The Role of Non-cardiac Multi-detector Computed Tomography in the Emergency Room

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Introduction

Trauma frequently affects young people; its high morbidity and mortality imply high socioeconomic costs. In European Trauma Centers, chest and abdominal traumas represent the major cause of hospitalization and are associated with a mortality of 15%, which rises to 77% when brain trauma is included [1].

Decisive, qualitative improvements have been made in the management of multi-traumatized patients, including surgical and intensive-care treatment at specialized centers. The implementation of Emergency Department algorithms [2], increased knowledge of shock and of resuscitation methods and also the advances made in diagnostic imaging and surgical techniques, have led to a considerable increase in the survival rate.

One of the most critical aspects of trauma care is the time-frame, which has a great impact on resuscitation and safety. The use of imaging modalities in the management of multi-traumatized patients makes for more reliable and faster identification of injuries, which is crucial in therapeutic decision-making [3]. The aim of diagnostic imaging is to identify all alterations through non-invasive and highly accurate early diagnosis with minimum stress for the patient.

Multi-detector computed tomography (MDCT) offers the longitudinal and temporal resolution that is essential for the multi-traumatized patient. Today, it represents the gold standard of imaging in a hospital’s Emergency Unit. High-speed techniques even for large volumes yield high-quality images, thereby improving the diagnostic accuracy for lesions involving any of the anatomical chest components (bone, lungs, tracheobronchial tree, blood vessels) [4].

The initial clinical assessment must take place during stabilization of the traumatized patient and includes an X-ray chest film and an abdominal ultrasound, performed by the Radiologist during intubation of the patient and insertion of central venous and arterial lines. Patients are then immediately checked with MDCT. Exclusion criteria are hemodynamic instability that is difficult to control and any resuscitation attempt involving immediate surgery.

MDCT: Technical Principles

Continuous monitoring of the circulation and of regular breathing by the patient while he or she is on the CT table should be guaranteed by the Nurses and the Anesthesiologist in the CT room.

According to the basic concept of biomechanical trauma, whereby a major traumatic event generally involves more than one anatomical sector (average of 2.5 lesions per patient), the MDCT examination begins with unenhanced CT of the skull, the cervical spine, and the abdominal cavity and is followed by contrast-enhanced CT of the trunk and abdominal cavity.

The CT standardized parameters used in our Institution for a 16-slice MDCT scanner are shown in Table 1. Intravenous contrast material (100–120 ml of 400 mg iodine/ml) is routinely administered, using a biphasic injection at 4 ml/s followed by 40 ml of saline flush at 3 ml/s, via the peripheral or central venous access of a programmable-injection dual pump.
The purpose of a contrast-medium examination is to obtain high-resolution images at the peak of arterial and parenchymal contrast enhancement. Bolus tracking is performed only in patients with circulatory instability; otherwise, scanning starts with an early delay of 30 s for an abdominal volume and 75 s for a whole-body volume.

When fluid collection is demonstrated on previous biphasic images, delayed images should be routinely obtained 2–3 min following the injection of intravenous contrast medium to evaluate vascular bleeding from injuries.

Oral contrast material is not routinely administered.

CT Findings

Chest Trauma

The critical clinical issues to be addressed by an immediate MDCT evaluation of chest trauma are the discovery of the causes of hypoxia, to prevent metabolic acidosis, and of hypovolemia, to prevent tissue hypoxia [5]. Hypoxia may be caused by a compromised lung parenchyma, by a great quantity of intrapleural and extrapleural air, by a compromised tracheobronchial tree, or by a flail chest. Hypovolemia may be the consequence of cardiovascular traumatic lesions [5].

Table 1. CT standardized parameters used in our Institution

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
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<tbody>
<tr>
<td>Slice profile</td>
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</tr>
<tr>
<td>Rotation time</td>
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<tr>
<td>Field of view</td>
<td>360°</td>
</tr>
<tr>
<td><strong>ARTERIAL PHASE</strong></td>
<td></td>
</tr>
<tr>
<td>Scan delay</td>
<td>Bolus triggered</td>
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<tr>
<td>Collimation</td>
<td>16 × 1 mm</td>
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<tr>
<td><strong>PORTAL VENOUS PHASE</strong></td>
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<tr>
<td>Scan delay</td>
<td>20 s after the start of arterial phase</td>
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<tr>
<td>Collimation</td>
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</tr>
<tr>
<td><strong>LATE VENOUS PHASE</strong></td>
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<tr>
<td>Scan delay</td>
<td>120 s after the start of portal phase</td>
</tr>
<tr>
<td>Collimation</td>
<td>16 × 3.0 mm</td>
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<td><strong>CONTRAST MATERIAL</strong></td>
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<td>Contrast medium concentration</td>
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<tr>
<td>Volume in ml</td>
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<tr>
<td>Injection rate ml/sec</td>
<td>4 ml</td>
</tr>
<tr>
<td>Saline flush (volume in ml)</td>
<td>30-40</td>
</tr>
<tr>
<td>Injection rate ml/s</td>
<td>3 ml</td>
</tr>
</tbody>
</table>

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Oral contrast material is not routinely administered.

Hypoxia: Lung Contusion

Lung contusion and compromised parenchymal volume represent the most frequent causes of hypoxia. Some studies have shown that blood and interstitial fluid can accumulate in the damaged parenchyma, modifying the relationship between arterial blood gas and the oxygen concentration in inspired air at the time of Pao2 measurement (Pao2/Fio2). This is a relevant predictor of outcome and is positively related to the contused lung volume [6].

Another study has showed that a reduction in PaO2 reflects the presence of lobar hemorrhage and edema [7].

Lung contusion decreases in time, although not uniformly, and most patients do not show a persistence of the condition after 10 days of trauma. There is no correlation between PaO2/Fio2 and the contused lung volume one week or more after trauma; instead, after one week, an altered ratio depends on other causes, such as pulmonary thromboembolism (PTE) or acute respiratory distress syndrome (ARDS) [6].

Contusion appears 4–6 h post-trauma and has different radiological patterns (patchy, poorly-defined, or large consolidated areas). The lesions clear rapidly, generally within 72 h, with complete healing in about a week.

Sometimes, there is a leak in the parenchymal contusion, which can lead to a laceration (Fig. 1) or a pneumatocele. If there is blood in the pneumatocele, a hematoma is observed.

In alveolar hemorrhage, the bleeding stops early because of the low pressure of the lung arterial blood and the high concentration of lung thromboplastin.
Abnormal Intrathoracic Air: Pneumothorax

Air in the pleural space is the result of a traumatic force that creates a tear in the visceral pleura due to a fractured rib (Fig. 2).

High-pressure pneumothorax is due to a communication of the pleural space that allows air to enter during inspiration but its exit is blocked during expiration. The accumulated air shifts the mediastinum and stops central venous blood flow [8].

Pneumomediastinum

This condition is present in up to 39% of chest traumas, and up to 2% of these cases may be associated with a tracheobronchial tear. For this reason, the presence of pneumomediastinum justifies a bronchoscopy [9].

The condition arises from the presence of air around the mediastinal structures, which dissects the fascial planes and spreads to the neck. In most cases, this can be explained by the Macklin effect, described in 1939 [10], in which three phases are recognized:

- Alveolar leak
- Air dissection along the peri-vascular sheet
- Spreading of interstitial emphysema into the mediastinum

Pneumomediastinum appears as translucent streaks near the small blood vessels of the lung and the bronchus and is caused by the breaking of the alveolar wall. A small amount of air spreads into the anterior mediastinum and the retropharyngeal space [11].

Subcutaneous emphysema created by rib fractures, with or without pneumothorax, can progress along the fascial planes of the neck and into the mediastinum, where the air can break the pleural sheet and cause a pneumothorax; generally, the reverse is not possible [12] (Fig. 3).

Tracheobronchial Tears

These account for less than 2% of closed-chest trauma. Their identification is extremely difficult and may be suspected when there is pneumothorax + pneumomediastinum + subcutaneous emphysema [13]. In up to 80% of cases, the tear is found to be about 2.5 cm from the carina; the most vulnerable tissue is the pars membranacea, which extends from the supraglottic plane to the main bronchial stems (Fig. 4).
Even by MDCT, it is always very difficult to recognize tracheobronchial tear. Indirect findings are the caudal dislocation of the upper bronchus, which becomes oriented obliquely, and bronchocele [9].

**Pneumopericardium**

This extremely rare condition occurs when air enters the pericardial sac through a leak; it is not a consequence of pneumomediastinum (Fig. 5). A compressive force on the sternum generating a heart vibration is the most common cause. Pneumopericardium is generally located along the left side, near the phrenic nerve, and can be long enough to cause a hernia of the heart [14].

**Flail Chest**

The incidence of flail chest is about 37% in patients with major chest trauma; it is characterized by contiguous multi-segmental rib fractures associated with a paradoxical breathing movement of the chest wall. The condition is always very difficult to observe in patients with superficial breathing, strong muscles, large breasts, or who are obese. While multiple rib fractures can be identified on X-ray, MDCT examination is relevant because the injury is often associated with major lung, vessel, and cardiac lesions [15].

**Hypovolemic**

**Vascular Lesions**

Fractures of the first two ribs are often associated with brachiocephalic vessel tears. Scapular-thoracic dislocation in up to 100% of cases is associated with tears of the axillary vessels or axillary pseudoaneurysm (Fig. 6), with large subcutaneous hemorrhage potentially involving the fascial planes of the chest cage [16].

In trauma affecting the cervical spine, tears may occur in the thyrocervical or vertebral arteries, or the azygos or mediastinal veins, resulting in each case in a large hematoma that can spread as far as the fascial planes of the neck and cause hypoxia and hypovolemia [17] (Fig. 7a, b).

Aortic traumatic injury is responsible for a high mortality; only 30% of the patients arrive alive at the trauma center [18]. Such injuries range from an intimal tear to the involvement of the entire wall. They may be < 1 mm or involve the entire vessel diameter.
The aortic isthmus is the maximum stress point. Pseudo-aneurysm is present in 90% of vascular lesions due to trauma and is considered focused if the anomaly involves less than half of the wall, and wide if more than half of the aortic diameter is affected [19] (Fig. 8).

Pseudo-aneurysm is associated in almost all cases with an intimal flap that is generally limited to the tear site and most often presents in one or more arches of low density in the vessel lumen. A flap may be associated with the presence of thrombus without any evidence of pseudo-aneurysm [18] (Fig. 9a, b).

**Cardiac Lesions**

These represent about 5% of cases and the spectrum is very wide; however, cardiac lesions are always associated with sternal fractures. The most vulnerable structures are the right ventricle, the left coronary artery, and the left valves [17]. Cardiac lesions are the highest cause of mortality at the vehicle-accident site [16].

**Abdominal Trauma**

Approximately 10% of all trauma deaths are due to abdominal injuries [20]. Abdominal injuries due to blunt trauma are often initially overlooked because the injuries may not manifest themselves clinically during the initial assessment and the presence of other, more obvious injuries (brain or chest injuries) may divert the attention of the initial assessor from potentially life-threatening intra-abdominal pathology.

Compressive forces can cause injuries of solid parenchymal organs, such as spleen, liver, and pancreas, or they can increase the intraluminal pressure in hollow organs, such as bowel, resulting in rupture.
Blunt abdominal trauma is frequently associated with peritoneal fluid collections (Fig. 10). CT is extremely sensitive in detecting even small quantities of intraperitoneal fluid [21, 22], may quantify the degree of hemoperitoneum (Fig. 11), and can reveal associated injuries of abdominal organs (Fig. 10). Density measurements are required for all fluid collections because it is important to distinguish ascites or urine (0–15 HU) from hematoma (20–40 HU) and active bleeding [23].

The “sentinel clot” sign refers to a collection of clotted blood (40–70 HU) located close to an organ injury (Fig. 12). Active bleeding is recognized as extravasated contrast medium (85–350 HU) [24] (Fig. 13).

Generally, free fluid is found in the posterior liver pouch (Morrison’s pouch), in the rectal-bladder

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**Fig. 9 a, b.** (a) Atypical descending blunt aortic lesion revealed by an intraluminal-filling defect (arrow) that corresponds to an intimal clot (b) with no evidence of pseudo-aneurysm. Posterior mediastinal hematoma and bilateral hemothorax are present.

**Fig. 10.** Free intraperitoneal blood spread in Morrison’s pouch (arrow), the peri-splenic space (arrow), and the pelvic space (arrow) associated with multiple liver lacerations (arrow)

**Fig. 11.** Massive intraperitoneal hemorrhage with a denser mesenteral hematoma (arrows)
pouch in males, and in Douglas’ pouch in females, in
the peri-hepatic and peri-splenic space, in the para-
colic gutter, and in mesenteric folds [25] (Figs. 10, 14).

Liver Lesions

The prevalence of liver injury in patients with blunt mul-
tiple trauma has been reported to be 1–8%. However,
organ injuries can be detected with MDCT in up to 25%
of patients [26]. Mortality ranges from 4.1 to 11.7% [27].

The right lobe, which is the largest portion of the liver,
is the most frequently affected. The superior-
posterior segments are the most vulnerable and are
involved in 65% of cases because they are related to
fixed structures, i.e., the coronary ligaments, ribs, and
spine (Fig. 15). In the left lobe, traumatic lesions are
extremely rare and are generally a result of anterior
compression of the liver against the spine.

Classification

Liver lesions are usually classified according to the
criteria of the American Association for the Surgery
of Trauma (AAST) [28]. The degree of injury to the

Fig. 12. Clotted blood collection of the posterior peri-hepatic space (white arrow). Note the liver laceration exten-
ing to the left portal branch (black arrow)

Fig. 13. Massive retroperitoneal and mesenterial hemorrhage with area of active bleeding (arrow) of the left an-
terior para-renal space. The renal veins and inferior vena ca-
va are collapsed (arrow)

Fig. 14. Free peritoneal and intermesenterial fluid in the upper abdomen adjacent to small-bowel wall thickening. At surgery, a jejunal injury was found

Fig. 15. Central liver laceration and posterior subcapsular hematoma with a minimal amount of pleural fluid (arrow)
spleen and liver is based on the extent of anatomic disruption of an individual organ and is scaled from 1 to 6, representing the least to most severe injury. Grades 1–5 represent increasingly complex injuries encountered in patients who can be rescued, while grade 6 is a destructive lesion that generally is incompatible with survival.

The classification does not give importance to hemoperitoneum, since its severity does not generally relate to lesion extension. The ruptured capsule of the liver is sometimes associated with minor lesions and may cause extensive peritoneal bleeding, whereas when the capsule is not involved even major lesions do not cause large-scale hemoperitoneum [29].

Peri-portal tracking has been described in blunt hepatic trauma. It is characterized by zones of low CT attenuation in the liver along the course of the portal vein and its branches. In liver trauma, periportal tracking is more frequently focal and associated with an adjacent laceration and hematoma. It is possible to observe the peri-portal tracking sign in non-traumatic conditions in which there is lymphatic obstruction; in these cases, it generally involves the entire liver [30].

Subcapsular hematoma appears as a biconvex homogenous or heterogeneous low-attenuation blood collection within the liver capsule (Fig. 16). Intrahepatic hematoma appears as a rounded low-attenuation zone within the liver parenchyma [31] (Fig. 17).

Laceration is a parenchymal tear with divaricated borders and is generally parallel to the suprahepatic vessels (Fig. 18) or perpendicular to the portal vessels. The mechanism of action is generally a force that acts close to the central vessels such that their vibration together with the transmission of the crash wave to contiguous parenchyma results in tears. Complex lesions are frequently associated with biliar tears [32].
Laceration of the posterior liver and extending to the bare liver area result in extraperitoneal bleeding within the retroperitoneum, in the anterior peri-renal space, around the right adrenal gland and kidney, or close to the inferior vena cava [33].

Liver fracture is a deep lesion that spreads from side to side; it can result in segmental or lobar avulsion (Fig. 20). A shattered liver involves severe parenchymal breaking with necrosis of the parenchyma.

About 90–95% of liver lesions are treated conservatively. The current therapeutic approach has undergone variations due to changes in diagnostic CT techniques and hemodynamic criteria [34]. Recent case studies have shown that even major lesions associated with hemoperitoneum may be conservatively treated with success, if the patient’s hemodynamic condition remains stable. Hemodynamic stability is usually guaranteed if the patient is under continuous observation, and immediate surgery is possible if the patient’s condition worsens [35]. Nowadays, therefore, the only lesions that need immediate surgery or interventional radiological treatment are those associated with vessel involvement, such as arterial transaction with liver infarct, hepatic branch artery pseudo-aneurysm (Fig. 21a, b), and portal branch avulsion, i.e., conditions associated with active vessel bleeding [36] (Fig. 22).

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**Fig. 19.** Multiple linear and branching low-attenuation areas in the right hepatic lobe represent complex lacerations. Hemoperitoneum in peri-hepatic and peri-splenic spaces are present (arrows)

**Fig. 20.** Deep hepatic laceration extending from the internal to the external side of the right lobe, representing fracture (black arrow). Hemoperitoneum (white arrow), right adrenal (red arrow), and peri-pancreatic hematoma are present (yellow arrow)

**Fig. 21.** (a) Deep left-lobe hepatic lacerations associated with a pseudo-aneurysm (arrow) of (b) a segmental branch of the left hepatic artery (arrow)
Splenic Lesions

The spleen, because of its spongy consistency and complex ligaments, is the organ most frequently involved in blunt abdominal trauma, accounting for about 40% of abdominal-organ injuries [20]. The spleen is also the most affected because it is only partially protected by the ribs (Fig. 23). Splenic lesions are classified according to AAST criteria [28] and are divided into low-grade (1–2) and high-grade (3–5) lesions. The current tendency is to treat low-grade lesions conservatively in order to preserve the spleen’s immunological function [37].

Lacerations extending through the splenic capsule result in hemoperitoneum. Transverse lesions are parallel to the trabecular vessels and may cause much more bleeding than longitudinal lesions, which cross trabecular vessels and lead to extensive hemoperitoneum [38] (Fig. 24). Both such lesions and centroparenchymal hematoma can show a contrast blush, indicative of an active hemorrhage or a pseudo-aneurysm (Fig. 25). Hemoperitoneum can have
a striped aspect due to intermittent bleeding. Splenic hilar avulsion may appear as a pseudo-aneurysm or with copious active bleeding.

**Mesenteric and Intestinal Injuries**

Bowel and mesenteric injuries are found in approximately 5% of all patients undergoing surgery after blunt abdominal trauma. The diagnosis of these injuries is critical in that life-threatening hemorrhage may result from disrupted mesenteric blood vessels, and peritonitis from bowel rupture or infarction (Fig. 26a, b).

Although the sensitivity of MDCT technology for the depiction and detection of solid-abdominal injuries has significantly improved, early clinical [39] and CT diagnosis of mesenteric and intestinal injuries remains difficult [40, 41]. Nevertheless, CT is still the primary imaging modality for diagnosing mesenteric/intestinal injuries by providing a wide spectrum of signs that often sufficiently correlate with the type, site, and extent of the damage [42-43].

The most frequent CT signs of mesenteric/intestinal injuries after blunt trauma are:

1. **Free fluid.** This very frequent finding may be the only sign of a significant mesenteric/intestinal injury after blunt trauma [44]. It is important to measure the density of the fluid and to examine its location [40, 43]. Fluid located between the mesenteric ligaments (mesenteric triangles) is a significant finding (Fig. 27). Larger amounts of fluid in additional locations increase the severity of the injury.

2. **Pneumoperitoneum.** This sign is commonly related to a hollow visceral perforation. However, in the trauma setting, it may be related to other conditions, even extraperitoneal sources (e.g., pneumothorax, barotrauma) [41]. Furthermore, bone or lung settings may be the site of pneumoperitoneum. The first CT exam may be negative [40, 43, 44].

3. **Oral contrast leak.** This is a specific sign of intestinal injury [40]. However, the use of oral contrast medium in a CT examination remains a controversial issue. The material spreads only in the low-resistance peritoneal spaces [40, 41].

4. **Thickened bowel wall.** This is an indirect sign that may refer to a full-thickness injury, in most cases an intramural hematoma (Fig. 14) [42]. Comparison of the injured bowel with adjacent nor-

![Fig. 26.](image)

*(a)* Free blood in the mesenterial folds, with active bleeding (*arrows*) and *(b)* associated with a jejunal traumatic infarction (*arrow*) caused by a laceration of the mesenteric arterial branch

![Fig. 27.](image)

Large hematoma at the hepatoduodenal ligament (*arrows*)
mal loops is useful. It is important to differentiate “thickened bowel wall” (Fig. 28) from “shock bowel” or submucosal edema due to perfusion therapy [42].

5. Bowel-wall enhancement. This “patchy increased density in the bowel with a thickened wall” is often associated with mesenteric edema [45]. This sign requires a careful follow-up. Again, comparison of the injured bowel with adjacent normal loops is useful (Fig. 28).

6. Bowel-wall discontinuity. Direct visualization of a tear in the bowel wall is a specific sign, although very rarely encountered [46].

7. Active extravasation of intravenous contrast material. This is an important sign of mesenteric injury and often necessitates surgical intervention and/or vascular embolization [40, 41, 47] (Fig. 13). It has become increasingly detectable by MDCT. Mesenteric hematoma must be searched for to ensure accurate management [47-49] (Fig. 29).

Pancreatic Lesions

Pancreatic traumatic lesions are rare, varying from 2 to 7% of abdominal traumas. Pancreatic bleeding in the first 24 h accounts for 10–25% of trauma-related mortality [50]. The classic traumatic mechanism is the pancreatic gland impacting against the spine.

Early diagnosis is difficult as clinical and laboratory findings are not specific. These lesions are frequently misinterpreted because of their small size [51]. Occasionally, the pancreas appears normal at CT when lacerations are present, since it may return to its original contour after these injuries have occurred [52].

Isolated injuries are rare; in 60% of cases these are associated with duodenal lesions or lesions affecting other abdominal organ (liver, spleen, kidney).

The classification mostly followed is the one proposed by Jeffrey [53] and is based on the severity of the pancreatic damage. Grade 1 is simple contusion caused by tissue attrition, without breaking of the capsule. The affected portion swells as a result of the presence of interstitial blood and fluid. Cephalic trauma is frequently associated with duodenal trauma, with a hematoma or gas bubble in the posterior right para-renal space (Fig. 30). Grade 2 corresponds to a minimal tear without involvement of the main duct. Grade 3 is a partial tear involving 50% of the pancreatic thickness but not the main duct. These tears are very thin and difficult to observe, even if the borders are separated by blood or pancreatic fluid [50] (Fig. 31). Grade 4 is a complex injury involving the main pancreatic duct. The presence of a large fluid collection should raise suspicion of this type of injury.

It is extremely important to differentiate between grade 1–2 and grade 3–4 lesions because the former can be treated conservatively, while the latter require surgery. In the first 6 h, there can be a high

Fig. 28. Enhanced segmental thickness in a small-bowel loop caused by parietal hematoma (arrows)

Fig. 29. Massive hemoperitoneum (black arrow) with mesenterial hematomas (white arrows) that displace small-bowel loops
rate of false-negative signs but also of indirect findings. The latter [54] include: peri-vascular fluid around the splenic branches (Fig. 32) or the superior mesenteric vessels [50]; a thickened anterior para-renal fascia (Fig. 33); fluid in the transverse mesocolon; fluid in the lesser sac; and blood in the mesenteric root.

The complication rate of misinterpreted pancreatic tears is about 18% in patients in whom the diagnosis was made in the first 12 h after the traumatic event.

Pancreatitis can be observed in 36% of patients and is due to post-traumatic stenosis of the main pancreatic duct. Other complications are pseudocysts, abscess (Fig. 34), and ductal fistulae.

Fig. 30. Hematoma at the pancreatic head displaces the duodenum (black arrows) and mesenteric vessels (white arrow)

Fig. 31. Laceration of the pancreatic tail, with separation of fragments by a small amount of fluid (arrows)

Fig. 32. Peri-pancreatic fluid collection surrounding the splenic vessels, oriented parallel to the long axis of the pancreatic tail (arrow)

Fig. 33. Large fluid collection in the left anterior para-renal space due to pancreatic injury (arrows). The pancreatic head is swollen and hypodense (arrow)

Fig. 34. Gas-bubble fluid collection of the peri-pancreatic space representing an abscess, with increased density of the surrounding fat (arrows)
Conclusions

Multi-traumatized patients, even those with altered degrees of consciousness, can be treated non-operatively without increased mortality or morbidity [55, 56]. In fact, this approach is currently accepted as the standard of care. The shift from surgical to non-surgical management of blunt trauma can be attributed to the generalized use of helical CT, which accurately delineates the pathologic anatomy, helps to determine the severity of injuries, quantifies the severity of blood collections, and reveals associated lesions of the body.

CT scan can also be used to assess the healing process, from the evaluation of high-grade lesions to the confirmation of a successful outcome.

References


