the biliopancreatic limb (arrow), with decompressed distal small bowel compatible with bowel obstruction or afferent limb obstruction. The obstruction was due to adhesions without local recurrence. There is resultant mild biliary dilatation (arrowhead). **(B)** Axial contrast-enhanced CT image of the abdomen shows acute inflammatory changes along the pancreatic remnant (arrows) due to the biliopancreatic limb obstruction, indicative of acute interstitial pancreatitis.

A low-attenuation collection with rim enhancement is the most common appearance at cross-sectional imaging. Liver abscesses tend to rapidly increase in size and can display a double target sign, seen in about 30% of cases (15,31). However, the CT signs may not be obvious during the early stage of infection. Clinical and laboratory parameters can suggest the diagnosis of an abscess. Analysis of the aspirate confirms the diagnosis of an abscess. Abscess formation can also lead to complications at anastomotic sites, including vascular erosions and hemorrhage.

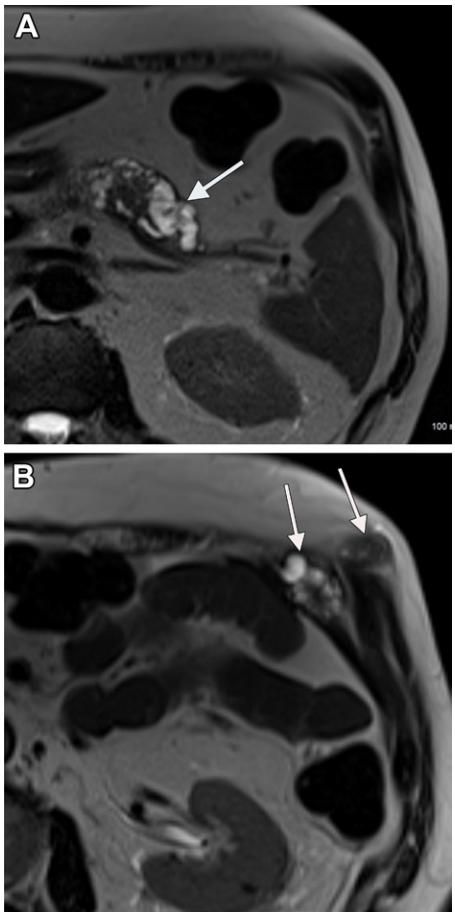


Figure 22. Seeding metastases in a 79-year-old man after distal pancreatectomy and splenectomy for pancreatic mucinous adenocarcinoma. **(A)** Preoperative axial T2-weighted MR image shows a distal pancreatic mass (arrow). **(B)** Axial T2-weighted MR image of the abdomen obtained 5 months after surgery shows two lesions (arrows) in the musculature and subcutaneous tissues of the left abdominal wall. The lesions have an imaging appearance similar to that of the primary tumor. Postcontrast sequences showed enhancement of the lesions (not shown). These masses were along the course of the postoperative drain. The lesions were resected and proved to be seeding metastases at pathologic analysis.

Tumor Recurrence.—Tumor recurrence can manifest locally at the surgical site or as metastatic disease, with the latter more common than the former (34). Local recurrence can manifest as soft-tissue thickening at the surgical site. It can occur surrounding the mesenteric vasculature or around the celiac axis/hepatic vasculature. It can also manifest as regional lymphadenopathy, albeit less common (31). A positive surgical margin is the most important predictor for local recurrence (15). Metastases in the abdomen commonly occur in the liver and peritoneum. Peritoneal metastases can present as peritoneal carcinomatosis and may be associated with ascites (31). Both CT and MRI can help in evaluation of recurrence. CT has the advantage of excellent spatial resolution, while MRI is superior in evaluation for metastatic disease in the liver. Serial follow-up imaging is essential in differentiating local recurrence from normal postoperative findings.

Seeding metastases, from pancreatic cancer following pancreatectomy or interventional procedures, is a rare complication with a few cases reported in the literature (73,74). In most cases, tumor recurrence occurred within the body wall (Fig 22) at the laparotomy site, along the course of the postsurgical drain (Fig 22), or along the tract of a needle biopsy or percutaneous transhepatic biliary drainage catheter. Seeding metastasis within the posterior wall of the stomach has also been documented following an endoscopic US-guided fine needle aspiration of pancreatic cancer (73,74). The imaging features of the metastatic deposits can be similar to those of the primary tumor (Fig 22).

Conclusion

Understanding the spectrum of pancreatic surgeries, indications, and commonly encountered complications is important for radiologists since imaging has become the primary method for investigating perioperative problems. There are multiple unique complications given the inherent technical challenges of operating on the pancreas. As described in this article, a systems-based approach for addressing potential complications provides a strong interpretive framework for reviewing postoperative CT or MRI examinations.

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References

1. Kuemmerli C, Schneider MA, Joliat GR, et al. Trends in pancreatic surgery in Switzerland: a survey and nationwide analysis over two decades. Langenbecks Arch Surg 2022;407(8):3423–3435.
2. Bouwense SAW, Kempeneers MA, van Santvoort HC, Boermeester MA, van Goor H, Besselink MG. Surgery in Chronic Pancreatitis: Indication, Timing and Procedures. Visc Med 2019;35(2):110–118.
3. Scialpi M, Reginelli A, D'Andrea A, et al. Pancreatic tumors imaging: An update. Int J Surg 2016;28(suppl 1):S142–S155.
4. Navadgi S, Pandanaboyana S, Windsor JA. Surgery for Acute Pancreatitis. Indian J Surg 2015;77(5):446–452.
5. Scognamiglio P, Stüben BO, Heumann A, et al. Advanced Robotic Surgery: Liver, Pancreas, and Esophagus: The State of the Art? Visc Med 2021;37(6):505–510.
6. Heckler M, Hackert T, Hu K, Halloran CM, Büchler MW, Neoptolemos JP. Severe acute pancreatitis: surgical indications and treatment. Langenbecks Arch Surg 2021;406(3):521–535.
7. Kim SS, Shin HC, Hwang JA. Various Congenital Abnormalities and Anatomic Variants of the Pancreas: A Pictorial Review. J Belg Soc Radiol 2019;103(1):39.
8. Borghei P, Sokhandon F, Shirkhoda A, Morgan DE. Anomalies, anatomic variants, and sources of diagnostic pitfalls in pancreatic imaging. Radiology 2013;266(1):28–36.
9. Cauquil P, Cauquil M, Verdier JP, et al. The Normal Radiologic Anatomy of the Pancreas. In: Baert, A.L., Delorme, G. (eds) Radiology of the Pancreas. Medical Radiology. Springer, 1994.
10. Ibukuro K. Vascular anatomy of the pancreas and clinical applications. Int J Gastrointest Cancer 2001;30(1-2):87–104.
11. Yamauchi FI, Ortega CD, Blasbalg R, Rocha MS, Jukemura J, Cerri GG. Multidetector CT evaluation of the postoperative pancreas. RadioGraphics 2012;32(3):743–764.
12. Russell TB, Aroori S. The pancreas from a surgical perspective: an illustrated overview. Art Surg 2022;6:1.
13. del Chiaro M, Besselink MG, Scholten L, et al. European evidence-based guidelines on pancreatic cystic neoplasms. Gut 2018;67(5):789–804.
14. Ziogas IA, Schmitz R, Moris D, Vatsaas CJ. The Role of Surgery for Pancreatic Neuroendocrine Tumors. Vol. 42, Anticancer Research. International Institute of Anticancer Research; 2022;629–39.
15. Raman SP, Horton KM, Cameron JL, Fishman EK. CT after pancreaticoduodenectomy: spectrum of normal findings and complications. AJR Am J Roentgenol 2013;201(1):2–13.
16. Lillemoe KD, Kaushal S, Cameron JL, Sohn TA, Pitt HA, Yeo CJ. Distal pancreatectomy: indications and outcomes in 235 patients. Ann Surg 1999;229(5):693–698; discussion 698–700.
17. Cannella R, Borhani AA, Zureikat AH, Tublin ME. Appleby Procedure (Distal Pancreatectomy With Celiac Artery Resection) for Locally Advanced Pancreatic Carcinoma: Indications, Outcomes, and Imaging. AJR Am J Roentgenol 2019;213(1):35–44.
18. Lin X, Lin R, Lu F, et al. "Kimura-first" strategy for robotic spleen-preserving distal pancreatectomy: experiences from 61 consecutive cases in a single institution. Gland Surg 2021;10(1):186–200.
19. Kulu Y, Schmied BM, Werner J, Muselli P, Büchler MW, Schmidt J. Total pancreatectomy for pancreatic cancer: indications and operative technique. HPB (Oxford) 2009;11(6):469–475.
20. Xiao W, Zhu J, Peng L, Hong L, Sun G, Li Y. The role of central pancreatectomy in pancreatic surgery: a systematic review and meta-analysis. HPB (Oxford) 2018;20(10):896–904.
21. Wolfgang CL, Corl F, Johnson PT, et al. Pancreatic surgery for the radiologist, 2011: an illustrated review of classic and newer surgical techniques for pancreatic tumor resection. AJR Am J Roentgenol 2011;197(6):1343–1350.
22. Ei S, Mihaljevic AL, Kulu Y, et al. Enucleation for benign or borderline tumors of the pancreas: comparing open and minimally invasive surgery. HPB (Oxford) 2021;23(6):921–926.
23. Tempero MA, Malafa MP, Behrman SW, et al. Pancreatic adenocarcinoma, version 2.2014: featured updates to the NCCN guidelines. J Natl Compr Canc Netw 2014;12(8):1083–1093.
24. Mollberg N, Rahbari NN, Koch M, et al. Arterial resection during pancreatectomy for pancreatic cancer: a systematic review and meta-analysis [Internet]. Ann Surg 2011;254(6):882–893.
25. Kung JWC, Parks RW. Vascular resections in minimally invasive surgery for pancreatic cancer, Vol 5. Laparoscopic, Endoscopic, and Robotic Surgery. KeAi Communications Co., 2022; 3–9.
26. Strobel O, Hank T, Hinz U, et al. Pancreatic Cancer Surgery: The New R-status Counts. Ann Surg 2017;265(3):565–573.
27. Bockhorn M, Uzunoglu FG, Adham M, et al; International Study Group of Pancreatic Surgery. Borderline resectable pancreatic cancer: a consensus statement by the International Study Group of Pancreatic Surgery (ISGPS). Surgery 2014;155(6):977–988.
28. Rebelo A, Michalski CW, Ukkat J, Kleeff J. Pancreatic cancer surgery with vascular resection: Current concepts and perspectives. J Pancreatol 2019;2(1):1–5.
29. Chaparala S, Truty MJ, Bower TC, Colglazier JJ, Mendes BC. Outcomes of Arterial Conduits in Vascular Reconstruction After Oncologic Resection of Locally Advanced Pancreatic Malignancies. J Vasc Surg 2020;72(1):e231–e232.
30. Perwaiz A, Singh A, Chaudhary A. Surgery for chronic pancreatitis. Indian J Surg 2012;74(1):47–54.
31. Chincarini M, Zamboni GA, Pozzi Mucelli R. Major pancreatic resections: normal postoperative findings and complications. Insights Imaging 2018;9(2):173–187.
32. Chu LC, Wang ZJ, Kambadakone A, et al. Postoperative surveillance of pancreatic ductal adenocarcinoma (PDAC) recurrence: practice pattern on standardized imaging and reporting from the society of abdominal radiology disease focus panel on PDAC. Abdom Radiol (NY) 2023;48(1):318–339.
33. Swensson J, Zaheer A, Conwell D, Sandrasegaran K, Manfredi R, Tirkes T. Secretin-Enhanced MRCP: How and Why-AJR Expert Panel Narrative Review. AJR Am J Roentgenol 2021;216(5):1139–1149.
34. Taher A, Mujtaba B, Ramani NS, Patel A, Morani AC. The Postoperative Pancreas Imaging. Journal of Gastrointestinal and Abdominal Radiology 2020;3(01):087–098.
35. Liu H, Imagawa D, Ward G, Dullet N, Lall C. Significance and Prevalence of Haziness Surrounding the Hepatic Artery and Celiac Axis on Computed Tomographic Imaging After Pancreaticoduodenectomy. J Comput Assist Tomogr 2018;42(4):637–641.
36. Hafezi-Nejad N, Fishman EK, Zaheer A. Imaging of post-operative pancreas and complications after pancreatic adenocarcinoma resection. Abdom Radiol (NY) 2018;43(2):476–488.
37. Ramia JM. Invited Commentary: Structured Training Programs for Minimally Invasive Pancreatic Surgery Should Be Mandatory. J Am Coll Surg 2022;235(3):390–391.
38. Büchler MW, Wagner M, Schmied BM, Uhl W, Friess H, Z'graggen K. Changes in morbidity after pancreatic resection: toward the end of completion pancreatectomy. Arch Surg 2003;138(12):1310–1315.
39. Halloran CM, Ghaneh P, Bosonnet L, Hartley MN, Sutton R, Neoptolemos JP. Complications of pancreatic cancer resection. Dig Surg 2002;19(2):138–146.

40. Wittel UA, Makowiec F, Sick O, et al. Retrospective analyses of trends in pancreatic surgery: indications, operative techniques, and postoperative outcome of 1,120 pancreatic resections. World J Surg Oncol 2015;13(1):102.
41. Ho CK, Kleeff J, Friess H, Büchler MW. Complications of pancreatic surgery. HPB (Oxford) 2005;7(2):99–108.
42. Beugniez C, Sauvanet A, Sulpice L, et al; French-ACHBT Working Group. Root-cause Analysis of Mortality After Pancreatic Resection (CARE Study): A Multicenter Cohort Study. Ann Surg 2021;274(5):789–796.
43. Harnoss JC, Ulrich AB, Harnoss JM, Diener MK, Büchler MW, Welsch T. Use and results of consensus definitions in pancreatic surgery: a systematic review. Surgery 2014;155(1):47–57.
44. Hain E, Challine A, Tzedakis S, et al. Study Protocol of the PreFiPS Study: Prevention of Postoperative Pancreatic Fistula by Somatostatin Compared With Octreotide, a Prospective Randomized Controlled Trial. Front Med (Lausanne) 2021;7:488.
45. Bassi C, Marchegiani G, Dervenis C, et al; International Study Group on Pancreatic Surgery (ISGPS). The 2016 update of the International Study Group (ISGPS) definition and grading of postoperative pancreatic fistula: 11 Years After. Surgery 2017;161(3):584–591.
46. Smits FJ, Henry AC, van Eijck CH, et al; Dutch Pancreatic Cancer Group. Care after pancreatic resection according to an algorithm for early detection and minimally invasive management of pancreatic fistula versus current practice (PORSCH-trial): design and rationale of a nationwide stepped-wedge cluster-randomized trial. Trials 2020;21(1):389.
47. Machado NO. Pancreatic fistula after pancreatectomy: definitions, risk factors, preventive measures, and management-review. Int J Surg Oncol 2012;2012:602478 .
48. Crippa S, Salvia R, Falconi M, Butturini G, Landoni L, Bassi C. Anastomotic leakage in pancreatic surgery. HPB (Oxford) 2007;9(1):8–15.
49. Kawaida H, Kono H, Hosomura N, et al. Surgical techniques and post-operative management to prevent postoperative pancreatic fistula after pancreatic surgery. World J Gastroenterol 2019;25(28):3722–3737.
50. Florentin LM, Dulcich G, López Grove R, Paladini JI, Spina JC. Imaging assessment after pancreaticoduodenectomy: reconstruction techniques-normal findings and complications. Insights Imaging 2022;13(1):170.
51. Girard E, Messager M, Sauvanet A, et al. Anastomotic leakage after gastrointestinal surgery: diagnosis and management. J Visc Surg 2014;151(6):441–450.
52. Kent TS, Callery MP, Vollmer CM Jr. The bridge stent technique for salvage of pancreaticojejunal anastomotic dehiscence. HPB (Oxford) 2010;12(8):577–582.
53. Bramis K, Vouros D, Kotsarinis V, et al. Completion Pancreatectomy as a Treatment Option for Complications Following Pancreatoduodenectomy. Am Surg 2023. 10.1177/00031348231175500. Published online May 9, 2023.
54. Ramouz A, Mehrabi A, Loos M. Acute pancreatitis following major pancreatic resection. Surgery in Practice and Science 2021;5:100036. [Published correction appears in Surgery in Practice and Science 2021;7: 100047.]
55. Cioffi JL, McDuffie LA, Roch AM, et al. Pancreaticojejunostomy Stricture After Pancreatoduodenectomy: Outcomes After Operative Revision. J Gastrointest Surg 2016;20(2):293–299.
56. Farooqui W, Penninga L, Burgdorf SK, Storkholm JH, Hansen CP. Biliary Leakage Following Pancreatoduodenectomy: Experience from a High-Volume Center. J Pancreat Cancer 2021;7(1):80–85.
57. Koch M, Garden OJ, Padbury R, et al. Bile leakage after hepatobiliary and pancreatic surgery: a definition and grading of severity by the International Study Group of Liver Surgery. Surgery 2011;149(5):680–688.
58. Sharma P, Kumar R, Das KJ, et al. Detection and localization of post-operative and post-traumatic bile leak: hybrid SPECT-CT with 99mTc-Mebrofenin. Abdom Radiol (NY) 2012;37(5):803–811.
59. House MG, Cameron JL, Schulick RD, et al. Incidence and outcome of biliary strictures after pancreaticoduodenectomy. Ann Surg 2006;243(5):571–578.
60. Wente MN, Veit JA, Bassi C, et al. Postpancreatectomy hemorrhage (PPH): an International Study Group of Pancreatic Surgery (ISGPS) definition. Surgery 2007;142(1):20–25.
61. Duarte Garcés AA, Andrianello S, Marchegiani G, et al. Reappraisal of post-pancreatectomy hemorrhage (PPH) classifications: do we need to redefine grades A and B? HPB (Oxford) 2018;20(8):702–707.
62. Ansari D, Tingstedt B, Lindell G, Keussen I, Ansari D, Andersson R. Hemorrhage after Major Pancreatic Resection: Incidence, Risk Factors, Management, and Outcome. Scand J Surg 2017;106(1):47–53.
63. Puppala S, Patel J, McPherson S, Nicholson A, Kessel D. Hemorrhagic complications after Whipple surgery: imaging and radiologic intervention. AJR Am J Roentgenol 2011;196(1):192–197.
64. Yoon W, Jeong YY, Shin SS, et al. Acute massive gastrointestinal bleeding: detection and localization with arterial phase multi-detector row helical CT. Radiology 2006;239(1):160–167.
65. Zaky AM, Wolfgang CL, Weiss MJ, Javed AA, Fishman EK, Zaheer A. Tumor-vessel relationships in pancreatic ductal adenocarcinoma at multidetector CT: Different classification systems and their influence on treatment planning. RadioGraphics 2017;37(1):93–112.
66. Deltenre P. Hepatic Artery Occlusion and Ischemic Cholangiopathy. In: Vascular Disorders of the Liver. Cham: Springer International Publishing, 2022; 35–47.
67. Kanasaki S, Furukawa A, Fumoto K, et al. Acute mesenteric Ischemia: Multidetector CT findings and endovascular management. RadioGraphics 2018;38(3):945–961.
68. Wente MN, Bassi C, Dervenis C, et al. Delayed gastric emptying (DGE) after pancreatic surgery: a suggested definition by the International Study Group of Pancreatic Surgery (ISGPS). Surgery 2007;142(5):761–768.
69. Levine MS, Carucci LR. Imaging of bariatric surgery: normal anatomy and postoperative complications. Radiology 2014;270(2):327–341.
70. Jha S, Levine MS, Rubesin SE, et al. Detection of strictures on upper gastrointestinal tract radiographic examinations after laparoscopic Roux-en-Y gastric bypass surgery: importance of projection. AJR Am J Roentgenol 2006;186(4):1090–1093.
71. Zulfiqar M, Ludwig DR, Strnad B, et al. Imaging features of marginal ulcers on multidetector CT. Clin Radiol 2023;78(3):227–233.
72. Sonoda K, Samdani RT, Ikoma N, et al. Gastric cancer in the remnant stomach after pancreaticoduodenectomy: A case series. J Surg Oncol 2019;120(7):1137–1141.
73. Zhou Q, Murthy S, Vingan H. Pancreatic cancer seeding of percutaneous needle tract. Radiol Case Rep 2017;12(1):50–53.
74. Sato N, Takano S, Yoshitomi H, et al. Needle tract seeding recurrence of pancreatic cancer in the gastric wall with paragastric lymph node metastasis after endoscopic ultrasound-guided fine needle aspiration followed by pancreatectomy: a case report and literature review. BMC Gastroenterol 2020;20(1):13.