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EMERGENCY RADIOLOGY (J YU, SECTION EDITOR)

Blunt Injury of the Bowel and Mesentery

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Abstract
Purpose of Review Although not common, blunt bowel and mesenteric trauma requires prompt identification and intervention to avoid significant morbidity and mortality.
Recent Findings Developments in MDCT technology especially with 64 and higher slice MDCT have improved image quality for better detection and depiction of bowel and mesenteric injury. Recent reports indicate that administration of oral contrast does not increase diagnostic accuracy, allowing for more rapid door to scan time. Dual-source CT (DS-CT) ability to generate iodine maps and virtual noncontrast images has the potential to increase conspicuity of bowel perfusion abnormalities, better distinguish hypo-perfused from nonperfused bowel, and reveal bowel wall hematoma obscured by mural enhancement.
Summary This article will review the current state-of-the-art approach in using direct and indirect MDCT signs of bowel injury in an attempt to differentiate surgical from nonsurgical lesions, and discuss imaging protocols used at our institution for follow-up imaging in nonsurgical lesions. We will also demonstrate the potential utility of DS-CT in blunt bowel injury.

Keywords Bowel injury · Emergency radiology · MDCT · DS-CT · Mesenteric trauma

Introduction

Bowel and mesenteric injuries after blunt trauma are relatively uncommon, occurring in approximately 1–6% of patients [1–3]. These injuries most often occur after motor vehicle accidents (MVA), falls, and automobile–pedestrian collisions [4]. Early recognition is important because of significant morbidity and mortality associated with complications of injury, such as peritonitis from perforation, sepsis, and life-threatening hemorrhage [5]. Delays in diagnosis, as brief as 8 h, have been shown to lead to increased rates of hemorrhage and sepsis with approximately half of the deaths attributable to delays [6, 7]. The most common site of injury is small bowel that constitutes approximately 70% of the total number of injuries, followed by colon (20%), duodenum (10%), and gastric injuries occurring in decreasing order of frequency [8, 9]. Mesenteric injuries occur three times more frequently than bowel injuries [10].

Pathophysiology

Bowel and mesenteric injuries most commonly result from motor vehicle accidents [11, 12]. The injuries are classified according to any of the physiological forces: namely,

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compression, deceleration, or a combination of both these forces [5].

Compression Forces

Compression injuries occur due to direct blow or when there is external compression of gastrointestinal tract between vertebrae and anterior abdominal wall. Compression injuries can be direct or indirect, direct injuries compress gastrointestinal tract between the spine and anterior abdominal wall resulting in mesenteric tears and perforation of bowel [5, 13, 14]. Indirect compression mechanism results in injury by transient increase in the intraluminal pressure resulting in bowel rupture, once the tensile strength of the intestinal wall is exceeded [15, 16]. Introduction of seat belts has increased the incidence of bowel and mesenteric injuries due to compression mechanism. Seat belts also cause hyper-flexion of the spine around the lap belt that acts as fulcrum resulting in distractive lumbar spine flexion fractures frequently at L2 or L3, abdominal visceral injuries, and soft-tissue injuries that include anterior abdominal wall abrasions, and in severe cases, rupture of abdominal wall musculature [5, 17] (Fig. 1). This complex of injuries is called “seat belt syndrome” and isolated abdominal wall abrasion is called “seat belt sign” [4, 18].

Deceleration Forces

Deceleration force causes stretching and linear shearing of the bowel and mesentery at the junction of fixed and mobile segments. Proximal jejunum near the ligament of Treitz, distal ileum near the ileo-cecal valve, and sigmoid colon are prone to injury from such a mechanism due to proximity to the point of anatomical fixation, where mobile and fixed portions of the gut are susceptible to shearing force [3, 19]. It was found that the speed of deceleration does not necessarily determine the severity of bowel and mesenteric injury, but rather the degree of their elongation from the anatomic attachment that determines the severity [20, 21].

Terminology

Bowel and mesenteric injuries can be classified into ‘surgical’ and ‘nonsurgical’ injuries [22]. Surgical bowel injuries include full-thickness tear of the intestinal wall with or without peritoneal or retroperitoneal contamination due to spillage of enteric contents, while surgical mesenteric injuries include active mesenteric bleeds, and mesenteric lacerations that result in devascularization of bowel (bucket-handle tear) [9, 21, 22]. Nonsurgical bowel injuries include intramural hematomas, serosal tears, and bowel contusions, while nonsurgical mesenteric injuries include mesenteric hematomas, and contusions [9, 22]. Although a majority of nonsurgical injuries remain stable, some injuries may evolve and result in secondary perforation, intractable bleeding, expanding hematomas, or bowel segment devascularization [9]. It is not always possible to separate bowel and mesenteric injuries and most frequently the two entities coexist.

Fig. 1 A 24-year-old female restrained rear seat passenger in a high-speed motor vehicle collision transferred from OSH after diagnosis of a lumbar Chance fracture. **a** Coronal image demonstrates a focal contused hypoattenuation jejunal segment (thick arrow). At surgery, adjacent mesenteric as well as long segment injury of the overlying transverse colon was seen. **b** Sagittal image (3b) shows a faint linear abdominal wall contusion (thin arrow) anterior to the mid-small bowel injury (thick arrow) and to an L1 Chance fracture (arrow head)

Clinical Manifestations

Physical examination is notoriously inaccurate in the diagnosis of bowel and mesenteric injuries. Moreover, concomitant injuries involving the intra-abdominal solid organs, or neurological injuries that can mask pain and guarding makes clinical examination difficult and inaccurate [4]. Peritonitis that occurs due to spilled intestinal contents and blood products may have a delayed onset and not manifest for several hours, depending on the anatomical site of the injury and is usually associated with higher rates of morbidity and mortality. Since, there is an association between bowel and mesenteric injuries with abdominal wall injuries (abdominal wall hematoma, seat belt sign, abdominal wall tear, traumatic lumbar hernias), the presence of any of the above signs should be considered as a potential predictor of bowel injury and meticulous analysis of MDCT images for bowel and mesenteric injuries should be performed [18].

Screening Protocol

Ultrasonography

Focused assessment with sonography for trauma (FAST) has become an accepted part of evaluation of blunt abdominal trauma patients in many hospitals in United States. FAST examination is usually performed by formally trained surgical resident or trauma surgeon. It involves evaluation of four windows: pericardial, perihepatic, perisplenic, and pelvis [23]. The test is considered positive if free intra-abdominal or pericardial fluid is visualized. Indeterminate FAST involves a suboptimal window with inadequate visualization or when there is a doubt about the results of the study [23]. A positive test is nonspecific for bowel and mesenteric injuries as free fluid can be seen in concomitant solid organ injuries and other physiological conditions like women of child-bearing age. The test's sensitivity is also limited by its dependence on the operator, the amount of fluid in the peritoneum, unreliability of peritoneal fluid as a sign of bowel and mesenteric injuries, and in the setting of retroperitoneal organ injuries including retroperitoneal bowel segments [23]. However, in patients who are hemodynamically unstable, when time is of essence, FAST serves as a useful screening test [23–25]. In contrast, in stable patients, given the poor sensitivity, the role of FAST has not been well established and it would be prudent for the patients to undergo CT to avoid missing injuries because of its high sensitivity [23].

Diagnostic Imaging

The advances in CT technology have made multi-detector CT (MDCT) the ideal diagnostic test for bowel and mesenteric injuries.

MDCT of the Abdomen and Pelvis

MDCT of the abdomen and pelvis has allowed in identification of bowel and mesenteric injuries with sensitivity ranging from 64 to 95% and specificity ranging from 94 to 100% [9, 26–28]. The high accuracy of MDCT is rendered due to the improved spatial resolution, better image quality, and ability for supplemental post-processing of the MDCT data. Such advancements in CT technology have led to recognition of greater number of subtle injuries. A Dual-phase imaging approach optimizes detection of both vascular and nonvascular injuries in the abdomen and pelvis. The initial scan involves image acquisition in the arterial phase that helps assess vascular injuries, active bleeding, and perfusion abnormalities of the bowel. The second scan is acquired about 60–70 s after contrast injection in the portal venous phase, helps in the detection of nonvascular parenchymal injuries in the solid organs, and differentiates hypoperfusion from nonperfusion of injured bowel segments. Use of oral contrast medium in patients with suspected blunt bowel and mesenteric injuries was a subject of controversy [29, 30, 31•]. A meta-analysis of 32 studies has shown that there was no difference in accuracy between CT performed with positive oral contrast agents or with no, neutral or negative oral contrast agent [32]. At our institution, oral contrast is not used for admission CT examinations due to its potential interference with assessment of perfusion abnormalities of the bowel wall and increased door to scan time. The number of trauma center routinely administering oral contrast material for admission "whole-body" or segmental abdominal CT is on the decline with availability of 64- or 128-slice MDCT.

CT Findings of Bowel Injury

Various surgical and nonsurgical CT signs of bowel and mesenteric injuries have been described in the literature with varying significance. The presence of a combination of CT signs increases the likelihood of injury.

CT Signs of Surgical Bowel Injury

(a) *Discontinuity of the bowel wall* is a highly specific finding for surgical bowel injury, but has low sensitivity (Figs. 2, 3). The reported sensitivity ranges from 5 to 11% and specificity approaches 100%

[27, 33•]. Discontinuity results from bowel perforation and direct visualization of the defect on CT is uncommon owing to the small size of many of these perforations. Such small perforations are usually identified at surgery on meticulous inspection.

(b) *Pneumoperitoneum and pneumoretroperitoneum* are specific CT signs ranging from 95 to 96.4%, but modest sensitivity that ranged from 21 to 79.5% [33•]. Extraluminal air results from bowel perforation (Fig. 3). Retroperitoneal air is seen due to the perforation of the retroperitoneal segments of the colon and the duodenum (Figs. 2, 4). Rarely, extraintestinal gas can result without bowel perforation secondary to a pneumothorax or pneumomediastinum from thoracic injuries decompressing into the peritoneum and retroperitoneum, or in cases of intraperitoneal urinary bladder rupture, where air introduced during insertion of a Foley catheter can enter the peritoneum through the bladder wall defect. For this reason, isolated pneumoperitoneum without ancillary CT findings should be approached with skepticism, before confirming the diagnosis of a full-thickness surgical bowel injury. A recent study has identified that the presence of free fluid, seat belt sign, or other imaging findings of bowel injury in the presence of pneumoperitoneum is highly predictive of injury requiring laparotomy [34]. The lower sensitivity may be due to a lack of bowel distension at the time of trauma, limiting the transmural pressure gradient for the air to escape into the extraintestinal space or by only presence of a small amount of extraintestinal air, escaping the detection unless searched for by using wide window setting.

Fig. 2 A 56-year-old male pedestrian struck by garbage truck. An open defect (thin arrow) of the distal D2 duodenal segment wall with extraluminal air (thick arrow), succus, and hemorrhage in the right anterior pararenal space. Zone 2 retroperitoneal hemorrhage on the left secondary to grade 4 renal (arrowhead, entire extent of renal injury not shown)

Fig. 3 A 45-year-old male restrained driver involved in a head-on motor vehicle collision. Focal small subtle bowel perforation (thin arrow) with extraluminal mesenteric gas (arrowhead) and hemoperitoneum in the right paracolic gutter (thick arrow) are present

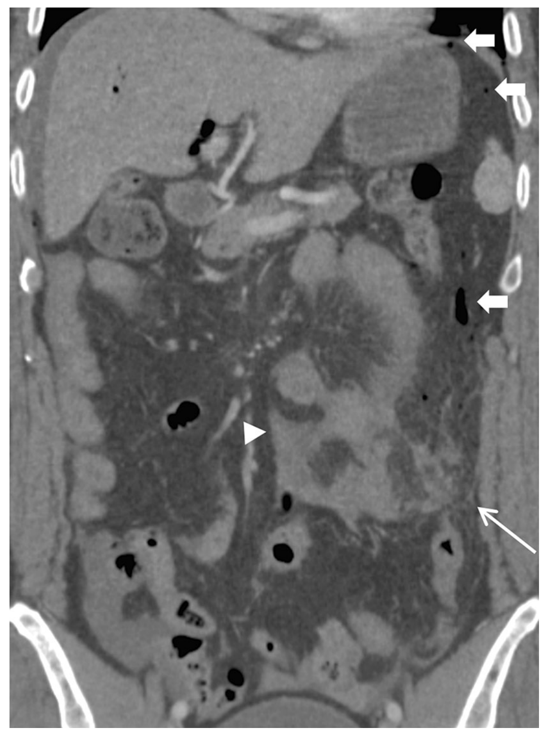

Fig. 4 A 74-year-old male restrained passenger of a large tour bus involved in a head-on collision with a car. **a** Coronal image demonstrates nonbleeding mesenteric contusion (arrow) with foci of mesenteric and free intraperitoneal air (thick arrow) and a small amount of triangular collection of mesenteric blood (arrowhead). **b** Axial image shows retroperitoneal hemorrhage and small foci of air (arrow). Mesenteric contusion (thick arrow) and free air (arrowhead) are again seen. A bucket handle injury and traumatic enterotomy of the ileum and free succus were identified at surgery. Additional surgical resection was required for a mesenteric rent of descending colon with multiple serosal tears and contusions

(c) *Extravasation of enteric contents or contrast material into the peritoneum or retroperitoneum* is seen in patients with bowel perforation. This CT sign is a highly specific sign of injury seen in 100% of cases, but suffers from low sensitivity ranging from 8 to 15% [33•]. If the CT is performed following administration of enteric contrast material, the extravasated enteric contrast sometimes may be confused with active bleeding or contrast-opacified urine within retroperitoneal or intraperitoneal urinoma. Careful review of the delayed images for changes in configuration, the anatomical site of origin of the extravasated contrast material and measuring the attenuation value of the leaked contrast if similar to attenuation values of administered oral contrast material can help in differentiation of the source of extravasated contrast material.

CT Signs of Nonsurgical Bowel Injury

(a) *Abnormal bowel wall enhancement* includes both hyperenhancement and hypoenhancement of bowel wall. This CT sign, though highly specific (90%) is a subjective finding. The sensitivity is low, ranging from 8 to 15% [33•]. Focal hypoenhancement of the wall is usually seen in patients with bowel contusion (Fig. 5). DS-CT has the potential to assist in depicting and to characterize the area of wall hypoattenuation. Obtaining virtual low (40 keV) monochromatic images compared to the standard 120 kVp images will increase the conspicuity and confidence of diagnosing areas of hypoattenuation due to bowel wall contusion (Fig. 5b). This results from maximizing the contrast difference between normally enhancing and the injured nonenhancing bowel wall by accentuating the attenuation of iodine. Iodine maps can be used to quantitatively and qualitatively assess iodine within bowel wall. Typically, there is decreased iodine in the areas of bowel wall injury (Fig. 5c). Future studies may help to determine if quantitative analysis of the concentration of iodine within the hypoattenuation area may help to predict surgical bowel injury. Conversely, hyperenhancement of the wall is less specific for bowel contusion and can be seen in patients with "shock bowel" and underdistension of the bowel loops mainly of the jejunum.

(b) *Bowel wall thickening* is usually seen in patients with wall contusion. The sensitivity ranges from 18 to 75% and specificity ranges from 76 to 97% [33•]. The wall thickening can be either circumferential, or eccentric and may involve a short or long segment of bowel. Bowel wall thickening can also result from intramural hematoma that is more frequently seen in duodenum and colonic injuries. The relative hyperattenuation of the hematoma in the bowel wall is commonly masked by the wall enhancement after intravenous contrast administration and is usually seen as wall thickening on contrast-enhanced CT studies. Wall thickening is defined as greater than 3 mm (small bowel) and 5 mm (large bowel) in the presence of adequate distension of the lumen [4]. Thickening of the wall involving a short bowel segment is more specific for injury than the thickening involving a long segment, as long segment bowel wall thickening, especially of the small bowel, can be typically seen in underdistension of the lumen, systemic volume overload, or "shock bowel syndrome."

(c) *Free intraperitoneal fluid* is a sensitive CT sign with sensitivity ranging from 81 to 100%, and specificity ranging from 15 to 66% [33•]. Free fluid can be seen in both bowel and mesenteric injuries. Free fluid, if found in isolation, may indicate an occult injury of the bowel or mesentery. False-positive sign can result from solid organ injuries, intraperitoneal urinary bladder rupture, gall bladder rupture, decompression of extraperitoneal pelvic hematomas into the peritoneal cavity, and physiological free fluid in women of child-bearing age. Small amount of simple fluid in the pelvis without an associated intra-abdominal injury is also seen in approximately 3% of male patients [35]. However, interloop or intermesenteric fluid (triangular collections within the mesentery), moderate to large volume of fluid, and high-attenuation of the fluid ($\geq$ 15 HU) are more likely associated with occult bowel and mesenteric injury.

CT Findings of Mesenteric Injury

Mesenteric Injuries

There are a broad spectrum of mesenteric injuries varying from contusions to mesenteric lacerations. Mesenteric injuries can be isolated or are associated with bowel injuries [22]. Similar to the injuries to the bowel, mesenteric injuries can be divided into surgical versus nonsurgical injuries.

CT Signs of Surgical Mesenteric Injuries

Mesenteric laceration with intestinal ischemia (bucket handle tear) This injury involves avulsion of mesentery from the bowel loop resulting in devascularization of the involved bowel loop [21]. These injuries result from shearing force at the junction of the mobile and the fixed segments of the bowel, namely in the right lower quadrant due to the fixed retroperitoneal right colon and mobile distal ileum (Fig. 6). Other locations include sigmoid mesocolon and near the

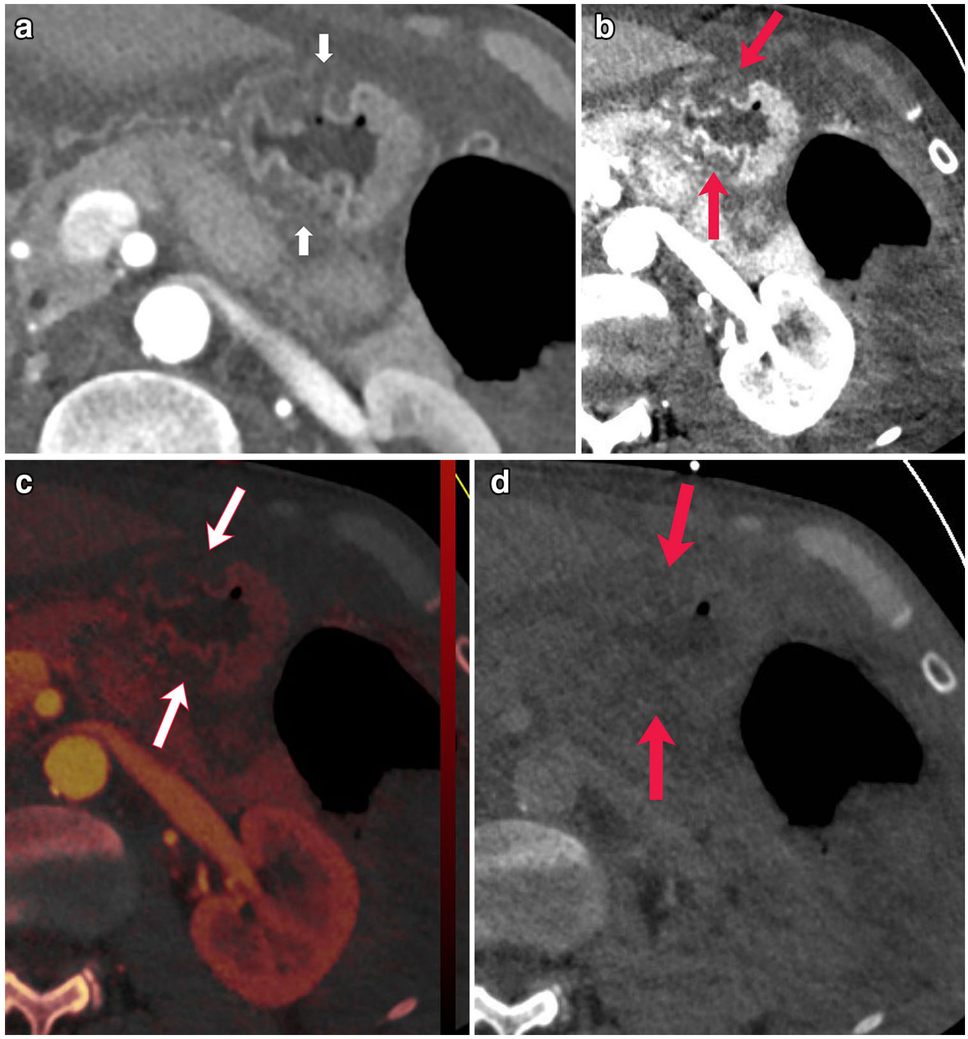

Fig. 5 Patient was found down with external signs of blunt force assault to the head, face, and abdomen. Axial **a** Mixed and **b** 40 keV DS-CT images demonstrate focal hypoattenuation within the anterior and posterior gastric walls (arrows) more conspicuous on 40 keV image. **c** Axial I_2 map image shows decreased I_2 uptake and **d** Axial 190 keV image demonstrates no hyperattenuation area indicating a hematoma in the same anatomical area. Surrounding hemoperitoneum is from grade 4 splenic injury (not shown). Gastric wall contusion without perforation was found at surgery

ligament of Treitz. Primarily, CT manifests as segmental non-enhancement of bowel loops DS-CT may further increase the sensitivity and diagnostic confidence in the detection of abnormal wall enhancement. Early studies have demonstrated the utility of monoenergetic images and iodine mapping to increase the conspicuity of ischemic bowel segments [36, 37••, 38] (Fig. 7). Other secondary findings associated with such injuries include mesenteric hematoma, mesenteric vascular lesions or active bleeding, mesenteric contusions, or hemoperitoneum [1, 39–41].

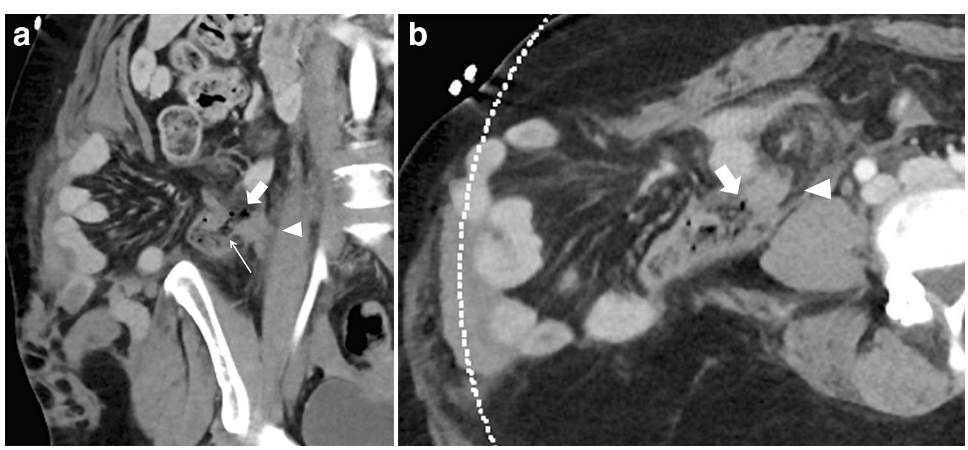

Fig. 6 A 47-year-old female with traumatic lumbar hernia following a motor vehicle collision. **a** Cornal and **b** Axial CT images show contusion/hematoma in the ileocolic mesentery (arrow heads) with focal perforation (thin arrow) of the proximal ascending colon, and small foci of extraluminal air (thick arrows). Damage control laparotomy showed gross fecal contamination in the pelvis from colonic perforation

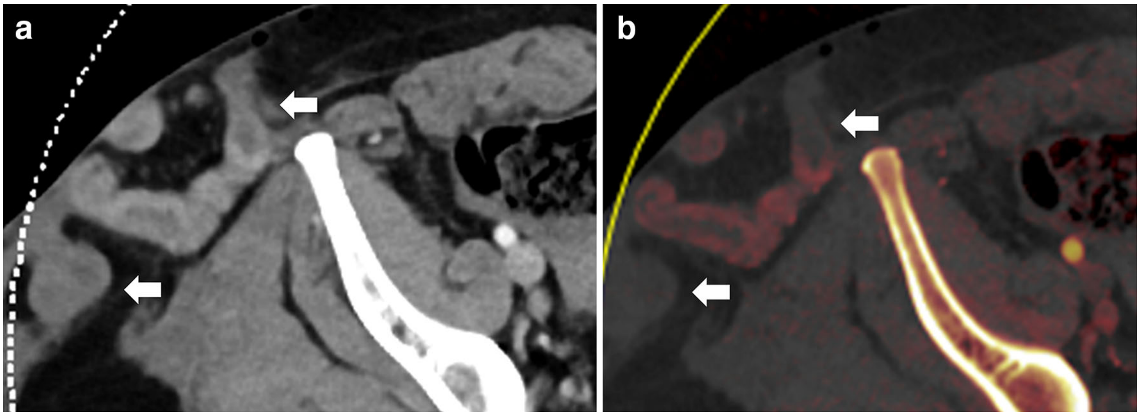

Fig. 7 Axial **a** 120 kVp and **b** I2 map images demonstrate multiple segments of circumferential mural nonenhancement of small bowel showing small bowel within the hernia on arterial phase images (thick arrows). Conspicuity is increased on the iodine map images (thick arrows). At surgery, two sites of bucket handle injury to the small bowel mesentery with corresponding devascularized ilium were found

Extravasation of contrast from Mesenteric vessels (active bleeding) is usually associated with mesenteric lacerations and manifests as contrast extravasation from the torn mesenteric blood vessels (Fig. 8). Active mesenteric bleeding can result in hemoperitoneum or mesenteric hematomas. A majority of the patients with active bleeding typically require surgical intervention due to the potential for uninterrupted bleeding due to lack of tamponade effect from the mesentery on the bleeding vessels [10, 42].

CT Signs of Nonsurgical Mesenteric Injuries

Mesenteric fat stranding with or without hemoperitoneum or mesenteric hematoma is a sensitive sign of mesenteric injury. Stable mesenteric hematomas without active bleeding, or intestinal devascularization are usually managed conservatively [43].

Mesenteric vascular beading or irregularity is a milder form of mesenteric vascular injury and managed conservatively, unless associated with intestinal devascularization.

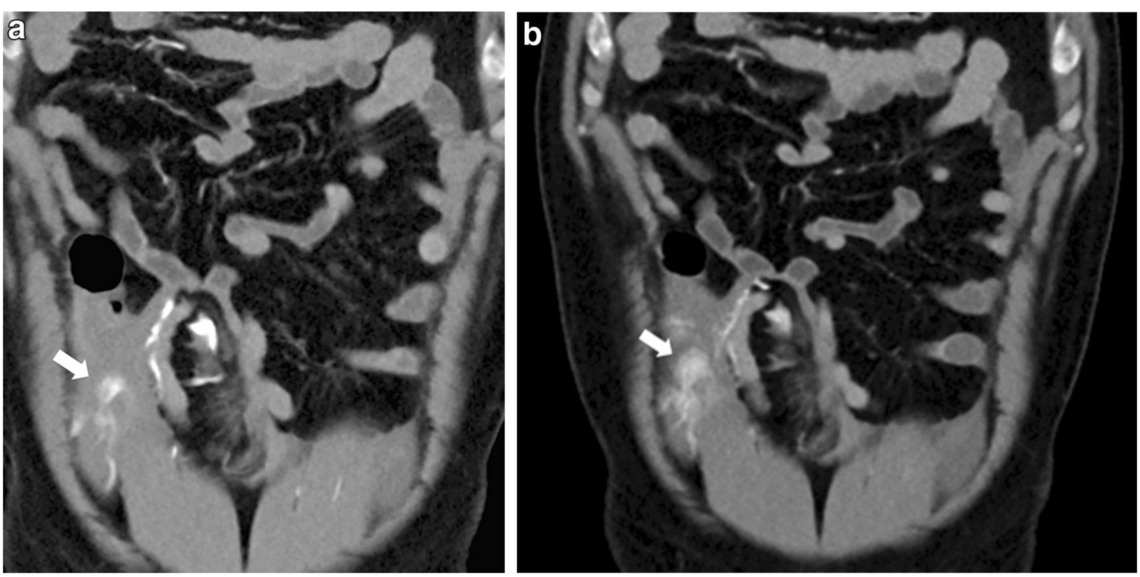

Fig. 8 **a**, **b** A 52-year-old male restrained driver involved in a rollover motor vehicle crash. CT demonstrates right lower quadrant mesenteric hematoma with multiple foci of arterial blush (6a thick arrow) that expands on the portal venous phase (6b thick arrow) consistent with active bleeding. Surgery found two separate areas of distal ilial mesenteric injury extending up to the bowel and deep into the root of the mesentery with active bleeding. No evidence of underlying bowel injury was found; however, the injured mesentery was not salvageable and the patient long segment partial small bowel resection

Free fluid in the peritoneum is a nonspecific CT finding and can be seen in either primary bowel or mesenteric injuries as described before.

Follow-up CT in Bowel and Mesenteric Injuries

The ideal management of patients with nonsurgical CT findings of bowel and mesenteric injuries should be to formulate a plan on an individual basis after taking into consideration the radiological and clinical findings and discussion between radiologist and trauma surgeon. Stable patients with nonsurgical CT findings of bowel and mesenteric injury as well as suspicious free fluid in the peritoneum for bowel and mesenteric injury are ideal candidates for follow-up CT in a busy trauma center. Typically, the follow-up CT is performed at 4–6 h after the initial study, using enteric and intravenous contrast material [1, 4, 39–41]. In specific circumstances, rectal contrast can be used. The follow-up study allows time for surgically important bowel and mesenteric injuries to evolve and manifest overt primary signs of injury or secondary signs due to complications such as peritonitis or bowel devascularization [4].

Conclusions

Prompt identification of bowel and mesenteric injuries is important in management of blunt abdominal trauma patients. Delayed or missed diagnosis can significantly increase the morbidity and mortality in such patients. Since, clinical signs and symptoms are often subtle and nonspecific, CT imaging plays an important role in rapid and comprehensive evaluation of patients to reach a correct diagnosis and help formulate the most appropriate treatment plan. Finally, patients with nonsurgical CT findings may warrant a follow-up study to confirm or exclude the evolution to surgical injuries, based on the institutional surgical practices.

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Compliance with Ethical Standards

Conflict of interest Matthew Dattwyler and Kathirkamanathan Shanmuganathan each declare no potential conflicts of interest.

Human and Animal Rights and Informed Consent This article does not contain any studies with human or animal subjects performed by any of the authors.

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- •• Of major importance

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