Multidisciplinary Management of Complicated Pancreatitis: What Every Interventional Radiologist Should Know

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Management of acute pancreatitis is challenging in the presence of local complications that include pancreatic and peripancreatic collections and vascular complications. This review, targeted for interventional radiologists, describes minimally invasive endoscopic, image-guided percutaneous, and surgical procedures for management of complicated pancreatitis and provides insight into the procedures' algorithmic application. Local complications are optimally managed in a multidisciplinary team setting that includes advanced endoscopists; pancreatic surgeons; diagnostic and interventional radiologists; and specialists in infectious disease, nutrition, and critical care medicine. Large symptomatic or complicated sterile collections and secondary infected collections warrant drainage or débridement. The drainage is usually delayed for 4–6 weeks unless clinical deterioration warrants early intervention. If collections are accessible by endoscopy, endoscopic procedures are preferred to avoid pancreaticocutaneous fistulas. Image-guided percutaneous drainage is indicated for symptomatic collections that are not accessible for endoscopic drainage or that present in the acute setting before developing a mature wall. Peripancreatic arterial pseudoaneurysms should be embolized before necrosectomy procedures to prevent potentially life-threatening hemorrhage. Surgical procedures are reserved for symptomatic collections that persist despite endoscopic or interventional drainage attempts. Understanding these procedures facilitates their integration by interventional radiologists into the complex longitudinal care of patients with complicated pancreatitis.

Acute pancreatitis has increased in incidence over the past decade and is estimated to cause more than 290,000 hospital admissions annually in the United States, with an annual cost of $2.8 billion [1–3]. Local complications of acute pancreatitis detected on imaging include collections such as acute peripancreatic fluid, pancreatic pseudocyst, acute necrotic collection, and walled-off necrosis [4, 5]. Approximately 30–60% of patients with acute pancreatitis develop such collections [6–8]. Management of these collections is challenging, particularly if they become infected, which has an associated 20–40% mortality rate [9, 10]. Vascular complications are also common in acute pancreatitis and pose management challenges.

Multidisciplinary expertise that includes advanced endoscopic gastroenterologists, pancreaticobiliary surgeons, diagnostic and interventional radiologists, infectious disease specialists, critical care specialists, and nutritionists is needed for the treatment of patients with complicated pancreatitis [11]. In patients with infected local complications, the historically preferred procedure was complete débridement of necrotic tissue by open surgery [12, 13]. However, this procedure has a high risk of morbidity and mortality. Less invasive procedures have been developed, including percutaneous drainage, endoscopic transgastric drainage, direct endoscopic necrosectomy, laparoscopic or open endoscopic transgastric drainage, and video-assisted retroperitoneal débridement (VARD). The primary objective of these procedures is to relieve symptoms, control potential infection, and prevent progression to sepsis and organ failure through a less invasive approach in patients who are often critically ill.

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Interventional radiology (IR) has a longitudinally integrated role in the care of patients with complicated pancreatitis. A comprehensive understanding of terminology, pathophysiology, imaging findings, minimally invasive procedures, and antimicrobial and critical care management is imperative for the modern-day clinical interventional radiologist in the management of local complications of pancreatitis. This review discusses the multidisciplinary approach and management algorithm of locally complicated pancreatitis, facilitating the integration of IR in the longitudinal care of these complex patients.

HIGHLIGHTS

- *Management of complicated pancreatitis, including local collections and vascular complications, is most effective in a multidisciplinary team manner.*
- *Interventional radiologists are integral in treating these patients and should be familiar with indications, complications, and techniques of procedures performed by gastroenterologists and surgeons.*
- *An algorithmic management approach is proposed to tailor treatments to individual patients based on clinical and imaging findings.*

Role of Imaging in Evaluation of Complicated Pancreatitis

Background

Although routine imaging is not needed to diagnose mild pancreatitis, imaging provides value in determining the cause. Ultrasound is routinely performed to identify gallstones [14]. Clinical history and laboratory evaluation provide insight into causes such as alcohol use, hypertriglyceridemia, trauma, ERCP, medications, and hypercalcemia [15]. If ultrasound results and history are inconclusive, additional evaluation with CT, MRI, MRCP, or ERCP may help determine other potential causes, such as neoplasms, occult common bile duct stones, microlithiasis, autoimmune inflammation, or anatomic changes such as pancreatic divisum [16]. Contrast-enhanced CT is performed when necrosis or local complications are suspected in a patient with acute pancreatitis (e.g., due to persistent abdominal pain, atypical symptoms, increasing pancreatic enzymes, increasing organ dysfunction, or evidence of sepsis) [16–18]. Areas within the pancreas that do not enhance indicate necrosis. In patients with acute kidney injury or estimated glomerular filtration rate less than 30 mL/min/1.73 m^2, contrast-enhanced CT with IV normal saline prophylaxis may be warranted [19].

Various clinical and imaging scoring systems have been developed to help treat patients with acute pancreatitis who are at risk of developing severe complications. The 2012 revised Atlanta classification uses contrast-enhanced CT criteria to designate acute pancreatitis as interstitial edematous pancreatitis or necrotizing pancreatitis [4, 5]. Ranson criteria and the Acute Physiology and Chronic Health Evaluation II scoring system also provide useful prognostic information [15, 20, 21]. The widely used modified CT severity index includes evaluation of pancreatic and peripancreatic complications (e.g., collections and necrosis) and extrapancreatic complications (e.g., pleural effusion, ascites, and vascular complications) and significantly correlates with outcomes such as need for future procedures, infection, and organ failure [22].

Collections

The revised Atlanta classification provides explicit criteria incorporating CT morphology for distinguishing four possible collections that may develop in acute pancreatitis (Table 1). This system reflects whether the collection contains homogeneous fluid alone or is heterogeneous with nonfluid areas indicative of pancreatic or peripancreatic necrosis. The system also reflects whether the collection is completely encapsulated with a well-defined wall, which typically requires more than 4 weeks since the onset of symptoms to mature. Collections without necrosis are designated as acute peripancreatic fluid collections when unencapsulated and as pancreatic pseudocysts when encapsulated (i.e., when delayed). Collections with necrosis are designated as acute necrotic collections when unencapsulated and as walled-off necrosis when encapsulated (i.e., when delayed).

The radiologic report should describe the anatomic relation of pancreatic or peripancreatic collections to adjacent structures and identify procedure-related risk factors such as adjacent large vessels or vascular pathology, which are critical in procedural planning. The presence of gas in a necrotic collection, in the absence of recent instrumentation or fistula, suggests secondary infection and should also be reported. Although routine use of prophylactic antibiotics to prevent infection of sterile necrosis is not recommended, any suspicion for infected necrosis should prompt initia-

TABLE 1: Nonvascular Local Complications of Acute Pancreatitis Using the Revised Atlanta Classification

Type of Pancreatitis, Collection	Time After Onset (wk)	Imaging Characteristic
Interstitial edematous pancreatitis		
Acute peripancreatic fluid collection	≤ 4	Extrapancreatic, homogeneous fluid, no or incomplete wall
Pseudocyst	> 4	Extrapancreatic, homogeneous fluid, complete wall
Necrotizing pancreatitis		
Acute necrotic collection	≤ 4	Intra- and/or extrapancreatic, heterogeneous with nonfluid content, no or incomplete wall
Walled-off necrosis	> 4	Intra- and/or extrapancreatic, heterogeneous with nonfluid content, complete wall

Note—The contents of this table are based on a discussion of the revised Atlanta classification by Thoeni [4].

tion of broad-spectrum IV antibiotics with the ability to penetrate pancreatic necrosis [23, 24]. Other pertinent findings, such as mass effect on the biliary tree or gastrointestinal tract (e.g., gastric outlet obstruction), should also be reported. Follow-up imaging after initial drainage and débridement procedures should document the improvement or resolution of a collection and guide additional procedures or procedure device removal.

MRI with MRCP also has a role in characterizing collections and in preprocedural planning [25]. T2-weighted images may better characterize fat and debris in a collection, thus helping to identify patients who would benefit more from necrosectomy than from drainage. MRCP can also better define pancreatic duct anatomy and potential duct disruption [5, 26], which may cause collections to recur. Viable but disconnected upstream pancreatic tissue is also associated with recurrence of pancreatic collections and may necessitate endoscopic treatment or distal pancreatectomy [27].

Vascular Complications

CT performed in arterial and portal venous phases helps to identify vascular complications of acute pancreatitis, such as arterial pseudoaneurysm, venous thrombosis, and varices. This evaluation is essential in patients who are candidates for any endoscopic, IR, or surgical intervention. For example, iatrogenic injury adjacent to an unidentified pseudoaneurysm could lead to fatal hemorrhage [28]. Contrast-enhanced MRI is an accepted alternate modality for evaluation of vascular complications [29].

Venous involvement manifests as portomesenteric thrombosis and occurs in 10–50% of patients with necrotizing acute pancreatitis [30, 31]. The pathogenesis includes intimal injury from surrounding inflammation or venous stasis secondary to compression from a large pseudocyst. Although venous thrombosis may be asymptomatic at diagnosis, it is important to detect because progression can result in portomesenteric venous obstruction and associated complications, such as severe hemorrhage, portal hypertension, and bowel infarct [32, 33]. Additionally, identification of venous thrombosis on imaging guides clinical consideration of the appropriateness of anticoagulation, which must be weighed against increased bleeding risk [34]. Although consensus is lacking, anticoagulation may be considered if thrombosis extends to the superior mesenteric vein or portal vein because of associated heightened concern of bowel perfusion compromise or hepatic dysfunction.

Arterial pseudoaneurysm is a less frequent complication of acute pancreatitis and occurs in up to 10% of patients [32, 35]. The most common sites of pseudoaneurysm formation are the splenic, gastroduodenal, and pancreaticoduodenal arteries; nevertheless, other mesenteric arteries as well as colic and hepatic arteries can be involved [36]. Radiologists must carefully review these vessels with a high index of suspicion and, if detecting a pseudoaneurysm, communicate to referring providers the need for immediate IR consultation given the potential for fatal hemorrhage from pseudoaneurysm rupture [37, 38]. Sudden expansion of a previously noted pancreatic fluid collection should also raise suspicion for a pseudoaneurysm with bleeding into the collection.

Supportive and Procedural Management

The management of acute pancreatitis includes goal-directed fluid replacement with isotonic crystalloid solutions, pain control, and nutritional support. In patients with evidence of end-organ dysfunction, rapid fluid resuscitation with a 20-mL/kg bolus followed by 3 mL/kg/h for 8–12 hours is preferred unless cardiovascular or renal conditions preclude aggressive fluid resuscitation. Fluid resuscitation in the first 12–24 hours is associated with improved morbidity and mortality in acute pancreatitis [2, 39]. Abdominal pain is often the main symptom in patients with acute pancreatitis, and uncontrolled pain can lead to hemodynamic instability. Thus, the pain should be treated with IV opioid analgesics and gradually transitioned to oral analgesics.

Early feeding within the first 72 hours of onset of symptoms improves outcomes in patients with acute pancreatitis [40, 41]. In some patients with moderately severe or severe pancreatitis, oral feeding may be poorly tolerated because of pain, nausea or emesis. Such patients benefit from nasoenteric (nasogastric or nasojejunal) feeding tube placement for feeding [42]. Percutaneous gastric or gastrojejunal tubes could be considered when a longer course of nutrition support is anticipated. Most local complications secondary to acute pancreatitis, including more than 90% of acute pancreatic fluid collections, will resolve with the aforementioned supportive care alone [43]. However, close clinical follow-up with appropriate imaging is essential to confirm resolution or persistent complications [6, 26, 44]. Up to 10% of patients with a pseudocyst and 21% of patients with walled-off necrosis may eventually require intervention [6, 44]. Indications for drainage or débridement of collections with a mature wall (i.e., pseudocyst or walled-off necrosis) include clinical suspicion of infected necrotizing pancreatitis with clinical deterioration; ongoing persistent organ failure for several weeks after onset of acute pancreatitis; ongoing gastric outlet, intestinal, or biliary obstruction due to mass effect; persistent unwellness (symptoms such as pain, nausea, lethargy, anorexia, or failure to thrive); and disconnected pancreatic duct syndrome [42, 45–47].

If possible, any surgical or endoscopic drainage procedure is delayed for at least 4–6 weeks after the onset of acute pancreatitis to allow maturation of the collection wall and liquefaction of any necrosis; a mature wall facilitates containment of contents during intervention, and liquefaction allows drainage of necrotic material [48]. Moreover, this time delay allows improvement of any organ failure, stabilization of the clinical condition, and reduction of the retroperitoneal inflammatory reaction [49]. However, infection with associated rapid deterioration of the clinical condition, new-onset organ failure, or other emergencies such as bowel perforation or abdominal compartment syndrome warrant early intervention [50–52].

Current treatment options include endoscopic-guided procedures, percutaneous IR procedures, and surgical procedures. Although open abdominal surgery was historically the preferred treatment method, recent studies report less mortality and better outcomes for procedures that are less invasive compared with open surgery [53, 54]. Several technical and anatomic considerations impact selection of the initial drainage procedure (Fig. 1). In general, if feasible, endoscopic drainage is primarily preferred because it foregoes the risk of pancreaticocutaneous fistula, a complication of percutaneous drainage that can be prolonged and difficult to control. However, when collections are not in proximity to the gastrointestinal lumen to allow a safe endoscopic intervention, or when critical structures are interposed be-

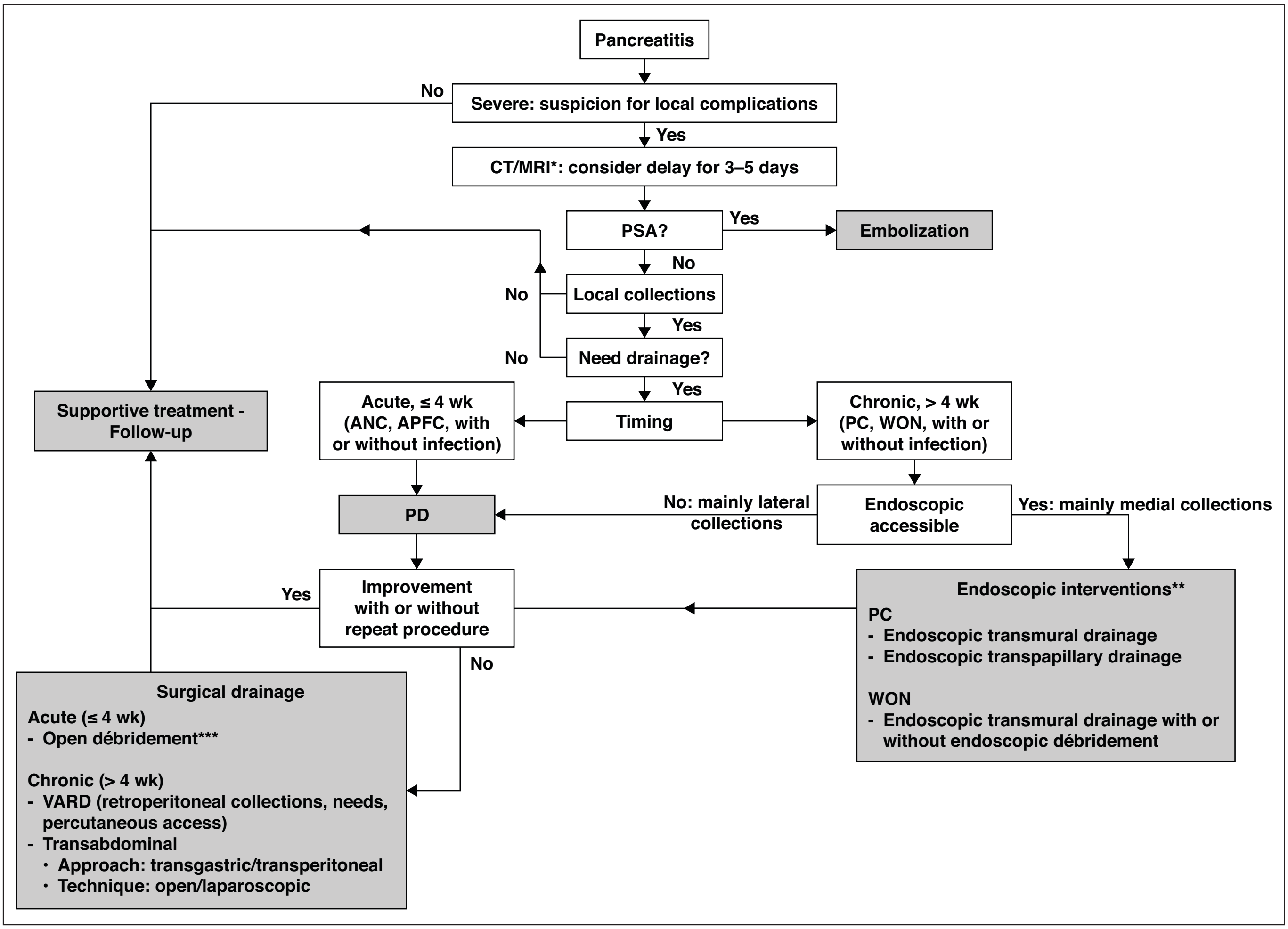


Fig. 1—Flowchart shows algorithm for interventions associated with vascular and nonvascular complications of pancreatitis. Single asterisk denotes contrast-enhanced imaging is preferred; in patients with acute kidney injury or estimated glomerular filtration rate less than 30 mL/min/1.73 m^2, contrast-enhanced CT with IV normal saline prophylaxis may be warranted. Double asterisks denote endoscopic interventions could be combined with percutaneous drainage (PD) in multiloculated collections with lateral portions. Triple asterisks denote early endoscopic drainage could be considered in selected patients with acute collection that failed to respond to PD. ANC = acute necrotic collection, APFC = acute peripancreatic fluid collection, PC = pseudocyst, PSA = pseudoaneurysm, VARD = video-assisted retroperitoneal débridement, WON = walled-off necrosis.

tween the collection and the gastrointestinal lumen, an alternate approach must be considered (Table 2).

IR procedures are performed in laterally located collections more often than endoscopic procedures because these collections are less likely to be successfully treated endoscopically. Conversely, medial collections, which require a longer transcutaneous approach, are more challenging for percutaneous drainage, especially when critical structures are interposed. A percutaneous approach is also favored when immediate drainage of an acute collection is required because of infection or clinical instability and endoscopic drainage is thought to be unsafe in the absence of a mature wall around the collection.

If additional drainage or débridement is needed, these procedures are used in a step-up approach in which initial endoscopic or percutaneous drainage is followed by endoscopic débridement or less invasive surgical procedures, such as VARD [55]. In more complicated cases, a combination of these less invasive procedures can be performed in an attempt to limit open surgical procedures.

Endoscopic Procedures

Endoscopic procedures have markedly evolved since their initial introduction for pancreatic complications in 1996 [56, 57]. Endoscopic-guided drainage can be performed by a transmural (transduodenal or transgastric) or transpapillary approach. The transmural and transpapillary drainage approaches have an efficacy of approximately 70–90%, depending on the type of collection [48]. Factors associated with higher rates of fluid collection resolution and lower rates of complication include underlying chronic pancreatitis or trauma, wall thickness of less than 1 cm, and absence of necrosis [48, 58–60].

Transmural Drainage

Indications—Transmural drainage is used to drain large mature collections that abut the stomach or duodenum.

Technique—Transmural drainage is performed by placement of a stent to create a tract between the collection and the lumen of the stomach or duodenum (Fig. 2). Endoscopic ultrasound guides

TABLE 2: Summary of Procedures in Management of Local Complications of Pancreatitis

Category, Procedure	Acute or Chronic[a]	Indication or Characteristics of Local Complication	Technique or Devices	Additional Consideration or Complications
Endoscopic procedure				
Transmural drainage	Mainly chronic	Chronic collection[b] abutting stomach or duodenum (endoscopically accessible)	Double pigtail stent Lumen-apposing stent (large caliber)	Risk of perforation
Transpapillary drainage	Mainly chronic	Small pseudocyst in communication with pancreatic duct	Small-caliber stent Placement during ERCP	Risk of postprocedure pancreatitis Morphologic changes of pancreatic duct expected on follow-up imaging May require additional procedures because of small stent diameter
DEN	Mainly chronic	Necrotic collection abutting stomach or duodenum (endoscopically accessible)	Snares, baskets, or forceps used to remove necrotic material Possible nasocystic catheter for lavage	Review preprocedural imaging for vascular complication given risk of fatal bleeding in presence of PSA May require additional or serial procedures
IR procedure				
CT-guided FNA	Both	Confirmation of secondary infection of necrosis or collection when results will affect treatment	20- to 22-gauge needle aspiration PD catheter placed at same session if purulent material aspirated	Reported positive in 49% of cases Risk of introduction of organisms to sterile collection
PD	Both	Bridging technique in acute setting Chronic collection[b] not accessible by endoscopy Access for VARD	Size and number of catheters based on size and amount of necrotic debris Most direct approach avoiding internal organs Rare transgastric approach (possible subsequent internal-ization)	May be performed alone (successful in up to 50% of cases) or in combination with other drainage approaches Risk of pancreaticocutaneous fistula (associated with disease severity)
Angiography and embolization	Both	Definitive diagnosis of PSA Treatment of PSA	Endovascular treatment (embolization or stent graft)	Risks of intervention-associated bleeding, nontarget embolization, end-organ ischemia or infarct, and rarely postembolization syndrome (fever, leukocytosis, malaise) Limited catheterization and treatment of distal branch PSA
Surgical débridement				
VARD	Mainly chronic	Failed response to less invasive endoscopic or percutaneous procedure	Require PD for access	Limited visualization and débridement vs transabdominal surgery
Transabdominal débridement	Mainly chronic[c]	Chronic collection[b] with failed response to VARD or to endoscopic or percutaneous procedure	Transgastric or transperitoneal approach Open or laparoscopic technique Drains left in place for subsequent lavage	Overall higher morbidity and mortality vs less invasive procedures

Note—DEN = direct endoscopic necrosectomy, PSA = pseudoaneurysm, IR = interventional radiology, FNA = fine-needle aspiration, PD = percutaneous drainage, VARD = video-assisted retroperitoneal débridement.
[a]Acute, < 4 weeks; chronic, > 4 weeks.
[b]Pseudocyst or walled-off necrosis.
[c]Acute in limited emergencies.

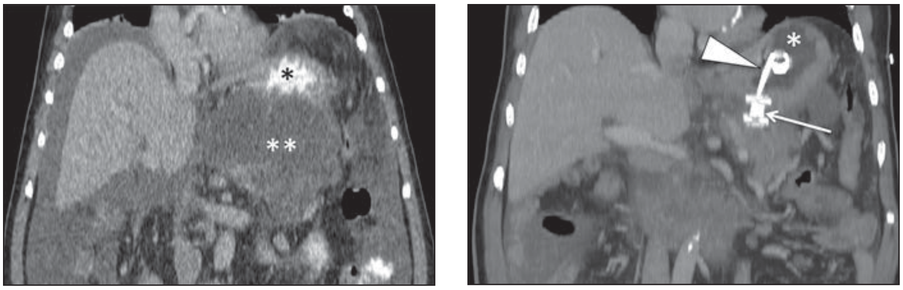


Fig. 2—63-year-old man who presented with abdominal pain several months after episode of pancreatitis.
A, Coronal oblique CT shows large walled-off necrosis (*white asterisks*) adjacent to stomach (*black asterisk*).
B, Follow-up coronal oblique maximum-intensity-projection image from CT performed 1 month after transmural drainage shows pigtail drainage catheter (*arrowhead*) passing through lumen-apposing stent (*arrow*). Proximal tip of pigtail catheter is placed in stomach lumen (*asterisk*). Interval near-complete resolution of collection was achieved.

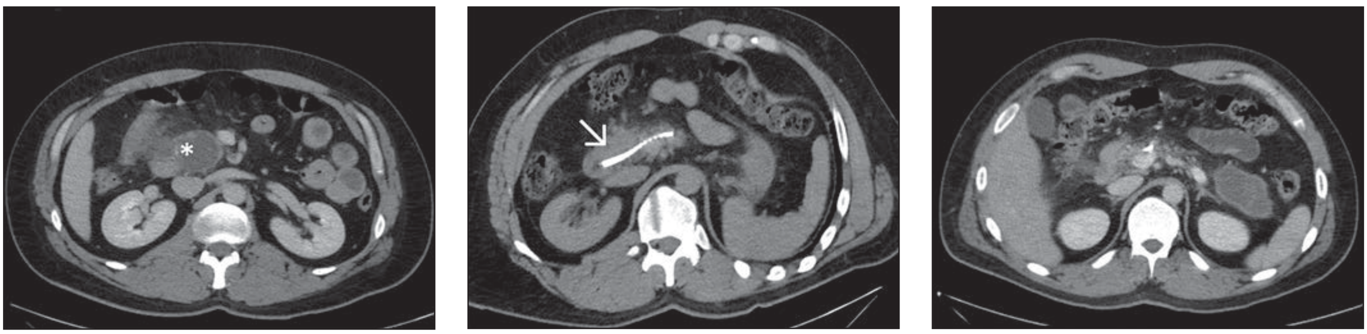


Fig. 3—33-year-old man who presented with acute pancreatitis.
A, Axial CT image obtained 24 months after initial pancreatitis shows simple pseudocyst (*asterisk*) adjacent to pancreatic duct at pancreatic head.
B, Axial oblique CT shows pigtail stent (*arrow*) extending along pancreatic duct 1 month after placement.
C, Axial CT shows resolution of previously noted collection 1 month after transpapillary catheter placement.

the puncture site. This is followed by creation of a fistula using a cautery, possible dilation, and placement of a drainage stent. The current widely used stents include plastic double pigtail stents (7–10 French) and larger diameter covered lumen-apposing metal stents (e.g., Axios, Boston Scientific; available in sizes of 10, 15, and 20 mm). Plastic double pigtail stents are standard for endoscopic transmural drainage procedures, which are typically performed when draining a collection containing predominantly fluid rather than solid debris. However, if the preprocedural imaging and/or direct visualization during the procedure shows thick fluid and/or solid debris, placement of a lumen-apposing metal stent is considered [61]. The larger diameter stents may provide better drainage and allow potential endoscopic necrosectomy through the stent lumen, though they may have a higher chance of causing bleeding compared with plastic double pigtail stents [62]. Preprocedure imaging can guide the location, number, and type of initial stents and help anticipate the need for a multifaceted approach (e.g., through the stomach and duodenum). Repeat procedures in the days or weeks after initial drainage may be required in the presence of solid necrotic debris.

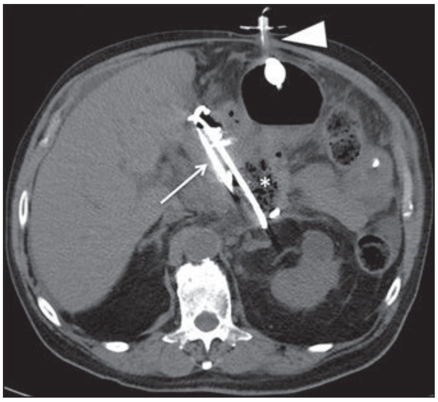
Considerations and complications—Complications after endoscopic drainage that should be recognized on postprocedural imaging include immediate or late bleeding, perforation, enlarging collection, worsened infection, and stent or catheter dislodgement or migration [48]. As previously noted, careful review of preprocedural imaging and identification of associated risk factors can help prevent these complications. Bleeding can occur in the setting of injury to an intervening blood vessel or an unrecognized pseudoaneurysm, highlighting the need for careful evaluation of vascular anatomy on preprocedural imaging. Perforation could present as new poorly delineated collections adjacent to or remote from the procedure site. Secondary stent malfunction could present as increased size of a drained collection or worsened infection; accordingly, evaluation of a stent on postprocedural imaging and early recognition of stent malfunction are necessary to ensure the stent's function and avoid secondary infection.

Transpapillary Stenting and Drainage

Indications—Transpapillary drainage may be indicated in the presence of pancreatic duct stenosis or in patients with a small pseudocyst that is in communication with the main pancreatic duct (Fig. 3).

Technique—This procedure entails placement of a stent through the pancreatic duct by ERCP to facilitate cyst drainage through the pancreatic duct. Transpapillary drainage often involves placement of smaller caliber stents (3–7 French), which can limit drainage relative to larger caliber stents placed via a transmural approach. The stent is generally removed after the pseudocyst is found to be resolved on follow-up imaging.

Considerations and complications—The most common complication of transpapillary drainage is pancreatitis, for which attention is warranted on follow-up imaging [63]. Follow-up imaging should also be evaluated for potential inward or outward stent migration. Occasional failure of proper transpapillary drainage or secondary infection of the collection may require subsequent transmural or percutaneous drainage. Additionally, the transpapillary drainage stent can result in new morphologic changes to the pancreatic duct (e.g., irregularity, strictures of the main duct, or side branch changes). However, the clinical significance of these changes is not clear, with most cases showing complete resolution on follow-up imaging after stent removal [64]. In many



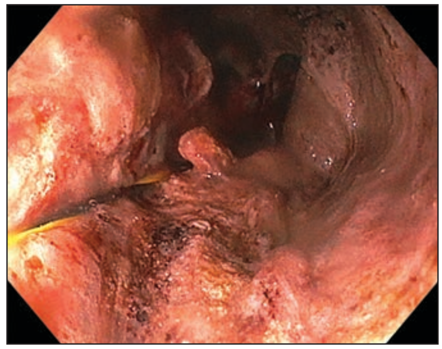


Fig. 4—69-year-old man with history of pancreatitis and prior large necrotic collection.
A, Axial CT shows residual necrotic collection (*asterisk*) despite placement of two transmural pigtail drainage catheters (*arrow*). Patient also had percutaneous gastrojejunostomy tube (*arrowhead*) for nutrition.
B, Endoscopic image from necrosectomy procedure shows necrotic material within collection.

cases, secondary endoscopic ultrasound-guided transmural or percutaneous drainage may be necessary when the transpapillary approach fails to provide sufficient drainage or is not feasible because of severe pancreatic duct stenosis, obstruction, or anatomic location of the targeted collection or when the instrumentation of a failed attempt causes an iatrogenic secondary infection of the fluid collection.

Direct Endoscopic Necrosectomy

Indications—Endoscopic necrosectomy is indicated if the initial drainage fails to resolve the collection and the patient continues to have persistent symptoms, particularly in the presence of solid necrotic debris within an endoscopically accessible sterile symptomatic collection or in the presence of infected pancreatic necrosis (Fig. 4). Although endoscopic interventions, and endoscopic necrosectomy in particular, are typically performed in chronic collections, these procedures may be safely performed in carefully selected acute cases [50].

Technique—This procedure is performed to remove the necrotic and devitalized pancreatic material by means of endoscopic tools such as snares, baskets, or larger rat-tooth forceps through a transmural approach [11, 65]. The necrosectomy can be performed at the time of initial endoscopy if lumen-apposing stents are used or after tract maturation in the following weeks (e.g., after 4 weeks). Occasionally, after direct endoscopic necrosectomy, a nasocystic catheter may be placed for postprocedure lavage [66]. Successful débridement of pancreatic necrosis often involves multiple sessions of direct endoscopic necrosectomy, guided by serial CT to evaluate resolution of the necrosis.

Considerations and complications—The most severe complication of endoscopic necrosectomy is bleeding from exposed blood vessels or an undiagnosed pseudoaneurysm, which may be massive and difficult to control. Other complications include perforation and infection. The overall clinical success of endoscopic necrosectomy ranges from 75% to 91% [67, 68]. As previously noted, patients may require repeated débridement in the following days to weeks [67, 68].

Diagnostic and Therapeutic Interventional Radiology Procedures

CT-Guided Fine-Needle Aspiration

Indications—CT-guided fine-needle aspiration of necrotic material can confirm secondary infection of a local collection and potentially guide choice of antibiotic agent and the need for accelerated drainage or débridement [69, 70].

Technique—Needle aspiration is performed with a 20- to 22-gauge needle from areas of pancreatic or peripancreatic necrosis [71]. Samples are sent for Gram stain and cultured for aerobic, anaerobic, and fungal bacteria.

Considerations and complications—One study reported that only 49% of patients who underwent CT-guided fine-needle aspiration based on systemic toxicity and preprocedural imaging findings had confirmed pancreatic infection [71]. The benefit of CT-guided fine-needle aspiration remains debated, reflecting the balance between the potential application of new potent antibiotics in patients with suspected or proven infection and the potential risk of introduction of organisms to a sterile collection [46, 72]. Accordingly, CT-guided fine-needle aspiration is considered only if the results would affect management [11, 72].

Percutaneous Image-Guided Drainage

Indications—Percutaneous image-guided drainage can be considered when collections are deemed inaccessible by an endoscopic approach [73]. In some patients with an acute infected necrotic collection and sepsis, percutaneous drainage can be used to decompress the retroperitoneal collection and stabilize the clinical condition as a bridge to subsequent, more definitive intervention. Percutaneous drainage may also be used in the setting of critical illness and the absence of a mature collection wall, as is necessary for endoscopic drainage [74]. This procedure can be performed alone or in combination with other drainage techniques [75, 76]. Indeed, up to 50% of peripancreatic collections can be managed by percutaneous drainage alone [9, 77, 78]. A percutaneous catheter could serve as access for a subsequent VARD procedure, which requires a left retroperitoneal access site.

Technique—Access for percutaneous drainage is most commonly obtained using the most direct pass through a transperitoneal or retroperitoneal approach while avoiding intervening bowel loops and solid organs. In rare situations, a transgastric approach with passage of a percutaneous drain through the stomach can help subsequent internalization with a double pigtail tube, particularly for long-term drainage (e.g., pancreatic duct fistula) [79, 80]. Before the procedure, patients should be informed that they may need more than one catheter and prolonged duration of drainage for several weeks to months [70, 81]. The size and number of catheters are based on collection size and amount

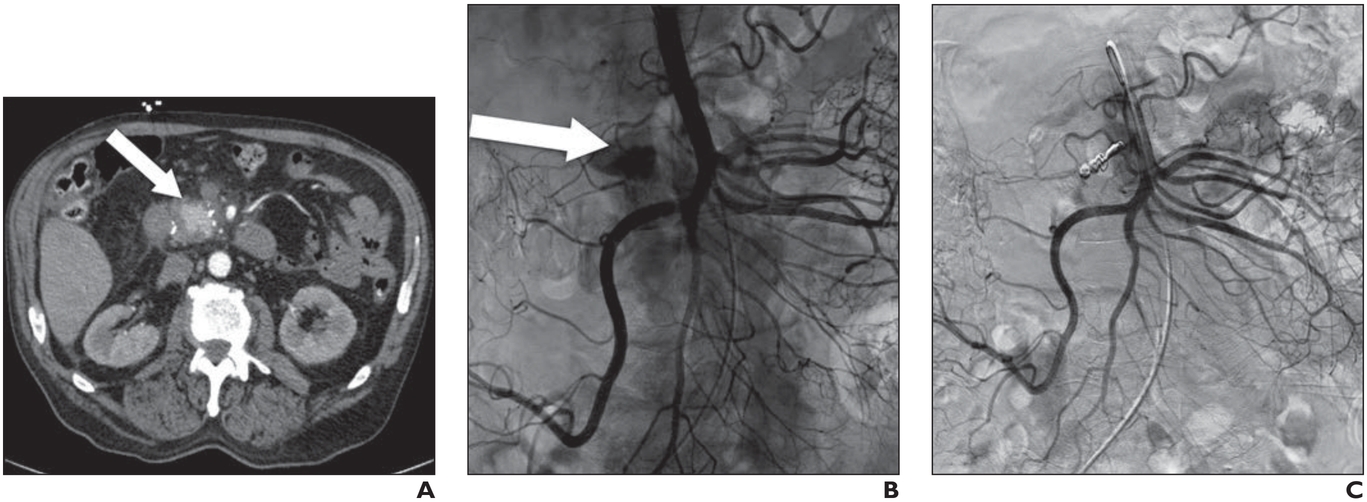


Fig. 5—72-year-old man with history of pancreatitis who presented with black stool and decreased hemoglobin level.
A, Arterial phase axial CT shows 3.2-cm pseudoaneurysm (*arrow*) in small branch of superior mesenteric artery at pancreatic head.
B and **C,** Angiographic images show pseudoaneurysm (*arrow*, **B**) before (**B**) and after (**C**) embolization.

of necrotic debris. A proactive strategy defined by frequent and early drain revision and upsizing in the case of lack of clinical improvement decreases the need for necrosectomy and improves the outcome [82, 83]. Although smaller bore (8- to 10-French) catheters could suffice to drain thin fluid, larger bore (12- to 24-French) tubes may be indicated in thick collections [81]. Safe manipulation of multiloculated collections using stiff wires and metallic stiffeners during the initial access procedure could facilitate breaking loculations. Large-volume irrigation (20–200 mL, depending on volume of the cavity, administered three to four times per day) or even continuous irrigation (e.g., in the presence of necrotic material and multiple catheters) of the catheter with normal saline facilitates the drainage of necrotic material and prevents catheter occlusion [70]. If any concern exists regarding drain patency (e.g., sudden reduction of drain output or no improvement of patient condition), fistulization to internal organs (e.g., drain output > 50–75 mL/day for several days), or need for repositioning, reassessment with cross-sectional imaging or fluoroscopic injection should be considered. Application of fibrinolytic therapy (e.g., tissue plasminogen activator, 4–6 mg in 50-mL normal saline, administered twice a day for 3 days) could facilitate the degradation of fibrin strips and improve the drainage; nevertheless, the benefit of this therapy should be weighed against the uncommon risk of bleeding [84, 85]. Drain removal may be considered when the drain output is less than 10–15 mL/min and the patient is in stable clinical condition.

Considerations and complications—Whereas minor complications such as pain or catheter site leak are common, major procedure-related complications such as bleeding or internal organ injury are rare [70]. The risk of persistent pancreaticocutaneous fistula after drain removal is associated with the severity of pancreatitis, with a frequency as high as 32% in patients with infected necrotic pancreatitis [78, 81]. This risk is decreased by using a transgastric approach or by combining simultaneous endoscopic drainage [11, 76, 78–80].

Angiography and Embolization

Vascular IR procedures play an important role in the diagnosis and treatment of peripancreatic arterial pseudoaneurysms. Pseudoaneurysms almost always warrant treatment because of the risk of spontaneous rupture and bleeding. Moreover, the presence of a pseudoaneurysm is considered an absolute contraindication for endoscopic drainage or débridement procedures because of potential iatrogenic fatal hemorrhage (Fig. 5). Although preprocedural imaging provides a helpful clue for delineation of arterial anatomy, angiography is still the definitive diagnostic test and allows therapeutic transcatheter angiographic embolization to be performed [28, 86]. Endovascular treatment is accomplished by coil or glue embolization or placement of a stent graft if preservation of distal flow is deemed necessary. After arterial embolization of a pseudoaneurysm is performed, patients can be reevaluated to determine whether they should undergo endoscopic or other drainage procedures. Angiographic transcatheter embolization can also be used in hemodynamically stable patients to manage postprocedural bleeding, which may arise from an undiagnosed pseudoaneurysm. In unstable patients, resuscitative efforts precede the transcatheter embolization.

Surgical Débridement

Indications

Surgical débridement is indicated in patients with acute peritonitis and sepsis, abdominal compartment syndrome, or bowel perforation and in patients for whom less invasive procedures are unsuccessful [52]. Moreover, extension of the necrotic material to the mesenteric root or bilateral paracolic gutters may require wide surgical débridement [87]. When endoscopic and radiologic approaches have a low likelihood of success, initial surgical débridement may be warranted.

Technique

Surgical débridement can be performed using a variety of methods (transgastric vs transperitoneal approach, open vs laparoscopic technique), depending on the clinical situation [49]. Transgastric débridement can be performed by an open or laparoscopic technique [88, 89]. The necrotic tissue is approached through a posterior gastrotomy after entering the stomach anteriorly. The pancreas is débrided in a single-stage procedure as opposed to endoscopic

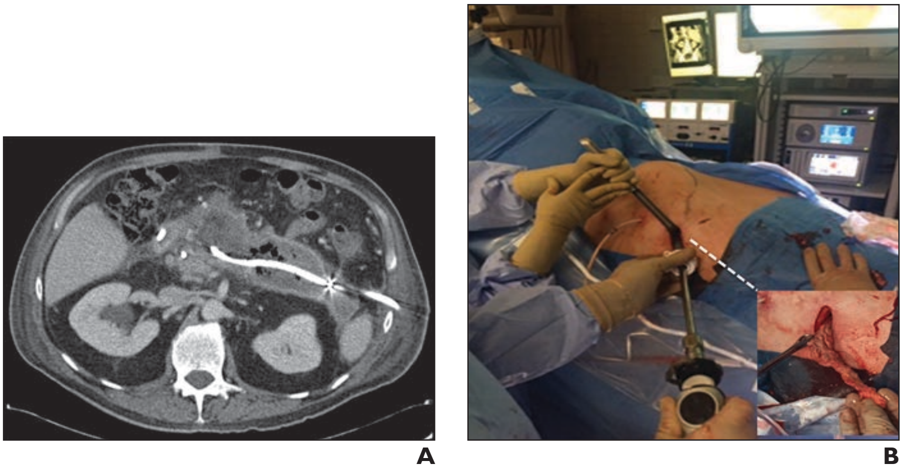


Fig. 6—65-year-old man with history of pancreatitis and chronic necrotic collection.
A, Axial CT shows left laterally approaching percutaneous drain placed in chronic necrotic collection to provide access for video-assisted retroperitoneal débridement (VARD).
B, Photograph shows incision created at location of percutaneous drain in left lateral abdomen during VARD. Inset shows removal of necrotic material, which is accomplished with various devices.

necrosectomy, which requires serial débridement procedures because of instrumentation. Transgastric débridement is best used in patients who have undergone serial endoscopic débridement procedures without success or in patients whom the gastroenterologist judges to be at an exceedingly high risk of failure with endoscopic necrosectomy. Because this is an internal drainage procedure, an external drain is not always in place postoperatively. Open transperitoneal pancreatic débridement accesses the pancreas through the gastrocolic ligament or transverse mesocolon. Multiple drains are often left in place, through which lavage of the retroperitoneum may be performed.

The VARD procedure is a surgical option that requires a percutaneously placed retroperitoneal access site before surgery, which is accomplished by an IR-placed catheter [90] (Fig. 6). The location of the drainage catheter is important to guide the surgery. After the incision, the drainage catheter guides the surgeon into the necrosis. Necrosectomy is then performed under direct visualization through the videoscope placed through the small incision. Direct visualization allows complete débridement of the necrotic material from the retroperitoneum. After the procedure, drains are placed in the necrotic collection for continued drainage. Compared with a transperitoneal open procedure, VARD has a lower risk of peritoneal contamination, with drawbacks of limited visualization, débridement through the smaller access site, and risk for hemorrhage or injury in the colon and spleen [87, 90].

Complications

Multiple studies report acceptable efficacy and morbidity for surgical necrosectomy, even when performed by an open technique [46, 91, 92]. However, one randomized clinical trial reported decreased morbidity with the step-up approach compared with open necrosectomy [52]. Potential complications after surgical débridement include intraabdominal fluid collections, bleeding, and persistent or worsened pancreatic fistula. Similar to endoscopic necrosectomy, bleeding can result from vascular injury or from rupture of an undiagnosed pseudoaneurysm.

Conclusion

The diagnosis and management of complicated pancreatitis is most effective when implemented in a multidisciplinary team manner that incorporates advanced endoscopists; pancreatic surgeons; diagnostic and interventional radiologists; and specialists in infectious disease, nutrition, and critical care medicine [93]. In fact, endoscopic procedures are only recommended in centers where interventional and surgical support is available for management of unanticipated complications [2]. During a multidisciplinary team consult, whether an in-person or virtual meeting, a unique patient-specific treatment strategy, possibly combining different procedural approaches, is developed to optimize outcomes (Fig. 7). A comprehensive understanding of the various procedures will facilitate their integration by interventional

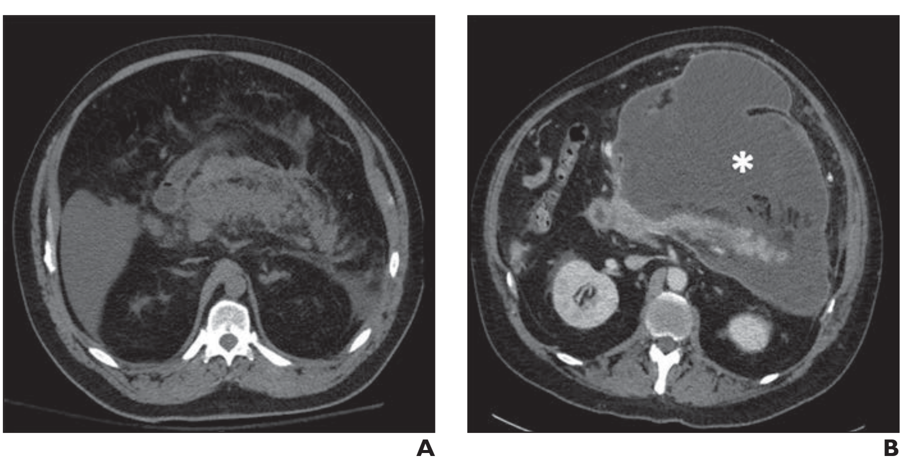
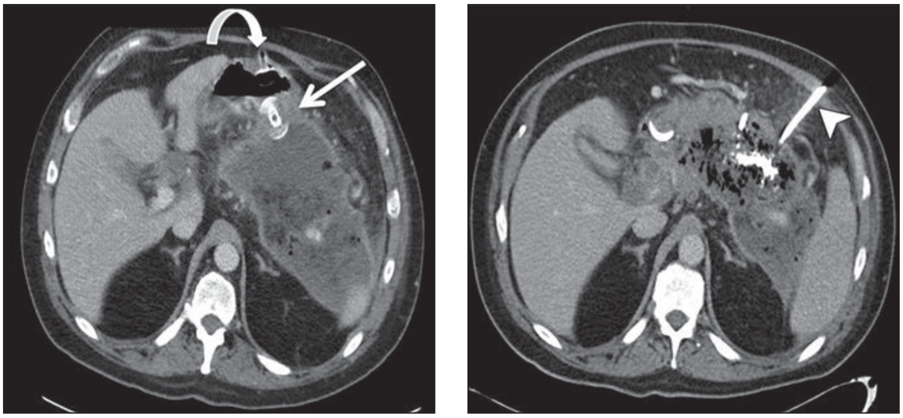


Fig. 7—48-year-old man with severe abdominal pain.
A, Axial CT shows severe pancreatitis.
B, Follow-up axial CT obtained 2 months after initial episode shows large walled-off necrosis (*asterisk*).
(Fig. 7 continues on next page)



C D

Fig. 7 (continued)—48-year-old man with severe abdominal pain.
C and **D,** Axial CT images obtained 2 weeks after multiple minimally invasive drainage procedures show transmural lumen-apposing stent (*straight arrow*, **C**), percutaneous gastric tube (*curved arrow*, **C**), and percutaneous drainage catheter (*arrowhead*, **D**). Procedures failed to adequately drain necrotic collection. Patient eventually underwent open surgical débridement.

radiologists into the complex longitudinal care of patients with complicated pancreatitis.

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