Imaging Predictors

6

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Introduction

Acute pancreatitis is a common cause for hospitalization in the Western world. Fortunately, most patients with acute pancreatitis follow a mild clinical course without significant complications [1, 2]. Imaging in these patients is rarely necessary aside from establishing the cause of pancreatitis, i.e., an ultrasound on admission is often requested for assessment of biliary stones. However, about one-quarter of patients develop clinically severe acute pancreatitis accompanied by prolonged hospitalization with high morbidity and mortality rates [1–3]. These patients are responsible for most of the healthcare expenses in acute pancreatitis that include the need for repeated imaging. Despite increased knowledge of the pathophysiology and natural course of acute pancreatitis and notwithstanding the improvements in imaging techniques and critical care, mortality rates in severe acute pancreatitis have been unchanged. Given these differences in length of hospitalization and intensive care stay, the differences in morbidity and mortality and in healthcare costs, a continuous effort for more than four decades has been made to develop a prognostic multifactorial scoring system (based on clinical, biochemical, and/or imaging parameters) for accurate severity stratification, preferably during the first days of admission.

Early severity stratification is deemed important for several reasons. Identification of patients with the highest morbidity and mortality is critical because these patients may benefit most from timely transfer to the intensive care unit or tertiary referral centers for supportive treatment or for targeted therapy (i.e., endoscopic intervention or enteral feeding). In addition, stratification is essential for reliable interinstitutional comparison of new methods of therapy and for inclusion of patients in randomized trials [2, 4].

This chapter will review existing radiologic prognostic systems with their respective advantages and limitations and addresses imaging features of acute pancreatitis with an emphasis on the prognostic significance of specific findings that impacts patient management.

Overview of Imaging Modalities

Multidetector computed tomography (MDCT) is the most widely available imaging modality and is the standard for the evaluation of acute pancreatitis [2, 5]. Other imaging modalities that are used for evaluation of acute pancreatitis include endoscopic and transabdominal ultrasound and magnetic resonance imaging (MRI). Imaging in acute pancreatitis is performed for several reasons that include confirmation of the diagnosis, detection of gallstones or biliary

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obstruction, assessment of severity of disease, and evaluation of complications related to acute pancreatitis [5–7].

Ultrasound

Ultrasound has only limited value in the assessment of acute pancreatitis and its severity, because overlying bowel gas often obscures portions of the pancreas. However, ultrasound has a high sensitivity for detecting gallstones and is useful for follow-up of established pancreatic fluid collections [8].

Magnetic Resonance Imaging

The use of MRI in the assessment of acute pancreatitis and its complications is gaining increasing acceptance. Indeed, MRI offers similar diagnostic capabilities compared with CT with better depiction of stones in gallbladder or common bile duct and better evaluation of the pancreatico-biliary ductal system [8, 9]. Additionally, MRI is more accurate than CT in characterizing the content of peripancreatic collections that may aid in allowing appropriate drainage techniques to be used [10]. Disadvantages of MRI are its limited availability in an acute setting and that acquisition times are significantly longer than with MDCT.

Computed Tomography

MDCT is the primary imaging modality used in the evaluation of patients with acute pancreatitis. Morphologic changes of the pancreas and peripancreatic region are easily depicted on CT that allows for confirmation of the diagnosis, for assessment of disease severity, and for evaluation of local pancreatic and extrapancreatic complications [11]. A monophasic CT protocol after intravenous contrast administration is usually adequate for assessment of acute pancreatitis [12, 13]. Typically, scans are performed during the pancreatic phase (delay of 40–50 s) or portal venous phase (delay 60–70 s). Multi-phase studies are recommended in case of hemorrhage, ischemia, or suspicion of an arterial pseudoaneurysm [12, 13]. Major disadvantages of CECT remain the radiation exposure and the limited capability of differentiating fluid from necrotic material in peripancreatic collections [10].

Radiologic Scoring Systems

Scoring systems related to CT are the most studied imaging test in acute pancreatitis [14]. Since the introduction of CT for diagnosis and severity assessment of acute pancreatitis in the 1980s, many imaging-based systems have been developed. In this section, the most relevant scoring systems will be reviewed in order of year of development. Determinants of most radiologic scoring systems include pancreatic changes, peripancreatic features, and extrapancreatic features (Table 6.1). Severity assessment of acute pancreatitis by CT can be done using unenhanced (Schröder index, Balthazar grade, Pancreatic size index (PSI), MOP score, retroperitoneal extension grade, and EPIC score) or contrast-enhanced CT studies (CT severity index and Modified CT severity index).

Schröder Index

In 1985, Kivisaari and Schröder were among the first to develop a CT scoring system for severity stratification in acute pancreatitis based on pancreatic and extra-pancreatic findings [15]. The pancreatic CT findings include edema in part of the pancreas and edema of the entire pancreas. Extrapancreatic findings include peritoneal fluid, perirenal fat edema, mesenteric fat edema, pleural effusion, and bowel paralysis. Each of these findings was assigned one point with a maximum score of 7. A total score of <4 correlates with predicted mild acute pancreatitis, and a score of 4 or more with predicted severe acute pancreatitis. This scoring system is relatively easy to apply and practical even among patients with renal failure when no intravenous contrast medium agents

Table 6.1 CT determinants that constitute radiologic scoring systems

Pancreatic features
Subjective pancreatic enlargement
Pancreatic size index (PSI)[a]
Pancreatic parenchymal necrosis (presence and extent)
Peripancreatic features
Peripancreatic fat stranding
Peripancreatic fluid collection (presence and number)
Perirenal edema
Mesenteric inflammation
Retroperitoneal extension
Extrapancreatic features
Pleural effusion (presence, uni-, bilateral)
Ascites (presence and number of locations)[b]
Vascular complications (venous thrombosis, hemorrhage, arterial pseudoaneurysm)
Extrapancreatic parenchymal complications (infarction, hemorrhage, subcapsular fluid collection)
Gastrointestinal complications (ileus, signs of ischemia, perforation, marked bowel wall thickening, intramural fluid collection)

[a]PSI defined as multiplication of maximum anteroposterior measurement of the pancreatic head and body. A score of <10 cm^2 is regarded as predicted mild pancreatitis and ≥10 cm^2 is regarded as predicted severe pancreatitis [23]
[b]Ascites in either one of these locations: perihepatic, perisplenic, interloop, or in pelvis [41]

can be administered. Limitations are that the presence of peritoneal fluid (especially in female patients) and perirenal fat edema can be a normal finding (especially in the elderly).

Balthazar Grade

In 1985, Balthazar and colleagues developed a CT grading system based on the presence of pancreatic and peripancreatic changes into five grades of severity, ranging from Grade A (normal pancreas) to Grade E (inflamed pancreas with two or more fluid collections) (Fig. 6.1) [16, 17]. In their original report, Grade A and B correlated with mild uncomplicated clinical course with no mortality, whereas Grade D and E signified severe disease with 54 % morbidity and 14 % mortality [16, 17]. These results have been confirmed in subsequent studies by different groups of investigators [18–20]. The advantages of the Balthazar grading system are that it can be applied at any point during the patient's hospitalization and requires no iodinated contrast medium. Limitations are the subjective assessment of pancreatic enlargement

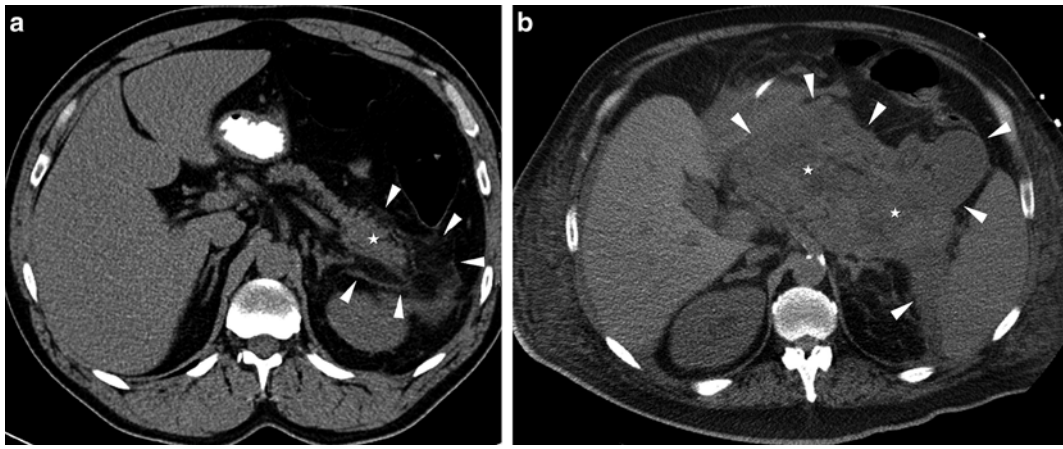

Fig. 6.1 (**a**) A 35-year-old man with acute pancreatitis (Balthazar Grade C). Unenhanced CT shows a swollen pancreatic tail (*white star*) with peripancreatic fat stranding (*arrowheads*). (**b**) A 56-year-old man with acute pancreatitis (Balthazar Grade E). Unenhanced CT shows a heterogeneous pancreas (*white stars*) surrounded by multiple peripancreatic collections (*arrowheads*)

(corresponding to Grade B), the arbitrarily chosen distinction between peripancreatic inflammatory changes ("fat stranding") and a peripancreatic collection (Grade C and D, respectively), and the need for counting peripancreatic collections (differentiating Grade D from Grade E), all of which are associated with moderate interobserver agreement. Some authors maintain that Balthazar grading system simplifies the retroperitoneal compartment rather than acknowledging the different components that constitute the retroperitoneum [21]. Another shortcoming (put forth by Balthazar himself) is that peripancreatic fluid collections (Grade D and E) have a variable natural history; in their study 54 % resolved spontaneously, whereas 46 % became infected necessitating intervention [16, 22].

Pancreatic Size Index

The PSI was first introduced in 1989 by London and colleagues [23]. The PSI (in cm^2) is calculated by multiplying the maximum anteroposterior measurement of the head and body of the pancreas resulting in an objective assessment of pancreatic enlargement (as opposed to subjective assessment in other CT scoring systems, such as Schröder index, CT severity index [CTSI], and modified CT severity index [MCTSI]). By using a cut-off of 10 cm^2 the authors found a sensitivity of 71 % and specificity of 77 % for clinically severe attacks [23]. In several other studies these results were confirmed [24, 25]. The underlying theory behind the PSI is that with increasing degree of pancreatic insult, the resultant swelling of the pancreas releases more toxic cytokines and pancreatic enzymes in the systemic circulation and peripancreatic area, respectively. Advantage of the PSI is the evaluation of only one parameter. Like other CT scoring systems, PSI measurement does not require the administration of intravenous contrast medium. Main limitation is that normal values of pancreatic size may vary considerably according to age and previous attacks.

Table 6.2 CT severity index

Characteristics	Points
Pancreatic inflammation	
Normal pancreas	0
Focal or diffuse enlargement of the pancreas	1
Peripancreatic inflammation	2
Single acute fluid collection	3
Two or more acute fluid collections	4
Pancreatic parenchymal necrosis	
None	0
Less than 30 %	2
Between 30 and 50 %	4
More than 50 %	6

CT Severity Index

The advent of incremental dynamic bolus CT technique and faster scanning equipment in the early 1990s resulted in considerable improvement of imaging assessment of acute pancreatitis; the use of intravenous contrast medium enabled to differentiate interstitial pancreatitis (with intact capillary network and homogeneous enhancement) from necrotizing pancreatitis (with portions of pancreas failing to enhance) [22]. In 1990, Balthazar made his CT grading system more sophisticated by incorporating the presence and extent of parenchymal nonenhancement (corresponding to parenchymal necrosis) by using intravenous iodinated contrast medium [22]. The resulting CT scoring system (CT severity index or CTSI) combines the Balthazar grade (0–4 points) with the extent of pancreatic necrosis (0–6 points) on a 10-point severity scale (Table 6.2). The calculated CTSI can then be subdivided in three categories (CTSI 0–3, 4–6, and 7–10; corresponding to predicted mild, moderate, and severe disease, respectively) that have subsequent increases in morbidity and mortality (Fig. 6.2). In the original study, patients with predicted mild disease (CTSI 0–3) had 8 % morbidity and 3 % mortality (of note, no mortality occurred in patients with CTSI 0–2), patients with predicted moderate severe pancreatitis had 35 % morbidity and 6 % mortality, and patients with predicted severe disease (CTSI 7–10) had

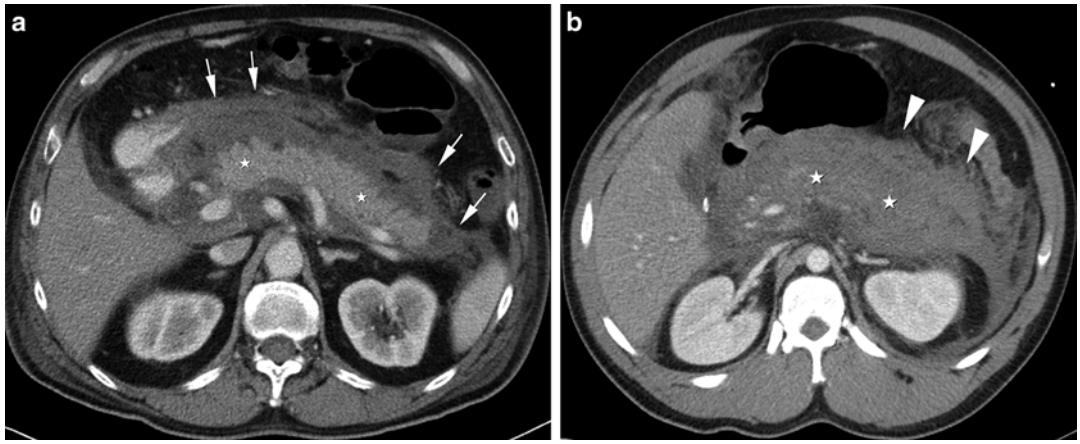

Fig. 6.2 (**a**) A 41-year-old man with acute pancreatitis (CTSI 4). Contrast-enhanced CT shows a normal enhancing pancreatic parenchyma (*white stars*) with more than two peripancreatic collections (*arrows*). (**b**) A 32-year-old man with acute necrotizing pancreatitis (CTSI 10). Contrast-enhanced CT shows extensive pancreatic nonenhancement (*white stars*), representing pancreatic necrosis. More than 50 % of the pancreatic volume is involved in the necrotic process. Peripancreatic collections (acute necrotic collections) are present (*arrowheads*)

92 % morbidity and 17 % mortality [22]. CTSI, of all radiologic scoring systems, is the most studied system, and many reports from different groups of investigators confirmed the utility of using CTSI in assessing patient outcomes [26–29]. However, some have found only a modest correlation between presence and extent of pancreatic necrosis and organ failure [30–32], between pancreatic necrosis and extrapancreatic parenchymal and vascular complications [33, 34], and between extent of parenchymal necrosis and clinical outcome (i.e., no significant differences in patient outcome are observed in patients with 30–50 % necrosis versus those with >50 % necrosis) [35]. Other limitations are the moderate interobserver agreement due to the specific categorization of the evaluation of pancreatic inflammation and necrosis and the need for intravenous contrast agent.

MOP Score

In 2003, King and co-authors tested a simple CT scoring system based on two CT features (mesenteric edema [MO] and peritoneal [P] fluid; resulting in the MOP score) in a cohort of patients [36]. MOP score correlated well with disease severity, especially when both features were present. This scoring system is appealing because it is simple and easy to evaluate even for non-radiologists, requiring no intravenous contrast medium. However, in the original study, patients were included of whom CT was performed up to 10 days after admission, limiting the predictive power of this scoring system.

Modified CT Severity Index

In 2004, Mortele and colleagues modified the existing CTSI accounting for the presumed shortcomings of this scoring system by incorporating extrapancreatic complications in the assessment and by simplification of the evaluation of peripancreatic collections and extent of parenchymal necrosis (Fig. 6.3) [26]. In the original study including 66 patients, the MCTSI, compared with CTSI, more closely correlated with patient outcome (length of hospital stay, need for intervention, and organ failure) with similar interobserver agreement [26]. In a larger cohort, these promising results could not be reproduced (no significant differences were observed between both CT scoring systems for the clinical parameters evaluated; intensive care stay, need for intervention, persistent organ failure, infected necrosis, severity of disease, and

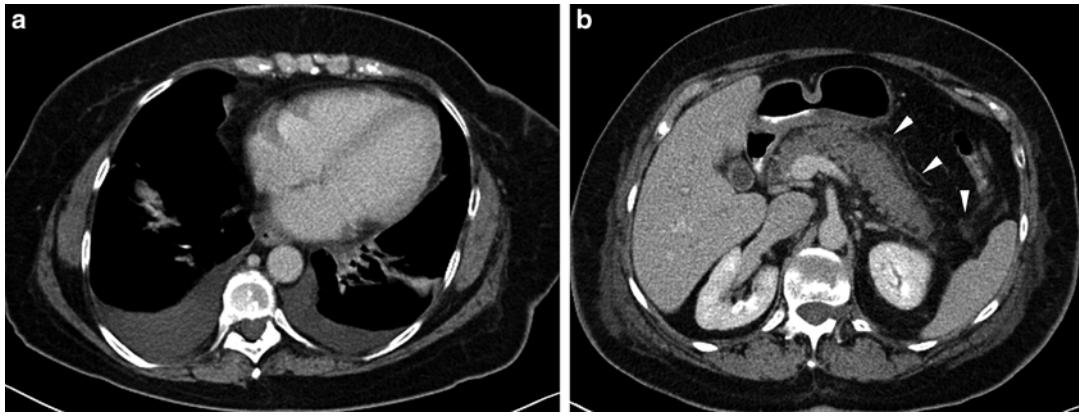

Fig. 6.3 A 65-year-old woman with acute interstitial pancreatitis (MCTSI 4). (**a**) Contrast-enhanced CT of the lung bases shows bilateral pleural effusion. (**b**) CT at the level of the pancreas shows a normal enhancing pancreatic parenchyma with little peripancreatic fat stranding (*arrowheads*). The CT severity index is 2 (predicted mild pancreatitis), while the modified CT severity index credits two extra points for pleural effusion (MCTSI 4, representing predicted moderate severe pancreatitis)

mortality) [37]. Possibly, because of the simplifications, the MCTSI may be easier to assess by less experienced readers.

Retroperitoneal Extension Grade

Traditionally, it was assumed that the retroperitoneum consisted of three compartments (anterior pararenal space, perirenal space, and posterior pararenal space) demarcated by three well-defined fascia (anterior renal fascia, posterior renal fascia, and lateroconal fascia). New anatomical insights are that each retroperitoneal fascia is composed of multiple layers (i.e., fused leaves of embryonic mesentery), creating potential spaces (the retroperitoneal interfascial planes) that may serve both as a reservoir for decompression of rapidly accumulating fluid collections (as in acute pancreatitis) and as a pathway for spread of an infiltrating neoplasm or inflammatory process [38–40]. In 2006, Ishikawa and collaborators used this new anatomic concept to design a CT grading system based on retroperitoneal extension of pancreatic fluid along the retroperitoneal interfascial planes on a 5-grade severity scale [21]. In their study, patients with Grade I–III (extension of pancreatic fluid from anterior pararenal space to the combined interfascial plane at the lower end of the perirenal space) had

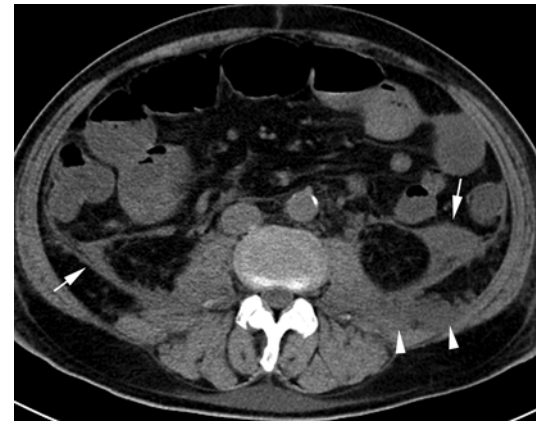

Fig. 6.4 A 49-year-old woman with acute pancreatitis (retroperitoneal extension grade V). Unenhanced CT shows extensive bilateral retroperitoneal inflammatory changes due to acute pancreatitis (*arrows*) with extension to the left posterior pararenal space (*arrowheads*), representing the highest grade of retroperitoneal extension (Grade V)

22 % morbidity and 0 % mortality, whereas patients with Grade IV–V (pancreatic fluid extending from the subfascial plane, located between the posterior pararenal space and the transverse fascia, into the posterior pararenal space) had 92 % morbidity and 39 % mortality (Fig. 6.4) [21]. This grading system can be assessed on unenhanced CT studies, but requires advanced radiologic interpretative skills and may not be easy to use for routine clinical practice.

EPIC Score

The latest CT scoring system is the ExtraPancreatic Inflammation on CT (EPIC score), developed in 2007, which measures exclusively extrapancreatic inflammatory changes hypothetically regarded as CT signs of systemic inflammation (presence of pleural effusion, ascites, and retroperitoneal and mesenteric inflammation on a 7-point severity scale) [41]. The EPIC score was validated in a small single-center study composed of 40 patients who received an abdominal CT within 24 h after admission and proved useful with an area under the receiver operating characteristics (AUC) curve for predicting severe disease and mortality of 0.91 (95 % confidence interval, 0.83–0.99) and 0.85 (95 % confidence interval, 0.71–0.99), respectively [41]. However, this study was biased towards inclusion of a high incidence of severe disease and high need for surgical intervention.

Value of Radiologic Scoring Systems for Severity Prediction

Since over four decades, an exhaustive search for the ideal scoring system has been undertaken to identify patients at risk for severe acute pancreatitis early in the disease process to guide patient triage and management, and to improve patient outcome. An ideal prognostic scoring system should be simple and easy to use in clinical practice, widely available, objective, reproducible, sufficiently accurate in differentiating mild from severe disease and applicable early in the disease process, preferably on day of admission, such that patients at risk for severe acute pancreatitis are more closely monitored or empirically treated (i.e., with tailored fluid resuscitation). Many clinical, biochemical, and imaging-based scoring systems have been developed but none fulfills all of the above-mentioned criteria. Several shortcomings are shared by all staging systems. The available staging systems were devised to identify groups of patients at risk of developing organ failure or clinically severe disease rather than identifying individual patients. Furthermore, about one fifth of patients with potentially fatal severe pancreatitis are inappropriately identified using the traditional scoring systems [42]. Indeed, scoring systems perform best at the extremes of the prediction range, while the discriminatory power is moderate at best in the middle prediction range (i.e., the range where the clinician needs most assistance). Also, the variable timing of patient presentation to the hospital affects the clinical, laboratory, and imaging parameters explaining the variability in scores obtained. Finally, scoring systems (radiologic and biochemical systems alike) do not correlate with the risk of particular extrapancreatic complications (e.g., abdominal compartment syndrome (ACS), bowel ischemia, or perforation or arterial pseudoaneurysm) and, therefore, fail to provide detailed information that impacts patient management on an individual basis.

Imaging-based systems have their specific shortcomings compared with clinical and biochemical scoring systems. It is commonly known that severe acute pancreatitis may run a highly variable clinical course; it may manifest early with SIRS, organ failure, and death in the first week or late with local complications demanding intervention [1, 2]. Biochemical scoring systems, compared with imaging-based systems, better correlate with early systemic effects of pancreatic injury (i.e., organ failure; the main determinant for severity of disease in the revised Atlanta Classification) and, thus, are better in predicting clinical severity early in the disease course. Conversely, radiologic scoring systems are best in predicting late local complications (infected necrosis, need for intervention) [37, 42]. Second, radiologic scoring systems are based on visual estimation and, therefore, are subject to variable interpretation, whereas most biochemical scoring systems are derived from objective parameters. Third, radiologic scoring systems do not account for patients preexisting clinical status; such as age, comorbid disease, and obesity which are well-known prognostic factors for morbidity and mortality. Institution of preventative measures requires early identification of patients with severe disease before the development of a complication. However, the timing of the CT scan in

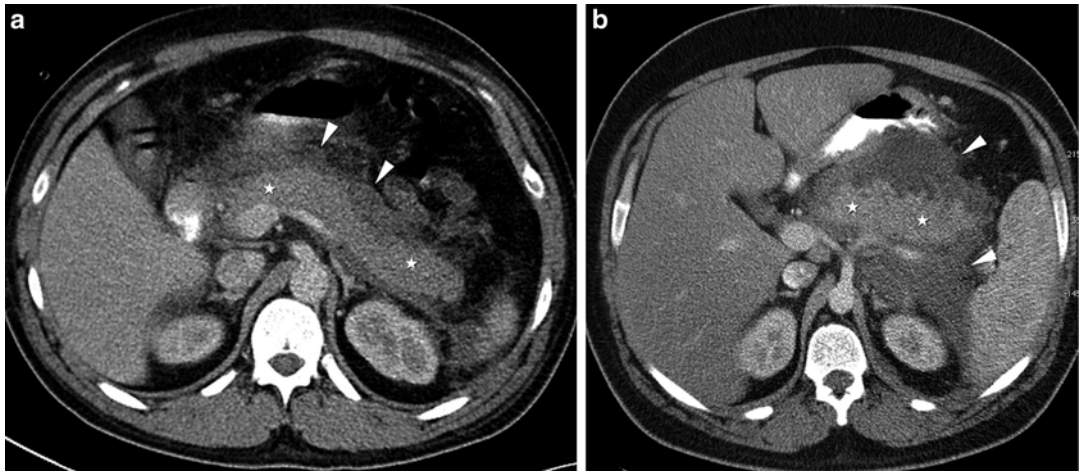

Fig. 6.5 Two different patients (**a**, **b**) with similar grades of severity but marked difference in magnitude of peripancreatic collections. (**a**) A 44-year-old man with limited peripancreatic collections (*arrowheads*). (**b**) A 37-year-old man with extensive peripancreatic collections (*arrowheads*). Both patients are appreciated with similar grades according to all radiologic scoring systems. *White stars* denote a normal enhancing pancreas in both patients

reports on the predictive power of radiologic scoring systems has varied from at admission to 10 days after admission [14]. Conversely, clinicobiochemical scoring systems are mostly tested early in the clinical course (within the first 24–48 h), i.e., in a timeframe where severity stratification is most useful. Finally, studies on imaging-based systems are biased toward more severe disease because patients with mild or minimal symptoms do not need cross-sectional imaging for clinical management while biochemical scoring systems are tested and applicable in all patients presenting with acute pancreatitis.

Reports on the discriminatory power of radiologic scoring systems all show a positive correlation between the scoring system studied and patient outcome. However, because of the profound lack of homogeneity in study design, differences in methodology used and the wide diversity in definitions for severe acute pancreatitis and clinical end points (e.g., variation in defining organ failure and systemic complications) comparison of these studies are rendered difficult [14]. A recent study comparing seven of the eight above-mentioned CT prognostic scoring systems on the day of admission accounted for these shortcomings by using definitions put forth by the working group on revising the Atlanta Classification [43]. This study did not detect significant differences between the studied CT scoring systems in predicting clinical severity or mortality (AUC ranging between 0.72–0.88 and 0.70–0.81, respectively). Moreover, CT scoring systems did not perform better than commonly used clinical scoring systems [43].

The use of early imaging for prognostication is limited by several factors: (1) In most imaging-based systems, the rating of peripancreatic inflammation and fluid is determined based on their presence rather than extent; the latter may vary considerably among patients appreciated with similar grades (Fig. 6.5). (2) Morphologic signs of severe disease are a time-dependent phenomenon. CT only takes a snapshot of a moment in time, while acute pancreatitis is a continuously evolving disease process. Consequently, patients may progress from mild to severe grades of CT severity. (3) Parenchymal necrosis may not be evident until after 24–48 h and, thus, may be underrated on early imaging (Fig. 6.6). (4) On the other hand, the presence and extent of parenchymal necrosis do not invariably correlate with organ failure and clinical severity, and (5) the evolution of CT findings does not always parallel the clinical course; CT may show little

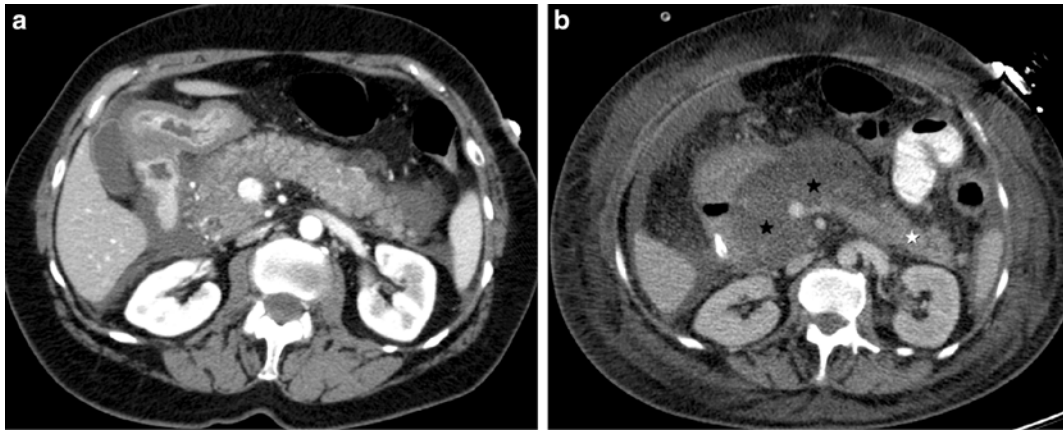

Fig. 6.6 A 47-year-old woman with false negative parenchymal necrosis on early CT. (**a**) Contrast-enhanced CT on day 1 shows a heterogeneous enhancing pancreatic parenchyma, but no apparent areas of nonenhancement. (**b**) Repeat CT was performed on day 4 showing clear nonenhancement of pancreatic head, neck and part of body (*black stars*), while the tail shows preserved enhancement (*white star*)

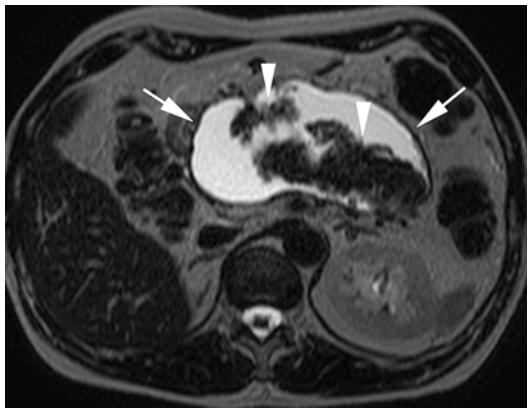

Fig. 6.7 A 50-year-old man with extensive necrosis and mild clinical symptoms. MRI was performed for continuing mild discomfort 6 weeks after an episode of acute pancreatitis. T2-weighted sequence shows a fully encapsulated collection (walled-off necrosis) in the pancreatic area (*arrows*) with dark material (*arrowheads*), representing necrotic pancreatic and peripancreatic tissue

morphologic signs of severe disease early in disease process (i.e., on day of admission) in patients who already have organ failure as sign of a severe attack. Conversely, imaging studies late in the disease process may show major morphologic changes (like extensive parenchymal necrosis and retroperitoneal collections) in patients who have only mild clinical discomfort (Fig. 6.7).

In summary, current evidence suggests that there is no role for radiologic scoring systems for prediction purposes. Additionally, given the high costs associated with acute pancreatitis [44], the radiation burden of (serial) CT [45, 46], and the lack of correlation between imaging utilization and patient outcome [46, 47], initial evaluation of a patient presenting with acute pancreatitis is best performed based on clinical assessment and biochemical scoring systems that better correlate with organ failure and systemic complications dominating the clinical picture in the first weeks after the initial attack. Performing a CT on admission (or within the first days after admission) is unlikely to affect patient management, unless a severe complication (like hemorrhage or bowel ischemia) is suspected or in case of a diagnostic dilemma. The decision about when to perform MDCT depends, therefore, on the overall clinical presentation. Unquestionably, the impact of CT is greater in the later phase of the disease process in patients who have predicted severe acute pancreatitis by clinical assessment or who fail to improve clinically despite conservative therapy when local complications (most commonly infection of parenchymal and peripancreatic tissues) predominantly dictate clinical management.

Prognostic Value of Specific Computed Tomography Findings

Morphologic findings of acute pancreatitis include necrosis of pancreatic parenchyma, peripancreatic inflammation with or without fluid and extrapancreatic retroperitoneal or subperitoneal fatty tissue necrosis, subsequent infection of pancreatic or extrapancreatic necrosis, vascular compromise of adjacent veins and arteries, extrapancreatic parenchyma complications, biliary complications, and gastrointestinal complications. Some of these findings or complications are detected on cross-sectional imaging only but nonetheless may harbor significant prognostic importance (Table 6.3). Given the aforementioned limitations of radiologic scoring systems, this section will review the key findings on cross-sectional imaging associated with prognostic significance, which may directly influence patient management.

Table 6.3 CT findings of complications in acute pancreatitis with clinical implications

CT findings	Clinical implications
Necrosis of pancreatic parenchyma: – Extended necrosis (>30 %) – Central gland necrosis	Increased risk for developing organ failure, infected necrosis, and higher need for intervention
Infected necrosis (gas bubbles in necrotic collections)	Institution of (empiric) antibiotics and/or intervention
Peripancreatic collections exerting mass effect on surrounding structures: – Biliary dilation – Obstructive hydronephrosis	If symptomatic, stent placement
Deep vein thrombosis of iliofemoral veins or pulmonary emboli/ infarction	Initiation of anticoagulant therapy
Hemorrhage/arterial pseudoaneurysm	Angiographic coiling/ embolization or surgical clipping
Cholecystitis or gallbladder perforation	Percutaneous drainage or surgical cholecystectomy
Bowel ischemia or perforation	Surgical resection
CT signs of abdominal compartment syndrome (ACS)	Percutaneous drainage of ascites (if present) or surgical decompression
Pulmonary complications: – Pleural empyema – Pulmonary infiltrate(s) – Pneumothorax	Initiation of antibiotics (empyema, pneumonia) or drain placement (empyema, pneumothorax)

Pancreatic Findings

Pancreatic Necrosis

Necrosis of pancreatic tissue signifies the most severe morphologic form of acute pancreatitis and represents the basis for most of the local complications [48]. Necrosis of pancreatic parenchyma results from severe disturbances in the pancreatic microcirculation and occurs early in the disease process [5, 22]. Generally, it is fully established by 72–96 h and tends to remain stable across time [5, 22, 49]. CECT is considered the noninvasive reference standard for diagnosing pancreatic necrosis. CECT is highly accurate in assessing parenchymal necrosis when performed after 72–96 h after symptom onset and when more than 30 % of pancreatic parenchyma is involved [5, 22]. Early CECT within 24–48 h of disease may miss the presence and extent of necrosis in about 30–40 % of cases [43]. Also, accuracy of pancreatic necrosis detection drops to about 50 % when small areas of pancreatic tissues are affected [5, 50]. Mortality rates in cases of pancreatic necrosis are about 20 %, as opposed to less than 5 % in patients without pancreatic necrosis [3]. Extended pancreatic necrosis (i.e., more than 30 %) is associated with SIRS, organ failure, and development of late local complications such as infection of necrosis [35]. Furthermore, patients with significant necrosis are prone to develop other infections (urinary, respiratory, and systemic infections) during both the early and late phases [51]. These infections complicate the clinical course of acute pancreatitis and prolong hospitalization. Some studies have shown that transparenchymal necrosis concerning the central area (pancreatic neck and/or body) or central gland necrosis also heralds prognostic significance because of the possible

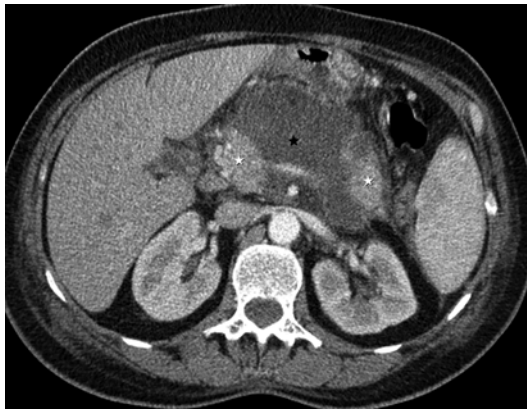

Fig. 6.8 A 42-year-old woman with central gland necrosis. Contrast-enhanced CT depicts necrosis of the neck and body of the pancreas (*black star*) among the viable pancreatic head and tail (*white stars*). This patient is at risk for having a pancreatic duct disruption with increased need for intervention

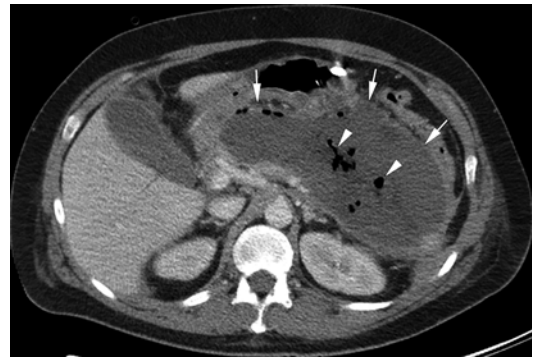

Fig. 6.9 A 51-year-old woman with infected necrosis. Contrast-enhanced CT performed on day 26 after symptom onset shows a nearly completely encapsulated necrotic collection (*arrows*) with impacted gas bubbles (*arrowheads*), virtually diagnostic for infection of necrosis

involvement of the pancreatic duct, resulting in the pancreatic duct disruption syndrome (Fig. 6.8) [52, 53]. In central gland necrosis, a viable pancreatic tail causes the ongoing secretion and extravasation of pancreatic fluid in the necrotic collection and peripancreatic area associated with increased need for percutaneous, endoscopic, or surgical intervention [53].

Infection of Necrosis

Necrosis of pancreatic parenchyma and peripancreatic fatty tissue serves as a nidus for bacterial superinfection, resulting in the most severe local complication in acute pancreatitis. Mortality rate in sterile necrosis is around 5–10 % and increases considerably when the necrosis becomes infected [3]. Indeed, infection of necrosis is a major prognostic risk factor in severe acute pancreatitis and sepsis-related multiple organ failure is the main life-threatening complication with a mortality rate up to 20–50 % [3]. On CECT, the presence of gas bubbles in an area of pancreatic and/or peripancreatic fatty tissue necrosis is virtually pathognomonic for the diagnosis of infected necrosis, especially in patients with clinical signs of infection (spiking fever, leukocytosis, elevated C-reactive protein, and/or (new onset) organ failure) (Fig. 6.9) [54]. In rare instances, gas bubbles can be seen in sterile collections associated with an enteric fistula. However, these patients often lack clinical signs of infection. Unfortunately, gas bubbles on CECT as sign of infected necrosis is only present in about 40 % of cases [54].

Peripancreatic Collections

In the more severe forms of acute pancreatitis peripancreatic (fluid) collections arise most commonly in the lesser sac, the retroperitoneum, and subperitoneal spaces of the mesenteries. According to the revised Atlanta Classification 2012, these are termed an acute peripancreatic fluid collection or pseudocyst in *interstitial* pancreatitis (collections contain fluid only) or acute necrotic collection or walled-off necrosis in *necrotizing* pancreatitis (collections contain a mixture of necrotic material and variable amounts of fluid) [48]. The natural history of these collections is highly unpredictable, ranging from spontaneous resolution in over half of cases, to persisting and increasing in size and giving rise to complications like secondary infection (in necrotizing pancreatitis, this is termed infected necrosis), mass effect on neighboring structures (e.g., biliary system resulting in biliary dilation, urogenital system resulting in hydronephrosis, venous system resulting in left-sided portal hypertension, splenomegaly and extensive collateral venous network when the portomesenteric

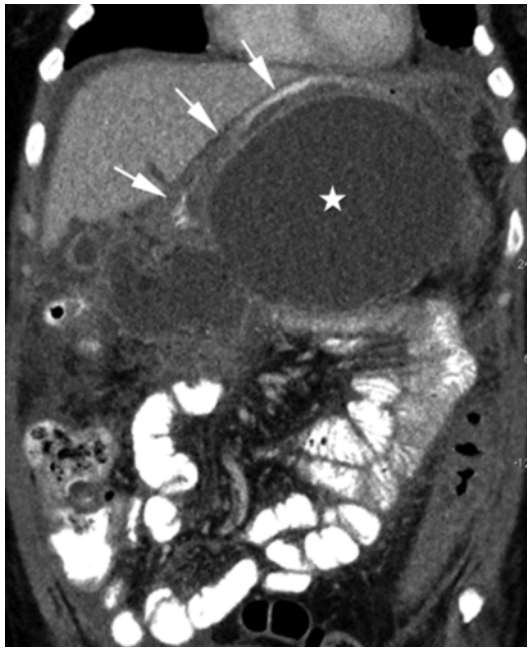

Fig. 6.10 A 49-year-old woman with large collection compressing the stomach. Coronal reformatted contrast-enhanced CT shows a large encapsulated necrotic collection (*white star*) exerting mass effect on the stomach (*arrows*), which is displaced medially and cranially

and splenic veins are involved, and gastric outlet obstruction), or rupture into the peritoneal cavity with development of acute peritonitis (Fig. 6.10) [5, 55, 56].

Extrapancreatic Findings

Vascular Complications

Vascular complications are common in patients with moderate severe and severe acute pancreatitis and include portomesenteric venous thrombosis, arterial pseudoaneurysm, and hemorrhage due to vessel erosion of arteries, veins, or small capillaries either through pancreatic enzymes or, iatrogenically, by surgical, endoscopic, or radiological drains.

Recent studies on splanchnic vein thrombosis report an incidence of about 50 % in patients with parenchymal necrosis, most frequently in the splenic vein, followed by portal and superior mesenteric vein (Fig. 6.11) [57, 58]. Most are

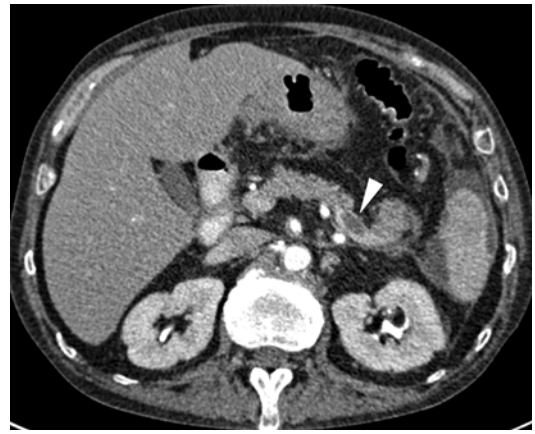

Fig. 6.11 A 56-year-old man with thrombus in the splenic vein. Contrast-enhanced CT depicts an intraluminal filling defect in the splenic vein (*arrowhead*), compatible with a thrombus. Usually, this is not an indication for initiation of anticoagulant therapy

asymptomatic, and spontaneous recanalization occurs in about one third of patients irrespective of the use of systemic anticoagulation. Reported complications include gastrointestinal bleeding and splenomegaly but are rare [59]. Current practice suggests that there is no need for initiation of anticoagulation unless there is propagation of thrombosis on serial CT scans [58]. In the literature, there is lack of data about the true incidence of deep vein thrombosis or pulmonary embolism on abdominal CT scans in acute pancreatitis. In the author's experience, this is rare and primarily seen in patients with severe necrotizing acute pancreatitis and prolonged hospitalization. However, opposed to portomesenteric vein thrombosis, the observation of intraluminal clots in the iliac or femoral vein necessitates the initiation of systemic anticoagulation to prevent a fatal outcome (Fig. 6.12).

Another vascular complication is the occurrence of an arterial pseudoaneurysm, which is often a late complication in acute pancreatitis, although rare (estimated incidence of less than 2 %) (Fig. 6.13) [60]. In order of frequency, the following arteries are involved: splenic artery, gastroduodenal artery, pancreaticoduodenal artery, gastric artery, hepatic artery, and others (superior mesenteric artery, jejunal or ileocolic artery) [60]. Generally, there is an indication for angiographic

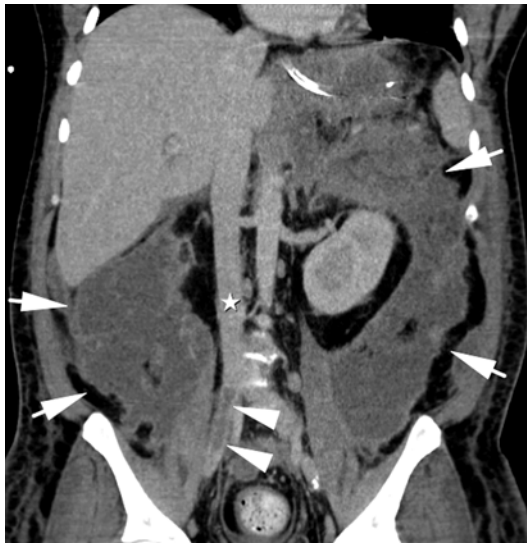

Fig. 6.12 A 43-year-old woman with thrombus in the right iliac vein during the course of acute necrotizing pancreatitis. Coronal reformatted contrast-enhanced CT depicts a large filling defect in the right iliac vein (*arrowheads*), diagnostic for deep vein thrombosis in a patient with necrotizing pancreatitis and extensive retroperitoneal collections (*arrows*). *White star* denotes the inferior vena cava. To prevent pulmonary embolism anticoagulant therapy is mandatory

embolization or coiling. Uncontrollable bleeding from a ruptured arterial pseudoaneurysm requires emergency surgical intervention.

Hemorrhage from erosion of a vascular wall may be a life-threatening complication if an artery is involved or may be an incidental finding in case of damage of small capillaries or veins. The vast majority of vascular complications are readily detectable on routine abdominal CT scans but some (e.g., small arterial pseudoaneurysms or insignificant hemorrhage) require a multiphasic scan protocol (including an unenhanced and arterial phase) for accurate detection [12].

Extrapancreatic Parenchymal Complications

Acute pancreatitis is capable of inflicting damage to adjacent parenchymal organs, like the spleen, liver, and kidneys, due to the central location of the pancreas in the upper abdomen and destructive nature of extravasated pancreatic enzymes. Splenic involvement in acute pancreatitis include hematoma, infarction, and perisplenic inflammatory fluid collections (sterile or infected) attributable to pancreatic secretions that dissect into the splenic hilum as the splenic capsule is continuous with the peritoneum covering the anterior surface of the pancreas (Fig. 6.14) [61, 62]. Similar complications may occur in the liver [63]. Renal involvement in acute pancreatitis includes perirenal fluid collections and parenchymal abnormalities (e.g., renal infarction) [33, 64]. Renal complications are most often an incidental finding and seem unrelated to the severity of pancreatitis. One renal complication with clinical impact is obstructive hydronephrosis as a result

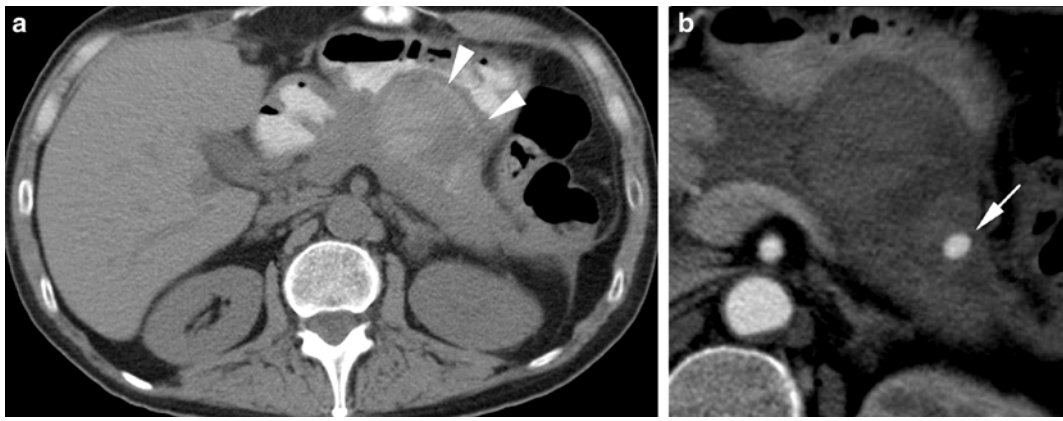

Fig. 6.13 A 40-year-old man with an arterial pseudoaneurysm after an episode of necrotizing pancreatitis. (**a**) Unenhanced CT shows a collection (*arrowheads*) with high density, suggestive of hemorrhage. (**b**) Contrast-enhanced CT in the arterial phase depicts a small arterial pseudoaneurysm (*arrow*) originating from the prepancreatic arcade. Pseudoaneurysm was successfully treated by embolization with platinum coils (not shown)

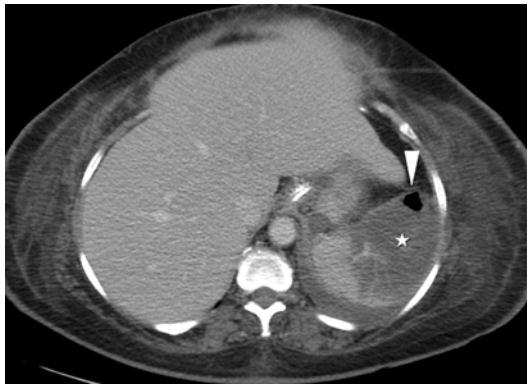

Fig. 6.14 A 61-year-old woman with splenic infarction and signs of infection (abscess) complicating acute pancreatitis. Contrast-enhanced CT shows an area of splenic infarction (*white star*) with a gas bubble (*arrowhead*) as a sign of a splenic abscess

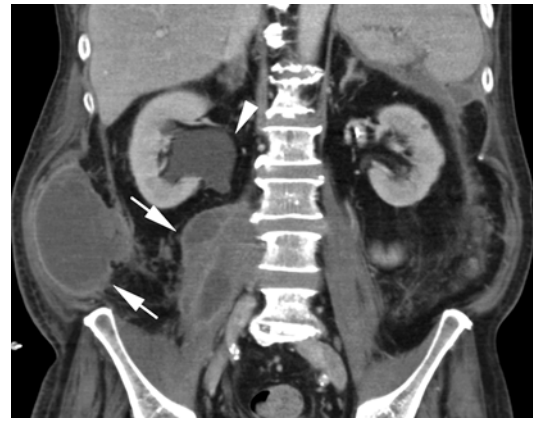

Fig. 6.15 A 72-year-old man with obstructive hydronephrosis of the right kidney due to extensive retroperitoneal collections. Coronal reformatted contrast-enhanced CT depicts a newly developed dilatation of the pyelocaliceal system of the right kidney (*arrowhead*), compatible with hydronephrosis due to obstruction by large retroperitoneal necrotic collections (*arrows*)

of eccentric compression of the proximal ureter by retroperitoneal pancreatic collections (Fig. 6.15) [65]. Most of the aforementioned complications lack any specific symptomatology, but are easily identifiable on CECT underlining the importance of CT for their diagnosis.

Biliary Complications

Concomitant acute cholecystitis and acute pancreatitis is a rare event [66] but development of acute cholecystitis during the course of acute biliary pancreatitis is not uncommon and is one of the reasons to perform a cholecystectomy shortly after an attack of acute biliary pancreatitis [67, 68]. Performing a cholecystectomy may be a surgical challenge, particularly in the presence of necrotic collections [69]. In these cases, percutaneous cholecystostomy may be an alternative treatment strategy. Assessment of gallbladder pathology can be difficult in the course of acute pancreatitis and findings on CECT may be helpful in the diagnosis and, thus, may directly influence patient management.

Direct extension of the inflammatory process to the duodenal wall and ampulla of Vater may result in transient inflammatory narrowing of the intrapancreatic segment of the common bile duct causing jaundice. Persistence of or development of jaundice a few weeks after the acute onset of pancreatitis, however, may indicate a more

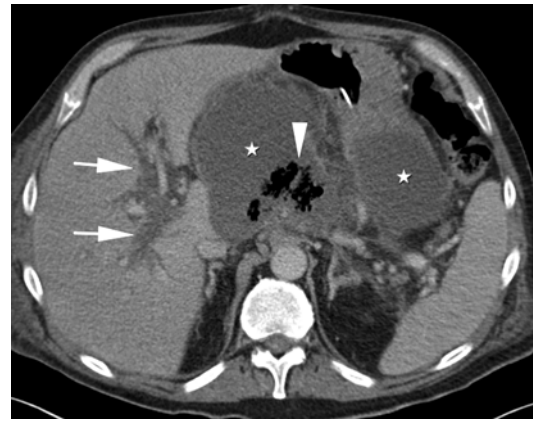

Fig. 6.16 A 76-year-old woman with infected necrotizing pancreatitis and biliary dilatation. Contrast-enhanced CT shows large necrotic collections (*white stars*) and impacted gas bubbles (*arrowhead*), indicative for infected necrosis. Also, dilatation of the intrahepatic bile ducts (*arrows*) is noted due to extrinsic compression of the common bile duct

significant complication such as a chronic obstruction due to a ductal stricture or compression of the common bile duct by peripancreatic collections (i.e., indication for endoscopic stent placement) [70]. CECT easily depicts biliary dilatation up to the level of obstruction (Fig. 6.16). Another severe, but extremely rare complication

is perforation of the gallbladder leading to biliary peritonitis [66]. CECT may diagnose this complication by depicting an interruption of the gallbladder wall with adjacent inflammatory fluid. Finally, erosion of the common bile duct wall by the inflammatory process may lead to a pancreaticobiliary fistula [71]. On CECT, the simultaneous presence of gas bubbles in the biliary tract and intrapancreatic collection is highly suggestive of a pancreatic choledochal fistula. Adequate drainage of the pancreatic/peripancreatic collection and bile duct is generally effective.

Gastrointestinal Complications

Involvement of gastrointestinal structures in acute pancreatitis is multifactorial and occurs primarily in necrotizing pancreatitis. Extravasated pancreatic enzymes may directly damage the gastrointestinal tract or may produce vascular thrombosis resulting in ischemic splanchnic injury. Also, early in the course of severe acute pancreatitis, hypovolemic shock with a splanchnic low flow state may occur because of inadequate fluid therapy and third-space loss responsible for further vascular compromise [72–74]. Rare but severe complications are perforation of the stomach (mainly the posterior wall of the stomach) and erosion of the medial wall of the duodenum in patients with pancreatic necrosis [75, 76]. A small but significant number of patients with necrotizing pancreatitis sustain ongoing abdominal pain, nausea, and inability to eat owing to centrally located pancreatic collections that displace and compress the stomach anteriorly giving rise to gastric outlet obstruction [77]. In these patients, endoscopic drainage may be indicated. The most severe small bowel and colonic complication in acute pancreatitis is ischemia and subsequent necrosis and perforation because of thrombosis of feeding or draining vessels in the mesentery (Fig. 6.17) [72, 73]. The usual sites of involvement of the colon are the transverse colon and the splenic flexure, because of their proximity to the pancreas, and the poor collateral flow [74]. These patients may present with prolonged ileus, gastrointestinal bleeding, and peritonitis along with features of necrotizing pancreatitis. Findings on CECT that are suggestive

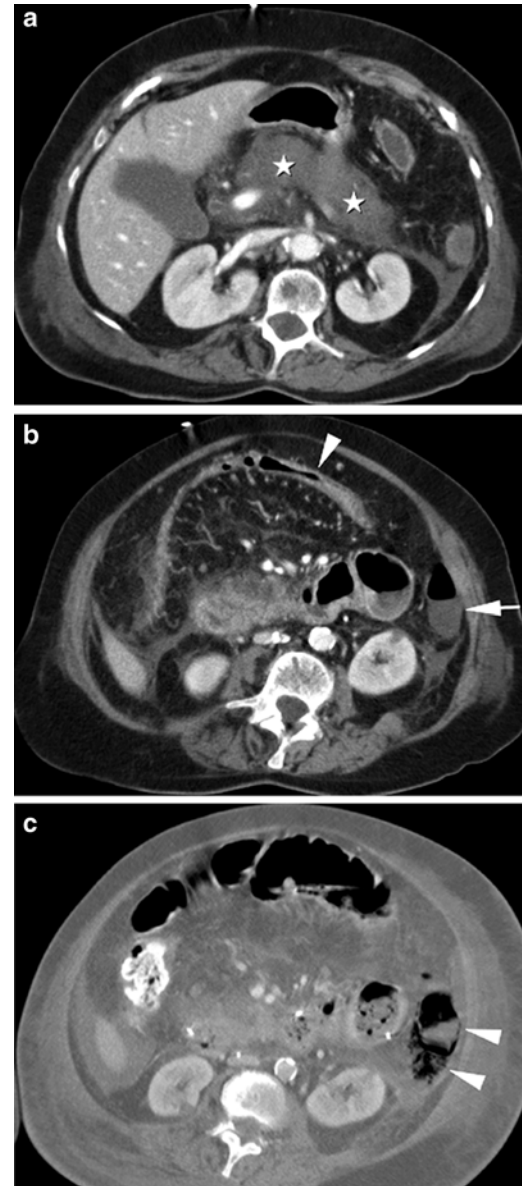

Fig. 6.17 A 58-year-old woman with bowel ischemia of descending colon complicating acute necrotizing pancreatitis. (**a**) Contrast-enhanced CT performed on day 2 after symptom onset shows extensive necrosis of pancreatic body and tail (*white stars*). (**b**) Same CT at a lower level shows normal enhancement of the bowel wall of the transverse colon (*arrowhead*), while the descending colon shows absent bowel wall enhancement indicative for ischemia, which was overlooked by the radiologist. (**c**) Repeat contrast-enhanced CT 24 h later for continuing severe sepsis depicts the development of gas in the bowel wall of the descending colon (pneumatosis intestinalis) and adjacent mesocolon (*arrowheads*) suggestive for bowel necrosis. Emergency laparotomy was performed which confirmed the CT findings

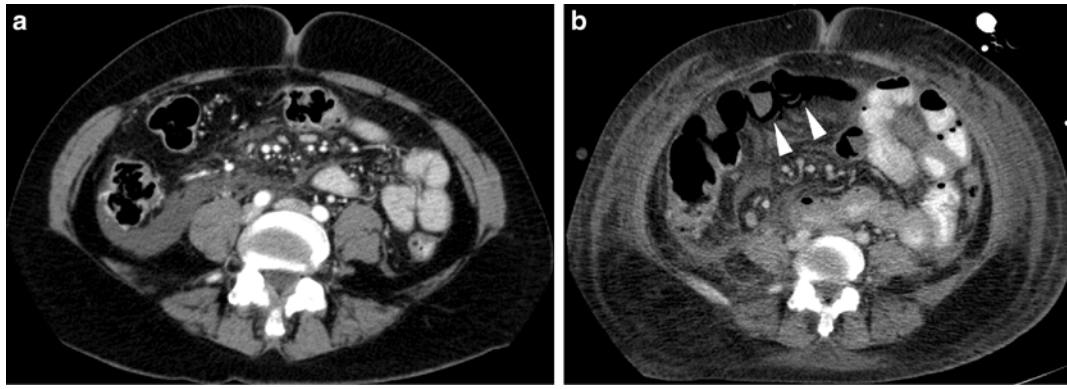

Fig. 6.18 A 47-year-old woman with development of ACS occurring early in the course of acute necrotizing pancreatitis (same patient as Fig. 6.6). (**a**) Contrast-enhanced CT (day 1) at the level of the umbilicus shows mesenterial and retroperitoneal inflammatory changes due to pancreatitis. Note, the normal configuration of the abdominal contour. (**b**) Repeat CT on day 4 shows a rounded appearance of the abdomen (round belly sign). Also note, pneumatosis intestinalis and absent bowel wall enhancement of ileal loops (*arrowheads*), indicative for small bowel ischemia. Patient underwent emergency laparotomy

for bowel necrosis are the presence of pneumatosis intestinalis, gas in the portomesenteric veins, diminished or absent bowel wall enhancement, clots or occlusion of feeding arteries, and free intraperitoneal gas (pneumoperitoneum; virtually diagnostic for a perforated hollow viscus). Identification of these CT signs is critical because intestinal ischemia has a very high mortality if not treated expediently. Other colonic complications with less clinical impact are ileus and fistula formation.

Abdominal Compartment Syndrome

ACS is caused by pathological elevation of intra-abdominal pressure in response to various diseases (including severe acute pancreatitis) leading to multiple organ dysfunction [78]. ACS is increasingly recognized in acute pancreatitis and since the condition is associated with high mortality, early diagnosis is imperative [79]. Usually, the diagnosis of ACS is straightforward by clinical assessment and intravesical pressure measurements; however, diagnosis may be delayed by interfering symptoms from the underlying illness. Abdominal CT scan may reveal subtle findings that include narrowing or collapse of the inferior vena cava, direct renal compression or displacement, bowel wall thickening with increased enhancement, bilateral inguinal herniation, elevated hemidiaphragm, and a rounded appearance of the abdomen (so-called "round-belly sign") [80, 81]. The "round-belly sign" is defined as abdominal distension with an increased ratio of anteroposterior-to-transverse abdominal diameter (ratio > 0.80). Especially, an increasing girth observed on serial CT scans performed at short intervals is worrisome (Fig. 6.18) [81]. Individually, these CT findings are neither specific nor sensitive, but when present in combination, radiologists should raise the possibility of this life-threatening complication and, in the proper clinical setting, should communicate the presence and significance of these CT findings to the referring clinician.

Miscellaneous Complications

Routine abdominal CT for acute pancreatitis can reveal some complications that may not always be clinically apparent. Among these are abdominal wall extension of infected collections (amenable for percutaneous drainage) and pulmonary complications such as pneumothorax, focal consolidations indicative for pulmonary infiltrates, pleural empyema, features of the adult respiratory distress syndrome, and pulmonary embolus or infarction (Fig. 6.19) [82].

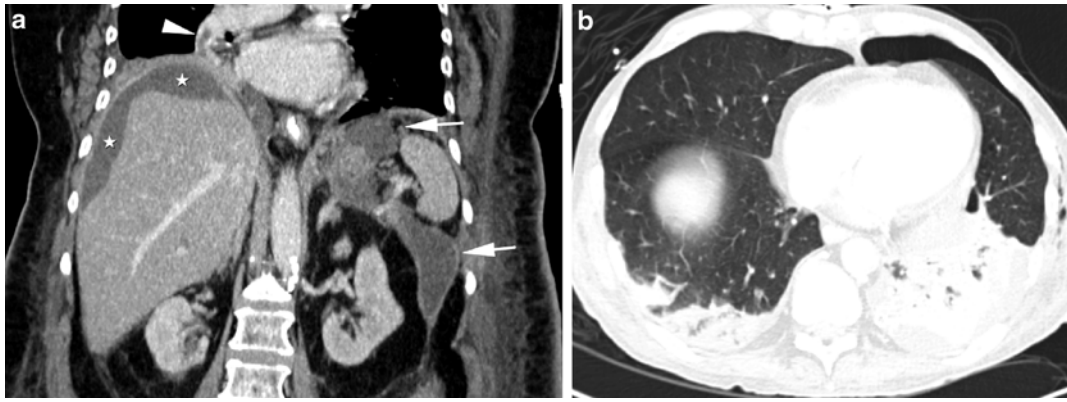

Fig. 6.19 Two different patients (**a**, **b**) with pulmonary complications during an episode of acute pancreatitis. (**a**) Coronal reformatted contrast-enhanced CT in a 69-year-old woman shows signs of acute necrotizing pancreatitis with necrotic collections in the left retroperitoneum (*arrows*) and perihepatic fluid (*white stars*). As incidental finding, a thrombus was noted in the right pulmonary artery (*arrowhead*). (**b**) CT at the lung bases in an 80-year-old man with acute pancreatitis, who experienced a sudden onset of dyspnea and fever, demonstrates a left-sided pneumothorax and bilateral consolidations in the lower lobes, indicative for pneumonia

Conclusion

Acute pancreatitis is a common but potentially devastating disease associated with significant morbidity, mortality, and public health impact in severe cases. Imaging-based predictive systems are useful for identifying groups of patients at risk for local complications or having severe disease rather than providing specific information changing clinical management on an individual basis. However, there are several individual CT features that may impact patient management significantly. Among these are the presence of significant necrosis (more than 30 %), especially in case of central gland necrosis (associated with increased need for intervention), imaging signs of infected necrosis (requiring empirical antibiotics or some kind of radiologic, endoscopic, or surgical intervention), massive hemorrhage or detection of an arterial pseudoaneurysm (indication for angiographic coiling or surgery), deep vein thrombosis (indication for anticoagulation), cholecystitis (amenable for percutaneous drainage), bowel ischemia or perforation (indication for surgery), and features of the ACS (requiring percutaneous drainage of ascites or surgery). The conveyance of these specific CT findings to clinicians caring for these challenging patients will have more clinical impact on patient management than providing any radiologic score.

References

1. Frossard JL, Steer ML, Pastor CM. Acute pancreatitis. Lancet. 2008;371(9607):143–52.
2. Forsmark CE, Baillie J. AGA Institute technical review on acute pancreatitis. Gastroenterology. 2007; 132:2022–44.
3. Banks PA, Freeman ML, Practice Parameters Committee of the American College of Gastroenterology. Practice guidelines in acute pancreatitis. Am J Gastroenterol. 2006;101:2379–400.
4. Papachristou GI, Whitcomb DC. Predictors of severity and necrosis in acute pancreatitis. Gastroenterol Clin North Am. 2004;33:871–90.
5. Balthazar EJ. Acute pancreatitis: assessment of severity with clinical and CT evaluation. Radiology. 2002; 223:603–13.
6. Bollen TL. Imaging of acute pancreatitis: update of the revised Atlanta classification. Radiol Clin North Am. 2012;50(3):429–45.
7. Thoeni RF. The revised Atlanta classification of acute pancreatitis: its importance for the radiologist and its effect on treatment. Radiology. 2012;262(3): 751–64.
8. Bollen TL, van Santvoort HC, Besselink MG, van Es WH, Gooszen HG, van Leeuwen MS. Update on acute pancreatitis: ultrasound, computed tomography, and magnetic resonance imaging features. Semin Ultrasound CT MR. 2007;28(5):371–83.

9. Arvanitakis M, Delhaye M, De Maertelaere V, Bali M, Winant C, Coppens E, et al. Computed tomography and magnetic resonance imaging in the assessment of acute pancreatitis. Gastroenterology. 2004;126: 715–23.
10. Morgan DE, Baron TH, Smith JK, Robbin ML, Kenney PJ. Pancreatic fluid collections prior to intervention: evaluation with MR imaging compared with CT and US. Radiology. 1997;203:773–8.
11. O'Connor OJ, McWilliams S, Maher MM. Imaging of acute pancreatitis. AJR Am J Roentgenol. 2011; 197(2):W221–5.
12. Working Group IAP/APA Acute Pancreatitis Guidelines. IAP/APA evidence-based guidelines for the management of acute pancreatitis. Pancreatology. 2013;13(4 Suppl 2):e1–15.
13. Kwon Y, Park HS, Kim YJ, Jung SI, Jeon HJ. Multidetector row computed tomography of acute pancreatitis: utility of single portal phase CT scan in short-term follow up. Eur J Radiol. 2012;81(8): 1728–34.
14. Delrue LJ, De Waele JJ, Duyck PO. Acute pancreatitis: radiologic scores in predicting severity and outcome. Abdom Imaging. 2010;35:349–61.
15. Schröder T, Kivisaari L, Somer K, Standertskjöld-Nordenstam CG, Kivilaakso E, Lempinen M. Significance of extrapancreatic findings in computed tomography (CT) of acute pancreatitis. Eur J Radiol. 1985;5:273–5.
16. Balthazar EJ, Ranson JH, Naidich DP, Megibow AJ, Caccavale R, Cooper MM. Acute pancreatitis: prognostic value of CT. Radiology. 1985;156:767–72.
17. Ranson JH, Balthazar E, Caccavale R, Cooper M. Computed tomography and the prediction of pancreatic abscess in acute pancreatitis. Ann Surg. 1985; 201(5):656–65.
18. Casas JD, Diaz R, Valderas G, Mariscal A, Cuadras P. Prognostic value of CT in the early assessment of patients with acute pancreatitis. AJR Am J Roentgenol. 2004;182:569–74.
19. Van den Biezenbos AR, Kruyt PM, Bosscha K, van Leeuwen MS, Feldberg MA, van der Schouw YT, et al. Added value of CT criteria compared to the clinical SAP score in patients with acute pancreatitis. Abdom Imaging. 1998;23:622–6.
20. Spitzer AL, Thoeni RF, Barcia AM, Schell MT, Harris HW. Early nonenhanced abdominal computed tomography can predict mortality in severe acute pancreatitis. J Gastrointest Surg. 2005;9(7):928–33.
21. Ishikawa K, Idoguchi K, Tanaka H, Tohma Y, Ukai I, Watanabe H, et al. Classification of acute pancreatitis based on retroperitoneal extension: application of the concept of interfascial planes. Eur J Radiol. 2006; 60:445–52.
22. Balthazar EJ, Robinson DL, Megibow AJ, Ranson JH. Acute pancreatitis: value of CT in establishing prognosis. Radiology. 1990;174:331–6.
23. London NJ, Neoptolemos JP, Lavelle J, Bailey I, James D. Contrast-enhanced abdominal computed tomography scanning and prediction of severity of acute pancreatitis: a prospective study. Br J Surg. 1989;76:268–72.
24. Knoepfli AS, Kinkel K, Berney T, Morel P, Becker CD, Poletti PA. Prospective study of 310 patients: can early CT predict the severity of acute pancreatitis? Abdom Imaging. 2007;32:111–5.
25. Ju S, Chen F, Liu S, Zheng K, Teng G. Value of CT and clinical criteria in assessment of patients with acute pancreatitis. Eur J Radiol. 2006;57:102–7.
26. Mortele KJ, Wiesner W, Intriere L, Shankar S, Zou KH, Kalantari BN, et al. A modified CT severity index for evaluating acute pancreatitis: improved correlation with patient outcome. AJR Am J Roentgenol. 2004;183:1261–5.
27. Simchuk EJ, Traverso LW, Nukui Y, Kozarek RA. Computed tomography severity index is a predictor of outcomes for severe pancreatitis. Am J Surg. 2000;179:352–5.
28. Vriens PW, van de Linde P, Slotema ET, Warmerdam PE, Breslau PJ. Computed tomography severity index is an early prognostic tool for acute pancreatitis. J Am Coll Surg. 2005;201:497–502.
29. Leung TK, Lee CM, Lin SY, Chen HC, Wang HJ, Shen LK, et al. Balthazar computed tomography severity index is superior to Ranson criteria and APACHE II scoring system in predicting acute pancreatitis outcome. World J Gastroenterol. 2005;11(38): 6049–52.
30. Lankisch PG, Pflichthofer D, Lehnick D. No strict correlation between necrosis and organ failure in acute pancreatitis. Pancreas. 2000;20:319–22.
31. Perez A, Whang EE, Brooks DC, Moore Jr FD, Hughes MD, Sica GT, et al. Is severity of necrotizing pancreatitis increased in extended necrosis and infected necrosis? Pancreas. 2002;25:229–33.
32. Isenmann R, Rünzi M, Kron M, Kahl S, Kraus D, Jung N, et al. Prophylactic antibiotic treatment in patients with predicted severe acute pancreatitis: a placebo-controlled, double-blind trial. Gastroenterology.2004; 126(4):997–1004.
33. Mortele KJ, Mergo PJ, Taylor HM, Ernst MD, Ros PR. Renal and perirenal space involvement in acute pancreatitis: spiral CT findings. Abdom Imaging. 2000;25:272–8.
34. Mortele KJ, Mergo PJ, Taylor HM, Wiesner W, Cantisani V, Ernst MD, et al. Peripancreatic vascular abnormalities complicating acute pancreatitis: contrast-enhanced helical CT findings. Eur J Radiol. 2004;52:67–72.
35. Van Santvoort HC, Bakker OJ, Bollen TL, Besselink MG, Ahmed Ali U, Schrijver AM, et al. A conservative and minimally invasive approach to necrotizing pancreatitis improves outcome. Gastroenterology. 2011;141(4):1254–63.
36. King NK, Powell JJ, Redhead D, Siriwardena AK. A simplified method for computed tomographic estimation of prognosis in acute pancreatitis. Scand J Gastroenterol. 2003;38:433–6.

37. Bollen TL, Singh VK, Maurer R, Repas K, van Es HW, Banks PA, et al. Comparative evaluation of the modified CT severity index and CT severity index in assessing severity of acute pancreatitis. AJR Am J Roentgenol. 2011;197(2):386–92.
38. Tirkes T, Sandrasegaran K, Patel AA, Hollar MA, Tejada JG, Tann M, et al. Peritoneal and retroperitoneal anatomy and its relevance for cross-sectional imaging. Radiographics. 2012;32(2):437–51.
39. Gore RM, Balfe DM, Aizenstein RI, Silverman PM. The great escape: interfascial decompression planes of the retroperitoneum. AJR Am J Roentgenol. 2000;175(2):363–70.
40. Vikram R, Balachandran A, Bhosale PR, Tamm EP, Marcal LP, Charnsangavej C. Pancreas: peritoneal reflections, ligamentous connections, and pathways of disease spread. Radiographics. 2009;29(2):e34.
41. De Waele JJ, Delrue L, Hoste EA, De Vos M, Duyck P, Colardyn FA. Extrapancreatic inflammation on abdominal computed tomography as an early predictor of disease severity in acute pancreatitis: evaluation of a new scoring system. Pancreas. 2007;34:185–90.
42. Rau BM. Predicting severity of acute pancreatitis. Curr Gastroenterol Rep. 2007;9(2):107–15.
43. Bollen TL, Singh VK, Maurer R, Repas K, van Es HW, Banks PA, et al. A comparative evaluation of radiologic and clinical scoring systems in the early prediction of severity in acute pancreatitis. Am J Gastroenterol. 2012;107(4):612–9.
44. Fagenholz PJ, Fernandez-del Castillo C, Harris NS, Pelletier AJ, Camargo Jr CA. Direct medical costs of acute pancreatitis hospitalizations in the United States. Pancreas. 2007;35:302–7.
45. Smith-Bindman R, Lipson J, Marcus R, Kim KP, Mahesh M, Gould R, et al. Radiation dose associated with common computed tomography examinations and the associated lifetime attributable risk of cancer. Arch Intern Med. 2009;169:2078–86.
46. Mortele KJ, Ip IK, Wu BU, Conwell DL, Banks PA, Khorasani R. Acute pancreatitis: imaging utilization practices in an urban teaching hospital-analysis of trends with assessment of independent predictors in correlation with patient outcomes. Radiology. 2011;258:174–81.
47. Spanier BW, Nio Y, van der Hulst RW, Tuynman HA, Dijkgraaf MG, Bruno MJ. Practice and yield of early CT scan in acute pancreatitis: a Dutch Observational Multicenter Study. Pancreatology. 2010;10(2–3):222–8.
48. Banks PA, Bollen TL, Dervenis C, Gooszen HG, Johnson CD, Sarr MG, et al. Classification of acute pancreatitis-2012: revision of the Atlanta classification and definitions by international consensus. Gut. 2013;62(1):102–11.
49. Isenmann R, Büchler M, Uhl W, Malfertheiner P, Martini M, Beger HG. Pancreatic necrosis: an early finding in severe acute pancreatitis. Pancreas. 1993;8(3):358–61.
50. Sainio VS, Puolakkainen PA, Kemppainen EJ, Kivisaari L, Haapiainen RK, Schröder TM, et al. Incorrect estimation of severity of acute pancreatitis by contrast-enhanced computed tomography. Ann Chir Gynaecol. 1997;86(3):214–21.
51. Besselink MG, van Santvoort HC, Boermeester MA, Nieuwenhuijs VB, van Goor H, Dejong CH, et al. Timing and impact of infections in acute pancreatitis. Br J Surg. 2009;96(3):267–73.
52. Ocampo C, Zandalazini H, Kohan G, Silva W, Szelagowsky C, Oría A. Computed tomographic prognostic factors for predicting local complications in patients with pancreatic necrosis. Pancreas. 2009; 38:137–42.
53. Freeny PC, Hauptmann E, Althaus SJ, Traverso LW, Sinanan M. Percutaneous CT-guided catheter drainage of infected acute necrotizing pancreatitis: techniques and results. AJR Am J Roentgenol. 1998; 170:969–75.
54. Van Baal MC, Bollen TL, Bakker OJ, van Goor H, Boermeester MA, Dejong CH, et al. The role of routine fine-needle aspiration in the diagnosis of infected necrotizing pancreatitis. Surgery. 2014; 155(3):442–8.
55. Balthazar EJ. Complications of acute pancreatitis: clinical and CT evaluation. Radiol Clin North Am. 2002;40:1211–27.
56. Lenhart DK, Balthazar EJ. MDCT of acute mild (non-necrotizing) pancreatitis: abdominal complications and fate of fluid collections. AJR Am J Roentgenol. 2008;190(3):643–9.
57. Harris S, Nadkarni NA, Naina HV, Vege SS. Splanchnic vein thrombosis in acute pancreatitis: a single-center experience. Pancreas. 2013;42(8): 1251–4.
58. Easler J, Muddana V, Furlan A, Dasyam A, Vipperla K, Slivka A, et al. Portosplenomesenteric venous thrombosis in patients with acute pancreatitis is associated with pancreatic necrosis and usually has a benign course. Clin Gastroenterol Hepatol. 2013. pii:S1542-3565(13)01643-1.
59. Thatipelli MR, McBane RD, Hodge DO, Wysokinski WE. Survival and recurrence in patients with splanchnic vein thromboses. Clin Gastroenterol Hepatol. 2010;8(2):200–5.
60. Balthazar EJ, Fisher LA. Hemorrhagic complications of pancreatitis: radiologic evaluation with emphasis on CT imaging. Pancreatology. 2001; 1(4):306–13.
61. Fishman EK, Soyer P, Bliss DF, Bluemke DA, Devine N. Splenic involvement in pancreatitis: spectrum of CT findings. AJR Am J Roentgenol. 1995; 164(3):631–5.
62. Mortele KJ, Mergo PJ, Taylor HM, Ernst MD, Ros PR. Splenic and perisplenic involvement in acute pancreatitis: determination of prevalence and morphologic helical CT features. J Comput Assist Tomogr. 2001;25:50–4.

63. Mofredj A, Cadranel JF, Dautreaux M, Kazerouni F, Hadj-Nacer K, Deplaix P, et al. Pancreatic pseudocyst located in the liver: a case report and literature review. J Clin Gastroenterol. 2000;30(1):81–3.
64. Li XH, Zhang XM, Ji YF, Jing ZL, Huang XH, Yang L, et al. Renal and perirenal space involvement in acute pancreatitis: an MRI study. Eur J Radiol. 2012; 81(8):e880–7.
65. Takeyama Y, Ueda T, Hori Y, Takase K, Fukumoto S, Kuroda Y. Hydronephrosis associated with acute pancreatitis. Pancreas. 2001;23(2):218–20.
66. Perera M, Pham T, Toshniwal S, Lennie Y, Chan S, Houli N. A case of concomitant perforated acute cholecystitis and pancreatitis. Case Rep Surg. 2013;2013: 263046.
67. Da Costa DW, Boerma D, van Santvoort HC, Horvath KD, Werner J, Carter CR, et al. Staged multidisciplinary step-up management for necrotizing pancreatitis. Br J Surg. 2014;101(1):e65–79.
68. Van Baal MC, Besselink MG, Bakker OJ, van Santvoort HC, Schaapherder AF, Nieuwenhuijs VB, et al. Timing of cholecystectomy after mild biliary pancreatitis: a systematic review. Ann Surg. 2012; 255(5):860–6.
69. Nealon WH, Bawduniak J, Walser EM. Appropriate timing of cholecystectomy in patients who present with moderate to severe gallstone-associated acute pancreatitis with peripancreatic fluid collections. Ann Surg. 2004;239:741–9.
70. Chaudhary A, Sachdev A, Negi S. Biliary complications of pancreatic necrosis. Int J Pancreatol. 2001; 29(3):129–31.
71. Brar R, Singh I, Brar P, Prasad A, Doley RP, Wig JD. Pancreatic choledochal fistula complicating acute pancreatitis. Am J Case Rep. 2012;13:47–50.
72. Ho HS, Frey CF. Gastrointestinal and pancreatic complications associated with severe pancreatitis. Arch Surg. 1995;130:817–22.
73. Van Minnen LP, Besselink MG, Bosscha K, van Leeuwen MS, Schipper ME, Gooszen HG. Colonic involvement in acute pancreatitis. A retrospective study of 16 patients. Dig Surg. 2004;21:33–8.
74. Mohamed SR, Siriwardena AK. Understanding the colonic complications of pancreatitis. Pancreatology. 2008;8(2):153–8.
75. Hsu CY, Lee KC, Chan CC, Lee FY, Lin HC. Gastric necrosis and perforation as a severe complication of pancreatic pseudocyst. J Chin Med Assoc. 2009; 72(11):603–6.
76. Takeyama Y, Ueda T, Hori Y, Shinkai M, Ajiki T, Kuroda Y. Duodenal necrosis associated with acute pancreatitis. Pancreas. 2001;22(2):217–9.
77. Baron TH, Harewood GC, Morgan DE, Yates MR. Outcome differences after endoscopic drainage of pancreatic necrosis, acute pancreatic pseudocysts, and chronic pancreatic pseudocysts. Gastrointest Endosc. 2002;56:7–17.
78. Kirkpatrick AW, Roberts DJ, De Waele J, Jaeschke R, Malbrain ML, De Keulenaer B, Pediatric Guidelines Sub-Committee for the World Society of the Abdominal Compartment Syndrome, et al. Intra-abdominal hypertension and the abdominal compartment syndrome: updated consensus definitions and clinical practice guidelines from the World Society of the Abdominal Compartment Syndrome. Intensive Care Med. 2013;39(7):1190–206.
79. Boone B, Zureikat A, Hughes SJ, Moser AJ, Yadav D, Zeh HJ, et al. Abdominal compartment syndrome is an early, lethal complication of acute pancreatitis. Am Surg. 2013;79(6):601–7.
80. Al-Bahrani AZ, Abid GH, Sahgal E, O'shea S, Lee S, Ammori BJ. A prospective evaluation of CT features predictive of intra-abdominal hypertension and abdominal compartment syndrome in critically ill surgical patients. Clin Radiol. 2007;62(7):676–82.
81. Patel A, Lall CG, Jennings SG, Sandrasegaran K. Abdominal compartment syndrome. AJR Am J Roentgenol. 2007;189(5):1037–43.
82. Raghu MG, Wig JD, Kochhar R, Gupta D, Gupta R, Yadav TD, et al. Lung complications in acute pancreatitis. JOP. 2007;8(2):177–85.