Abdominal Radiology
https://doi.org/10.1007/s00261-019-02319-2

SPECIAL SECTION: PANCREATITIS

Imaging guidelines for acute pancreatitis: when and when not to image

Ana Paola Campos Rocha[1] · Khoschy Schawkat[1,2] · Koenraad J. Mortele[1]

Abstract

In patients with acute pancreatitis (AP), diagnostic imaging is performed for various reasons, including the detection of the etiology (e.g., biliary obstruction caused by gallstones), diagnosis of pancreatitis in an unclear clinical setting, assessment of the severity of the process, and evaluation of its complications. In spite of the potential benefits of these imaging studies in the setting of AP, especially economic consequences but also medical risks are associated with diagnostic imaging, including increase of the effective radiation dose received by patients with AP and rising health care costs, frequently without impact on management. The rising incidence of acute pancreatitis in the Western world is escalating its financial burden with national health care expenses of over 2.5 billion dollars annually. Despite evidence-based national recommendations on utilization of diagnostic imaging in patients with AP, unnecessary imaging studies are still frequently performed, especially in the early hospital course. The purpose of this article is, therefore, to review the imaging guidelines for acute pancreatitis with regards to when and when not to image, with the aim to minimize inappropriate utilization.

Keywords Acute pancreatitis · Pancreas · Guidelines · Imaging · Cross-sectional imaging · Diagnosis

Abbreviations

AP	Acute pancreatitis
CT	Computed tomography (CT)
MR	Magnetic resonance
ERCP	Endoscopic retrograde cholangiopancreatography
ICU	Intensive care unit
SIRS	Systemic inflammatory response syndrome
US	Ultrasonography
IAP	Idiopathic acute pancreatitis
EUS	Endoscopic ultrasonography
S-MRCP	Secretin-stimulated magnetic resonance cholangiopancreatography
MRCP	Magnetic resonance cholangiopancreatography
ERCP	Endoscopic retrograde cholangiopancreatography
CTSI	CT severity index
GI	Gastrointestinal
CBD	Common bile duct
IOC	Intraoperative cholangiography
RCTs	Randomized controlled trials
CEUS	Contrast-enhanced US
DWI	Diffusion-weighted imaging
MDCT	Multidetector CT

Introduction

Rising health care expenditure associated with acute pancreatitis (AP) is attributed to multiple factors, including steadily rising incidence of AP, increased availability of high-cost cross-sectional studies such as computed tomography (CT) and magnetic resonance (MR) imaging, and importantly, because of inappropriate use of imaging examinations [1–4].

Despite the potential benefits of these studies, a number of medical and economic risks are associated with diagnostic imaging.

Mortele et al. have shown a substantial variation in imaging utilization in AP. However, even after case-mix adjustment for severity and other patient level factors, there is still increasing use of imaging over the course

✉ Khoschy Schawkat
kschawka@bidmc.harvard.edu

[1] Division of Abdominal Imaging, Department of Radiology, Beth Israel Deaconess Medical Center, Harvard Medical School, 330 Brookline Avenue, Boston, MA 02215, USA

[2] Institute of Diagnostic and Interventional Radiology, University Hospital Zurich, University Zurich, Zurich, Switzerland

Published online: 11 November 2019

of time without notable improvement in patient outcome [3]. These outcomes included mortality, need for surgery, persistent systemic inflammatory response syndrome (SIRS), organ failure, and intensive care unit stay [3]. A recent study demonstrated that CT imaging is unnecessary when uncomplicated AP is diagnosed clinically and biochemically, and concluded that reducing overutilization will decrease healthcare expenditure and patients' radiation exposure [4]. Another investigation has shown that in patients with necrotizing pancreatitis, because of repeated CT scans, the received effective radiation dose is significant without impact on patients' management. This evidence raises the concern that the ubiquitous use of CT in patients with pancreatitis contributes to substantial health care costs [5]. Careful reassessment of the utility of diagnostic imaging in the setting of AP is mandated. Therefore, referring physicians and radiologists are committed to select the appropriate imaging technique to ensure cost-effective and high-quality patient care [3, 6].

The purpose of this article is to review the imaging guidelines for acute pancreatitis in regard to when and when not to image.

Background

Acute pancreatitis is one of the most common gastrointestinal causes for hospital admissions in the United States, with approximately 275,000 admissions each year [7]. The incidence of AP is increasing, which is caused by increasing incidence of obesity, known to contribute to gallstone formation. Gallstones are the most common cause of acute pancreatitis in the United States (Fig. 1), followed by binge alcohol consumption. Acute pancreatitis affects men and women in similar proportion. However, the etiology is different. Alcohol-related pancreatitis is more common in men, whereas women are more likely to develop pancreatitis related to gallstones, autoimmune diseases, endoscopic

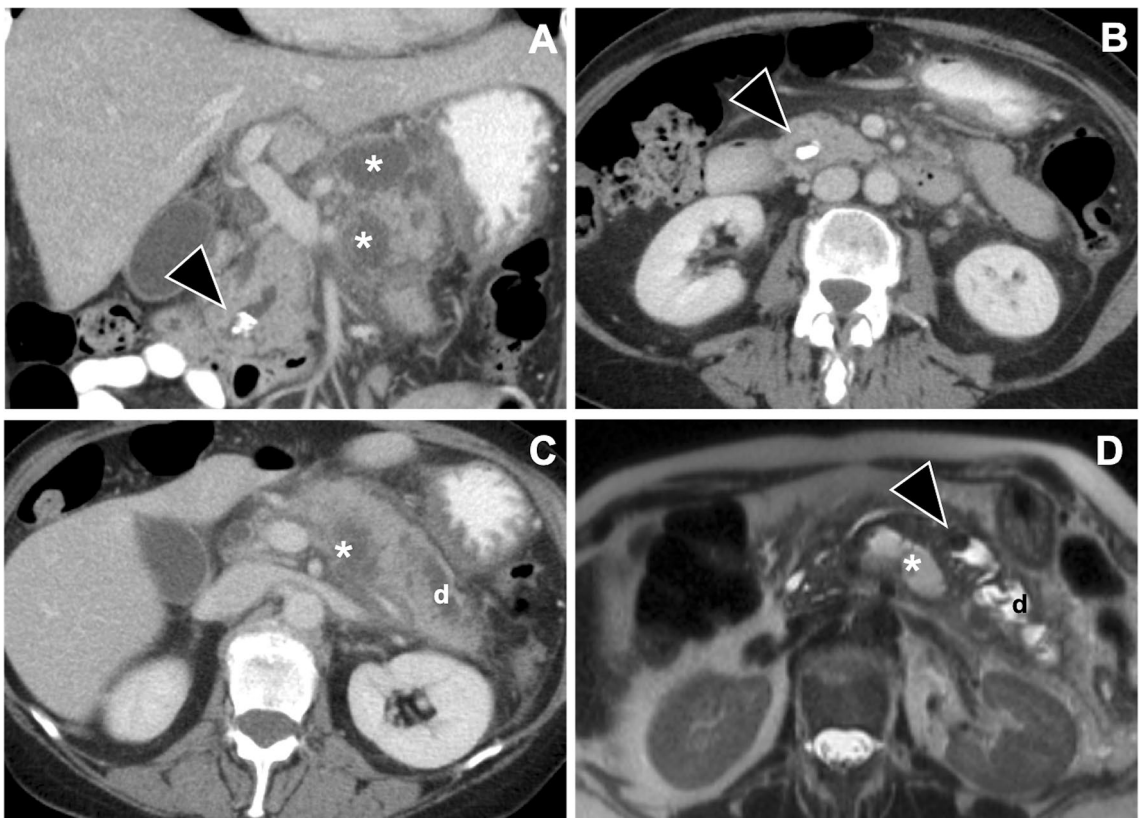

Fig. 1 61-year-old female with recent recurrent bout of pancreatitis. **a** and **b** The contrast-enhanced CT scan reveals a 9 mm calcified stone (arrow head) in the pre-ampullary region of the main pancreatic duct with short segment dilation of the upstream main pancreatic duct segment. Signs of acute pancreatitis are present, such as peripancreatic fluid collections surrounding the pancreatic body and tail (*) and blurring of the peripancreatic fat planes with streaky soft tissue stranding. **c** Abrupt dilation of the main pancreatic duct in the tail is seen (d) without evidence of an additional stone formation or mass causing the obstruction on CT. An ill-circumscribed fluid collection is present adjacent to the pancreatic body (*). **d** On T2-weighted MR imaging a non-calcified intraductal concrement is detected (arrow head) with low signal intensity on T2 causing the upstream main pancreatic duct dilatation (d) in the pancreatic tail

retrograde cholangiopancreatography (ERCP), or an idiopathic origin [7].

Types and severity of acute pancreatitis

According to the revised Atlanta classification, there are two morphological types of acute pancreatitis: interstitial edematous pancreatitis and necrotizing pancreatitis. Interstitial edematous pancreatitis is characterized by diffuse (or occasionally localized) inflammatory enlargement of the pancreas due to edema, typically with inflammatory changes of the peripancreatic fat and peripancreatic fluid. The clinical symptoms of interstitial edematous pancreatitis usually resolve within the first week [8]. Up to 10% of patients develop necrotizing pancreatitis, which is further subdivided by whether the necrosis involves the pancreatic parenchyma, the peripancreatic tissues, or both. Necrosis involving both the pancreatic parenchyma and the peripancreatic tissues is the most common form, whereas necrosis only involving the pancreatic parenchyma is least common [8].

The clinical severity of acute pancreatitis is classified clinically into mild, moderately severe, and severe. Mild acute pancreatitis is characterized by no organ failure and no local or systemic complications. In moderately severe acute pancreatitis, there is transient organ failure (less than 48 h), local complications in the retroperitoneum, or exacerbation of comorbid diseases (e.g., chronic lung disease). Severe acute pancreatitis is characterized by persistent organ failure (more than 48 h) that may involve one or more organ systems, most commonly renal, pulmonary or cardiovascular, and local and/or systemic complications [8].

Mild pancreatitis is a self-limited condition and requires only supportive care. Mortality is very low, and imaging is usually unnecessary. When performed, imaging typically shows interstitial edematous pancreatitis [8, 9]. Severe pancreatitis is mostly seen in necrotizing pancreatitis and can be life threatening, with morbidity and mortality as high as 36–50%. The classification of the degree of severity of pancreatitis is an important component of managing patients with acute pancreatitis with the objective of identifying the approximately 15% of patients who are likely to have severe courses. Patients with severe acute pancreatitis require aggressive treatment and often need management in an intensive care unit (ICU). Both clinical data and morphologic information provided by imaging are used in staging moderately severe and severe acute pancreatitis [8, 9].

Clinical course of acute pancreatitis

According to the revised Atlanta classification, the clinical course of pancreatitis is divided into an early phase and a late phase, and the timing of imaging is based on the clinical phase. The onset of pancreatitis is defined by the onset of abdominal pain (not the time of admission or presentation to the hospital). The early phase of pancreatitis lasts approximately one week and the late phase starts after the first week and can last for weeks to months [8].

The early phase of an AP is characterized by the systemic response to cytokine release from the initial pancreatic injury, or the SIRS [8, 10]. SIRS is the main cause of early complications in AP, whereas superimposed infection and fluid collections are the cause of late complications. Within the early phase, the severity of pancreatitis is based on clinical criteria, care is supportive, and imaging findings have a less important role, with an exception of evaluation of unclear cases. There is no direct correlation between the morphologic changes seen on imaging and the severity of organ failure in the early phase [8, 10].

The late phase occurs in patients with moderately severe or severe pancreatitis. It manifests after the first week and is characterized by local complications and SIRS [8]. Persistent organ failure is still the main determinant of severity in the late phase; however, local complications have important consequences for management and their morphology is typically diagnosed by imaging [8–10].

When and when not to image?

Imaging is usually needed to diagnose acute pancreatitis when the clinical situation is unclear, to determine the underlying cause of AP, to evaluate complications and disease severity, and to guide intervention [9]. We summarized the main important clinical scenarios when imaging should be performed (Table 1) and discussed each situation separately in the sections below.

However, it is also important to emphasize the situations when imaging tests are not recommended, such as in the acute setting of typical clinical and laboratory presentation of AP, to predict the severity of AP, or routinely for initial assessment, as summarized in Table 2, and also discussed below.

Diagnosis of acute pancreatitis

For the diagnosis of AP, the presence of two of the following three criteria are necessary: acute onset of persistent severe epigastric pain, often radiating to the back, increase in serum lipase or amylase to three times or greater than the upper limit of normal, characteristic findings of acute pancreatitis on contrast-enhanced CT, and less commonly MR imaging or transabdominal ultrasonography (US) [8].

If AP is diagnosed clinically by the presence of abdominal pain and elevated serum pancreatic enzymes, a contrast-enhanced CT is not required at the timepoint of admission

Table 1 When to image?

US is primarily used to assess for gallstones and *should be* performed early in patients who present for the first time and in whom the cause is uncertain.
In the acute setting, a contrast-enhanced CT *should be* performed if the clinical presentation and amylase and lipase levels are equivocal.
Contrast-enhanced CT *should be* performed when there is a significant deterioration of the patient's condition, including an acute drop in hemoglobin and hematocrit, tachycardia, hypotension, an abrupt change in fever, or leukocytosis.
Delayed contrast-enhanced CT (> 7–21 days after the onset of symptoms) is very effective in assessing severity and will guide management, including image-guided aspiration and/or drainage as well as other forms of minimally invasive procedures.
If indicated, the optimal timing for ERCP in biliary pancreatitis is within the first 24 h, and urgent ERCP (< 24 h) is required in patients with acute cholangitis.

This table summarizes the most important clinical scenarios in which imaging is needed

US ultrasound, *CT* computed tomography, *ERCP* endoscopic retrograde cholangiopancreatography

Table 2 When not to image?

In the acute setting (< 48–72 h after the onset of symptoms), a contrast-enhanced CT *should not be* performed when a typical clinical presentation and unequivocal elevations of amylase and lipase are present.
Early (within the first 72 h) imaging with CT may underestimate the severity of the disease, and therefore *should not be* performed.
Imaging *should not be* performed to predict severity of AP early in the course of the disease.
Routine CT for initial assessment *should not be* performed, because the vast majority of complications can be suspected by clinical and biochemical assessment.
MRCP, EUS and ERCP are generally *not indicated* in patients with mild biliary pancreatitis without clinical evidence of persistent common bile duct obstruction, which can be treated with (early) cholecystectomy with/without intraoperative cholangiography.

This table summarizes the most important clinical scenarios in which imaging is not needed

CT computed tomography, *AP* acute pancreatitis, *MRCP* magnetic resonance cholangiopancreatography, *EUS* endoscopic ultrasound, *ERCP* endoscopic retrograde cholangiopancreatography

to the hospital or in the emergency unit [4, 11]. Clinical situations where cross-sectional imaging is sometimes performed, include confirmation of diagnosis in sedated or unconscious patients, clinical suspicion of duodenal perforation, or a prolonged period between onset of symptoms and presentation (lipase and amylase may have normalized) [11].

Etiology

It is recommended to perform a transabdominal US on admission in patients with suspected acute pancreatitis, because the treatment and follow-up depend on the etiology of pancreatitis (e.g., cholecystectomy for biliary pancreatitis) [11, 12]. The primary aim of the US is to identify gallstones and secondarily, to identify ductal dilation of the biliary system and/or choledocholithiasis.

In patients considered to have idiopathic acute pancreatitis (IAP), after negative routine work-up for biliary etiology (e.g., repeated right upper quadrant ultrasonography), it is recommended to perform endoscopic ultrasonography (EUS) as a second step to assess occult microlithiasis, neoplasms, or chronic pancreatitis. A systematic review showed a diagnostic yield of EUS of 32–88% in detecting either biliary sludge or signs of chronic pancreatitis [13].

In case of negative EUS, secretin-stimulated magnetic resonance cholangiopancreatography (S-MRCP) is advised as the next step with the objective to identify rare morphologic abnormalities [11]. Particularly in recurrent AP (patients with more than one episode of AP), a S-MRCP has been reported to be more sensitive than conventional MR in diagnosing an underlying cause for recurrent AP when clinical and laboratory findings are inconclusive [14, 15].

A recent meta-analysis demonstrated that EUS and magnetic resonance cholangiopancreatography (MRCP) can be used as complementary techniques in the diagnostic evaluation of IAP. S-MRCP has been shown to be superior to EUS and MRCP in diagnosing anatomic alterations in the biliopancreatic duct system, such as pancreas divisum, whereas EUS is found to have a higher diagnostic accuracy than MRCP (64% vs 34%, respectively) in determining the etiology of IAP [16].

Initial assessment with CT

The most common indications for initial CT assessment in AP are: (a) diagnostic uncertainly, (b) confirmation of severity based on clinical predictors of severe AP, (c) absence of clinical improvement after conservative treatment or (d) in

the setting of clinical deterioration. Optimal timing for initial CT assessment is at least 72–96 h after onset of symptoms [11].

In the majority of patients, CT is not necessary for the diagnosis of acute pancreatitis, since they represent mild self-limited conditions [4]. Reasons why routine early CT in AP is not recommended are: (a) there is no evidence that early CT improves clinical outcome or that diagnosing early necrosis will change treatment management [17, 18]; (b) CT scoring systems are not better then clinical scoring systems in predicting prognosis and severity of disease [12]; (c) evidence suggests that an early (inappropriate) CT may increase the length of hospital stay [13], has low yield without direct management implications [18, 19], does not improve clinical outcomes [3], waste resources [18], and is associated with risks such as contrast allergy and nephrotoxicity [11].

A recent retrospective study in 166 patients supports the current guidelines, demonstrating that early cross-sectional abdominal imaging (CT or MR) in patients with suspected acute mild pancreatitis does not change medical management. Imaging may lead to unnecessary use of resource and patient radiation [17].

Importantly, the extent of peripancreatic and pancreatic necrosis may become evident only 72 h after the onset of AP (in up to 30% of patients), which must be considered when indicating a CT to assess the severity of pancreatitis using the CT severity index (CTSI) criteria, which should be performed only thereafter (Fig. 2). The clinical scenarios when early CT may be helpful, include ruling out intra-abdominal gastrointestinal (GI) perforations or bowel ischemia in patients presenting with both clinically diagnosed AP and acute abdomen (Fig. 3) [11].

Prognostication/prediction of severity

There are many different predictive scoring systems for acute pancreatitis (e.g., APACHE II, Ranson and modified Glasgow score), including single serum markers (C-reactive protein, hematocrit, procalcitonin, and blood urea nitrogen) and CTSI. However, none of them are superior (or inferior) to the evaluation of persistent SIRS [11, 20–22]. SIRS predict severe AP if present at admission or if it persists for 48 h. Therefore, no imaging should be performed to predict severity of AP [11].

Regarding the prediction of disease severity based on imaging, the modified CTSI has been shown to correlate better with patient outcome compared to CTSI, with similar inter-observer variability [23]. Another prospective study also showed that the modified CTSI makes the scoring easier to calculate, reduces the inter-observer variation and has a strong statistical correlation for clinical outcomes [24].

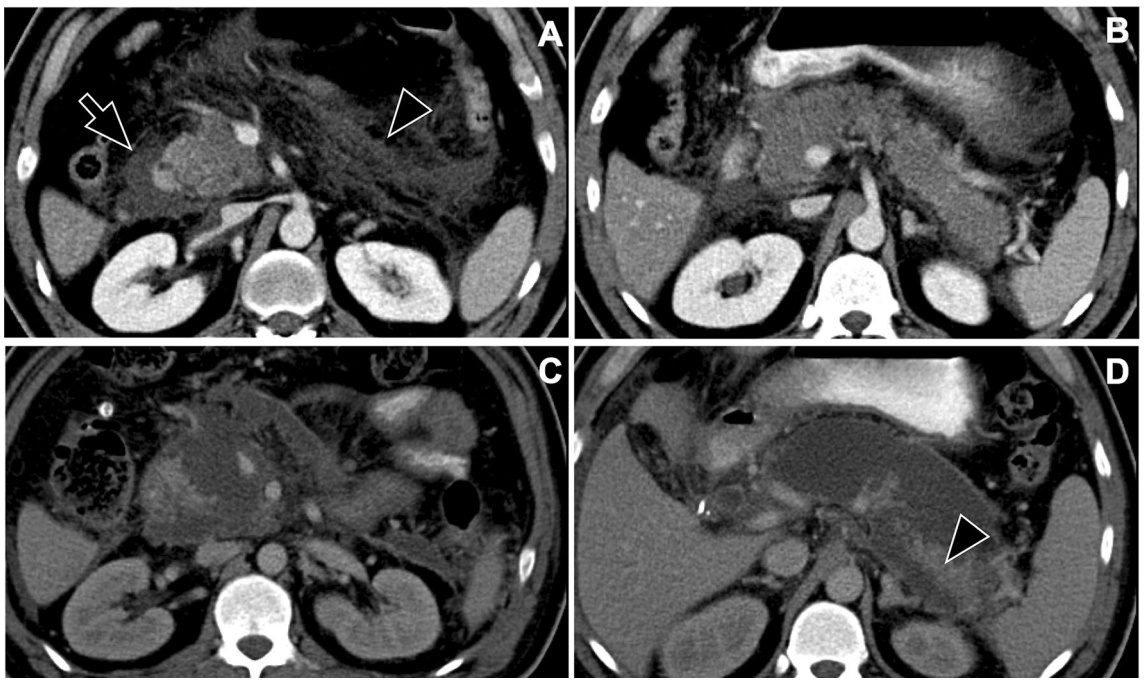

Fig. 2 Patient presenting with unspecific epigastric pain. **a** and **b**: The initial contrast-enhanced CT scan displays signs of acute pancreatitis with a diffusely enlarged pancreas, peripancreatic free fluid (arrow) and fat stranding (arrow head). The contrast-enhancement of the entire gland is diffusely decreased without clear evidence of necrotic areas. **c** and **d**: The follow-up scan 4 days later shows large areas of pancreatic necrosis. The remaining pancreatic parenchyma in the pancreatic tail shows diminished contrast-enhancement (arrow head)

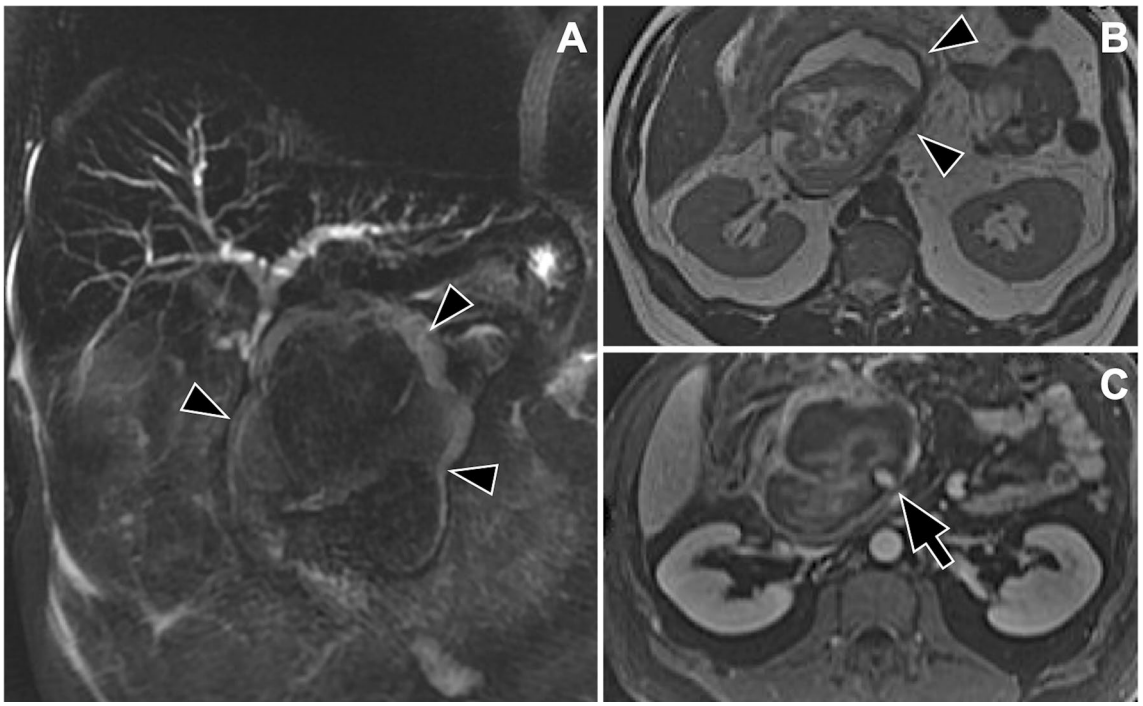

Fig. 3 Patient with recurrent severe alcoholic pancreatitis presents with abdominal pain. **a**: Coronal heavily T2-weighted thick slices show a well-circumscribed collection in the region of the pancreatic head with predominantly solid component (arrow head). **b**: Axial T2-weighted imaging shows an inhomogeneous encapsulated collection with irregular hypointense boundaries (arrow head). **c**: Contrast-enhanced axial T1-weighted imaging with fat saturation depicts a pseudoaneurysm (arrow) causing the hematoma, a known complication of acute pancreatitis

Recently, some investigators showed an inverse relationship between portal vein diameter and morbidity, and also an inverse relationship between splenic vein diameter and mortality in patients with AP. These findings seem to be associated with increased severity of AP, but further research is still necessary to prove that these results should be implemented into predictive scoring systems [25].

Management of peripancreatic collections

Endoscopic draining methods have proven to be equal to superior compared to surgical and percutaneous drainage in the management of complications associated with acute pancreatitis [26, 27]. Natural orifice transluminal endoscopic surgery (NOTES), a minimal invasive technique, has become a common approach to manage peripancreatic fluid collections. In line with the principle of NOTES, this intervention uses the oral entry for intraluminal access to collections in the setting of pancreatitis [28].

Indications, contraindications and timing are critical in the management of peripancreatic fluid collections. Imaging plays an important role in defining these components. Drainage is required if the collection causes symptoms or displays signs of infection [29]. Signs of infection such as presence of air inside the collection are best evaluated with CT (Fig. 4). However, air can also be indirectly detected by MR imaging through susceptibility artifacts and diffusion-weighted imaging is a great tool to assess collections. Regarding the timing, it is important to delay any intervention until the collection has become encapsulated—usually not before 4 weeks after the initial injury—and liquified, which is accessed using imaging methods [26]. In addition, contraindications for interventional management are defined using imaging. Such contraindications include among others a distance between the lumen wall and the collection of greater than 1 cm, extensive varices and large amount of internal debris.

Follow-up imaging

The most important indications for follow-up CT or MR imaging in AP are: (a) lack of clinical improvement despite optimized treatment, (b) clinical deterioration, (c) and when invasive intervention is considered.

Even though routine follow-up CT (e.g., weekly) in AP is advocated in some guidelines, evidence for this practice is lacking [11]. The IAP/APA Acute Pancreatitis Guidelines does not recommend routine CT follow-up, since the

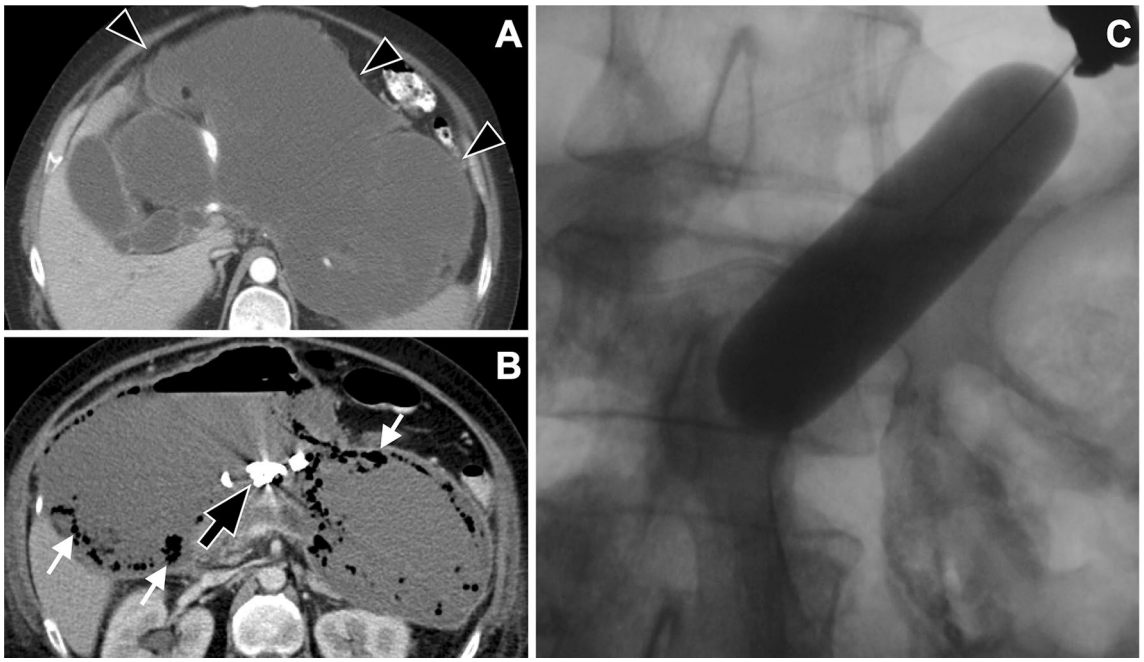

Fig. 4 Patient with > 4 weeks history of acute necrotizing pancreatitis displays an encapsulated space occupying lesion in the upper abdomen (**a**: arrow head) with presence of air in the follow-up imaging (**b**: white arrows), consistent with infected walled-off necrosis. Ultrasound guided endoscopy (**c**) was performed to drain the correction with placement of a transgastric intraluminal drainage (B: black arrow)

majority of AP complications can be diagnosed by clinical and biochemical assessment. Arterial pseudoaneurysm formation, an important complication, may not become clinically evident until bleeding occurs, but because of its rarity it does not justify a routine follow-up (Fig. 5) [11]. An unicentric retrospective study including 545 patients demonstrated that venous thromboembolism is extremely common in necrotizing pancreatitis and suggests that upper and lower extremity duplex ultrasound screening should be considered for early diagnosis in this high-risk population [30].

Often CT is not able to detect necrosis in a fluid-predominant collection [11, 31]. Therefore, ultrasound or MR imaging may be indicated to distinguish between pseudocysts and walled-off necrosis as defined by the revised Atlanta classification at least four weeks after the onset of AP [8, 11].

Biliary tract evaluation

Advanced methods to evaluate the biliary duct system, such as MRCP, EUS and ERCP are not generally indicated for patients with mild biliary pancreatitis without clinical evidence of persistent common bile duct (CBD) obstruction.

A recent prospective study compared intraoperative cholangiography (IOC) versus MRCP for evaluation of CBD stones in patients with mild acute biliary pancreatitis. This study suggests IOC as the superior method in some medical centers because it reduces delay for surgery and hospital stay compared to MRCP [32]. However, this is a short-term, non-randomized study with only 47 patients; other randomized controlled trials (RCTs) comparing both methods and its impact on the length of waiting days for surgery and the hospital stay are needed.

ERCP is indicated in patients with biliary pancreatitis and cholangitis [11]. A meta-analysis of seven RCTs including 757 patients showed no evidence that early routine ERCP significantly changes mortality or local/systemic complications, regardless of the predicted severity of biliary pancreatitis [33]. The meta-analysis also supports ERCP in patients with cholangitis or coexisting biliary obstruction. It should be highlighted that predicting the presence of CBD stones in the early stages of biliary pancreatitis with laboratory findings, transabdominal ultrasonography or CT is insufficient [34].

The optimal timing for ERCP in biliary pancreatitis, if indicated, is within the first 24 h of onset of AP. Urgent ERCP (< 24 h) is needed in patients with acute cholangitis. The optimal timing of ERCP in patients with biliary pancreatitis without cholangitis is not well established. A recent meta-analysis found no statistically significant effect of the timing of ERCP (< 24 vs. < 72 h) on mortality

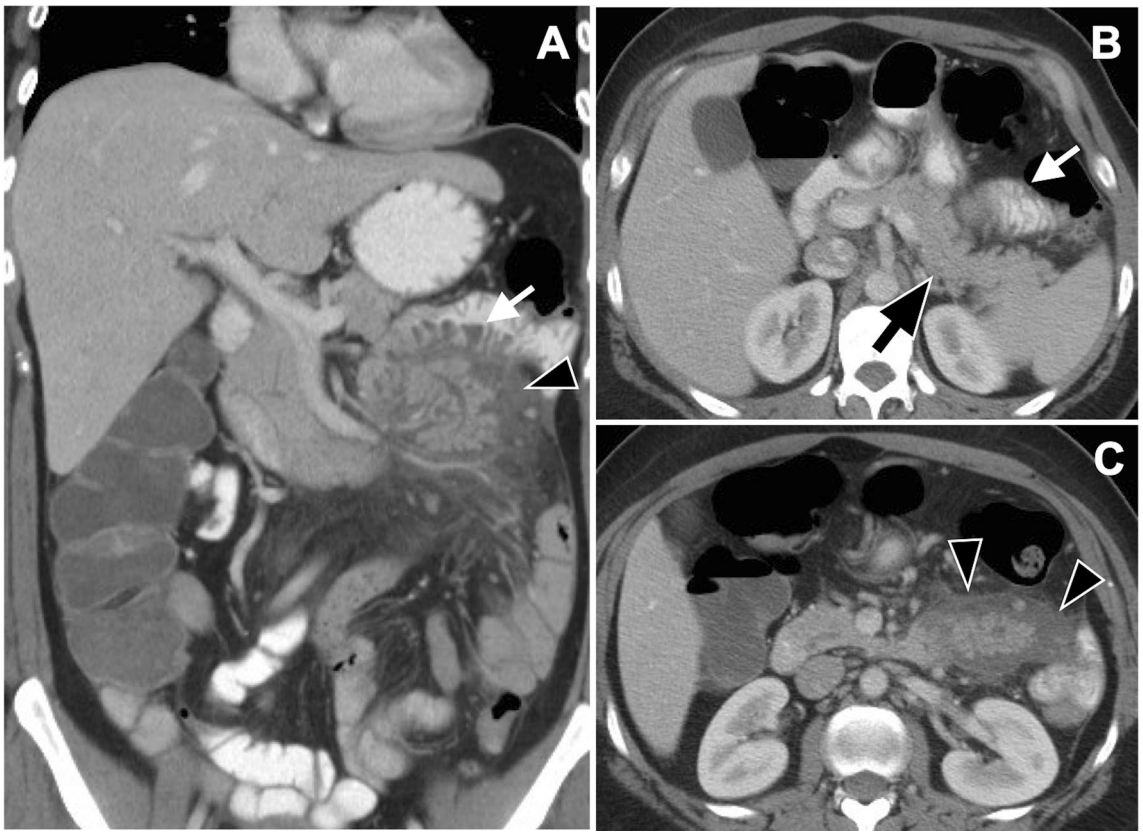

Fig. 5 Contrast-enhanced CT was performed in a patient with unclear abdominal pain and elevated lipase. **a**: Coronal reformation shows an ectopic pancreas in the right middle quadrant with peripancreatic free fluid and fat stranding (arrow head). The adjacent fluid-filled jejunum shows reactive wall thickening (white arrow). **b**: Axial orientation shows a normal orthotopic pancreas without any evidence of inflammation. **c**: The ectopic pancreas is located further down with clear evidence of inflammation (arrow head: peripancreatic free fluid)

[33]. However, none of these studies were specifically designed to evaluate timing of ERCP in biliary pancreatitis. Because it is unclear what the exact timing of early ERCP should be (24–72 h), IPA/APA guidelines advocate that it is reasonable to await spontaneous improvement of biliary obstruction for 24–48 h. However, it is important that ERCP is performed as soon as possible in patients with acute cholangitis [11].

MRCP and EUS have an important role in prevention of ERCPs that would otherwise be performed for suspected CBD stones in patients with biliary pancreatitis without cholangitis, lacking influence in the clinical course [11, 35]. EUS is superior to MRCP in exclusion of small (< 5 mm) gallstones. MRCP is less invasive, less operator-dependent and probably more widely available than EUS. Therefore, there is no clear superiority for either MRCP or EUS in clinical practice [11]. Modifi et al. [36] showed that MRCP is an accurate modality for imaging the biliary tree in patients with acute gallstone pancreatitis and selective use of this method reduces the need for ERCP and results in shorter hospital stay.

One RCT found that EUS could safely replace diagnostic ERCP in patients with biliary pancreatitis [37]. However, access to urgent MRCP and EUS is likely to be limited in most hospitals. A negative MRCP does not exclude the presence of small (< 5 mm) common bile duct stones [38], which can cause biliary pancreatitis [19].

Imaging modalities

Evaluation of the pancreas can be safely performed with US in order to demonstrate features of acute pancreatitis, including diffuse glandular enlargement, hypoechoic echotexture of the pancreas consistent with edema, and ascites. However, this modality is limited in the majority of patients with AP, usually due to overlying bowel gas, particularly in the setting of associated focal adynamic ileus restricting the visibility of the pancreas by US. Therefore, US has limited effectiveness in the evaluation of pancreatic inflammation, peripancreatic inflammation and fluid, and pancreatic necrosis [39].

The most important utility of US in patients with AP is identifying gallstones or biliary ductal dilatation/choledocholithiasis [11]. US has limited sensitivity (20%) for diagnosing choledocholithiasis, compared to 40% in CT and 80% in MRCP [40].

Contrast-enhanced US (CEUS) is being used in some centers to evaluate patients with acute pancreatitis and is found to be equivalent to contrast-enhanced CT and clinical scoring [41, 42]. One study showed the usefulness of CEUS in quantifying the necrotic area in acute pancreatitis, with comparable results to those obtained by CT [41]. Other researchers demonstrated that CEUS is similar to CT in detecting pancreatic necrosis as well as predicting the clinical course of AP, suggesting that when CT is contraindicated CEUS may be a valid alternative [42]. But this technique is operator-dependent, which is a downside of this modality. In addition, US contrast agents are not approved in the United States for this indication.

The current modality of choice for evaluating patients with acute pancreatitis is CT with intravenous contrast, due to widespread availability of this method and rapid acquisition [9].

CT scans can be performed by using a wide variation of CT protocols, and there are no strict radiological guidelines on how to perform a CT scan in the setting of acute pancreatitis. The recent recommendation is to perform multidetector CT with thin collimation and slice thickness (i.e., 5 mm or less) and to administer 100–150 ml of non-ionic intravenous contrast material at a rate of 3 ml/s, during the pancreatic and/or portal venous phase (i.e., 50–70 s delay). If follow-up is necessary, a portal venous phase (monophasic) is generally sufficient. Contrast-enhanced CT is clearly preferable, although in patients with impending renal failure an initial non-contrast CT may be an option [11]. The benefit of adding a non-contrast CT scan to the protocol is the detection of parenchymal calcifications and stone formations. An elegant way of combing a multiphasic CT scan with a virtual non-contrast phase is dual-energy CT. Dual-energy CT can also be beneficial in identifying non-calcified gallstones causing pancreatitis [43].

When performing CT scans, both the pancreatic and portal venous phase are sufficient for the discrimination of viable and non-viable pancreatic tissue [11]. However, a recent retrospective European study demonstrated a moderate inter-observer agreement when using the revised Atlanta classification to categorize pancreatic and peripancreatic collections by CT during the first month of AP, showing that it is often challenging [44]. Another study showed good agreement for the revised Atlanta classification, supporting the importance for widespread adaption of this revised Atlanta classification for clinical and research communications [45].

There are some indications that require a multiphasic protocol, such as hemorrhage, arterial pseudoaneurysm and mesenteric ischemia (Fig. 6) [11]. It is important to note

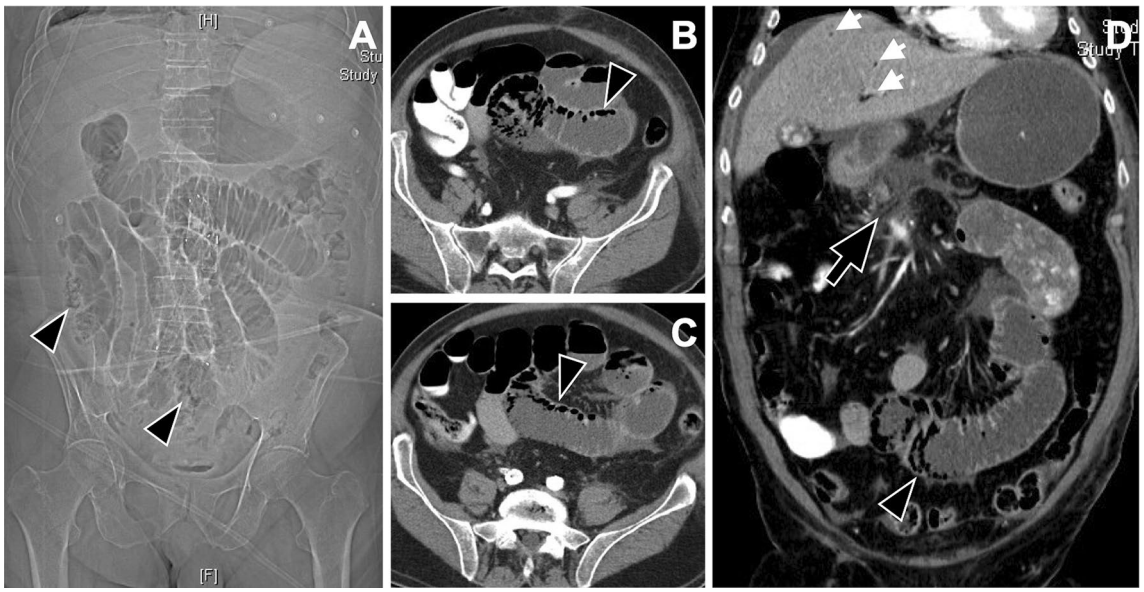

Fig. 6 Mesenteric ischemia as a complication of pancreatitis in a critically ill patient. **a**: On the scout, dilatation of small bowl segments is present with the suspicion of intramural air in the right lower quadrant (arrow head). **b** and **c**: Axial contrast-enhanced CT confirms intramural air in dilated fluid-filled small bowl in the lower abdomen (intestinal pneumatosis: arrow head). **d**: On coronal reformation of the contrast-enhanced CT peripancreatic free fluid is present (arrow), intramural air in small bowl segments (arrow head) is better appreciated on the coronal reformation and air in the portal venous system as a manifestation of mesenteric ischemia (pneumatosis portalis: white arrows)

that the presence of hemorrhage in AP is common and its presence correlates with poor clinical outcome (Fig. 7) [46].

For MR imaging, it is recommended to acquire axial fat-saturated T2 and axial fat-saturated T1 before and after intravenous gadolinium contrast administration [11]. When MR imaging includes heavily T2-weighted MRCP images, it obviates multimodality imaging, since MRCP demonstrates high sensitivity and specificity for evaluation of the pancreatic duct and biliary tree and has the added benefit of potentially prevent the more invasive ERCP [9].

Diffusion-weighted imaging (DWI) may best show findings of AP in some patients, since the findings on conventional T1- and T2 weighted-imaging may be subtle [14]. In addition, the sensitivity and accuracy of DWI-MR surpassed CT in identifying the presence of infection in peripancreatic fluid collections [14, 47].

MR imaging is advised when the differentiation between pseudocysts and collections with necrosis (i.e., acute necrotic collection and walled-off necrosis) is clinically relevant and in young patients because of the radiation burden of CT [11]. Other advantages of MR imaging are: (a) bile duct stones and gallstones detection, the pancreatic duct can be followed in its entirety, and duct disruption can often be assessed easily; (b) its effectiveness for evaluating morphologic changes to the pancreas and peripancreatic regions is similar to that of multidetector CT (MDCT) [9, 10, 36, 39, 48–50].

The most important disadvantages of MR imaging are: (a) it is often not readily available in an acute setting; (b) it is often challenging to perform in acutely ill patients; and (c) the acquisition times are considerably longer compared to MDCT.

Conclusion

Imaging is often needed to diagnose acute pancreatitis when the clinical situation is uncertain, to determine the underlying cause of AP, to evaluate complications and disease severity, and to guide intervention. CT has been the most studied imaging modality used for evaluating patients with acute pancreatitis; however, other imaging modalities can be useful, including transabdominal ultrasound, endoscopic ultrasound, magnetic resonance imaging and magnetic resonance cholangiopancreatography.

Despite their potential benefits, a number of medical risks and economic consequences are associated with diagnostic imaging in the setting of AP, including increase of the effective radiation dose and rising health care costs. Thus, it is of the utmost importance that referring physicians and radiologists select the appropriate imaging technique by evaluating

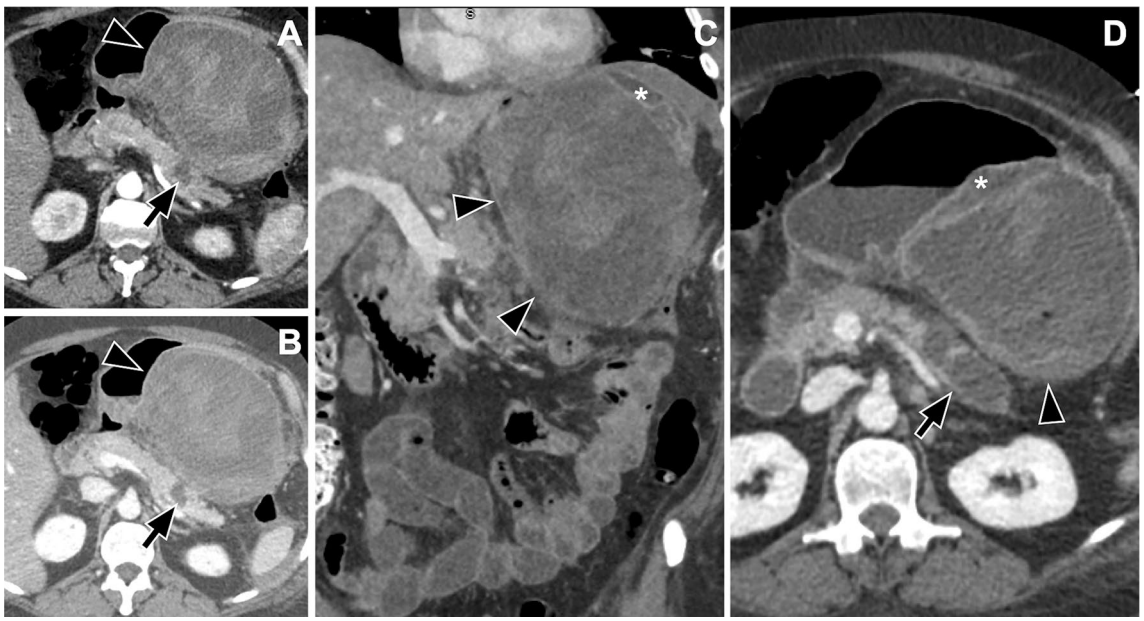

Fig. 7 A 51-year-old male patient with a history of abdominal pain (duration: 4–6 week) presented with acute pancreatitis. On axial (**a** and **b**) and coronal (**c**) contrast-enhanced CT scan a focal non-enhancing area in the pancreatic tail (arrow) is present with an encapsulated inhomogeneous fluid collection (arrow head: 23.4 × 12.6 mm) adjacent to it, consistent with necrotic pancreatitis with associated hemorrhagic fluid collection. On arterial (**a**) and venous (**b**) phase no active extravasation is seen. The stomach is displaced and shows wall thickening (*) in (**c**) and (**d**). Follow-up imaging three days later shows a thicker encapsulation of the hematoma (arrow head) and more extensive necrotic areas in the pancreatic tail (arrow)

each single AP case individually for the necessity of imaging in order to ensure cost-effective, high-quality patient care.

Acknowledgements Khoschy Schawkat received a grant from the Swiss National Science Foundation (SNSF) with Grant No. 181917 and Swiss Society of Radiology.

Disclosures The authors have nothing to disclose.

References

1. Bhargavan M, Sunshine JH (2005) Utilization of radiology services in the United States: levels and trends in modalities, regions, and populations. Radiology 234 (3):824-832. https://doi.org/10.1148/radiol.2343031536
2. Matin A, Bates DW, Sussman A, Ros P, Hanson R, Khorasani R (2006) Inpatient radiology utilization: trends over the past decade. AJR American journal of roentgenology 186 (1):7-11. https://doi.org/10.2214/ajr.04.0633
3. Mortele KJ, Ip IK, Wu BU, Conwell DL, Banks PA, Khorasani R (2011) Acute pancreatitis: imaging utilization practices in an urban teaching hospital–analysis of trends with assessment of independent predictors in correlation with patient outcomes. Radiology 258 (1):174-181. https://doi.org/10.1148/radiol.10100320
4. Kothari S, Kalinowski M, Kobeszko M, Almouradi T (2019) Computed tomography scan imaging in diagnosing acute uncomplicated pancreatitis: Usefulness vs cost. World journal of gastroenterology 25 (9):1080-1087. https://doi.org/10.3748/wjg.v25.i9.1080
5. Ball CG, Correa-Gallego C, Howard TJ, Zyromski NJ, House MG, Pitt HA, Nakeeb A, Schmidt CM, Akisik F, Lillemoe KD (2010) Radiation dose from computed tomography in patients with necrotizing pancreatitis: how much is too much? Journal of gastrointestinal surgery : official journal of the Society for Surgery of the Alimentary Tract 14 (10):1529-1535. https://doi.org/10.1007/s11605-010-1314-8
6. Iglehart JK (2009) Health insurers and medical-imaging policy–a work in progress. N Engl J Med 360 (10):1030-1037. https://doi.org/10.1056/nejmhpr0808703
7. Yadav D, Lowenfels AB (2013) The epidemiology of pancreatitis and pancreatic cancer. Gastroenterology 144 (6):1252-1261. https://doi.org/10.1053/j.gastro.2013.01.068
8. Banks PA, Bollen TL, Dervenis C, Gooszen HG, Johnson CD, Sarr MG, Tsiotos GG, Vege SS (2013) Classification of acute pancreatitis–2012: revision of the Atlanta classification and definitions by international consensus. Gut 62 (1):102-111. https://doi.org/10.1136/gutjnl-2012-302779
9. Porter KK, Cason DE, Morgan DE (2018) Acute Pancreatitis: How Can MR Imaging Help. Magnetic resonance imaging clinics of North America 26 (3):439-450. https://doi.org/10.1016/j.mric.2018.03.011
10. Thoeni RF (2015) Imaging of Acute Pancreatitis. Radiologic clinics of North America 53 (6):1189-1208. https://doi.org/10.1016/j.rcl.2015.06.006
11. IAP/APA evidence-based guidelines for the management of acute pancreatitis (2013). Pancreatology 13 (4, Supplement 2):e1-e15. doi:https://doi.org/10.1016/j.pan.2013.07.063
12. Bollen TL, Singh VK, Maurer R, Repas K, van Es HW, Banks PA, Mortele KJ (2012) A comparative evaluation of radiologic and clinical scoring systems in the early prediction of severity in acute pancreatitis. The American journal of gastroenterology 107 (4):612-619. https://doi.org/10.1038/ajg.2011.438
13. Fleszler F, Friedenberg F, Krevsky B, Friedel D, Braitman LE (2003) Abdominal computed tomography prolongs length of stay and is frequently unnecessary in the evaluation of acute pancreatitis. The American journal of the medical sciences 325 (5):251-255
14. Siddiqui N, Vendrami CL, Chatterjee A, Miller FH (2018) Advanced MR Imaging Techniques for Pancreas Imaging. Magnetic resonance imaging clinics of North America 26 (3):323-344. https://doi.org/10.1016/j.mric.2018.03.002
15. Sandrasegaran K, Tahir B, Barad U, Fogel E, Akisik F, Tirkes T, Sherman S (2017) The Value of Secretin-Enhanced MRCP in Patients With Recurrent Acute Pancreatitis. AJR American journal of roentgenology 208 (2):315-321. https://doi.org/10.2214/ajr.16.16566
16. Wan J, Ouyang Y, Yu C, Yang X, Xia L, Lu N (2018) Comparison of EUS with MRCP in idiopathic acute pancreatitis: a systematic review and meta-analysis. Gastrointestinal endoscopy 87 (5):1180-1188.e1189. https://doi.org/10.1016/j.gie.2017.11.028
17. Reynolds PT, Brady EK, Chawla S (2018) The utility of early cross-sectional imaging to evaluate suspected acute mild pancreatitis. Annals of gastroenterology 31 (5):628-632. https://doi.org/10.20524/aog.2018.0291
18. Dobbs NW, Budak MJ, Weir-McCall JR, Vinnicombe SJ, Zealley IA (2016) Acute pancreatitis: a comparison of intervention rates precipitated by early vs guideline CT scan timing. Clinical radiology 71 (10):993-996. https://doi.org/10.1016/j.crad.2016.06.113
19. Spanier BW, Nio Y, van der Hulst RW, Tuynman HA, Dijkgraaf MG, Bruno MJ (2010) Practice and yield of early CT scan in acute pancreatitis: a Dutch Observational Multicenter Study. Pancreatology 10 (2-3):222-228. https://doi.org/10.1159/000243731
20. Nordback I, Pelli H, Lappalainen-Lehto R, Jarvinen S, Raty S, Sand J (2009) The recurrence of acute alcohol-associated pancreatitis can be reduced: a randomized controlled trial. Gastroenterology 136 (3):848-855. https://doi.org/10.1053/j.gastro.2008.11.044
21. Wilcox CM, Varadarajulu S, Eloubeidi M (2006) Role of endoscopic evaluation in idiopathic pancreatitis: a systematic review. Gastrointestinal endoscopy 63 (7):1037-1045. https://doi.org/10.1016/j.gie.2006.02.024
22. Papachristou GI, Muddana V, Yadav D, O'Connell M, Sanders MK, Slivka A, Whitcomb DC (2010) Comparison of BISAP, Ranson's, APACHE-II, and CTSI scores in predicting organ failure, complications, and mortality in acute pancreatitis. The American journal of gastroenterology 105 (2):435-441; quiz 442. https://doi.org/10.1038/ajg.2009.622
23. Mortele KJ, Wiesner W, Intriere L, Shankar S, Zou KH, Kalantari BN, Perez A, vanSonnenberg E, Ros PR, Banks PA, Silverman SG (2004) A modified CT severity index for evaluating acute pancreatitis: improved correlation with patient outcome. AJR American journal of roentgenology 183 (5):1261-1265. https://doi.org/10.2214/ajr.183.5.1831261
24. Raghuwanshi S, Gupta R, Vyas MM, Sharma R (2016) CT Evaluation of Acute Pancreatitis and its Prognostic Correlation with CT Severity Index. Journal of clinical and diagnostic research : JCDR 10 (6):Tc06-11. https://doi.org/10.7860/jcdr/2016/19849.7934
25. Smeets X, Litjens G, da Costa DW, Kievit W, van Santvoort HC, Besselink MGH, Fockens P, Bruno MJ, Kolkman JJ, Drenth JPH, Bollen TL, van Geenen EJM (2018) The association between portal system vein diameters and outcomes in acute pancreatitis. Pancreatology. https://doi.org/10.1016/j.pan.2018.05.007
26. Vilmann AS, Menachery J, Tang SJ, Srinivasan I, Vilmann P (2015) Endosonography guided management of pancreatic fluid collections. World journal of gastroenterology 21 (41):11842-11853. https://doi.org/10.3748/wjg.v21.i41.11842
27. Varadarajulu S, Bang JY, Sutton BS, Trevino JM, Christein JD, Wilcox CM (2013) Equal Efficacy of Endoscopic and Surgical Cystogastrostomy for Pancreatic Pseudocyst Drainage in a

Randomized Trial. Gastroenterology 145 (3):583-590.e581. https://doi.org/10.1053/j.gastro.2013.05.046
28. Bingener J, Ibrahim-zada I (2014) Natural orifice transluminal endoscopic surgery for intra-abdominal emergency conditions. The British journal of surgery 101 (1):e80-89. https://doi.org/10.1002/bjs.9352
29. Gardner TB (2012) Endoscopic management of necrotizing pancreatitis. Gastrointestinal endoscopy 76 (6):1214-1223. https://doi.org/10.1016/j.gie.2012.05.028
30. Roch AM, Maatman TK, Carr RA, Colgate CL, Ceppa EP, House MG, Lopes J, Nakeeb A, Schmidt CM, Zyromski NJ (2019) Venous Thromboembolism in Necrotizing Pancreatitis: an Underappreciated Risk. Journal of gastrointestinal surgery : official journal of the Society for Surgery of the Alimentary Tract. https://doi.org/10.1007/s11605-019-04124-0
31. Morgan DE, Baron TH, Smith JK, Robbin ML, Kenney PJ (1997) Pancreatic fluid collections prior to intervention: evaluation with MR imaging compared with CT and US. Radiology 203 (3):773-778. https://doi.org/10.1148/radiology.203.3.9169703
32. Gomez-Torres GA, Gonzalez-Hernandez J, Lopez-Lizarraga CR, Navarro-Muniz E, Ortega-Garcia OS, Bonnet-Lemus FM, Abarca-Rendon FM, De la Cerda-Trujillo LF (2018) Intraoperative cholangiography versus magnetic resonance cholangiography in patients with mild acute biliary pancreatitis: A prospective study in a second-level hospital. Medicine (Baltimore) 97 (44):e12976. https://doi.org/10.1097/md.0000000000012976
33. Tse F, Yuan Y (2012) Early routine endoscopic retrograde cholangiopancreatography strategy versus early conservative management strategy in acute gallstone pancreatitis. The Cochrane database of systematic reviews (5):Cd009779. https://doi.org/10.1002/14651858.cd009779.pub2
34. van Santvoort HC, Bakker OJ, Besselink MG, Bollen TL, Fischer K, Nieuwenhuijs VB, Gooszen HG, Erpecum KJ (2011) Prediction of common bile duct stones in the earliest stages of acute biliary pancreatitis. Endoscopy 43 (1):8-13. https://doi.org/10.1055/s-0030-1255866
35. Lee SL, Kim HK, Choi HH, Jeon BS, Kim TH, Choi JM, Ku YM, Kim SW, Kim SS, Chae HS (2018) Diagnostic value of magnetic resonance cholangiopancreatography to detect bile duct stones in acute biliary pancreatitis. Pancreatology 18 (1):22-28. https://doi.org/10.1016/j.pan.2017.12.004
36. Mofidi R, Lee AC, Madhavan KK, Garden OJ, Parks RW (2008) The selective use of magnetic resonance cholangiopancreatography in the imaging of the axial biliary tree in patients with acute gallstone pancreatitis. Pancreatology 8 (1):55-60. https://doi.org/10.1159/000115667
37. Liu CL, Fan ST, Lo CM, Tso WK, Wong Y, Poon RT, Lam CM, Wong BC, Wong J (2005) Comparison of early endoscopic ultrasonography and endoscopic retrograde cholangiopancreatography in the management of acute biliary pancreatitis: a prospective randomized study. Clinical gastroenterology and hepatology : the official clinical practice journal of the American Gastroenterological Association 3 (12):1238-1244
38. Kondo S, Isayama H, Akahane M, Toda N, Sasahira N, Nakai Y, Yamamoto N, Hirano K, Komatsu Y, Tada M, Yoshida H, Kawabe T, Ohtomo K, Omata M (2005) Detection of common bile duct stones: comparison between endoscopic ultrasonography, magnetic resonance cholangiography, and helical-computed-tomographic cholangiography. European journal of radiology 54 (2):271-275. https://doi.org/10.1016/j.ejrad.2004.07.007
39. Baker ME, Nelson RC, Rosen MP, Blake MA, Cash BD, Hindman NM, Kamel IR, Kaur H, Piorkowski RJ, Qayyum A, Yarmish GM (2014) ACR Appropriateness Criteria(R) acute pancreatitis. Ultrasound quarterly 30 (4):267-273. https://doi.org/10.1097/ruq.0000000000000099
40. Moon JH, Cho YD, Cha SW, Cheon YK, Ahn HC, Kim YS, Kim YS, Lee JS, Lee MS, Lee HK, Shim CS, Kim BS (2005) The detection of bile duct stones in suspected biliary pancreatitis: comparison of MRCP, ERCP, and intraductal US. The American journal of gastroenterology 100 (5):1051-1057. https://doi.org/10.1111/j.1572-0241.2005.41057.x
41. Golea A, Badea R, Socaciu M, Diaconu B, Iacob D (2010) Quantitative analysis of tissue perfusion using contrast-enhanced transabdominal ultrasound (CEUS) in the evaluation of the severity of acute pancreatitis. Medical ultrasonography 12 (3):198-204
42. Ripolles T, Martinez MJ, Lopez E, Castello I, Delgado F (2010) Contrast-enhanced ultrasound in the staging of acute pancreatitis. European radiology 20 (10):2518-2523. https://doi.org/10.1007/s00330-010-1824-5
43. George E, Wortman JR, Fulwadhva UP, Uyeda JW, Sodickson AD (2017) Dual energy CT applications in pancreatic pathologies. The British Journal of Radiology 90 (1080):20170411. https://doi.org/10.1259/bjr.20170411
44. Badat N, Millet I, Corno L, Khaled W, Boulay-Coletta I, Zins M (2019) Revised Atlanta classification for CT pancreatic and peripancreatic collections in the first month of acute pancreatitis: interobserver agreement. European radiology 29 (5):2302-2310. https://doi.org/10.1007/s00330-018-5906-0
45. Bouwense SA, van Brunschot S, van Santvoort HC, Besselink MG, Bollen TL, Bakker OJ, Banks PA, Boermeester MA, Cappendijk VC, Carter R, Charnley R, van Eijck CH, Freeny PC, Hermans JJ, Hough DM, Johnson CD, Lameris JS, Lerch MM, Mayerle J, Mortele KJ, Sarr MG, Stedman B, Vege SS, Werner J, Dijkgraaf MG, Gooszen HG, Horvath KD (2017) Describing Peripancreatic Collections According to the Revised Atlanta Classification of Acute Pancreatitis: An International Interobserver Agreement Study. Pancreas 46 (7):850-857. https://doi.org/10.1097/mpa.0000000000000863
46. Tang MY, Chen TW, Bollen TL, Wang YX, Xue HD, Jin ZY, Huang XH, Xiao B, Li XH, Ji YF, Zhang XM (2018) MR imaging of hemorrhage associated with acute pancreatitis. Pancreatology 18 (4):363-369. https://doi.org/10.1016/j.pan.2018.03.004
47. Islim F, Salik AE, Bayramoglu S, Guven K, Alis H, Turhan AN (2014) Non-invasive detection of infection in acute pancreatic and acute necrotic collections with diffusion-weighted magnetic resonance imaging: preliminary findings. Abdominal imaging 39 (3):472-481. https://doi.org/10.1007/s00261-014-0076-2
48. Arvanitakis M, Koustiani G, Gantzarou A, Grollios G, Tsitouridis I, Haritandi-Kouridou A, Dimitriadis A, Arvanitakis C (2007) Staging of severity and prognosis of acute pancreatitis by computed tomography and magnetic resonance imaging-a comparative study. Digestive and liver disease : official journal of the Italian Society of Gastroenterology and the Italian Association for the Study of the Liver 39 (5):473-482. https://doi.org/10.1016/j.dld.2007.01.015
49. Viremouneix L, Monneuse O, Gautier G, Gruner L, Giorgi R, Allaouchiche B, Pilleul F (2007) Prospective evaluation of nonenhanced MR imaging in acute pancreatitis. Journal of magnetic resonance imaging : JMRI 26 (2):331-338. https://doi.org/10.1002/jmri.21037
50. Kim YK, Kim CS, Han YM (2009) Role of fat-suppressed t1-weighted magnetic resonance imaging in predicting severity and prognosis of acute pancreatitis: an intraindividual comparison with multidetector computed tomography. Journal of computer assisted tomography 33 (5):651-656. https://doi.org/10.1097/rct.0b013e3181979282