Review Article

Role of multidetector computed tomography in the assessment of pancreatic injuries after blunt trauma: a multicenter experience

Francesca Iacobellis[1], Ettore Laccetti[2], Stefania Tamburrini[3], Michele Altiero[2], Francesco Iaselli[3], Marco Di Serafino[1], Nicola Gagliardi[1], Roberta Danzi[2], Alessandro Rengo[2], Luigia Romano[1], Refky Nicola[4], Mariano Scaglione[2,5]

[1]Department of General and Emergency Radiology, "A. Cardarelli" Hospital, Naples, Italy; [2]Department of Diagnostic Imaging, "Pineta Grande" Hospital, Castel Volturno, CE, Italy; [3]Department of Radiology, "Ospedale del Mare" ASL NA1 Centro-Napoli, Naples, Italy; [4]Department of Radiology, SUNY-Upstate University and Medical Center, Syracuse, NY, USA; [5]Department of Radiology, Sunderland Royal Hospital, NHS, Sunderland, UK

Contributions: (I) Conception and design: M Scaglione, F Iacobellis; (II) Administrative support: M Scaglione; (III) Provision of study materials or patients: All authors; (IV) Collection and assembly of data: All authors; (V) Data analysis and interpretation: All authors; (VI) Manuscript writing: All authors; (VII) Final approval of manuscript: All authors.

Correspondence to: Dr. Francesca Iacobellis, MD, PhD. Department of General and Emergency Radiology, "A. Cardarelli" Hospital, Via A. Cardarelli 9, 80131 Naples, Italy. Email: iacobellisf@gmail.com.

Abstract: Pancreatic injuries can occur from either penetrating or blunt abdominal trauma. While there are rare, especially in the setting of blunt abdominal trauma, they are associated with a mortality of up to 30%, and a morbidity of 60%. Multidetector computed tomography (MDCT) is the preferred imaging modality in patients with acute blunt abdominal trauma and for the detection of acute pancreatic injury. Magnetic resonance (MR) and magnetic resonance cholangiopancreatography (MRCP) plays an important role in the follow-up of pancreatic injury. In this brief review, we discuss the main MDCT acute imaging findings as well as the complications. Finally, we discuss the role of MR and MRCP in follow up of patients with pancreatic injuries.

Keywords: Pancreatic trauma; pancreatic injuries; blunt trauma; computed tomography (CT); magnetic resonance cholangiopancreatography (MRCP)

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Introduction

Traumatic pancreatic injuries typically occur from acute penetrating or blunt abdominal trauma. They are considered rare and occur only between 0.2–12% of acute blunt abdominal trauma (1-5) with a mortality rate up to 30%, and a morbidity of 60% (1,4,6).

Because of its anatomic location and its relatively fixed position anterior to the spine, traumatic injuries to the pancreas are infrequent. Concomitant injuries are common (50–98%), with the liver most commonly affected (46.8% of cases) followed by stomach (42.3%), major vessels (41.3%), spleen (28.0%), kidney (23.4%), and duodenum (19.3%) (2). Since pancreatic injuries are an uncommon injury and are typically associated with other abdominal organ injuries, the diagnosis can be frequently missed (2).

The first step in order to avoid missing pancreatic injuries, is to consider the mechanism of trauma and then, evaluate the anatomical structures which are involved (7,8). Severe abdominal trauma antero-posteriorly directed, compressing the pancreatic gland against the spine, such as seat-belt injuries, acceleration-deceleration trauma, and handlebar compression trauma, represent the most common mechanism of injury (4). The most commonly injured segment of the pancreas is the body, which occurs in 65% of the cases (4).

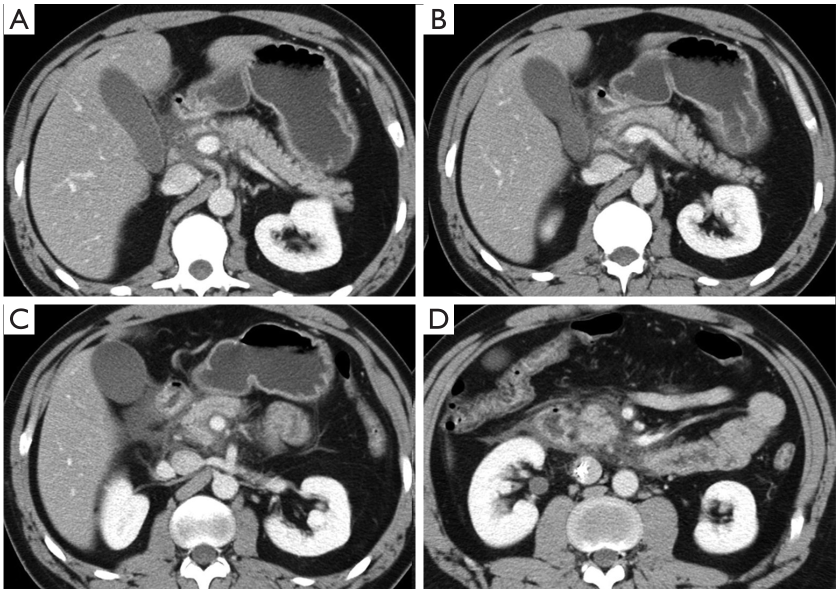

Figure 1 Enhanced CT of a 34-year-old man with onset of abdominal pain two days after motor vehicle accident. There is extensive peripancreatic fat stranding (A,B,C,D) and fluid surrounding the pancreatic head and the duodenum (A,C,D) due to post-traumatic inflammatory phenomena, not previously seen at the admission CT. Although no extraintestinal air is detected, with this appearance a duodenal injury cannot be completely excluded. The arterial and venous peripancreatic vessels are patent.

The detection and grading of pancreatic injuries are important in order to facilitate a proper treatment plan (2,9).

Imaging of pancreatic injuries

Multidetector computed tomography (MDCT) is the preferred imaging modality in patients with blunt trauma and, particularly, is the imaging modality of choice for the detection of acute pancreatic injury with a sensitivity of up to 80% (10-12). The MDCT sensitivity is variable as imaging findings are subtle within the first 12 hours of injury (2,13). This is secondary to the small amount of peripancreatic fat tissue that limit the MDCT detection of pancreatic injury, or with the time needed to develop imaging manifestations of post-traumatic inflammatory phenomena (*Figure 1*). As the presence of these kind of injuries affect the treatment, they deserve to be accurately identified, and so, in these cases, magnetic resonance (MR) imaging is indicated in combination with endoscopic retrograde cholangiopancreatography (ERCP) (9,14).

MDCT protocol

MDCT protocol in polytraumatized patients basically includes an unenhanced computed tomography (CT) of the head and an arterial and venous phase extended from the circle of Willis to the symphysis pubis (7).

Intravenous contrast material consists of 100–120 mL iodinated contrast agent at high iodine concentration 370–400 mg/mL, injected at 4–5 mL/s, followed by 40 mL of saline chaser at the same flow rate, to obtain optimal vessel depiction.

To time the beginning of the arterial phase, it is suggested the adoption of an automated bolus tracking, with region of interest placed in the aortic arch at an attenuation threshold of 100 HU. The venous phase was performed at 60–70 s delay from the end of the injection. A delayed, excretory phase (180 s delay from the end of the venous phase or later) can be added in select cases, for further evaluation of suspected slight bleeding or if there was suspected injury to the collecting system or bladder.

All initial MDCT scans for trauma patients are obtained without oral contrast material. The use of oral contrast material is reserved for follow-up CT studies or "second look" evaluations. In the follow-up CT of patients with suspected or diagnosed pancreatic trauma, it can be useful to obtain an adequate distension of the duodenal lumen to facilitate the depiction of possible coexistent injuries in

Figure 2 Unenhanced (A) and enhanced (B,C,D) CT scan of a polytraumatized patient acquired few days after pancreatic trauma in arterial (C) and portal venous phases (B,D). There is a small traumatic laceration in the uncinate process (B, arrow), associated with an hematoma spreading in the spaces between the pancreas and duodenum (A, unenhanced CT acquisition showing the spontaneous hyperdensity of the hematoma) and compressing the inferior knee of the duodenum and the pancreatic head (C,D). The pancreatic gland shows no further densitometric changes and the Wirsung duct is not dilated. In the arterial phase, no vascular injuries are detected. The stomach is dilated with endo-luminal nasogastric tube.

this area.

The examination should be obtained with thin slice thickness (1.2 mm), thinner reconstructed (0.625 mm) to allow for optimal three-dimensional multiplanar reconstructions (MPR). The use of MPR, maximum intensity projection (MIP) and minimum intensity projection (MinIP) is critical in assessing for biliary duct anomalies.

MDCT findings

Signs of pancreatic injuries may be indirectly suspected or directly depicted at imaging.

Indirect signs may be considered the trajectory of injury through the region of the pancreas and the presence of peripancreatic fat stranding (1).

Direct signs at CT scans may vary from contusion, edema or hematoma of the pancreatic parenchyma, lacerations or fractures of the pancreas (14).

Pancreatic contusion is seen as focal or diffuse area of low attenuation within the normally enhancing pancreas. It can be defined as minor when involves one focal region of the organ (uncinate process/head/isthmus/body/tail) or major when more than one region is involved (5).

Pancreatic edema depends on the edematous infiltration of the parenchyma due to inflammatory phenomena following trauma (*Figure 1*) (13).

Hematoma represents a blood collection that may be limited to the parenchyma, or may extend in the peripancreatic tissue, and in severe cases can be associated with active bleeding. Large hematomas may also cause mass effect obstructing the duodenal lumen (*Figure 2*) or the pancreatic duct (5,15).

Pancreatic laceration is identified as a low-density

Figure 3 Enhanced CT scan of a young polytraumatized patient performed after emergency splenectomy. Note the hypodense line of transection of the pancreatic tail (AAST grade III injury) surrounded by fluid, in the early arterial (A) and portal venous (B, arrow) phases and the coexistence of left kidney injury (C).

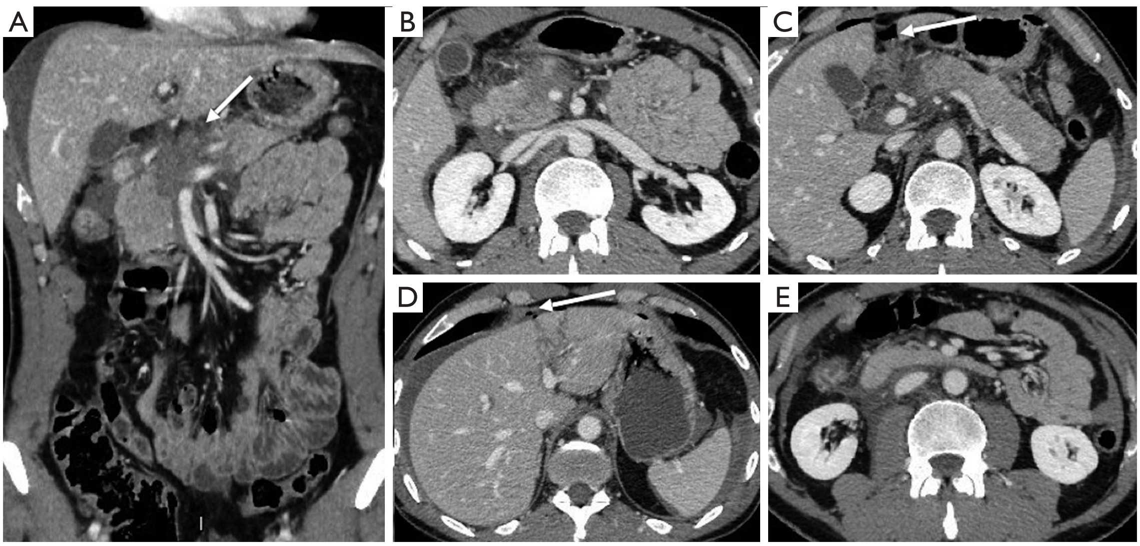

Figure 4 Enhanced CT acquired after high energy blunt trauma. There is an high grade injury of the pancreatic isthmus (AAST grade IV) (A, arrow) leading to gland transection (B,C). A small amount of hemoperitoneum and hemoretroperitoneum is also present (D,E). Furthermore, a careful evaluation allows to detect small free air bubbles related with duodenal traumatic perforation (C,D, arrows). There is indication for surgery. Traumatic lacerations of the left liver lobe are also present.

line or band oriented perpendicular or oblique to the long axis of the gland (5) (*Figures 3,4*). Depending on the extension, lacerations may be superficial (less than 50% depth or thickness of the gland) or deep (beyond 50% of the depth of the gland reaching up to the plane of the main pancreatic duct and thus likely to be involving the duct). The pancreatic duct is inconsistently visualized directly on MDCT and a laceration involving more than 50% of the depth of the pancreas is taken as indirect evidence of ductal injury on CT (5) (*Figure 4*).

Extensive lacerations may lead to complete transection/fracture of the gland (5) (*Figures 4,5*).

Once pancreatic injury is detected, it is important to evaluate its severity, as it correlates with the need for surgery and with the rate of complications (16), and the presence of coexistent injuries.

To describe the injury grade in the report, it is suggested the adoption of the AAST classification, thus ensuring a uniform communication of the relevant findings (17), related with injuries of the pancreatic duct or of the pancreatic head (for the involvement of the ampulla), as they change the patient prognosis and management (*Figures 6,7*) (9).

AAST classification considers as grade I minor contusion or superficial lacerations without duct injury, grade II major contusion or laceration without duct injuries or tissue loss, grade III distal transection or parenchymal injury with duct injury, grade IV proximal transection or parenchymal injury involving ampulla, grade V massive disruption of the pancreatic head (17).

However, there are further injuries not considered in the AAST classification, deserving an accurate evaluation at admission MDCT after trauma due to their importance in patient's survival: vascular injuries. To properly identify and characterize vascular injuries it is recommended the acquisition of at least two phases (arterial and portal venous) after IV injection (*Figure 8*) (8,18,19). This allows the radiologist to depict the origin (arterial or venous) and to estimate the entity of the bleeding, assuming a crucial role in the patient's management, as slight venous bleeding may be conservatively treated in stable patients, whereas jet or pooling of active bleeding need to be managed by endovascular approach, if possible, in arterial bleeding, or by surgical approach (7,18) (*Figure 9*).

Figure 5 Enhanced CT after high energy blunt trauma showing the avulsion of pancreatic tail. Courtesy of G. Casola and C. Sirlin, University of California San Diego, USA.

In trauma patients with persisted hypoperfusion, may be encountered alterations of pancreatic enhancement known as "shock pancreas". The pancreas may demonstrate hypoenhancement in early phase or hyperenhancement (20-24). The decreased enhancement depends on the reduced blood supply and may cause difficulties in discerning from pancreatic injury, although these injuries are usually more focal (20). The pathophysiological causes of increased density are still not well known, and may depend on the decompensation in the blood flow regulation. The persistent pancreatic hyperdensity is more frequently observed in critical shocked patients and is related with poor prognosis (20,21,25) (*Figure 10*).

A crucial point to be considered in the evaluation of parenchymal injury is the involvement of the pancreatic duct, as ductal injuries deserve to be operatively approached (*Figure 11*), and lead to a major percentage of complications (*Figure 12*). Indeed, the risk of development of abscess or fistula in patients with disruption of the pancreatic duct is 25% and 50%, respectively, in comparison with 10% without duct injuries (13). However, the accuracy of MDCT in the detection of ductal injury has been reported to be as low as 43%, for this reason the pancreatic duct is indirectly considered as injured on MDCT if the parenchymal laceration involves more than 50% of the depth of the pancreas. In such cases a magnetic resonance cholangiopancreatography (MRCP) or ERCP is recommended (5,13). Sometimes the ductal injury may also be seen at CT, this is made easier with the adoption of MPR and MinIP (*Figures 11,12*).

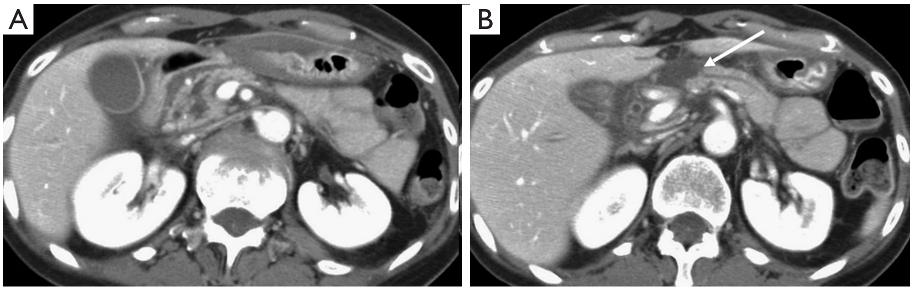

Figure 6 Enhanced-CT of a patient underwent high energy blunt trauma. There is an extensive injury of the pancreatic head (A,B) with amputation of the main duct at the isthmus (B, arrow) and doubtful involvement of the main biliary duct and the ampulla. There is indication for further diagnostic investigation with MRCP and operative management. Courtesy of G. Casola and C. Sirlin, University of California San Diego, USA. MRCP, magnetic resonance cholangiopancreatography.

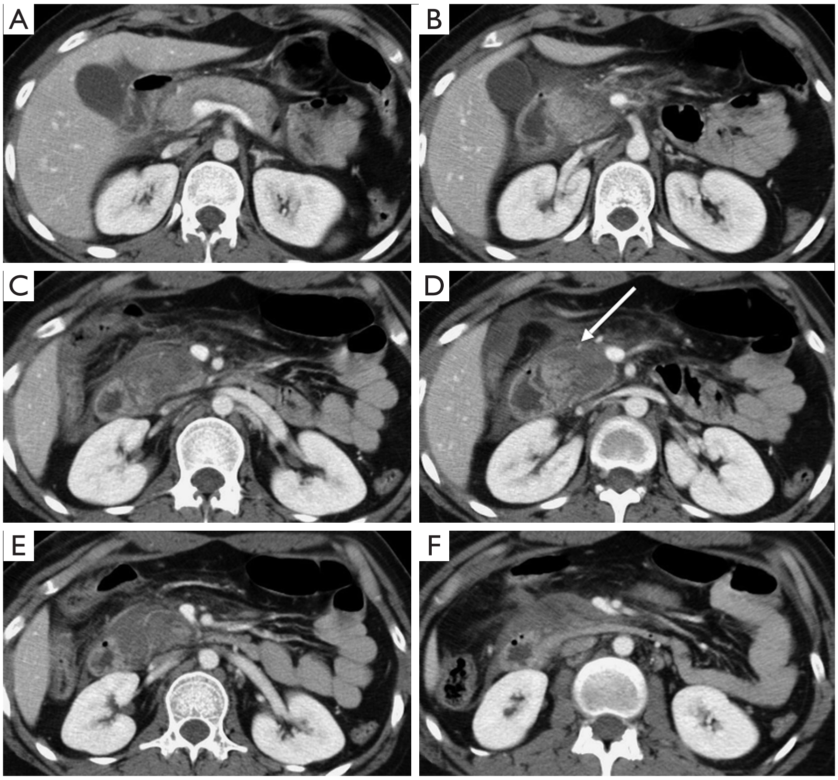

Figure 7 Enhanced-CT of a patient underwent high energy blunt trauma. There is an extensive injury of the pancreatic head (A,B,C,D,E,F) with intrapancreatic hematoma spreading into the surrounding fat, and involvement of the main duct (D, arrow). There is indication for further diagnostic investigation with MRCP and operative management. Courtesy of G. Casola and C. Sirlin, University of California San Diego, USA. MRCP, magnetic resonance cholangiopancreatography.

Figure 8 Multiphasic enhanced-CT study in patient underwent high energy blunt trauma. There is an extensive pancreatic contusion with a jet of active bleeding (A,B,C, arrows) detected in the arterial phase (A,B, arrows) and increasing in the following venous phase (C, arrow). Courtesy of G. Casola and C. Sirlin, University of California San Diego, USA.

The primary pitfall in the diagnosis of pancreatic trauma is related with the presence of parenchymal cleft mimicking lacerations (*Figure 13*) (4).

When there is a pancreatic involvement in trauma, it is particularly important to carefully evaluate the duodenum (*Figure 14*), as it is frequently injured together with the pancreas (*Figure 15*). Also imaging findings of duodenal injury may be subtle and a slight thickness of the wall or the presence of small air bubbles in the adjacent extraluminal spaces may represent signs of injury (4) (*Figure 4*).

Complications

Complications of pancreatic injuries develop in up to one-

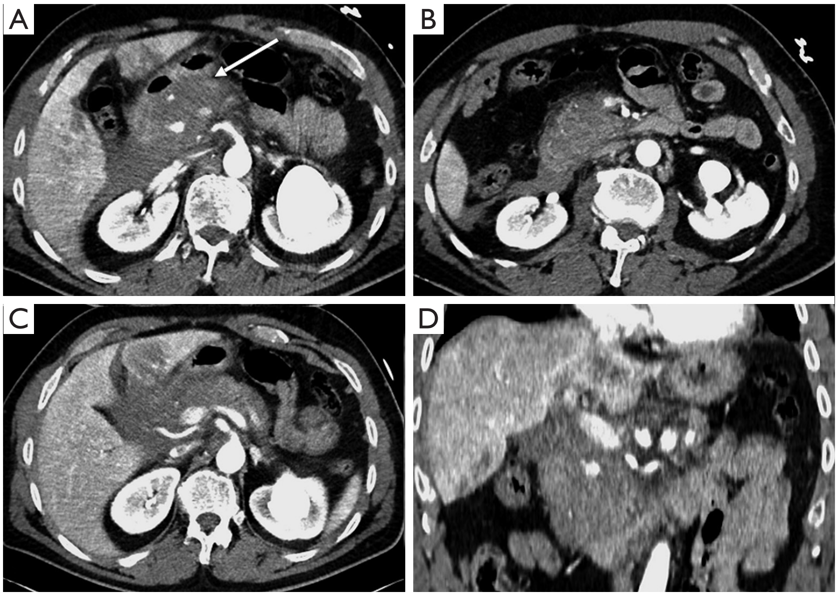

Figure 9 Admission enhanced CT of a patient underwent high energy blunt trauma. There is a laceration of the pancreatic head, that appear enlarged and hypodense (A, arrow), with multiple jets of arterial active bleeding and with surrounding hemoretroperitoneum (B,C,D). There are also lacerations in the left liver lobe and duodenal contusion.

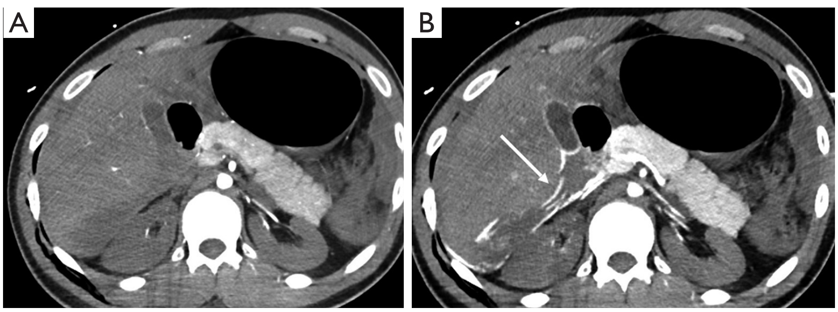

Figure 10 Enhanced CT of a young patients who attempted suicide by defenestration. Note the persistent hyperdensity of the pancreatic parenchyma (A,B) related to severe hypoperfusion: there is a pooling of active arterial bleeding (B, arrow) and a flattened vena cava. Liver and right kidney lacerations are also faintly seen in these CT acquisitions.

third of the patients and include pancreatitis, pseudocysts, fistulas, intra-abdominal abscesses, or bowel anastomosis breakdown, and may lead to sepsis and multiorgan failure (16). Post-traumatic leakage of pancreatic enzymes may lead to pseudocyst formation (*Figures 12,16,17*) with further complication as abscesses, or may predispose to abnormal fistulization between the pancreas and adjacent organs. Furthermore, leakage of enzymes may lead to vascular wall erosion forming pseudoaneurysm that may complicate with delayed hemorrhage (16).

Pseudoaneurysm development after trauma may also depend on variation in the blood flow following stenosis or occlusion of the celiac or hepatic arteries (26).

Post-traumatic strictures of the pancreatic duct, which can predispose to recurrent pancreatitis, have also been reported (4).

Follow-up

Due to low sensitivity of MDCT in early phases of trauma, it is important to select an appropriate imaging modality for follow-up. In our Institutions, the imaging modality of

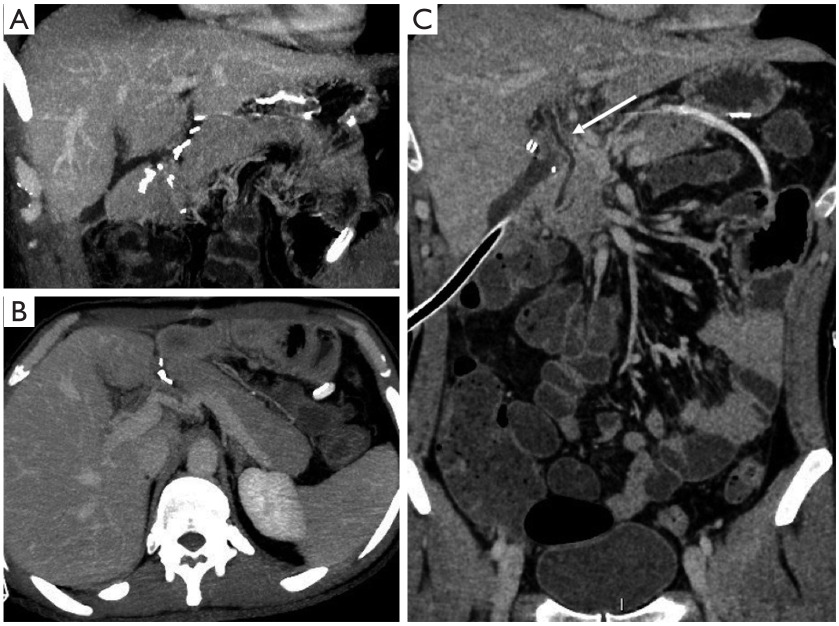

Figure 11 Enhanced CT acquired after surgery for high grade pancreatic injury (same patient of *Figure 4*). MIP (A,B) and MPR MinIP (C) reconstructions. There are surgical clips for pancreatic suture (A,B). MinIP reconstructions facilitate the depiction of the main bile duct (C, arrow). MIP, maximum intensity projection; MPR, multiplanar reconstruction; MinIP, minimum intensity projection.

Figure 12 Enhanced CT showing a common complication after pancreatic high-grade injury: the presence of pseudocyst directly communicating with the main pancreatic duct (same patient of *Figure 4*). MinIP reconstruction helps in the visualization of the pancreatic duct. MinIP, minimum intensity projection.

choice for follow-up is MR. MR provides a high contrast resolution, the multiplanar and good spatial resolution without using IV (27). First MR follow-up is usually performed between 48 and 60 hours from trauma. Imaging protocol basically consists in: T2W sequences acquired in axial, coronal and, if needed, sagittal planes, to evaluate the presence of fluid collections, T1W fat sat and T1W in and out sequences in axial planes to explore the pancreatic parenchyma and the presence of blood collections, and the MRCP sequences to evaluate the ductal injury and the relationship with peripancreatic fluid collections (*Figure 18*). The acquisitions of post-contrast T1W fat sat sequences helps in the evaluation of vascular complications and in the estimation of pancreatic lacerations and necrosis (5,28). Furthermore, the use of hepatobiliary contrast agent [gadobenate dimeglumine (Gd-BOPTA), MultiHance, Bracco; or gadoxetic acid (Gd-EOB-DTPA), Primovist in Europe; Eovist in the USA; Bayer Healthcare] may help in the evaluation of concomitant adjacent biliary duct injuries (*Figure 9*). The timing of further follow-up examinations depends on the injuries detected and on the therapeutic choices. In patients with injuries in multiple anatomical districts, i.e. deserving also the evaluation of major thoracic injuries, MDCT remains the modality of choice also for the follow-up (*Figure 19*).

Conclusions

Pancreatic injuries which occur due to high energy blunt abdominal trauma are rare and commonly are associated with abdominal organ injuries. Contrast-enhanced MDCT represents the imaging modality of choice immediately

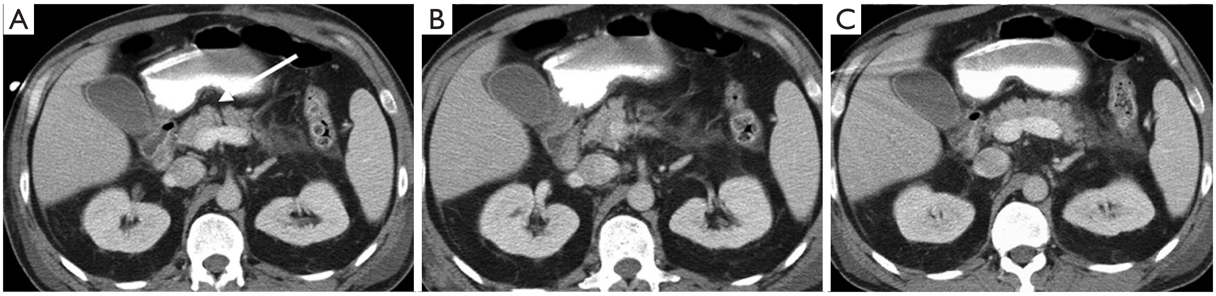

Figure 13 Enhanced-CT in patient underwent high energy blunt trauma. There is a deep pancreatic cleft located at the isthmus (A, arrow) mimicking a laceration. Actually, the injury involves the pancreatic tail, where an inhomogeneity of the parenchyma is detected with associated peripancreatic fluid (A,B,C). Courtesy of G. Casola and C. Sirlin, University of California San Diego, USA.

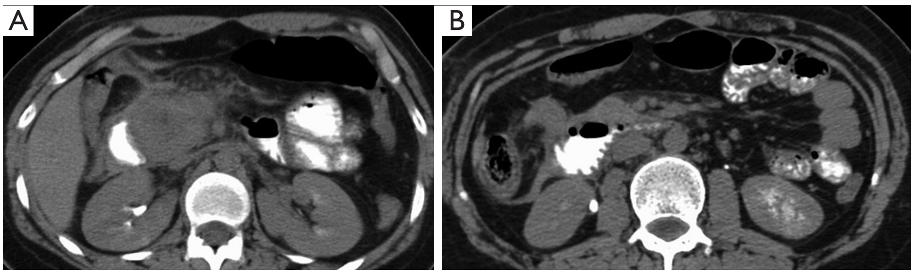

Figure 14 CT after oral administration of iodinated contrast medium. Same patient of *Figure 7*. Duodenal wall thickness is normal and extra luminal leakages of the contrast medium are not detected. Courtesy of G. Casola and C. Sirlin, University of California San Diego, USA.

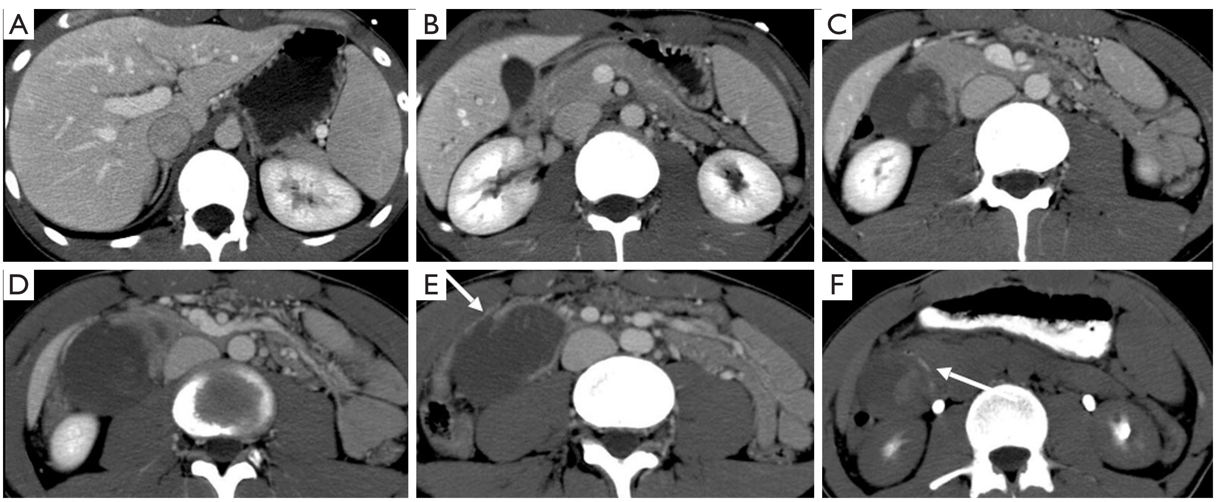

Figure 15 Enhanced CT acquired after high energy blunt trauma. There is gastric lumen distension (A) related with trauma of the pancreatic head (B,C,D) and the presence of a huge duodenal wall hematoma (C,D,E, arrow), compressing the lumen (F, arrow). Courtesy of G. Casola and C. Sirlin, University of California San Diego, USA.

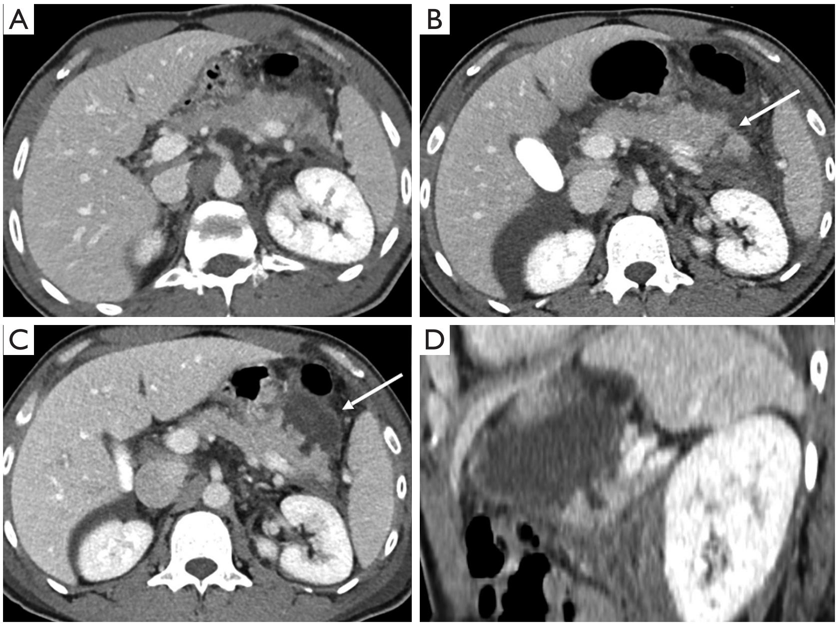

Figure 16 Admission enhanced CT after blunt trauma (A,B). There is a laceration of the pancreatic tail (AAST grade III injury) (B, arrow) suspected for pancreatic duct involvement (A,B). Indeed, at the follow-up CT was depicted the development of a pseudocyst (C, arrow; D).

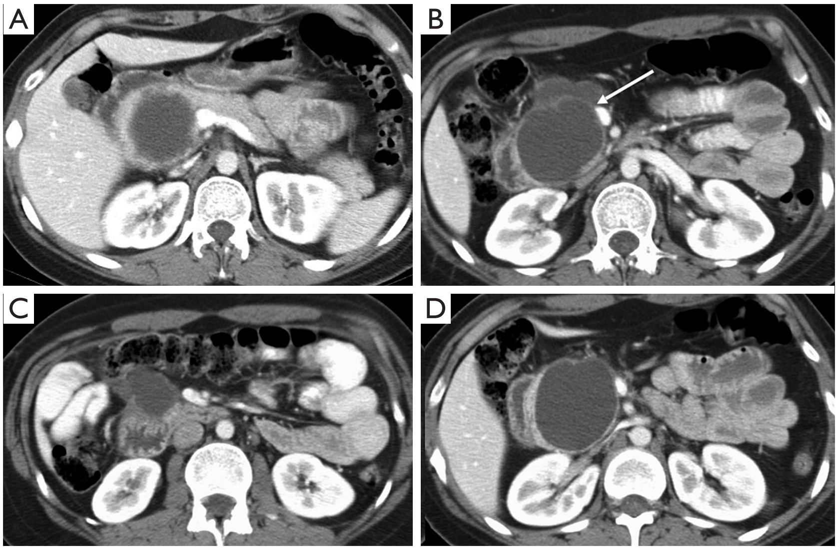

Figure 17 Follow-up enhanced CT acquired 1 month after trauma. Same patient of *Figure 7*. There is the development of a huge pseudocyst (A,B,C,D; B, arrow), due to the massive disruption of the main biliary tract. Courtesy of G. Casola and C. Sirlin, University of California San Diego, USA.

after trauma, allowing a complete and fast evaluation, even though sometimes it has a low sensitivity. So, in these cases, in the pre-operative assessment and in the patient follow-up, is indicated the additional use of MR and MRCP, due to its high contrast resolution properties particularly useful for the study of the pancreatobiliary tract.

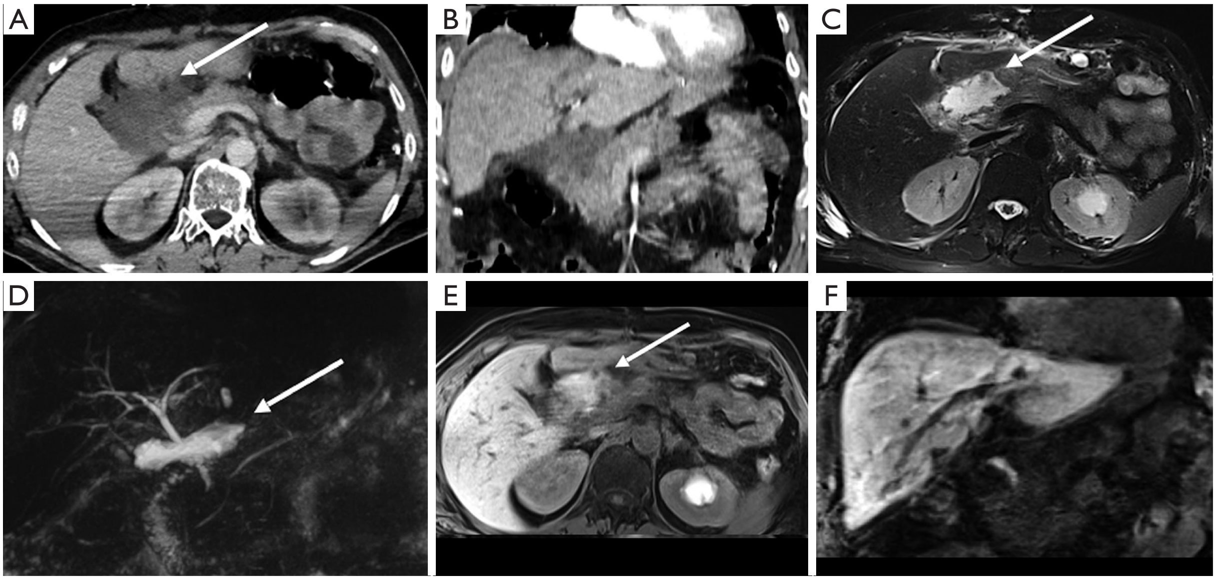

Figure 18 Follow-up imaging studies of the same patient of *Figure 4*. CT acquired few days after surgery shows the presence of a sub-hepatic fluid collection (A, arrow) and multiple hypodense areas in the pancreatic head consistent with lacerations (A,B). There is indication for MR to explore the pancreaticobiliary duct involvement. MR sequences (C, T2W; D, MRCP; E, T1W FS in delayed hepatobiliary phase after IV injection of hepatospecific contrast agent) well depict the sub-hepatic fluid collection (C, arrow), not related with main pancreatic duct involvement whereas due to partial injuries of the main biliary duct (D,E, arrows), with residual lumen opacification in the hepatobiliary phase (F). MRCP, magnetic resonance cholangiopancreatography.

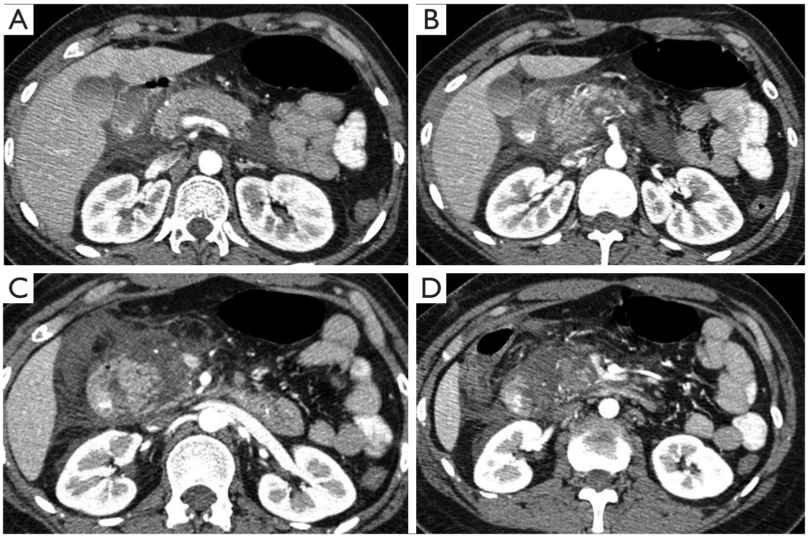

Figure 19 Follow-up enhanced CT in pancreatic phase (acquisition timed at 40–45 s after IV contrast injection) after administration of oral contrast medium. Same patients of *Figure* 7. There is inhomogeneity of the pancreatic head parenchyma due to the extensive laceration, associated with peripancreatic fluid. No duodenal extra luminal leakage, neither abnormal wall thickening are detected. Courtesy of G. Casola and C. Sirlin, University of California San Diego, USA.

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Footnote

Conflicts of Interest: The authors have no conflicts of interest to declare.

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