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Evaluation of blunt abdominal trauma with multi detector CT: special emphasis to bowel and mesenteric injury

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Abstract
Multidetector computed tomography (CT) is the primary imaging modality for diagnosing bowel and mesenteric blunt trauma. Pneumoperitoneum is the commonly observed for imaging sign among radiologists. There are, however, other CT findings with different clinical significances. The aim of this article is to heighten radiologist awareness regarding the diagnostic capability of CT in bowel and mesenteric blunt trauma, and to illuminate potential pitfalls to be avoided in this patient population. This guide was developed to enhance the knowledge and awareness of non-expert radiologists that may be less aware of the nuances of abdominal CT imaging in a blunt trauma setting. This enhanced knowledge and awareness will improve patient diagnosis, treatment, and outcomes.

Introduction

Bowel and mesentery are injured in an estimated 1–5% of cases after blunt trauma[1], and this is the third most com- mon type of injury from blunt trauma to the abdomen[2]. Delayed or missed diagnosis is multifactorial. Symptoms may be absent on initial presentation and, when present, may be nonspecific. Moreover, clinical assessment alone can be unreliable due to the presence of concomitant injuries[3].

Investigation by cross-sectional imaging in blunt trauma depends on the hemodynamic status of the patient. If the patient is hemodynamically unstable with overt signs of abdominal injury, the patient should undergo surgery immediately with no need to perform any imaging method. When three abdominal solid organs are injured, the risk of bowel injury is 34%[4]. Bowel and mesenteric injury can be difficult to detect for several reasons, including the presence of concurrent injuries, injury to multiple bowel segments, and the presence of subtle imaging features.

Diagnostic tools in patients with abdominal injury include peritoneal lavage, sonography, and computed tomography. Of these three modalities, CT is the most sensitive and specific for diagnosis of bowel and coexisting mesenteric injury. Among the spectrum of imaging findings in bowel injury, pneumoperitoneum is a commonly observed imaging sign among radiologists. However, there are other CT findings with differing levels of clinical significance. The aim of this article was to heighten radiologist awareness regarding the diagnostic capability of CT in traumatic bowel injury with and without coexisting mesenteric injury, and to illuminate potential pitfalls to be avoided in this patient population.

The role of the radiologist

In this clinical setting, the role of the radiologist is

to pro- vide all essential related information, including detection of bowel injury and/or mesenteric injury, identification of patients requiring immediate surgical management, and assessment of severity and related complications, including active bleeding, ischemic complications, and peritonitis.

Common sites of Bowel Injury

The most common site of bowel injury is the small intestine, with the proximal jejunum near the duodenojejunal junction or ligament of Treitz, and the terminal ileum being most commonly affected. Both are relatively mobile bowel sections that share a common border with fixed segment, which can result in shearing injury. Large intestinal injury is comparatively uncommon, with this type of injury found in only about 20% of cases[5], and most of these injuries are partial-thickness tears. The duodenum is the segment least frequently involved in blunt abdominal trauma; however, cases that involve the duodenum are frequently associated with pancreatic injury[6].

Importance of early detection of bowel and mesenteric injury

The high rate of delayed and missed diagnosis in bowel injury can be attributed to many factors, including the infrequency of bowel injury compared to other abdominal organ injuries, the limited ability of non-expert radiologists to recognize the imaging features of bowel and mesenteric injury, and the limited specificity of associated clinical signs and laboratory findings. Delayed diagnosis by as few as 8 h may result in high mortality rate and severe complications, including bleeding, peritonitis, and sepsis[3,4] (Fig. 1).

Fig. 1 Delayed diagnosis of bowel injury. A 40-year-old man with motor vehicle accident 2 weeks before the scan, presented with sep- sis. Axial contrast-enhanced CT performed 7 days after the patient sustained blunt abdominal trauma shows segmental jejunal wall thickening (arrow) and jejunal perforation with bowel content at the site of wall disruption (arrowhead). A large intra-abdominal collection can be observed (star)

Identification of bowel and mesenteric injuries that require surgery

Full-thickness tear or perforation, devascularized bowel, and serosomuscular tear are findings that require early recognition and surgical treatment [6, 7]. A potential pitfall is that perforations and tears are sometimes too small to identify on CT. Diagnosis, therefore, relies on indirect imaging signs. Active mesenteric bleeding and mesenteric vascular injuries that cause bowel devascularization are emergent surgical conditions. The imaging signs of mesenteric injuries are more subtle than those of bowel injury, but early recognition is important to ensure appropriate surgical management.

Diagnostic imaging modalities in bowel trauma

Plain radiograph

Plain radiograph is not sensitive enough to exclude surgically significant bowel and/or mesenteric injury, but it remains a useful tool for detecting pneumoperitoneum in certain cases. Plain radiographs require larger amounts of free intraperitoneal air for detection, but small amounts

of extraluminal air or pneumoperitoneum may not be detectable. Nonspecific findings of bowel injury may be detected, including dilated bowel loops, soft tissue density, and mass effect, which suggest fluid and loss of psoas margin. More than 800 ml of free intraperitoneal fluid must be present to be detected radiographically[8]. Plain radiographs are of little utility in the setting of blunt trauma, but they are often obtained following penetrating trauma to detect metallic bullets, shrapnel, or foreign bodies.

Ultrasonography (US)

Although focused ultrasound assessment in trauma has been widely accepted as a valid tool for evaluating patients with abdominal trauma, US has a sensitivity of 86% for detection of free intra-abdominal fluid, but is nonspecific for organ injury and bowel injury[9]. Potential pitfalls include physiologic fluid, such as intra-abdominal fluid found in young woman in puberty, aggressive hydration, and other pathologic conditions, such as hemoperitoneum that can be caused by various diseases. Other potential pitfalls include bowel wall thickening or disruption and intramural bowel wall hematoma, because they are difficult to identify for reasons that include anatomical factors relating to the location of the injury (e.g., retroperitoneal location), sectoriality of the examination, and lack of patient cooperation in an acute trauma setting[10].

Magnetic resonance imaging (MRI)

Although MRI has the advantage of no patient radiation exposure, MRI is not routinely used for the initial evaluation of patients with blunt abdominal trauma or traumatic bowel injury due to prolonged scanning time, presence of artifacts from bowel movement, limited sensitivity for detecting pneumoperitoneum, and the requirement for an experienced interpreter.

Computed tomography (CT)

In hemodynamically stable patients, multidetector CT is the imaging modality of choice in this clinical setting. It pro- vides more information than diagnostic peritoneal lavage (DPL) and US, to include grading, sites of injury, and presence of complication. The retroperitoneum, which is difficult to assess by US or DPL is also well visualized.

CT imaging protocol

Multidetector CT with high-resolution protocol, slice thick- ness, and reconstruction interval values equal to 1 mm should be performed, and then completed by multiplanar reconstruction [11–13]. Non-contrast-enhanced CT is essential in patients with clinical suspicion of bowel and mesenteric trauma for the following reasons:

- The density of luminal fluid and bowel wall will be assessed at baseline before contrast enhancement to facilitate differentiation between intramural hematoma and bowel wall enhancement (Fig. 2).
- Comparison of fluid density between non-enhanced and enhanced phase helps to distinguish hemoperitoneum from other intra-abdominal fluid collection.
- Mesenteric stranding can be easily identified in non- enhanced phase of mesenteric vessels [13].
- A biphasic technique, including arterial and venous assessment after intravenous infusion of 120–150 ml of iodinated contrast agent at a flow rate ≥ 3 ml/s, is recommended to detect active bleeding and abnormal enhancement of the bowel loops[13]. The delayed phase can be useful for excluding low-flow active bleeding. Reformatted images on coronal and sagittal view are also obtained.

The advantages of using oral contrast include improved delineation of bowel wall thickness and improved ability to identify contrast leak; however, administration of oral contrast in blunt abdominal trauma remains controversial. Oral contrast administration is currently discouraged or is not routinely used in patients with blunt abdominal trauma, because it is time-consuming process that may significantly adversely affect the

patient's prognosis by delaying the identification of active bleeding that requires urgent intervention. Time-related factors include the time required to prepare and administer the contrast, and the relatively long transit time that is required to completely opacify bowel loops. Potential pitfalls include spread of the extravasation of contrast from intraperitoneal bladder rupture that may mimic the spillage of oral contrast material from bowel loops, and extraluminal oral contrast material from traumatic bowel loop may mimic extravasated contrast material from ruptured vessel [11, 14–17].

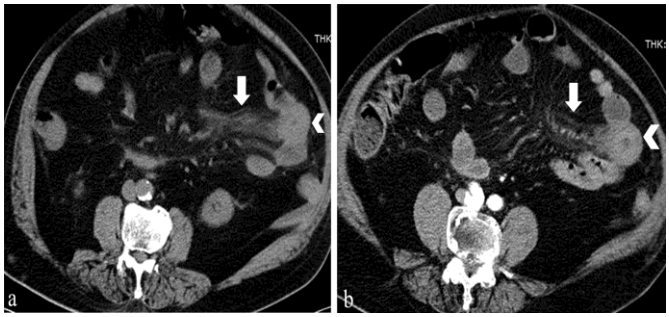

Fig. 2 A 29-year-old man with blunt abdominal trauma. **a** Axial non- contrast-enhanced CT shows short segment of high-density hematoma at mid-jejunum (arrowhead), and moderate mesenteric stranding at medial aspect of this jejunal segment (arrow). **b** Axial contrast- enhanced CT shows wall thickening at the segment of jejunal hematoma (arrowhead) and mesenteric stranding (arrow)

Common features in bowel and mesenteric injuries

Intra-abdominal fluid

Intra-abdominal fluid identified in a trauma patient can be related or not related to bowel and/or mesenteric injury. A careful search for other more specific findings is needed to identify the source of the fluid. Observed fluid could be one or more of the followings: blood from bowel or solid organ injury, urine from urinary tract injury, bile from biliary tract injury, fluid from prior DPL, pancreatic fluid from pancreatic duct disruption, and/or bowel content from bowel injury[6].

Fluid location is the key imaging factor. If fluid, such as blood or bowel content, occurs within the inter bowel loop and between leaves of mesentery, it is more likely to be bowel or mesenteric injury. If, however, blood or fluid is observed in the pelvic or paracolic gutter, it is more likely to associate with solid organ injury. In some instances, the exact location of fluid can provide a clue to the source of injury. For example, fluid in the anterior pararenal space is associated with injury at the second and third portions of the duodenum (Fig. 3).

About 3% of male patients may have a small amount of hypo attenuating simple fluid in the pelvis without an associated intra-abdominal injury[18]. Female patients, in particular premenopausal female patients, frequently have a small amount of simple physiologic fluid[18]. Some trauma centers will admit patients for clinical observation when isolated free fluid is observed in a trauma setting[19]. Surgery may be indicated in patients with an increase in free fluid or in those who remain hemodynamically unstable over time.

The potential pitfall is that abdominal fluid can accumulate from a combination of injury sources, such as combined bowel/mesenteric and solid organ injury. It is important to point out that diagnosis of bowel or mesenteric injury often goes unrecognized in combined injury settings.

Another important potential interpretation pitfall is failure to differentiate inter loop fluid from fluid within bowel loops. Shape or configuration of fluid is a helpful feature for distinguishing between these two types of fluid accumulation. Mesenteric or inter loop fluid frequently manifests as triangular or V-shaped between mesenteric leaves[20, 21], which is easily distinguished from the more rounded shape of fluid within bowel loops. In equivocal cases, follow-up CT with oral contrast agent is recommended to opacify the bowel loops. Preexisting ascites may also cause confusion, since ascites accumulation may mimic fluid observed in bowel or mesenteric injury. Another pitfall is that free peritoneal fluid will

accumulate in the peritoneal cavity following massive fluid resuscitation without any evidence of bowel injury[22].

Pneumoperitoneum: significance and pitfalls

Pneumoperitoneum is found on CT in 20–75% of patients with proven bowel perforation[23]. The amount of extra intestinal air can vary, ranging from air that occupies the entire peritoneal cavity to a very small amount with only a few air bubbles observed outside the bowel lumen [24, 25] (Fig. 4). Small amounts of free air can easily be overlooked [15,26]. To avoid this potential pitfall, the use of wide-window set- tings on CT can help to improve detection. Observation for pneumoperitoneum in all phases (non-contrast, venous, and delayed contrast) is recommended, because extraluminal air will sometimes appear in only one acquisition, and when foci of extraluminal air are identified in association with thickened

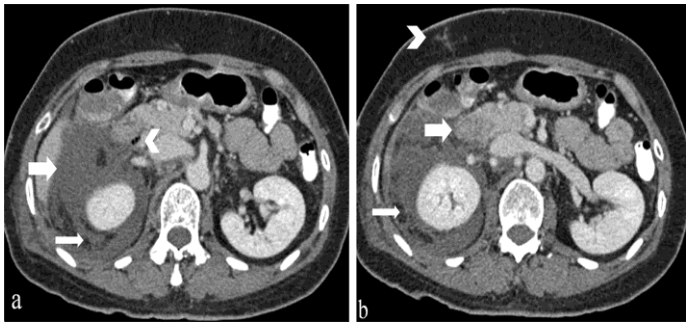

Fig. 3 A 36-year-old man with duodenal injury. **a** Axial contrast- enhanced CT shows duodenal injury with small extraluminal air bubbles (arrowhead). A moderate amount of fluid is seen at right anterior pararenal space (arrow), with extension of fluid into right perinephric space (thin arrow). **b** Axial contrast-enhanced CT shows duodenal wall thickening (arrow) and fluid at right retroperitoneal space (thin arrow). Abdominal wall injury can be observed as mild skin thickening and subcutaneous fat stranding at right anterior abdominal wall (arrowhead)

Fig. 4 A 55-year-old man with jejunal injury. Axial contrast- enhanced CT shows localized jejunal wall thickening (arrow) and adjacent extraluminal air (arrowhead). Jejunal full-thickness tear was found at surgery. A moderate amount of intra-abdominal fluid and pneumoperitoneum can be observed (thin arrow)

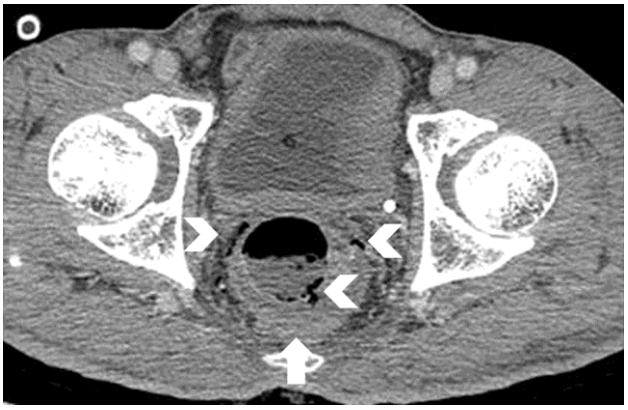

Fig. 5 A 44-year-old man with pelvic blunt trauma. Axial contrast- enhanced CT shows multiple areas of extraluminal air at the extra-peritoneal portion of rectum (arrowheads). Perirectal hematoma can also be observed (arrow). Rectal full-thickness tear was found at surgery

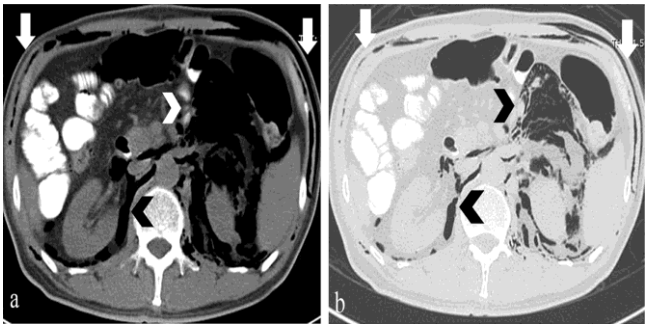

Fig. 6 Pseudopneumoperito- neum. **a** Axial non-contrast- enhanced CT shows air accumulation in both the abdominal wall (arrows) and the bilateral retroperitoneal spaces (black and white arrowheads). **b** Axial non-contrast-enhanced CT on lung display setting shows better delineation and extension of air in the abdominal wall (arrows) and bilateral retroperitoneal spaces (black arrowheads) bowel loop, mesenteric stranding, or interloop fluid, the possibility of bowel injury is increased[26].

In addition, no visualized pneumoperitoneum on cross-sectional imaging or CT does not exclude the presence of bowel perforation, because small extra intestinal air can be spontaneously reabsorbed by the peritoneum, the development of ileus can prevent gas leakage, and the perforation can be partially sealed off.

Another potential pitfall is that air that is confined between the parietal peritoneum and the inner layer of the abdominal wall can mimic pneumoperitoneum on the axial plane. This can be caused by rib fracture, injury to the extraperitoneal portion of the rectum (Fig. 5), and injury to retroperitoneal organ[27,28] (Fig. 6). Although pneumoperitoneum is a suggestive imaging sign, but not a pathognomonic sign of bowel perforation, other intraabdominal pathol- ogies can cause pneumoperitoneum, including recent post-surgical abdominal laparotomy; benign causes, such as scleroderma; intra- peritoneal rupture of urinary bladder; and massive pneumothorax with diaphragmatic rupture.

Radiologists must, therefore, remember to observe for associated mesenteric injury and other specific and less specific signs—not just for pneumoperitoneum.

Direct CT findings in bowel injury

Bowel discontinuity or interruption of the bowel wall

Although this finding is 100% specific, it has a low sensitivity of about 7%[29]. This is due to the fact that the majority of lesions in bowel injury cases are small and not of "full thickness", which makes them difficult to identify on CT. Often- times, these lesions become evident only after meticulous inspection at surgery. Therefore, all loops of bowel must be carefully assessed on CT in patients with abdominal trauma (Fig. 7).

Fig. 7 A 25-year-old patient with upper rectal injury. Axial contrast- enhanced CT shows upper rectal wall disruption (peritonealized part of rectum) with extraluminal air (arrowhead). A few areas of pneumoperitoneum are seen (arrows). Fluid accumulation can also be observed at the right lower abdomen (star)

Extraluminal contrast extravasation

Extraluminal oral contrast extravasation (in the rare setting in which oral contrast material is administered) is another specific sign of bowel perforation[29] (Fig. 8). The pitfalls that lead to a false-negative finding include scanning too early before the contrast reaches the location of the bowel perforation, and dilu- tion of a small volume of extraluminal oral contrast in a large volume of intraperitoneal fluid. Another potential pitfall that needs to be considered is the possible presence of intraperitoneal bladder rupture, given that extravasation of contrast from

Fig. 8 A 45-year-old man with jejunal injury. Axial non-contrast- enhanced CT performed with oral contrast administration shows jeju- nal wall thickening (arrowhead), jejunal full-thickness tear, and extra- luminal contrast (arrow), and fluid collection at the left side of the abdomen (star) bladder injury may resemble oral contrast agent from bowel injury. Importantly, this finding is detected only on the delayed bladder phase, which serves as the key difference.

Indirect CT findings in bowel injury

Bowel wall thickening and abnormal enhancement

Bowel wall thickening may take concentric or eccentric form, and can be observed in 45–75% of cases[30]. A potential pitfall is that actual bowel wall thickening needs to be differentiated from artifactual thickening or inadequate distention, which makes this interpretation largely subjective. Bowel walls were considered thick if they were greater than 3 mm for the small bowel and 5 mm for the colon [23, 25, 31]. Bowel wall thickening was considered as focal if it was less than 10 cm in length, and non-focal if it was longer than 10 cm[32]. However, isolated mesenteric vascular injury can cause localized or segmental bowel wall thickening, which may indicate bowel ischemia. It is, there- fore, important to evaluate both bowel wall enhancement and bowel wall thickening to rule out bowel ischemia.

It is uncommon to observe diffuse bowel wall thickening in bowel contusion. However, it may be observed in cases with hypoperfusion complex or after excess fluid resuscitation[33]. In hypoperfusion complex, there are other associated imaging features, such as inferior vena cava flattening, increased bowel wall enhancement, increased adrenal enhancement, and decreased splenic enhancement (Fig. 9). However, there is no increased bowel wall enhancement in

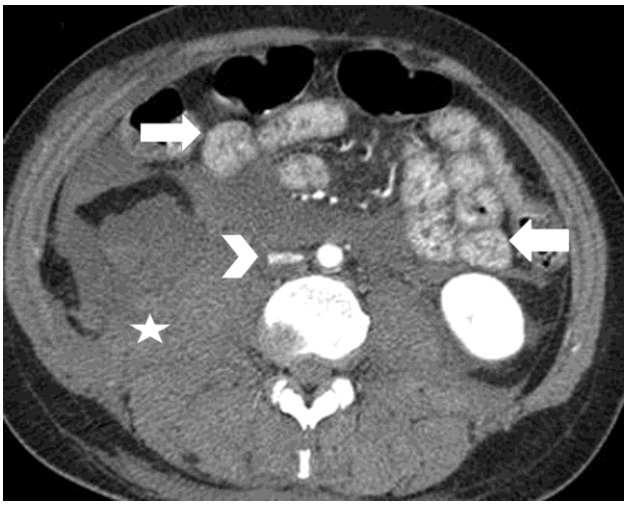

Fig. 9 A 33-year-old man with hypoperfusion complex. Axial con- trastenhanced CT shows diffuse bowel wall thickening and increased enhancement (arrows), flattened inferior vena cava (arrowhead), and right retroperitoneal hematoma (star) diffuse bowel wall thickening that associates with volume overload.

Abnormal bowel wall enhancement is not a specific sign of injury. Abnormal bowel wall enhancement can be classified as homogeneous, patchy/inhomogeneous, or absent. Homogeneous increased enhancement of long segments of bowel that is caused by increased vascular permeability can be observed in trauma patients with prolonged hypoperfusion. Patchy/inhomogeneous increased enhancement, although uncommon, can also be observed in bowel injury. Absent bowel wall enhancement can occasionally be observed in bowel injury, but more often in bowel ischemia associated with mesenteric vascular injury.

Direct CT findings in mesenteric injury

Active contrast extravasation

This sign has 100% specificity for diagnosis of significant mesenteric injury. Mesenteric tear that is associated with mesenteric vascular injury can

cause catastrophic hemorrhage or hemoperitoneum[34]. CT findings in patients with active contrast extravasation or active hemorrhage reveal high-density linear or irregular jet of contrast material characterized by densitometric values similar to those of contrast medium in the lumen of arterial vessels, with increases in size over time or on delayed phase [34] (Figs. 10, 11). This finding is a strong indication for immediate surgical exploration. Bowel infarction or ischemia due to vascular deprivation can also occur. The pitfall is that mesenteric vascular injury with potential bowel ischemia will not likely be conspicuous on the initial CT, so follow-up CT may be necessary.

Injury to the mesenteric vasculature

Mesenteric vascular beading (vessel irregularity), pseudoaneurysm, and termination or abrupt cut-off of mesenteric vessel are highly specific for significant mesenteric injury (Fig. 12). Trauma only rarely results in arterial dissection. The pitfall is that mesenteric vascular injury may not be recognized on the axial plane, but may be more conspicuous on the sagittal or coronal plane. The authors recommend multiplanar reformation using the coronal, sagittal, and axial views to evaluate mesenteric vasculature due to the orientation of mesenteric vessels (Fig. 13). Mesenteric vascular injury is associated with potential risk for bowel ischemia; therefore, surgical repair is usually performed[34].

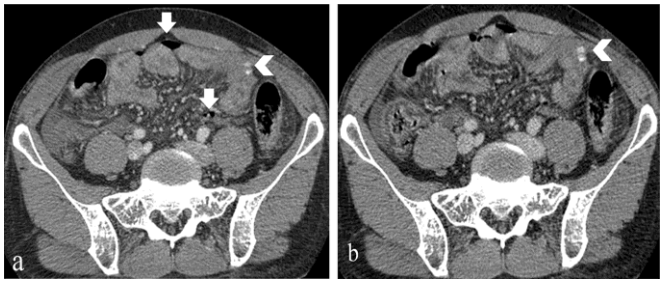

Fig. 10 A 45-year-old man with jejunal mesenteric vascular injury. **a** Axial contrast-enhanced CT on portal venous phase shows active contrast extravasation near the wall of jejunum (arrowhead), and small volume of mesenteric air and free peritoneal air (arrows). Surgery confirmed jejunal perforation and vascular injury. **b** Axial contrast-enhanced CT on delayed phase shows increased area of active contrast extravasation near the wall of jejunum (arrowhead)

Fig. 11 A 35-year-old man with jejunal mesenteric vascular injury. Axial contrast-enhanced CT shows a puddle of active contrast extravasation at jejunal mesentery (arrow) and proximal jejunal wall thickening (arrowheads)

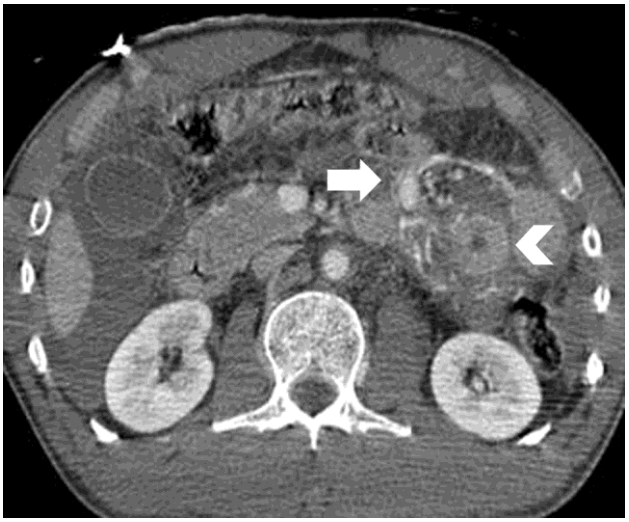

Fig. 12 A 27-year-old man with mesenteric vascular injury. Axial contrast-enhanced CT shows mesenteric vascular injury seen as pseudoaneurysm and areas of irregularity of mesenteric vessel (arrow). Associated bowel wall thickening in the region of mesenteric vascular territory and inter bowel loop fluid (arrowhead) are shown

Fig. 13 A 23-year-old man with jejunal mesenteric vascular injury. Coronal-enhanced CT shows mesenteric vessel irregularity and extravasation (arrowheads) around a thickened jejunal loop. Contrast extravasation can be observed outlining the mesenteric border of another jejunal loop (arrow)

Indirect CT findings in mesenteric injury

Mesenteric infiltration

Mesenteric infiltration or stranding is characterized by an ill-defined area of increased attenuation in fatty mesenteric folds, which is usually caused by perivascular microhemorrhage in a trauma setting. This sign has high sensitivity, but low specificity, because it can be found in various conditions, such as mesenteric panniculitis due to mesenteric inflammatory infiltrate. Mesenteric infiltration can be associated with mesenteric injury alone or combined bowel and mesenteric injury. Mesenteric infiltration or stranding is more common when bowel injury occurs along the mesenteric border[35].

Mesenteric hematoma

Mesenteric hematoma in the absence of other mesenteric or bowel injury is considered a nonsurgical condition. However, the presence of mesenteric hematoma should alert the radiologist to carefully search for any evidence of mesenteric vascular injury or associated significant bowel injury. Interloop hematoma was reported to be significantly associated with bowel or mesenteric injury, because it is not a common feature in solid organ injury[21,36]. Mesenteric hematoma that borders a thickened bowel wall is a finding suggestive of bowel injury, and is an indication for surgery.

Conclusion

Radiologist familiarity with all CT findings in bowel and mesenteric blunt trauma, as well as the pitfalls described herein, is essential for making a timely diagnosis and providing essential information to the emergency team to help guide proper and timely treatment. This guide was developed to enhance the knowledge and awareness of non- expert radiologists that may be less aware of the nuances of abdominal CT imaging in a blunt trauma setting. This enhanced knowledge and awareness will improve patient diagnosis, treatment, and outcomes.

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