Endoscopic Interventions in Acute Pancreatitis: What the Advanced Endoscopist Wants to Know

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Endoscopic interventions play an important role in the modern management of pancreatic fluid collections. Successful management of pancreatitis is dependent on proper classification of the disease and its local complications. The 2012 revised Atlanta classification divides acute pancreatitis into subtypes of necrotizing pancreatitis and interstitial edematous pancreatitis (IEP) on the basis of the radiologic presence or absence of necrosis, respectively. Local complications of IEP include acute pancreatic fluid collections and pseudocysts, which contain fluid only and are differentiated by the time elapsed since the onset of symptoms. Local complications of necrotizing pancreatitis include acute necrotic collections and walled-off necrosis, which contain nonliquefied necrotic debris and are differentiated by the time elapsed since the onset of symptoms. Endoscopic techniques are used to treat local complications of pancreatitis, often in a step-up approach, by which less invasive techniques are preferred initially with potential subsequent use of more invasive procedures, dependent on the patient's clinical response and collection evolution. Common interventions performed by the advanced endoscopist include endoscopic transmural drainage and endoscopic transmural necrosectomy. However, some collections require a multimodal approach with adjunctive placement of percutaneous drainage catheters or the use of videoscopic-assisted retroperitoneal débridement. Additional endoscopic interventions may be required in the setting of pancreatic or biliary duct stones or strictures. Common complications of endoscopic intervention in the setting of pancreatitis include bleeding, infection, perforation, and stent migration. This article reviews the classification of acute pancreatitis, familiarizes radiologists with the common endoscopic techniques used in its management, and improves identification of the clinically relevant imaging findings and procedural complications related to endoscopic interventions in pancreatitis.

Abbreviations: ANC = acute necrotic collection, APFC = acute peripancreatic fluid collection, ETD = endoscopic transmural drainage, ETN = endoscopic transmural necrosectomy, ERCP = endoscopic retrograde cholangiopancreatography, IEP = interstitial edematous pancreatitis, LAMS = lumen-apposing metal stent, MRCP = MR cholangiopancreatography, VARD = videoscopic-assisted retroperitoneal débridement, WON = walled-off necrosis

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SA-CME LEARNING OBJECTIVES

After completing this journal-based SA-CME activity, participants will be able to:

- Differentiate among pancreatic and peripancreatic collections and describe these collections using the appropriate Atlanta classification nomenclature.
- Describe findings in acute pancreatitis that are essential for planning endoscopic interventions.
- Identify complications from endoscopic interventions for acute pancreatitis.

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Introduction

Acute pancreatitis is a common yet complex disease with a wide array of manifestations. It is the most common gastrointestinal cause for hospitalization in the United States, accounting for approximately 300 000 admissions annually (1,2). Successful management of acute pancreatitis is dependent on accurate imaging diagnosis, classification, and identification of complications (3). In the setting of complicated pancreatitis, endoscopic interventions have been shown to reduce length of hospital stay, lower costs, and improve patient outcomes and as a result now play a substantial role in management (4–6). It is important for radiologists to understand the range of available endoscopic techniques and their potential complications to identify the clinically relevant imaging features that the endoscopist needs to know and provide appropriate guidance for treatment

TEACHING POINTS

- The four distinct types of pancreatic and peripancreatic collections are defined at imaging on the basis of the presence or absence of necrosis and the time elapsed since the onset of acute pancreatitis. Nonnecrotic collections contain homogeneous fluid contents, while necrotic collections are inhomogeneous with nonliquefied contents. Nonliquefied contents include fat, hemorrhage, and necrotic material. APFC and pseudocysts arise only in patients with IEP, while ANC and WON arise only in patients with necrotizing pancreatitis.
- An important principle in modern pancreatic fluid collection intervention is the step-up approach, by which minimally invasive techniques are used initially, and definitive necrosectomy is delayed or avoided altogether, which is dependent on the evolution of the cavity and the clinical course of the patient. With recent technological advances, endoscopic methods have been shown to be safer when compared with more invasive surgical techniques, with equal efficacy, lower costs, and improved quality of life. Therefore, endoscopic transmural drainage (ETD) and endoscopic transmural necrosectomy (ETN) are now considered the first-line and often definitive treatments for WON when intervention is indicated.
- Whenever possible, intervention should be delayed to allow time for the collection to mature and become walled-off. In addition to reducing the risk of gastric perforation into the peritoneum, delaying intervention facilitates improved demarcation and increased liquefaction of necrosis, minimizing the resection of vital tissue if necrosectomy is required, thereby improving morbidity and mortality. If source control is required in patients with sepsis before maturation of the collection, percutaneous catheter drainage may be an appropriate temporizing measure. Overall, radiologists can help the advanced endoscopist by using the revised Atlanta classification system when describing collections and reporting the presence or absence of a well-defined wall, intervening vessels between the gastric wall and the pancreatic fluid collection, or pseudoaneurysm within the collection.
- At follow-up CT after any intervention, the radiologist should report the treatment response by detailing a change in size, presence, and location of persistent necrotic debris within a collection. This information is useful to endoscopists, directing them to the portion of the collection with the most necrotic debris.
- Despite its relatively high incidence, disconnected duct syndrome is often overlooked at imaging. It is recognized by the presence of a discrete intrapancreatic collection along the expected course of the main duct, usually within the neck or body, with viable enhancing upstream pancreatic tail. The diagnosis is further supported when the upstream pancreatic duct is oriented perpendicular to the collection or seen in direct communication with the collection. In contrast, a duct that is oriented at an oblique angle to the collection may reflect mass effect and displacement by the collection rather than disconnection of the duct. Radiologists should have a high level of suspicion for disconnected duct in any patient with a necrotic collection involving the neck and/or body of the pancreas.

planning. This article reviews the classification of pancreatitis and familiarizes radiologists with the clinically relevant imaging findings, common endoscopic interventions, and radiologic appearances of procedural complications related to acute pancreatitis.

Diagnosis and Classification of Acute Pancreatitis

The 2012 revision of the original 1992 Atlanta classification system of acute pancreatitis significantly updated the terminology related to the clinical severity of the disease and provided standardized nomenclature to describe local complications of acute pancreatitis to facilitate effective communication and treatment planning among radiologists, gastroenterologists, and surgeons (7). Per the revised classification system, diagnosis of acute pancreatitis requires that two of the following three criteria are met: *(a)* characteristic abdominal pain (acute, severe, or epigastric), *(b)* serum amylase or lipase levels three times the upper limit of normal, and *(c)* characteristic imaging findings at any modality. Most commonly, the first two criteria alone are sufficient to make the initial diagnosis of acute pancreatitis. Typically, imaging is generally not indicated within the first few days of patient presentation, as necrosis and local complications are rarely seen before 5–7 days and initial management is dictated by scoring systems assessing clinical severity (7).

The revised Atlanta classification system clearly divides the clinical course of acute pancreatitis into early and late phases. The early phase occurs in the 1st week after pain onset and is characterized by a systemic inflammatory response, which can lead to organ failure. The late phase begins 1 week after onset and may last weeks to months, characterized by the persistence of organ failure or development of local complications (eg, pancreatic and peripancreatic collections) (7).

Severity of disease, which is also defined by the 2012 revision, can be classified as mild, moderately severe, or severe acute pancreatitis. Mild acute pancreatitis, which occurs in the majority of patients, is characterized by the absence of organ failure or local or systemic complications. Moderately severe acute pancreatitis is characterized by transient organ failure that resolves within 48 hours, local complications such as pancreatic and peripancreatic collections, or systemic complications in the absence of persistent organ failure. Severe acute pancreatitis is defined by persistent organ failure lasting greater than 48 hours and carries a mortality rate as high as 36%–50%. These patients often also suffer from local complications (7–9).

The revised Atlanta classification system also updates the definitions of the two subtypes of acute pancreatitis, interstitial edematous pancreatitis (IEP) and necrotizing pancreatitis. In IEP, which comprises approximately 90%–95% of cases of acute pancreatitis, the gland enhances completely without any nonenhancing necrotic areas, and peripancreatic inflammation is seen (Fig 1).

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Figures 1, 2. **(1)** IEP in a 41-year-old woman. Axial contrast material–enhanced CT image shows a homogeneously enhancing pancreas, with wispy peripancreatic inflammation (arrows). **(2)** Necrotizing pancreatitis in a 49-year-old man. Axial contrast-enhanced CT image shows nonenhancement of the pancreas neck and body (arrow) and a normally enhancing tail.

Table 1: Pancreatic and Peripancreatic Collections

Collection	Pancreatitis Subcategory	Time after Onset of Pain (wk)	Location	Imaging Features
APFC	IEP	≤4	Extrapancreatic	Homogeneous, fluid attenuation, no wall, conforms to retroperitoneal structures
Pseudocyst	IEP	>4	Extrapancreatic	Homogeneous, fluid attenuation, circumscribed, encapsulated with wall
ANC	Necrotizing pancreatitis	≤4	Intra- and/or extrapancreatic	Inhomogeneous, nonliquefied components, no wall
WON	Necrotizing pancreatitis	>4	Intra- and/or extrapancreatic	Inhomogeneous, nonliquefied components, encapsulated with wall

Note.—Adapted and reprinted, with permission, from reference 14. ANC = acute necrotic collection, APFC = acute peripancreatic fluid collection, WON = walled-off necrosis.

In necrotizing pancreatitis, which occurs in the remaining 5%–10% of cases of acute pancreatitis, imaging shows variable areas of nonenhancing parenchyma and/or necrotic collections (Fig 2) (7). Necrotizing pancreatitis can be subdivided at CT or MRI into three subtypes: *(a)* combined pancreatic and peripancreatic necrosis (75%–80% of cases), *(b)* peripancreatic necrosis only (20% of cases), or *(c)* parenchymal necrosis only (5% of cases) (7). Severity of necrosis can be determined by the extent of parenchymal involvement and is described as less than 30%, between 30% and 50%, or greater than 50% of the pancreas (10,11). Identification of necrosis is critically important, as morbidity and mortality rates in the setting of necrotizing pancreatitis range from 34% to 95% and 2% to 39%, respectively (12,13).

Radiologists play a key role in diagnosing and describing local complications of acute pancreatitis by using specific nomenclature from the revised Atlanta classification system. Local complications should be clinically suspected in the setting of persistent or recurrent abdominal pain, a secondary increase in pancreatic enzyme levels, worsening organ dysfunction, or sepsis. A precise description of local complications is important because treatment varies by collection type (7).

The four distinct types of pancreatic and peripancreatic collections are defined at imaging on the basis of the presence or absence of necrosis and the time elapsed since the onset of acute pancreatitis (Table 1) (7,14). Nonnecrotic collections contain homogeneous fluid contents (Figs 3, 4), while necrotic collections are inhomogeneous with nonliquefied contents (Fig 5). Nonliquefied contents include fat, hemorrhage, and necrotic material. APFC (Fig 3) and pseudocysts (Fig 4) arise only in patients with IEP, while

3.

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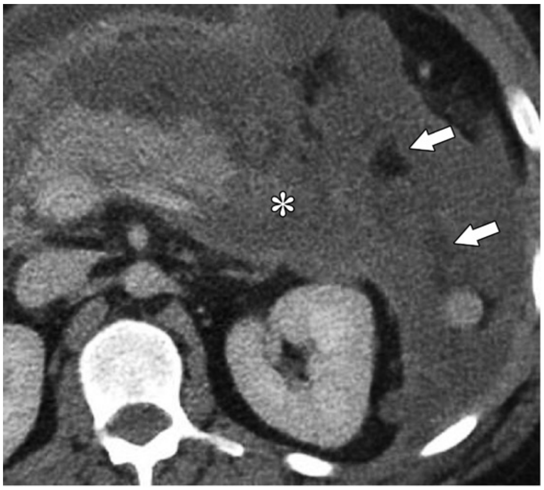
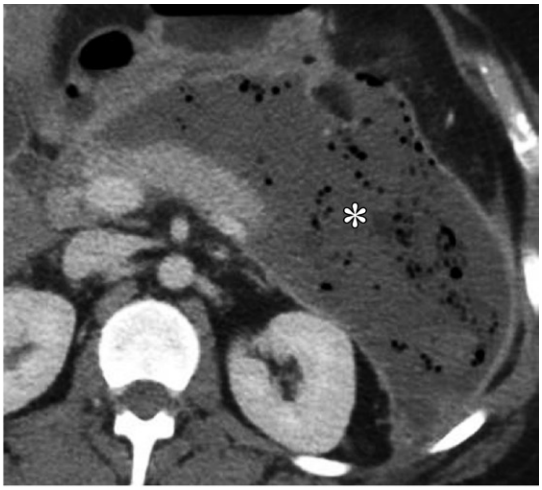
Figures 3, 4. **(3)** Nonnecrotic peripancreatic fluid collection in a 36-year-old woman with IEP, 7 days after the onset of acute pancreatitis. Axial contrast-enhanced CT image shows a peripancreatic collection (arrow) with homogeneous fluid attenuation and without a well-defined wall, consistent with APFC. Note the normal enhancement of the pancreas. **(4)** Nonnecrotic peripancreatic fluid collection in a 52-year-old man with IEP, 7 weeks after the onset of acute pancreatitis. Axial contrast-enhanced CT image shows a homogeneous peripancreatic collection (arrow), with a well-defined wall compressing the stomach, consistent with a pseudocyst.



a.



b.

Figure 5. Necrotic peripancreatic fluid collection in a 37-year-old woman with necrotizing pancreatitis. **(a)** Axial contrast-enhanced CT image obtained 3 weeks after the onset of necrotizing pancreatitis shows a nonenhancing pancreatic tail (*) and large peripancreatic ANC containing nonliquefied debris, including foci of fat attenuation (arrows). **(b)** Axial contrast-enhanced CT image obtained 6 weeks after the onset of necrotizing pancreatitis owing to patient decompensation and readmission shows greater organization of the collection (*), as evidenced by the well-defined enhancing wall. The collection contains multiple foci of gas, consistent with infected WON.

ANC (Fig 5a) and WON (Fig 5b) arise only in patients with necrotizing pancreatitis.

APFC and ANC occur within the first 4 weeks of disease onset; if they persist after 4 weeks, they develop a mature wall to become a pseudocyst or WON, respectively. Because it is not descriptive of the pathologic condition and may be confusing, the term *pancreatic abscess* should not be used. Any pancreatic or peripancreatic collection may be sterile or infected, with the presence of gas within the collection being the only reliable imaging finding to suggest infection, although it can be mimicked by other causes, as discussed later in this article (Fig 5b) (7).

APFCs are nonwalled collections confined by fascial planes, generally in the retroperitoneum, and may be multiple contiguous or discontiguous collections. However, if any pancreatic parenchymal necrosis manifests, the associated nonwalled collection is instead classified as an ANC (7,15). Most APFCs remain sterile and resolve spontaneously without developing into a pseudocyst,

while 80% of ANCs develop into a WON (6,16). Any wall-forming collection that occupies or replaces pancreatic parenchyma is by definition a necrotic collection (ANC or WON), regardless of the appearance of its contents (15).

Conversely, a pseudocyst must be peripancreatic (14). The sole exception to this rule occurs in the setting of disconnected duct syndrome, where parenchymal necrosis isolates a viable portion of the upstream pancreatic gland; following drainage or débridement of the necrotic collection, the persistent leakage of pancreatic juices into the cavity results in the accumulation of a pseudocyst (17,18). This entity will be discussed in more detail later in the article.

Local complications develop only in patients with moderately severe or severe acute pancreatitis (7,19). However, early identification and characterization of pancreatic necrosis and local complications do not necessarily correlate with the patient's symptoms, change the treatment approach, or alter outcomes. Therefore, imaging plays a limited role in the early phase of acute pancreatitis (1st week of onset). Additionally, necrotizing pancreatitis is often not identified at imaging until days 5–7, and almost all patients appear to have IEP if imaged too early. However, in the late phase, after the 1st week, imaging is essential for diagnosing and evaluating necrotizing pancreatitis and local complications, determining the timing and type of intervention, and assessing the response to therapy (3,7,20,21).

Imaging Features of Acute Pancreatitis

Contrast-enhanced CT is generally the most prevalent imaging modality used in patients with acute pancreatitis because of its availability, speed, and accuracy. Routine contrast-enhanced CT in the portal venous phase is often sufficient to evaluate for local complications. If bleeding or pancreatic malignancy is suspected, a multiphase pancreas protocol CT with both nonenhanced arterial and enhanced portal phases is beneficial. Noncontrast CT is commonly used in severe pancreatitis in the setting of acute renal failure. While limited in the evaluation of pancreatic necrosis, it generally allows for accurate determination of the collection subtype.

At CT, necrotic collections are distinguished from nonnecrotic collections by the presence of nonliquefied debris, which may include fat attenuation, slightly-higher-than-water attenuation areas layering dependently within fluid, high-attenuation dependent material, thick septa, or clotted blood. Even the detection of a very small area of fat or debris within an otherwise large simple fluid collection confirms the diagnosis of a necrotic collection. However, it is important to note that necrotic collection contents can be underestimated at CT because of their similar attenuation to that of fluid, sometimes leading to misdiagnosis as a bland fluid-containing APFC or pseudocyst.

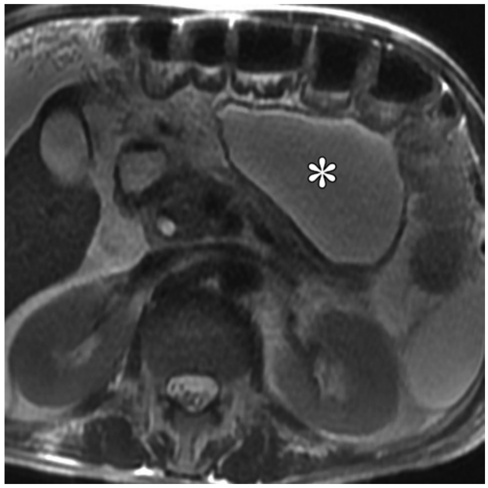


Figure 6. Peripancreatic fluid collection in a 27-year-old man, 5 weeks after the onset of pancreatitis. Axial T2-weighted MR image shows a peripancreatic collection (*), containing homogeneous T2-hyperintense fluid with no debris, consistent with a pseudocyst.

MRI is particularly useful in the classification of collection type because of its superior soft-tissue enhancement compared with that of CT (3,22). A pseudocyst (Fig 6) shows uniform hyperintense signal on T2-weighted images, while collections containing necrotic debris (Fig 7) will appear heterogeneous and contain regions of relative T2 hypointensity and occasionally T1 hyperintensity from blood products and fat lobules (14).

Infection occurs in about 20% of cases of necrotizing pancreatitis and is associated with a mortality rate as high as 39% (23,24). It is not prevalent in the 1st week and occurs most commonly 2–4 weeks after the onset of symptoms, likely owing to the translocation of intestinal bacteria into the necrotic collection (25). The presence of gas is the only reliable imaging finding to suggest infection but is found in only 12%–22% of patients with infection (Fig 5b) (3). The presence of gas can also be seen in the setting of collections complicated by fistulas to the gastrointestinal tract or following intervention (14,26). Importantly, the lack of gas in a collection does not exclude infection if suspected clinically. CT is the preferred modality for the detection of gas because of its high sensitivity for detecting minute amounts of gas. MRI is much less sensitive for identification of infection in comparison to that of CT (27).

Principles of Endoscopic Intervention

Historically, surgical débridement has been the definitive treatment for management of necrotizing pancreatitis. However, complication rates as

Table 2: Imaging Features to Report in the Setting of Acute Pancreatitis

Findings to report in all cases of acute pancreatitis
Presence or absence of pancreatic and/or peripancreatic necrosis
Presence or absence of local complications (eg, pancreatic or peripancreatic fluid collections, vascular complications)
Findings to report in the setting of pancreatic and/or peripancreatic collections before intervention
Collection contents (eg, simple fluid vs nonliquefied debris)
Presence or absence of a well-defined wall
Evidence of infection (eg, gas within the collection)
Proximity to the stomach or duodenum
Interposed vessels between the gastric wall and the collection
Presence of a pseudoaneurysm or vessel traversing the collection
Findings to report following endoscopic intervention
Change in collection size
Presence and location of necrotic debris within the collection
Immediate complications (eg, bleeding, infection, perforation)
Stent position and evidence of migration

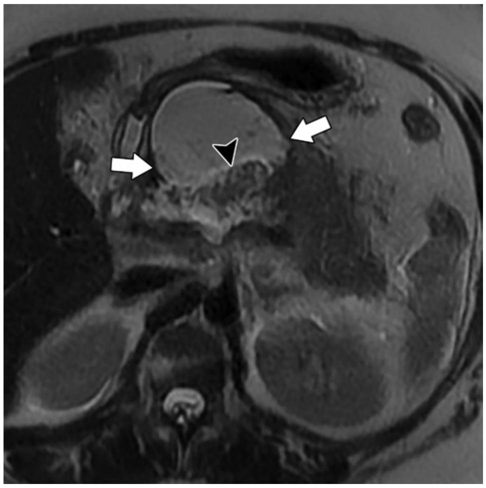


Figure 7. Peripancreatic fluid collection in a 48-year-old woman, 3 weeks after the onset of pancreatitis. Axial T2-weighted MR image shows a pancreatic and peripancreatic T2-hyperintense collection (arrows) containing fluid and nonliquefied debris, including necrotic pancreatic neck and body parenchyma (arrowhead), consistent with ANC.

high as 64%–95% and mortality rates of 15%–40% prompted the development of less invasive strategies, including percutaneous and transoral routes of therapy. An important principle in modern pancreatic fluid collection intervention is the step-up approach, by which minimally invasive techniques are used initially, and definitive necrosectomy is delayed or avoided altogether, which is dependent on the evolution of the cavity and the clinical course of the patient. With recent technological advances, endoscopic methods have been shown to be safer when compared with more invasive surgical techniques, with equal efficacy, lower costs, and improved quality of life (28–30). Therefore, endoscopic transmural drainage (ETD) and endoscopic transmural necrosectomy (ETN) are now considered the first-line and often definitive treatments for WON when intervention is indicated.

The primary indication for intervention is the presence of *(a)* substantial symptoms (the inability to eat, persistent pain, etc), *(b)* infection of the collection contents, *(c)* sepsis, *(d)* organ failure, *(e)* gastrointestinal or biliary obstruction, and/or *(f)* fluid leakage secondary to a disconnected pancreatic duct (31). According to consensus guidelines established by the International Association of Pancreatology and American Pancreatic Association, intervention is rarely indicated for patients with sterile collections (32). APFCs undergo spontaneous resolution 70% of the time, and only 10% of patients with a pseudocyst ultimately require intervention (16).

Per the American College of Gastroenterology guidelines for the management of acute pancreatitis, an asymptomatic WON does not require intervention regardless of size, location, and/or extension, as it will often resolve spontaneously (33,34). Whenever possible, intervention should be delayed to allow time for the collection to mature and become walled-off (32,34). In addition to reducing the risk of gastric perforation into the peritoneum, delaying intervention facilitates improved demarcation and increased liquefaction of necrosis, minimizing the resection of vital tissue if necrosectomy is required, thereby improving morbidity and mortality (33,35). If source control is required in patients with sepsis before maturation of the collection, percutaneous catheter drainage may be an appropriate temporizing measure (31). Overall, radiologists can help the advanced endoscopist by using the revised Atlanta classification system when describing collections and reporting the presence or absence of a well-defined wall, intervening vessels between the gastric wall and the pancreatic fluid collection, or pseudoaneurysm within the collection (Table 2).

Endoscopic Transmural Drainage

Endoscopic drainage of a pseudocyst or WON requires the creation of a fistula between the gastrointestinal lumen and the pancreatic or peripancreatic collection and the placement of either plastic or metal stents under endoscopic, fluoroscopic, and endoscopic US guidance (Figs 8, 9). This connection is referred to as a cystogastrostomy if

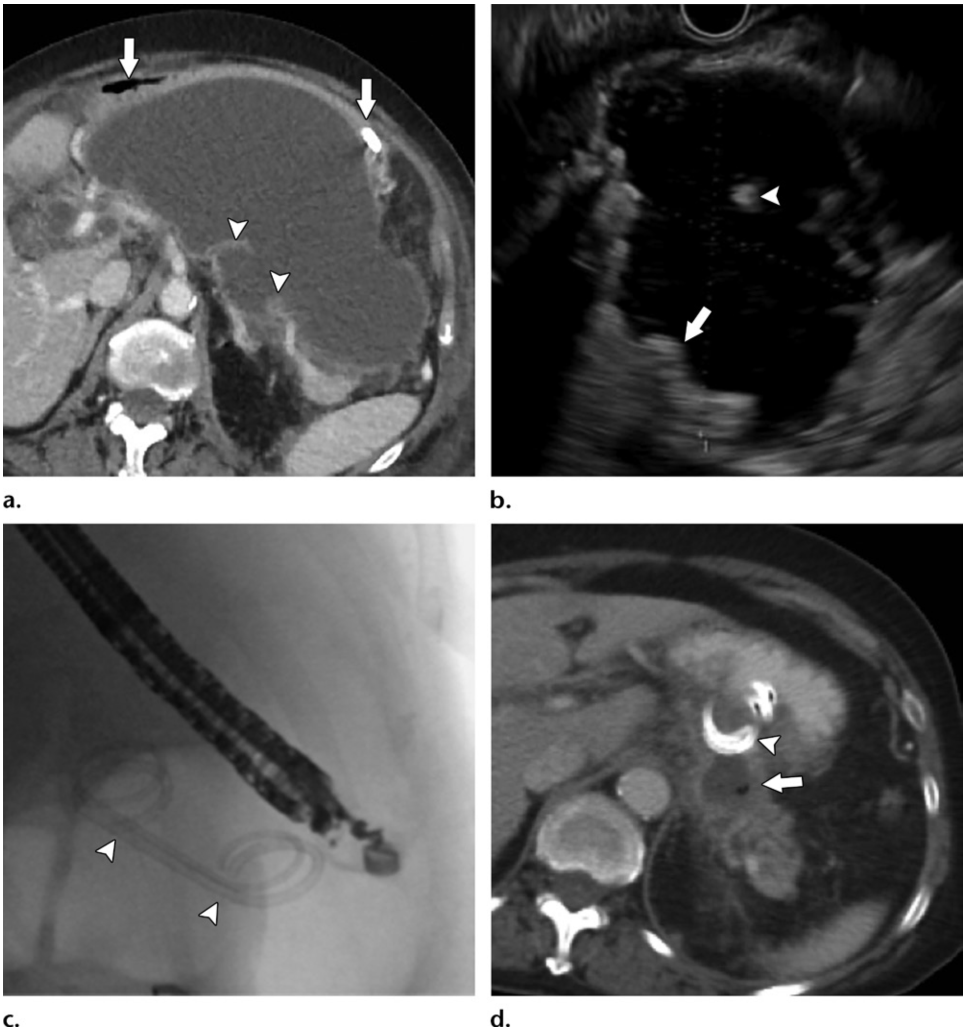


Figure 8. ETD using pigtail stents in a 77-year-old woman with WON. **(a)** Axial contrast-enhanced CT image shows a large pancreatic and peripancreatic WON, containing a large amount of fluid and dependent debris (arrowheads) in the pancreatic necrosis bed, in close proximity (<1 cm) to the stomach (arrows). **(b)** Endoscopic US image shows the collection before the needle puncture, which is composed of a large amount of anechoic fluid, floating debris (arrowhead), and dependent necrotic debris (arrow) with dirty shadowing. The patient was imaged using color Doppler US (not shown) to avoid vessels along the puncture tract. **(c)** Fluoroscopic image shows the dilated tract and two tandem double-pigtail stents (arrowheads) that were placed under combined endoscopic and fluoroscopic guidance. **(d)** Axial contrast-enhanced CT image obtained 1 month after the procedure shows a significantly decreased WON (arrow), with appropriately positioned cystogastrostomy stents (arrowhead).

the collection is accessed through the gastric lumen (more prevalent) or a cystoduodenostomy if accessed through the duodenal lumen.

Owing to the presence of nonliquefied contents, WON is significantly more difficult to treat than a pseudocyst, with overall treatment success rates of 63% for WON compared with 94% for pseudocyst. Likewise, the need for repeat procedures, hospital length of stay, and complication rates all increase in the setting of WON (5). Successful ETD requires proximity of the walled-off collection to the gastrointestinal tract, preferably less than 1 cm from the gastric or duodenal wall (31). Therefore, ETD can only treat collections immediately adjacent to the stomach and/or duodenum, which is the most common location.

The basic procedural steps involve *(a)* performing endoscopic US for visualization of the collection before puncture, using color Doppler US to avoid vessels along the puncture tract; *(b)* gaining needle and wire access to the collection through either the stomach or duodenal wall; *(c)* dilating the tract with a 6–10-mm balloon; and *(d)* placing multiple double-pigtail stents (Fig 8) or a single large-diameter metallic stent (Fig 9) that extends from the gastrointestinal lumen to the collection lumen (29,31). Following stent placement, an optional transnasal catheter may be placed over a wire into the cavity for intermittent irrigation of the collection.

In the setting of a pseudocyst, double-pigtail stents (7–10 F) are typically preferred over

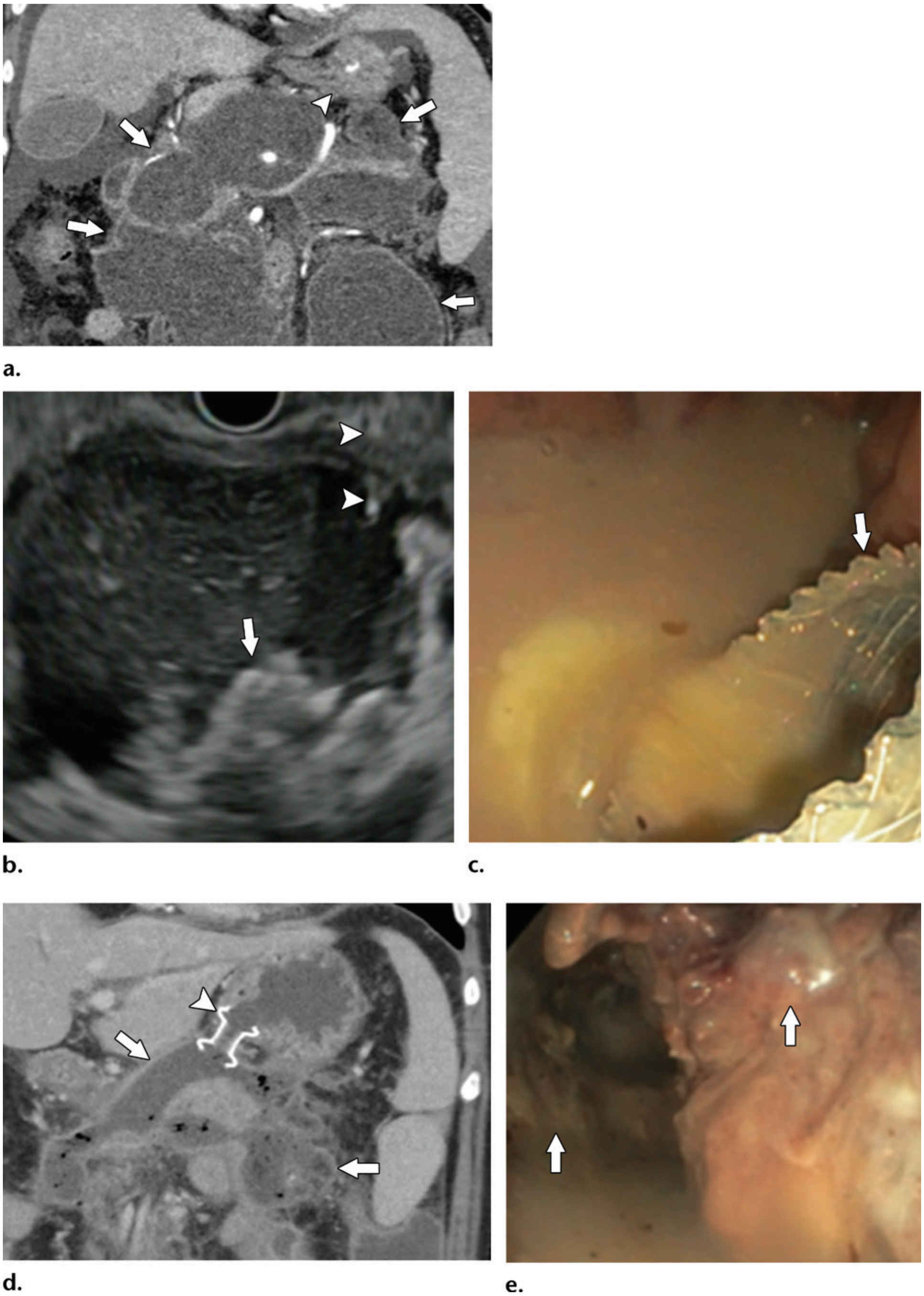


Figure 9. ETD using a lumen-apposing metal stent (LAMS) with subsequent ETN in a 59-year-old man with sepsis and WON. **(a)** Coronal contrast-enhanced CT image shows a large WON (arrows) in the peripancreatic space and mesentery. Note its proximity to the stomach (arrowhead). **(b)** Endoscopic US image of the stomach shows heterogeneous fluid and solid debris (arrow) within the WON. Needle access (arrowheads) allows wire passage before balloon dilatation of the tract and placement of the LAMS. **(c)** Endoscopic image from the stomach shows immediate drainage of purulent fluid into the stomach after the placement of the LAMS (arrow). **(d)** Coronal contrast-enhanced CT image obtained 5 days later shows a cystogastrostomy LAMS (arrowhead) in the appropriate position and smaller but persistent WON (arrows). **(e)** Endoscopic image obtained from a repeat endoscopy with the endoscope driven through the stent shows a view into the collection that allows for the assessment and débridement of the necrotic material (arrows), which appears adherent to the wall of the collection.

metal stents owing to their low risk of migration, ease of removal, and lower cost (29). However, owing to their small lumen diameter, they are prone to occlusion with subsequent development of infection, a risk that is further increased in the case of WON owing to the presence of necrotic debris and viscous liquid contents (36).

Because of these risks, large-diameter metallic stents, particularly LAMSs, have recently become available and have gained substantial popularity

among endoscopists. When compared to a plastic stent, a LAMS is associated with a lower risk of migration, has a larger diameter to facilitate the passage of solid contents, and allows for ETN through the stent (29). However, metallic stents are more expensive, and while long-term safety data are lacking, early studies have found an increased risk of bleeding (37,38).

Owing to the potential bleeding risk, as well as data showing no difference in outcomes for metallic over plastic stents in the setting of nonnecrotic fluid collections, plastic stents remain the recommended means of treatment of pseudocysts, for which they have a greater than 90% success rate. However, large-bore metallic stents have been shown to be superior to plastic stents in the setting of WON. Given its higher technical and clinical success rates, a LAMS is often used for treatment of WON (29,36,39). Therefore, in addition to accurate collection description to facilitate appropriate stent selection, it is important for the radiologist to identify vessels traversing the collection or interposed along the potential puncture tract (Fig 10). At follow-up imaging after stent placement, it is important for the endoscopist to know if the collection has decreased in size and if the stent(s) traverse the gastric and cyst walls appropriately (Table 2).

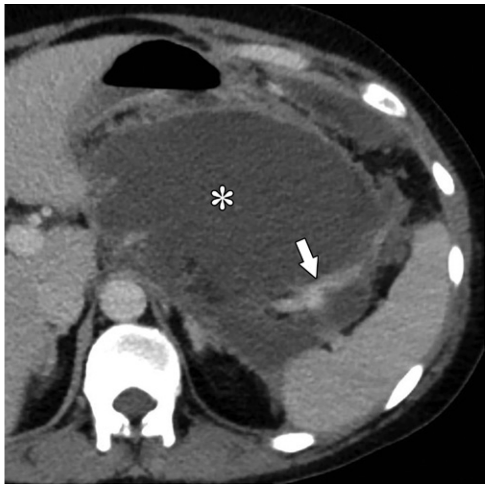


Figure 10. WON in a 40-year-old man with gallstone pancreatitis. Axial contrast-enhanced CT image obtained immediately before endoscopic cystogastrostomy shows a large WON (*), with the patent splenic artery and vein (arrow) traversing the posterior aspect of the collection. This is important to identify before performing ETN.

Endoscopic Transmural Necrosectomy

Because of the semisolid nonliquefied nature of the contents within necrotic collections, drainage by cystogastrostomy alone, even with the use of a LAMS, may be inadequate (40). After ETD, if follow-up cross-sectional imaging shows inadequate collection resolution, a step-up approach can be considered with subsequent treatment with ETN (Fig 11).

ETN uses endoscopic tools to perform mechanical débridement of necrotic debris contained within the collection that is either adherent to the wall or too large or thick to spontaneously drain through a cystogastrostomy or percutaneous catheters. ETN steps involve *(a)* passing a peroral flexible endoscope into the necrotic cavity through the cystogastrostomy or cystoduodenostomy, *(b)* inspecting the cavity to identify viable and nonviable tissue, and *(c)* irrigating and débriding solid contents using a variety of devices including graspers, balloons, baskets, and snares (Fig 11). Débridement and lavage are repeated on a regular basis (eg, every 3–7 days) until the cavity is clean, with oozing walls representing the presence of viable tissue (31).

Success rates of ETN for WON have been shown to be around 80% (41). However, ETN has significantly higher rates of complication compared with those of cystogastrostomy alone and is associated with up to 7.5% mortality (41,42).

At follow-up CT after any intervention, the radiologist should report the treatment response by detailing a change in size, presence, and location of persistent necrotic debris within a collection (Table 2). This information is useful to endoscopists, directing them to the portion of the collection with the most necrotic debris. Any additional collections in communication with the pancreatic fluid collection that is being drained must also be reported. While follow-up imaging is used to monitor treatment response, it is important to remember that the treatment endpoint should be the resolution of significant symptoms rather than radiologic resolution (29).

Multimodal Therapy

Multimodal therapy uses endoscopic techniques in conjunction with a variety of adjunctive techniques performed during an interventional radiology procedure or surgery to aid in irrigation and débridement of collections. While centrally located collections are nearly always accessible through endoscopic approaches, collections that extend inferiorly into the retroperitoneal spaces and pelvis or arise elsewhere in the abdomen, particularly on the left side, may be less amenable to endoscopic techniques alone (33). In these cases and in cases where clinical deterioration or sepsis requires intervention before the development of a well-defined wall, a variety of techniques are commonly employed including percutaneous drainage and videoscopic-assisted retroperitoneal débridement (VARD) (31).

Image-guided percutaneous drain placement may serve as either a primary therapy or as an

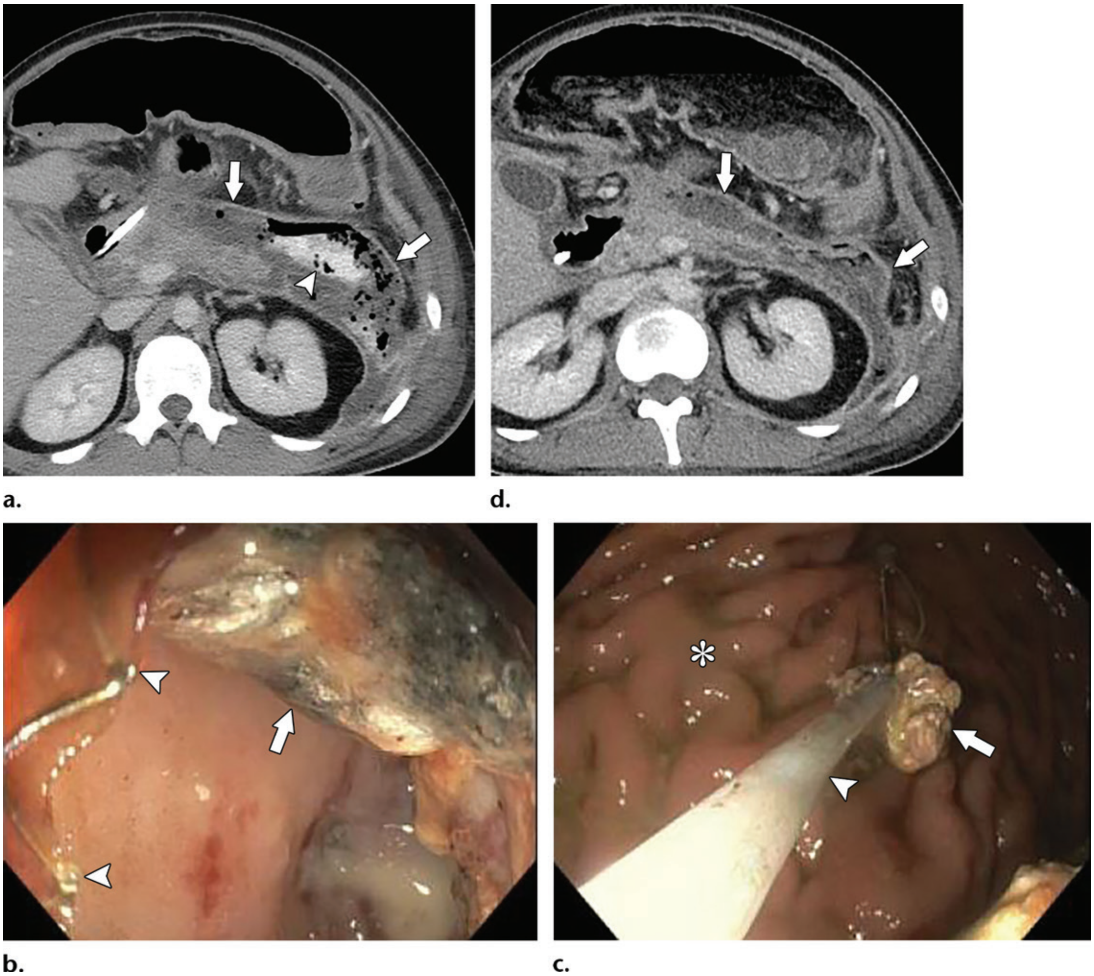


Figure 11. Step-up approach in a 27-year-old man with sepsis and severe alcoholic pancreatitis complicated by a large WON. **(a)** Axial contrast-enhanced CT image obtained 4 days after ETD with cystogastrostomy and LAMS placement (not shown) shows a persistent large complex WON in the peripancreatic space (arrows). Areas of high attenuation (arrowhead) represent oral contrast material passing into the collection from the stomach. **(b)** Endoscopic image obtained during necrosectomy looking into the WON through the LAMS (arrowheads) shows focal necrotic material (arrow) along the wall of the collection. **(c)** Endoscopic image shows necrotic material (arrow) being removed piecemeal by grasping with a snare (arrowhead) and retracting into the stomach (*). **(d)** Axial contrast-enhanced CT image obtained 1 week later shows decreased size of the necrotic collection (arrows) after necrosectomy.

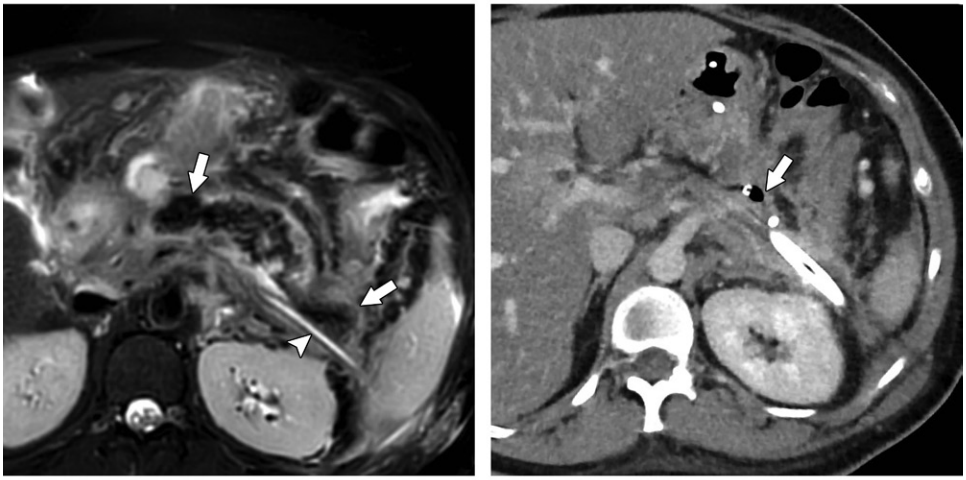
adjunct to endoscopic techniques. While transperitoneal or retroperitoneal approaches may be taken, a retroperitoneal approach is always preferred as it carries less risk of peritoneal contamination and enteric injury (3). Irrigation is often performed through the catheter, and the drain may be manipulated, replaced, or upsized, depending on the patient's clinical course and evolution of the collection as defined at imaging (33,43). However, percutaneous drainage alone has an approximately 50% failure rate, likely owing to the inability of nonliquefied material to pass through even large-bore catheters (44).

Another limitation of percutaneous drainage is the potential development of pancreatico-cutaneous fistulas, which occurs in up to 20% of patients, often owing to communication with a disconnected pancreatic duct (6,33). Furthermore, percutaneous drains frequently introduce air into the collection, limiting evaluation of infection at imaging and interfering with endoscopic US visualization during endoscopic intervention. Therefore, some practitioners prefer that endoscopic drainage be performed first, even if performed on the same day as percutaneous drainage (29,31).

If ETN fails, or if there are inferiorly extending necrotic collections in the retroperitoneum that cannot be accessed by endoscopic approach, VARD is a minimally invasive alternative treatment option that may be performed by surgeons. VARD involves the insertion of a rigid or flexible scope (often a cystoscope) alongside a previously placed percutaneous drain to access a necrotic cavity (Fig 12). Then, grasping instruments can be used to carefully débride necrotic material. In addition to performing retroperitoneal necrosectomy, drainage catheters may be placed under direct videoscopic guidance (33).

a.

Figure 12. Multimodal therapy in a 28-year-old woman with gallstone pancreatitis and infected WON. **(a)** Axial contrast-enhanced CT image shows a large pancreatic and peripancreatic WON (*). **(b)** Axial T2-weighted fat-saturated MR image obtained after the placement of a cystogastrostomy stent and 16-F percutaneous catheter (arrowhead) shows decreased size and resolution of the fluid component but substantial remaining T2-hypointense solid necrotic material (arrows) in the collection. VARD was performed along the existing percutaneous catheter. **(c)** Axial CT image shows nearly complete resolution of the collection (arrow), containing plastic cystogastrostomy stents and a percutaneous drain.



b. c.

In keeping with the consensus guidelines of the American College of Gastroenterology, International Association of Pancreatology, and American Pancreatic Association, a step-up approach consists of percutaneous drainage and/or ETD as the preferred first-line therapies. If drainage fails to control the patient's symptoms or infection, ETN is often the next option, although VARD may also be considered at that time. If those measures fail, laparoscopy or open surgery may be required (31–34).

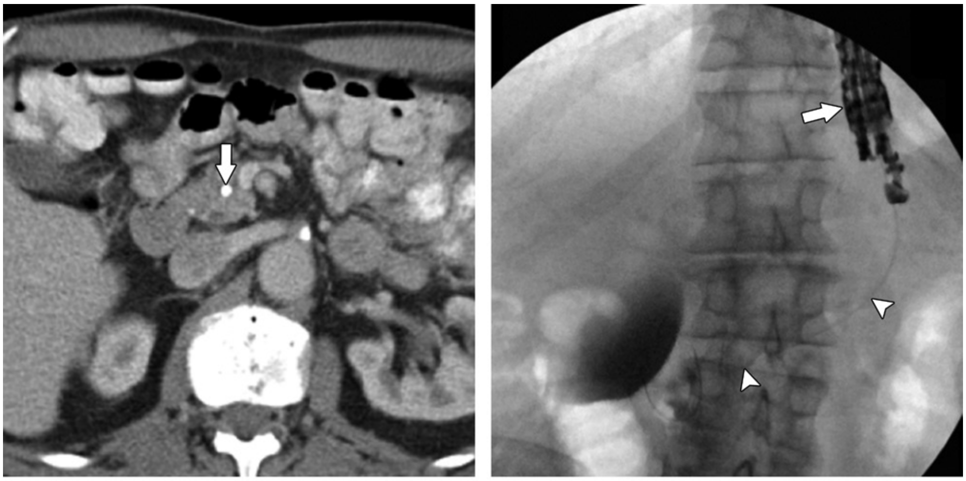
Pancreatic Duct Interventions

Pancreatic duct stent placement is used to facilitate drainage of the gland, particularly in the setting of an active duct leak contributing to abdominal collections or pancreatic ascites. Duct leaks can be identified at endoscopic retrograde cholangiopancreatography (ERCP) by the leakage of contrast material from the main pancreatic duct or a side branch into a collection or freely into the peritoneum or clinically by detection of amylase-rich fluid from a percutaneous drain. Pancreatic duct stents are generally 3–7 F and may have a single pigtail on the duodenal end, as well as flanges to keep them in place. However, they may spontaneously become displaced in up to 7.5% of cases (45), which can be identified on an abdominal radiograph.

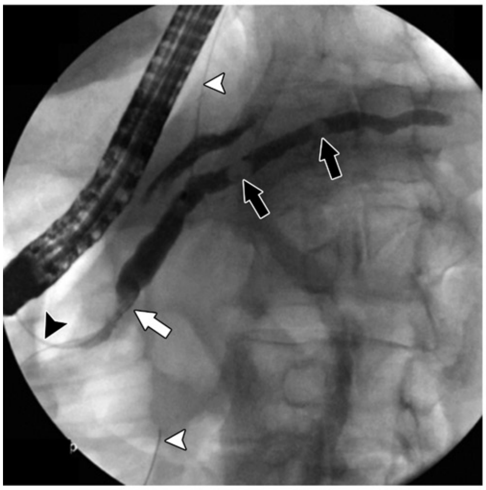
Pancreatic duct stricture is a late complication of acute pancreatitis, occurring as a result of fibrosis from prior inflammation or with healing after drainage of a necrotic collection. Upstream dilatation of the pancreatic duct often manifests and is readily visible at CT and MR cholangiopancreatography (MRCP). To relieve obstruction, pancreatic duct stent placement may be performed either by a transpapillary approach or through the orifice created at cystogastrostomy (46).

Pancreatic duct stones are another potential cause of duct obstruction and may predispose a patient with chronic pancreatitis to recurrent acute pancreatitis or chronic pain. Stones may be difficult to remove because they are frequently adherent to the wall or within a branch duct. Additionally, stones are often associated with main duct strictures, which may be difficult to cross,

Figure 13. Pancreatic duct rendezvous procedure in a 77-year-old man with recurrent acute pancreatitis secondary to alcohol use. **(a)** Axial contrast-enhanced CT image shows a pancreatic duct stone (arrow) within the head of the pancreas, causing upstream duct dilatation (not shown). Retrograde pancreatic duct cannulation by ERCP for stone removal was unsuccessful. **(b)** Anteroposterior (AP) fluoroscopic image obtained after endoscopic US-guided needle access from the stomach into the dilated pancreatic duct shows the wire passage (arrowheads) from the endoscope (arrow) through the main pancreatic duct antegrade into the second portion of the duodenum. **(c)** AP fluoroscopic image shows a rendezvous wire (white arrowheads) left in situ, allowing for retrograde transpapillary access of a catheter (black arrowhead) and subsequent pancreatogram, and a dominant pancreatic head stricture (white arrow) and multiple pancreatic duct filling defects (black arrows), representing stones.



a. b.



c.

further complicating removal. Several procedures, however, are available for stone extraction. ERCP with sphincterotomy followed by stone extraction and transpapillary stent placement is one available intervention but often requires multiple procedures and has a poor success rate and long-term stent durability. Extracorporeal shock wave lithotripsy may be employed to help disrupt stones into smaller fragments to facilitate passage either spontaneously or in combination with ERCP and sphincterotomy. However, this method requires a more lengthy procedure, and its efficacy is often limited by body habitus (46,47).

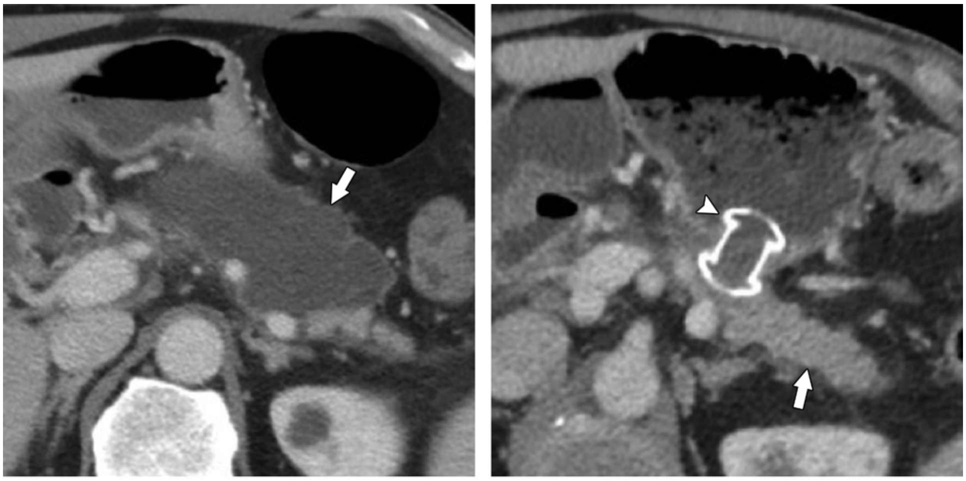
Finally, an endoscopic US–guided rendezvous procedure may be employed to remove pancreatic duct stones in cases where pancreatic duct strictures cannot be crossed from the papilla. A rendezvous procedure involves *(a)* transgastric needle access to the dilated upstream pancreatic duct guided by endoscopic US; *(b)* antegrade passage of a wire across the stricture into the main duct, through the papilla, and into the duodenum; *(c)* capture of the wire through a duodenal endoscope; and *(d)* retrograde passage of endoscopic devices, including stents and balloons, for stone extraction and stricture dilatation (Fig 13) (48).

In summary, radiologists can help the advanced endoscopist plan pancreatic duct interventions by describing the size, number, and location of strictures or stones. At follow-up imaging, radiologists should look for residual stones or fragments and evaluate the upstream duct for improvement in dilatation.

Disconnected Pancreatic Duct Syndrome

Disconnected pancreatic duct syndrome occurs in up to one-third of patients with necrotizing pancreatitis. This entity develops following complete dissolution or débridement of the central portion of the pancreas with disruption of the main pancreatic duct, leaving a functioning portion of upstream pancreas tail in direct communication with a necrotic cavity (33,49). While the collections involving the necrotic central pancreas

Figure 14. Disconnected duct syndrome in a 60-year-old man with gallstone pancreatitis. **(a)** Axial contrast-enhanced CT image shows WON (arrow) within the body of the pancreas. **(b)** Axial CT image obtained 6 weeks after cystogastrostomy with placement of a LAMS (arrowhead) shows complete resolution of the pancreatic fluid collection. Note the normally enhancing pancreatic tail (arrow) and absence of pancreatic body. The LAMS was subsequently removed. **(c)** Axial CT image obtained 1 year later owing to worsening abdominal pain shows a large homogeneous fluid-attenuation pseudocyst within the body of the pancreas, with normal enhancing upstream pancreatic tail (arrow). Note the perpendicular orientation of the pancreatic duct (arrowhead), draining directly into the pseudocyst.



a. **b.**

c.

are initially ANC or WON, chronic or recurrent collections are often pseudocysts rather than WON, since over time disconnection of the duct allows for accumulation of pancreatic secretions within the previous necrotic cavity.

Despite its relatively high incidence, disconnected duct syndrome is often overlooked at imaging. It is recognized by the presence of a discrete intrapancreatic collection along the expected course of the main duct, usually within the neck or body, with viable enhancing upstream pancreatic tail (Fig 14). The diagnosis is further supported when the upstream pancreatic duct is oriented perpendicular to the collection or seen in direct communication with the collection. In contrast, a duct that is oriented at an oblique angle to the collection may reflect mass effect and displacement by the collection rather than disconnection of the duct (17). Radiologists should have a high level of suspicion for disconnected duct in any patient with a necrotic collection involving the neck and/or body of the pancreas (18).

While some authors advocate for pancreatography to confirm the diagnosis, others believe the risks do not outweigh the benefits, as transpapillary injection of contrast material may result in infection of a previously sterile necrotic collection, which is associated with a fivefold increase in mortality (17,50,51).

Because the disconnected pancreatic duct output does not drain into the bowel, and owing to the caustic nature of pancreatic secretions, the fistulous connection with the disconnected duct is unlikely to resolve with conservative drainage measures alone (17). Transpapillary stent placement of the main pancreatic duct across the disruption into the tail by ERCP may be performed in an attempt to heal the pancreatic duct leak. However, pancreatic collection recurrence is common after transpapillary stent placement, so cystogastrostomy stents are often left in place, sometimes indefinitely, to divert pancreatic secretions into the gastrointestinal lumen (18,52).

In refractory cases of disconnected duct with persistent fistulas or recurrent collections, combined percutaneous and endoscopic interventions may be performed. If these measures fail, more invasive options are Roux-en-Y pancreaticojejunostomy or distal pancreatectomy with or without islet cell autotransplantation (33).

Figure 15. WON complicated by immediate post-procedure hemorrhage in a 57-year-old man. Coronal contrast-enhanced CT image obtained 1 day after the placement of four tandem cystogastrostomy stents (arrowhead) shows intracystic (arrows) and free retroperitoneal (*) hyperattenuating collections, representing a large acute hemorrhage.

Biliary Interventions

In the setting of suspected gallstone pancreatitis, imaging is performed to evaluate for choledocholithiasis. For detecting choledocholithiasis, MRCP has the highest sensitivity (89%–95%) and specificity (95%–100%) versus conventional CT (sensitivity, 69%–87%; specificity, 83%–92%), given the variable composition of gallstones (53). Assessment of the biliary tree for potential stones or strictures should be performed at all cross-sectional imaging of acute pancreatitis, even at conventional CT, as this is the most commonly performed initial study. MRCP may also identify biliary strictures owing to mass effect on the common bile duct by peripancreatic collections or from pancreatitis-related inflammation and gland swelling (54).

While endoscopic intervention in pancreatitis-related collections should be delayed as long as possible, early endoscopic intervention of biliary complications to perform sphincterotomy and extract stones may be needed, particularly if the patient is jaundiced or if values from liver function tests are increasing (55). If a biliary stricture is found by MRCP or ERCP, endoscopic biliary stent placement may be required (56). Therefore, the radiologist can help impact clinical management by identifying and describing the location of choledocholithiasis or biliary duct narrowing at imaging. MRCP should be recommended if findings are equivocal on CT images.

Complications of Endoscopic Therapy

Despite recent advances in minimally invasive techniques, there continues to be significant morbidity and mortality associated with the treatment of pancreatic fluid collections and infected WON in particular (29). The overall complication rate of endoscopic intervention ranges from 15% to 30%, with the risk increasing with increasing number of interventions (57). The most common complications include bleeding, perforation, secondary infection, and stent migration (58).

Bleeding is the most common endoscopic complication overall. It may occur during the initial access to the collection if a vessel is punctured or ruptured, during débridement of the cavity if nearby vessels are injured, or as a delayed complication weeks or months after intervention (31). Effort should be made to identify intervening blood vessels along the potential puncture tract, and the presence of the splenic vessels or portal vein within a collection should be noted.

While endoscopic US-guided puncture lowers the risk of bleeding, one study found bleeding rates of 19% with the use of metal stents compared with 1% with the use of plastic stents (59,60). One theory is that this observation may be due to the more rapid collapse of the collection when metal stents are used, causing impingement of the stent on blood vessels in the cyst wall, with development of pseudoaneurysm and delayed hemorrhage. Given the lack of robust long-term follow-up data, multiple authors have recommended follow-up CT 3 weeks after LAMS placement to assess for complications, with stent removal once resolution of the collection is achieved (38,61).

Pseudoaneurysms may also develop as sequelae of acute pancreatitis before intervention, further increasing the risk of periprocedural hemorrhage. Splenic artery pseudoaneurysms develop in up to 10% of patients with acute pancreatitis, while less commonly affected arteries include the gastroduodenal, pancreaticoduodenal, hepatic, and gastric arteries (62). Varices, most commonly secondary to chronic splenic vein thrombosis, also increase the risk of bleeding (43).

Hemorrhage may occur into the gastrointestinal tract, peritoneal cavity, collection, or pancreatic parenchyma and is identified at CT as high-attenuation contrast material filling the collection or in areas of intervention (Fig 15). The presence of high-attenuation material in these locations should be regarded as a reliable indicator of acute hemorrhage. Bleeding into the collection is particularly worrisome as it is often not manageable by endoscopic techniques, requiring immediate referral for angiography and/or surgery (43). When bleeding is found at imaging, the location and extent should be described, and a careful search for pseudoaneurysm should be performed. Noncontrast CT and portal phase CT are limited

for arterial assessment, and if bleeding is identified on these images, immediate CT angiography may be indicated.

Infection occurs in approximately one-third of patients with pancreatic necrosis and is common in cases of WON following ETD alone without irrigation or débridement (31). Infection rates have been shown to be higher in patients with plastic stents than those with metallic stents (31% vs 16%, respectively), likely owing to the smaller caliber and increased rates of obstruction of plastic stents (36). Collections extending into the peritoneal cavity have a higher risk of disseminated abdominal infection (3,31).

Radiologic diagnosis of infection following intervention is difficult. Postprocedural imaging findings may mimic infection, with gas often present within the collection or at the site of necrosectomy. However, postnecrosectomy changes are expected to resolve; therefore, any increase in size of the collection or formation of a new collection should raise suspicion for infection, although this is a relatively nonspecific finding that may alternatively indicate inadequate drainage of a sterile collection (3).

Perforation occurs in less than 5% of cases of ETD and ETN but when present may lead to dissemination of infection into the peritoneal cavity. It may occur during initial cystogastrostomy, with repeat tract dilatation, during débridement, or as a result of separation of the gastric or duodenal wall from the collection (31,61). Perforation is diagnosed at CT by pneumoperitoneum and generalized signs of peritonitis such as interval increase in peritoneal fluid and enhancement of the peritoneum. Additionally, a new poorly defined fluid and gas collection adjacent to the site of intervention is highly suggestive (Fig 16).

Among these findings, identification of pneumoperitoneum or a new poorly defined collection near the site of intervention is a more reliable indicator of perforation than the presence of peritoneal fluid or enhancement alone. If identified, the size, location, and extent of the perforation should be described, as these factors may affect whether conservative, percutaneous, repeat endoscopic, or surgical management is selected (61).

Stent migration may occur either into the gastrointestinal tract or into the collection. Plastic stents have a higher rate of migration compared with that of LAMSs. Although most studies report the migration rate of LAMSs to be around 5%, some have demonstrated rates as high as 19% (29,61). While a plastic stent that migrates into the gastrointestinal tract often passes spontaneously (Fig 17), bowel obstruction secondary to intraluminal LAMS migration has been reported and may require endoscopic or surgical retrieval (61,63). Migration of a stent into the collection may increase the risk of bleeding if there is erosion into an adjacent blood vessel.

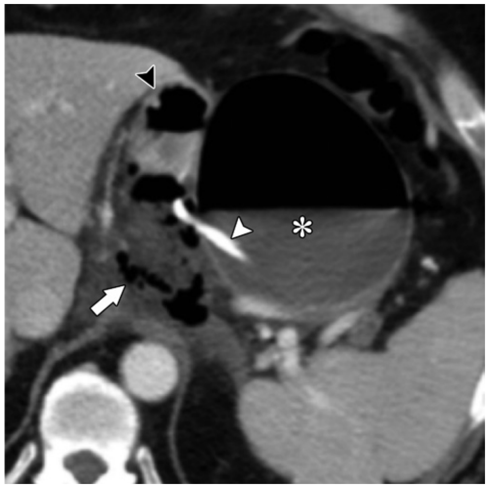


Figure 16. Perforation following cystogastrostomy in a 43-year-old man with alcoholic pancreatitis and a large pseudocyst. Axial contrast-enhanced CT image obtained 1 day after cystogastrostomy with tandem stent placement owing to worsening abdominal pain shows loculated fluid and gas collection (arrow) between the stomach (black arrowhead) and an air-containing pseudocyst (*) along the course of the stents (white arrowhead), secondary to perforation and leak.

Buried-stent syndrome is a phenomenon that occurs when gastric or enteric mucosa covers the end of a LAMS. It is thought to occur owing to the relatively low profile of the stent and the tight apposition to the wall but may also be induced by stent migration (Fig 18). It occurs in up to 17% of cases (38,61).

At each imaging assessment, the radiologist should identify the location of the stents, paying careful attention to the ends of the stents and their proper position within the gastrointestinal and collection lumens. Multiplanar imaging often facilitates this evaluation. If migration into the collection or a buried stent is found, the endoscopist should be alerted, as this often requires more invasive techniques, including re-establishment of the cystogastrostomy tract (61).

Conclusion

Acute pancreatitis is a prevalent and often serious condition associated with high morbidity and mortality rates. Imaging plays a critical role in the diagnosis of necrotizing pancreatitis and the identification of local complications, and the revised Atlanta classification system provides a standardized lexicon that should be used by all radiologists when reporting pancreatic and peripancreatic fluid collections. Endoscopic interventions have become the first-line therapy for the management of pancreatic and peripan-

Figure 17. Migration of a plastic stent in a 43-year-old man with alcoholic pancreatitis and a pseudocyst. Axial contrast-enhanced CT image obtained 2 weeks after cystogastrostomy with tandem stent placement shows migration of the double-pigtail plastic stent (arrow) to the sigmoid colon. The stent eventually passed rectally without complication.

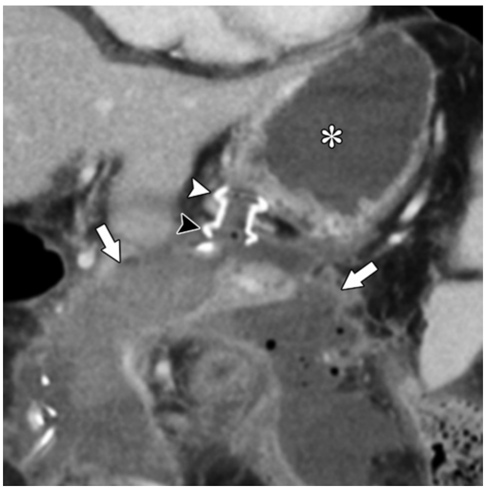


Figure 18. LAMS migration and buried-stent syndrome in a 59-year-old man with WON. Coronal contrast-enhanced CT image obtained 3 weeks after cystogastrostomy with LAMS placement shows a distal flange (black arrowhead) in the collection (arrows) but a proximal flange (white arrowhead) displaced from the gastric lumen (*), buried beneath the gastric wall.

creatic collections in the setting of acute pancreatitis and are commonly used in a step-up and sometimes multimodal approach. Accurate interpretation and description of imaging findings are vital for treatment planning, identification of procedural complications, and evaluation of response to therapy.

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