CT of Major Vascular Injury in Blunt Abdominopelvic Trauma[1]

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Abbreviations: DSA = digital subtraction angiography, MIP = maximum intensity projection, SMA = superior mesenteric artery

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SA-CME LEARNING OBJECTIVES

After completing this journal-based SA-CME activity, participants will be able to:

- Describe common mechanisms of vascular injury in blunt abdominopelvic trauma.
- Identify the broad spectrum of imaging presentations of vascular trauma in major vessels and visceral organs.
- Discuss the appropriate imaging techniques to highlight the suspected location and type of major vascular injury in blunt abdominopelvic trauma.

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Blunt abdominopelvic trauma remains one of the leading causes of morbidity and mortality nationwide. Delays in diagnosis can be catastrophic, underscoring the crucial importance of prompt injury detection. Identification of vascular injuries in the setting of blunt abdominal trauma can pose a diagnostic challenge, as detection is reliant on appropriate multidetector computed tomography (CT) scanning protocols and familiarity with the various imaging presentations of vessel injury. The advent of multidetector CT and fine-tuning of department protocols has led to fast, accurate, and efficient diagnosis of the broad spectrum of major vascular injuries that can result from blunt abdominopelvic trauma. CT allows timely diagnosis, differentiation between various types of major vascular injury, identification of associated findings, and specific localization of the source of bleeding. Accurate and early diagnosis of major abdominopelvic vascular injuries is fundamental to initiation of appropriate treatment strategies and improvement of clinical outcomes in this patient population.

Introduction

Trauma is an enormous nationwide concern, representing one of the leading causes of death in all age groups (1). The majority of traumatic injuries presenting to the emergency department are due to blunt trauma, with the most common mechanism of injury being motor vehicle collisions (2,3). Up to 70% of motor vehicle collision–related injuries undergo diagnostic imaging (3). Abdominopelvic trauma can present as a wide spectrum of injuries, ranging from fractures, solid organ injury, and hollow viscus injury to vascular injury. Vascular injury in particular is an important imaging diagnosis given its association with potential rapid deterioration of the patient's hemodynamic status, leading to hypotensive shock and, in turn, higher morbidity and mortality (4).

In the past, clinical suspicion for vascular injury frequently led to catheter angiography for diagnostic and, in some cases, therapeutic purposes. Although a highly accurate technique, catheter angiography is fundamentally more invasive and labor intensive than multidetector computed tomography (CT), leading to a longer time to diagnosis, which is of critical concern in the trauma patient population. With the advent of multidetector CT, major vascular injury can be accurately diagnosed in a noninvasive timely fashion, allowing optimization of patient care and efficient use of department resources.

After experiencing blunt abdominopelvic trauma, patients may display specific or nonspecific clinical signs that vascular injury is present. In addition, the mechanism of injury should be ascertained to raise awareness of the potential for vascular injury.

TEACHING POINTS

- Common blunt trauma mechanisms of injury include motor vehicle collisions, bicycle collisions, motorcycle collisions, falls, and assault. These major blunt mechanisms of trauma can generate force vectors that result in direct impact injury, shear injury, and burst injury.
- In the case of blunt pelvic trauma, by performing initial pelvic CT angiography followed by our routine portal venous phase acquisition, the radiologist may confidently distinguish between arterial and venous extravasation in the pelvis. Accurate diagnosis of pelvic arterial injury is crucial to facilitate prompt endovascular treatment, given its association with increased patient morbidity and mortality.
- In cases of active hemorrhage, it is important to distinguish between arterial and venous hemorrhage, given the potential differences in management.
- Management of aortic injury is highly dependent on the imaging features. Shalhub et al demonstrated that intimal tears less than 10 mm in length can be managed nonoperatively with blood pressure control and repeat imaging. Large intimal tears (considered to be >10 mm in length) are managed on a case-by-case basis, since there is a higher risk for large thrombus formation or downstream arterial insufficiency.
- In major liver trauma, repeat imaging should be considered in cases of hepatic artery injury to assess for evolution of the injury, including posttraumatic pseudoaneurysm, biloma formation, or hemobilia.

In this article, we describe important protocol considerations for optimal multidetector CT acquisitions and review the pertinent imaging findings in direct major vessel injury as well as end-organ injury. Furthermore, we discuss the implications of the mechanism of injury and the patients' presenting clinical signs and symptoms for the likelihood and potential pattern of major abdominopelvic vascular injury. In addition, the impact of the various imaging findings of major vascular injury on patient management with respect to subsequent treatment strategies, such as emergent laparotomy or endovascular repair, is highlighted. Finally, we review potential pitfalls in imaging diagnosis of vascular injury.

Clinical Presentation

Patients who experience blunt abdominopelvic trauma may present with specific clinical signs and symptoms that increase the index of suspicion for a major vascular injury. At admission to the emergency department, 50% of patients with major vascular injury have signs of hemorrhagic shock (systolic blood pressure < 80 mm Hg) (5). Abdominal arterial injuries are typically accompanied by abdominal tenderness at physical examination. Signs of vascular injury include asymmetric pulses or absent distal pulses in the extremities (6). Vessel injury that can be suspected includes dissection, laceration, or intraluminal thrombosis. Over 90% of patients with an absent distal pulse have a major arterial injury (6). Evidence of abdominal tenderness and abdominal wall hematoma at physical examination can also be highly suspicious for intra-abdominal vascular injury.

Trauma from the seat belt, specifically the lap band, can cause abdominal wall bruising or laceration. This physical examination finding should raise suspicion for injuries affecting abdominal structures such as soft tissues, visceral organs, and major vessels (7–9). Approximately 30% of patients presenting with classic seat belt–related abdominal wall bruises at physical examination have associated significant intra-abdominal injury (7). Additional nonspecific clinical signs include tachycardia, which may be due to hypovolemia caused by a vascular injury; however, it may also simply be secondary to patient pain. Given that physical examination findings are generally unreliable, multidetector CT is the mainstay of initial evaluation of the injured patient to avoid missing occult injuries (10).

Mechanism of Injury

It is important to understand how the mechanism of injury correlates with the imaging findings, as it may allow a deeper understanding of potential vascular injury patterns and hint at various potentially overlooked injuries. After learning the mechanism of injury, the radiologist should construct hypothetical models of force vectors to better understand the pathogenesis of potential vascular trauma and avoid missing injuries. Common blunt trauma mechanisms of injury include motor vehicle collisions, bicycle collisions, motorcycle collisions, falls, and assault. These major blunt mechanisms of trauma can generate force vectors that result in direct impact injury, shear injury, and burst injury.

Direct Impact and Crush Injury

Direct impact injury can occur, for example, when the chest or upper abdomen is impacted onto the steering wheel in a motor vehicle collision. An additional example includes direct impact of the upper abdomen onto motorcycle or bicycle handlebars as well as the impact of a blunt weapon used to strike a victim. Relatively obvious findings of direct impact injury at CT include chest wall deformities such as sternal or rib fractures, which can lead to organ and vessel laceration. Transverse process fractures and vertebral body fractures can cause laceration and extravasation of the lumbar arteries.

Direct impact injuries can also cause "crush" injury as a result of compression of the internal organs between the abdominal wall, posterior

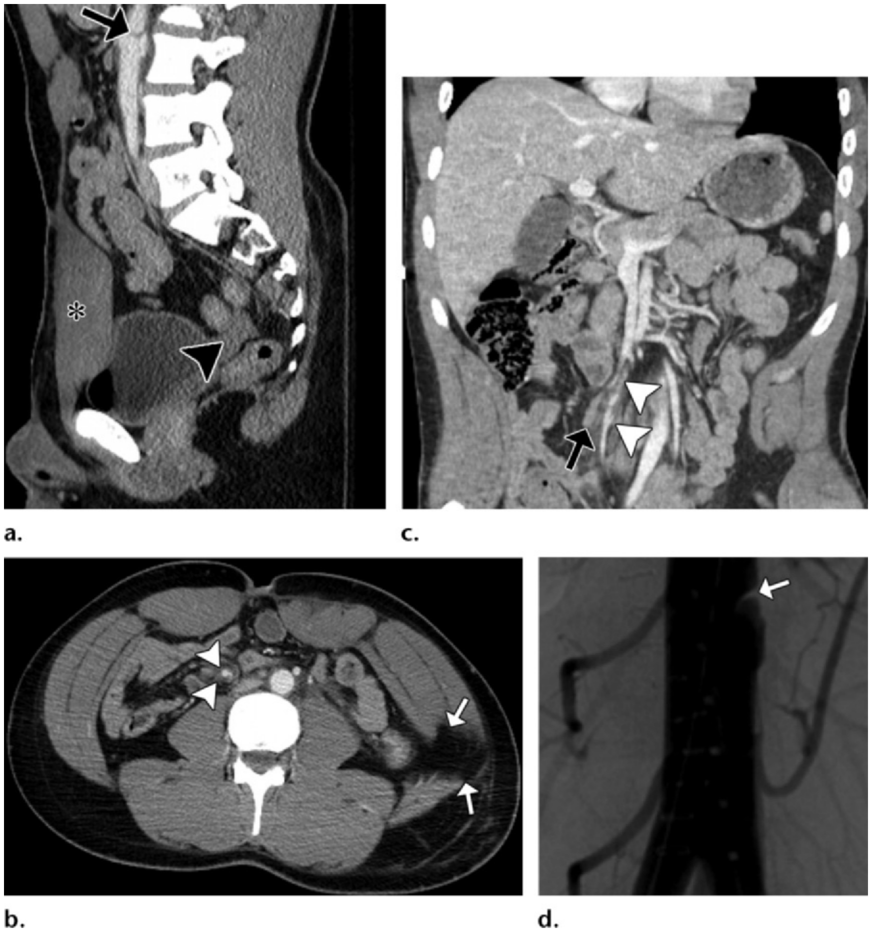


Figure 1. Imaging findings in a 21-year-old man after a motor vehicle accident with rollover. At physical examination, contusions were seen at the left neck, left upper thorax, and lower abdominal wall, raising suspicion for seat belt injury. **(a)** Sagittal contrast-enhanced CT image shows an intimal flap (arrow) at the infrarenal abdominal aorta, suggestive of an intimal tear. Additional findings included an avulsion of the rectus abdominis muscle with intramuscular hematoma (*) and simple fluid layering in the pelvis (arrowhead). **(b)** Axial contrast-enhanced CT image shows fat stranding (arrowheads) adjacent to the mesenteric vessels in the right lower quadrant, as well as complete rupture of the internal oblique, external oblique, and transversus abdominis muscles (arrows) related to seat belt trauma. **(c)** Coronal contrast-enhanced CT image shows irregularity along the mesenteric vessels (arrowheads) as well as free fluid layering in the mesenteric fold (arrow), raising suspicion for mesenteric injury. The patient was taken to the operating room and noted to have a 5-cm segment of ischemic terminal ileum with tears in the adjacent mesentery. Given the bowel injury, open aortic repair was aborted. Conventional aortography was later performed. **(d)** Digital subtraction angiography (DSA) image shows an intraluminal curvilinear filling defect (arrow) in the infrarenal abdominal aorta. An endovascular stent was subsequently deployed.

thoracic cage, and axial skeleton (2). Contusions can occur at sites of compression of solid organs against the appendicular skeleton as well as lacerations at sites of compression against blunt bony edges, such as the transverse processes. Similarly, compression of the seat belt against the anterior abdominal wall may also lead to a crush injury and yield a similar mechanism of organ compression or vascular injury. Seat belt compression injuries, as discussed earlier, are associated with bowel, mesenteric, and vascular trauma. Vascular tears in seat belt trauma commonly occur on the mesenteric side of the bowel (Fig 1) (7).

Shear Injury

Shear injury is a second mechanism of trauma that generates differential force vectors. Anatomic structures such as the aorta, mesenteric vessels, and vascular pedicles of the spleen, kidney, and liver all have both mechanically fixed and more mobile components. In the case of motor vehicle collisions, rapid deceleration can cause opposing force vectors to form between these stationary and mobile anatomic components of major organs or vessels, leading to shear injury in the form of intimal tearing, dissection, or laceration. An example of a vessel location at risk for shear injury is the

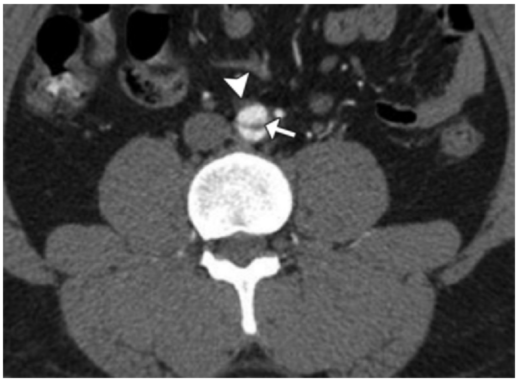


Figure 2. Aortic dissection in a 45-year-old man after a motor vehicle collision. Contrast-enhanced CT image shows rapid deceleration injury leading to a focal dissection in the abdominal aorta (arrow) with periaortic hemorrhage (arrowhead).

abdominal aorta at the aortic hiatus. The aortic hiatus is a ring formed by the crura of the diaphragm attached along their posterior aspect to the vertebral column, specifically the anterior longitudinal ligament. If the aorta is mobilized in rapid deceleration injury, the immobile aortic hiatus can lead to abdominal aortic intimal tear or rupture (Fig 2) (2,11).

The splenorenal ligament extends from the anterior layer of the renal fascia and encases the vascular pedicle of the spleen, which is further tethered to the stomach. Thus, differential forces can move the splenic parenchyma in the opposite direction from its tethered attachments, leading to potential vascular pedicle injury. The same mechanism of opposing forces occurs at the duodenojejunal junction near the attachment site of the ligament of Treitz. The ligament of Treitz is a connective tissue anchored to the diaphragmatic crus and attaching on the duodenojejunal junction. Shear injury can occur from "tugging" of the ligament of Treitz on its attachment to the mobile jejunum, potentially resulting in bowel wall hematoma or perforation (12).

Burst Injury

Burst injury occurs when a blunt force against the abdominal wall increases the intraluminal pressure of hollow viscera, leading to rupture. Burst injury is most commonly associated with stomach or bowel trauma (2). Burst injuries of major vessels are unlikely to occur. The tensile strength of the vessel wall can withstand high intraluminal pressures of over 1000 mm Hg (13).

High-Impact Injury

An additional pertinent consideration with respect to blunt trauma is the so-called high-impact injuries. For example, high-speed motor vehicle collisions may lead to high-impact imaging findings such as first to third rib fractures, sternal fractures, and femur fractures. When high-impact imaging findings are seen at admission radiography, both thoracic and abdominopelvic CT is mandated and the index of suspicion for underlying major vascular injury is heightened. High-impact injuries result in transfer of kinetic injury throughout the body, which is dissipated by the internal organs/viscera. In severe trauma, higher kinetic energy transfer can induce mobility of the stationary organs and vessels. Opposing force vectors created by the attachments of vessels or organs can result in shear injury, as described earlier (2,14–17).

A final note with respect to high-impact injury is in regards to patient rigidity. An intoxicated patient in a high-speed motor vehicle collision may suffer less severe injuries than a sober patient due to patient rigidity in the latter. The transfer of kinetic injury is less severe when the patient's body is relaxed when compared with a more rigid patient contracting the musculature immediately before impact, thereby causing rapid dissipation of the transferred kinetic injury into the intra-abdominal compartment, often resulting in more severe injury. Therefore, although high-speed motor vehicle collisions typically result in polytrauma, patient rigidity may, in part, explain differences in injury severity between patients experiencing similar mechanisms of injury (18).

CT Protocol Considerations

At our level 1 trauma center, we employ 64-channel multidetector CT scanners (Lightspeed VCT; GE Healthcare, Milwaukee, Wis), which allow rapid acquisition of near-isotropic voxels. Axial datasets of all series acquired are reconstructed with 1.25- and 3.75-mm section thickness. A single intravenous injection of contrast material is used for all torso trauma imaging studies, regardless of the number of phases of image acquisitions. A standard dose of 100 mL of iodinated contrast material (iodine, 350–370 mg/mL) is administered using an 18- or 20-gauge cannula at a rate of 4–5 mL/sec. A dual-syringe power injector is used, and a 30-mL saline solution is injected as a "chasing" bolus to follow the intravenous contrast material.

At our institution, we use selective "segmental scanning" (as opposed to a whole-body continuous "panscan"), with a customized set of 10 blunt trauma department protocols, each differing in the number, order, and timing of image acquisitions. Selection of the appropriate trauma protocol is based on patient clinical history, mechanism of injury, and hemodynamic status. In addition, in the trauma bay, polytrauma patients undergo portable chest, pelvic, and extremity radiography. The trauma team, inclusive of trauma surgeons and emergency physicians, will choose the appropriate CT protocol based on the clinical history, examination results, and radiographic findings. Experience at our level 1 trauma center has demonstrated that in the trauma setting, an accurate history is not always provided; rather, the word "trauma" is written in the clinical history. To ensure accurate protocoling of studies is performed, our trauma team has been versed in an algorithmic approach on which of these 10 blunt trauma protocols to choose from, given that they vary based on factors such as presence of upper extremity, lower extremity, and/or pelvic fractures.

Blunt Abdominopelvic Trauma CT Techniques

Description of the following CT techniques will focus on our three abdominopelvic CT protocols used for blunt abdominopelvic trauma, given our focus on blunt abdominopelvic vascular injury. Our segmental scanning technique allows reduction of radiation dose produced through overlapping acquisitions of the abdomen or pelvis. The protocol for minor blunt trauma of the abdomen solely includes CT of the abdomen and pelvis performed from the dome of the diaphragm to the greater trochanters in the portal venous phase after a standard 70-second delay following injection of a contrast material bolus.

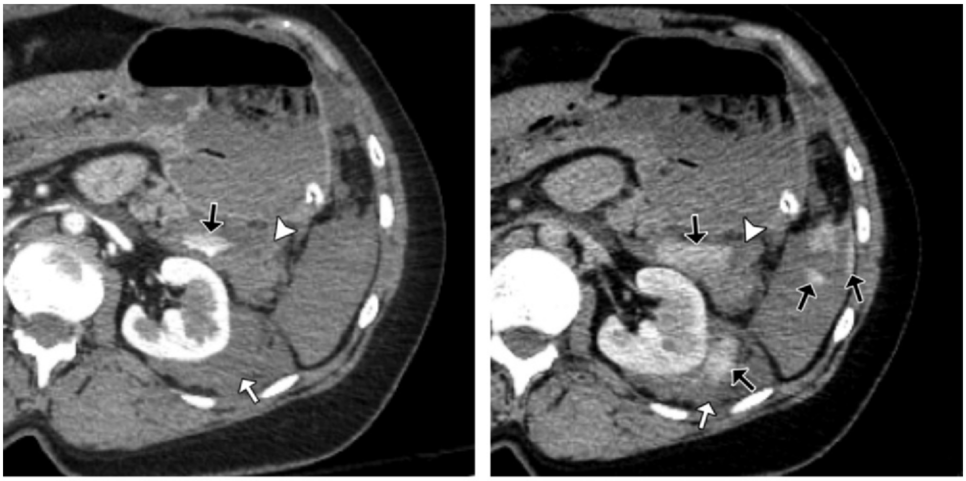
If there is clinical suspicion for polytrauma, a more extensive trauma protocol is initiated. Our most frequently used trauma protocol in blunt polytrauma involves initial CT angiography of the chest and upper abdomen using a standard delay of 30 seconds; the next image acquisition includes the abdomen and pelvis in the portal venous phase using a standard delay of 70 seconds. Image acquisition parameters for the chest CT angiography extend from the thoracic inlet through the upper abdomen, with inclusion of the liver, spleen, and upper abdominal aorta to the level of the superior mesenteric artery (SMA). Consequently, accurate assessment of potential major upper abdominal arterial injury as well as complete evaluation of the liver and spleen for traumatic arterial injuries are achieved (19). Image acquisition parameters for the portal venous phase extend from the dome of the diaphragm to the greater trochanters. Consequently, the portal venous phase acquisition allows optimal assessment of parenchymal injury of the solid abdominal organs (20).

An example of how we further customize our segmental scanning protocols is demonstrated in the polytrauma patient with signs of blunt pelvic injury. As described earlier, all trauma patients in the trauma bay undergo portable pelvic and extremity radiography. If there is a pelvic fracture at admission radiography or clinical suspicion for pelvic vascular injury, the initial image acquisition includes pelvic CT angiography using a standard 23-second delay after bolus injection, with selective inclusion of the lower extremities if complex extremity fractures are present. CT angiography of the chest and portal venous phase abdominopelvic CT follow with the standard 30-second and 70-second delayed image acquisitions and parameters detailed earlier. In the case of blunt pelvic trauma, by performing initial pelvic CT angiography followed by our routine portal venous phase acquisition, the radiologist may confidently distinguish between arterial and venous extravasation in the pelvis. Accurate diagnosis of pelvic arterial injury is crucial to facilitate prompt endovascular treatment, given its association with increased patient morbidity and mortality (21).

Delayed Phase Image Acquisition.—Finally, regardless of which of the 10 blunt trauma protocols a patient undergoes, an additional delayed phase image acquisition may be performed at the discretion of the radiologist at 5–7 minutes after contrast material injection. The delayed phase series is obtained only after a radiologist reviews the preceding images at the CT scanner and is indicated when acute traumatic injuries are identified in the chest, abdomen, or pelvis. This delayed phase series is routinely acquired with a low radiation dose technique, since its main purpose is characterization and confirmation of potential injuries rather than lesion detection (22).

It is important to note that hypotensive patients may have arterial injury that is not evident at the initial 30-second image acquisition of the chest and upper abdomen due to hypotension-related delay of contrast material opacification of the arterial vasculature. In this scenario, a delayed phase image acquisition may demonstrate arterial contrast material extravasation that may have been missed otherwise (Fig 3). Therefore, at our institution, a hypotensive patient with lack of contrast material opacification of the arterial vasculature at our initial arterial phase scan will typically undergo an additional delayed phase scan to accurately assess for vascular injury.

As mentioned, at our institution the radiologist reviews the initial images with the trauma surgery team at the CT scanner, with the fortunate benefit of obtaining a detailed clinical history. However, this may not be the case at other trauma centers. If an adequate clinical history is not provided, various imaging clues can hint at possible hypotension that may require additional delayed phase image acquisitions. Lack of contrast material in the renal pelvises (bilateral



a. b.

Figure 3. Arterial extravasation in a 46-year-old female pedestrian struck by a motor vehicle, hypotensive at admission. **(a)** Axial contrast-enhanced CT image acquired with a 70-second delay shows a delayed corticomedullary phase as well as dense opacification of a diminutive aorta, suggestive of delayed transit of intravascular contrast material in the setting of hypotension. There is suspicion for active extravasation (black arrow) within a hematoma (arrowhead) in the splenorenal space. Also note the perinephric hematoma (white arrow). **(b)** Delayed phase CT image shows active extravasation in the splenorenal space hematoma (arrowhead), which appears as growth in size with decreased attenuation (top black arrow). Additional foci of contrast material extravasation are also seen in the spleen (right black arrows), not previously visualized. There is another focus of contrast material extravasation (bottom black arrow) in the left perinephric hematoma (white arrow). Catheter angiography demonstrated active extravasation from branches of the splenic artery, which were embolized.

persistent nephrogram) at delayed phase image acquisition is a clue to hypotension-related slow transit of contrast material–opacified blood through the renal vasculature (Fig 3b) (23). Additional imaging signs of hypotension include flattening of the inferior vena cava, hyperenhancement of the adrenal glands, diffuse bowel wall mucosal hyperenhancement and submucosal thickening (shock bowel), as well as abnormal hypoenhancement of the spleen and liver (Fig 4) (24).

Panscan.—There is variability at multiple trauma centers with respect to the CT protocol technique used in a polytrauma patient. The two most commonly used CT techniques are segmental scanning and the "panscan." The panscan technique involves a continuous whole-body acquisition in the arterial phase typically extending from the circle of Willis to the pubic symphysis, with selective inclusion of the lower extremities when injury is suspected. Next, an abdominopelvic portal venous phase acquisition is typically performed, extending from the dome of the diaphragm to the iliac crests. Optional delayed phase imaging can be performed when acute injury is visualized at initial review (2).

The advantage of a continuous whole-body acquisition in the arterial phase is accurate diagnosis of arterial injury, since it can potentially lead to endovascular intervention (2). Although there is continued debate as to which technique is ideal in the polytrauma patient with respect to accuracy in diagnosis and radiation dosing, both techniques have respective benefits and ultimately should lead to a similar diagnosis.

Multiplanar Reformatting and 3D Postprocessing

We currently employ a "direct multiplanar" function that automatically generates coronal and sagittal reformatted images over the entire acquisition volume using a 2.5-mm reconstructed section thickness and no overlap. Furthermore, integrated postprocessing software (Advantage Windows suite incorporated into Centricity PACS workstations; GE Healthcare) is used to answer specific questions and clarify findings. Curved planar reformatted images and maximum intensity projection (MIP) images are particularly applicable. The MIP reconstructions that are generated depend on the radiologists' preference and particular area of interest, and may range from thin images only 3–8 mm thick to thicker slabs, typically one to several centimeters thick; any section thickness is freely available with the interactive software.

Select images generated by this postprocessing application are archived as a separate series in the picture archiving and communication system (PACS) and are available for review shortly thereafter by both radiologists and members of the

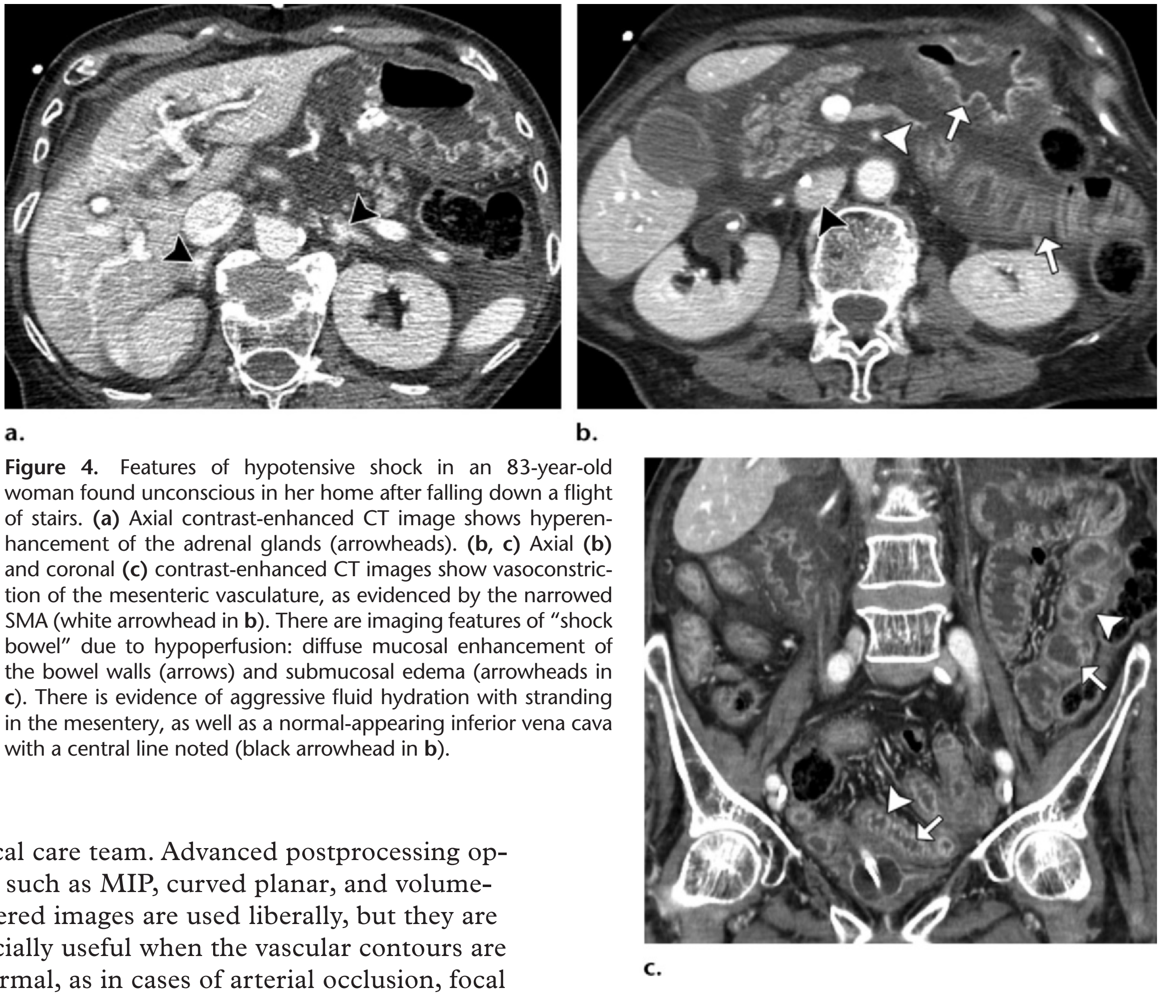


Figure 4. Features of hypotensive shock in an 83-year-old woman found unconscious in her home after falling down a flight of stairs. **(a)** Axial contrast-enhanced CT image shows hyperenhancement of the adrenal glands (arrowheads). **(b, c)** Axial **(b)** and coronal **(c)** contrast-enhanced CT images show vasoconstriction of the mesenteric vasculature, as evidenced by the narrowed SMA (white arrowhead in **b**). There are imaging features of "shock bowel" due to hypoperfusion: diffuse mucosal enhancement of the bowel walls (arrows) and submucosal edema (arrowheads in **c**). There is evidence of aggressive fluid hydration with stranding in the mesentery, as well as a normal-appearing inferior vena cava with a central line noted (black arrowhead in **b**).

clinical care team. Advanced postprocessing options such as MIP, curved planar, and volume-rendered images are used liberally, but they are especially useful when the vascular contours are abnormal, as in cases of arterial occlusion, focal narrowing or spasm, and formation of a pseudoaneurysm (Fig 5) (21). Multiplanar reformation (MPR) as well as three-dimensional reconstructions may be used to appreciate subtle injuries and allow evaluation of a vessel along its long axis (25–27). Sole use of MPR images has been reported to result in overlooked injuries; therefore, MPR images should be viewed in combination with axial datasets and with the same index of suspicion for injury as when reviewing the axial datasets (28).

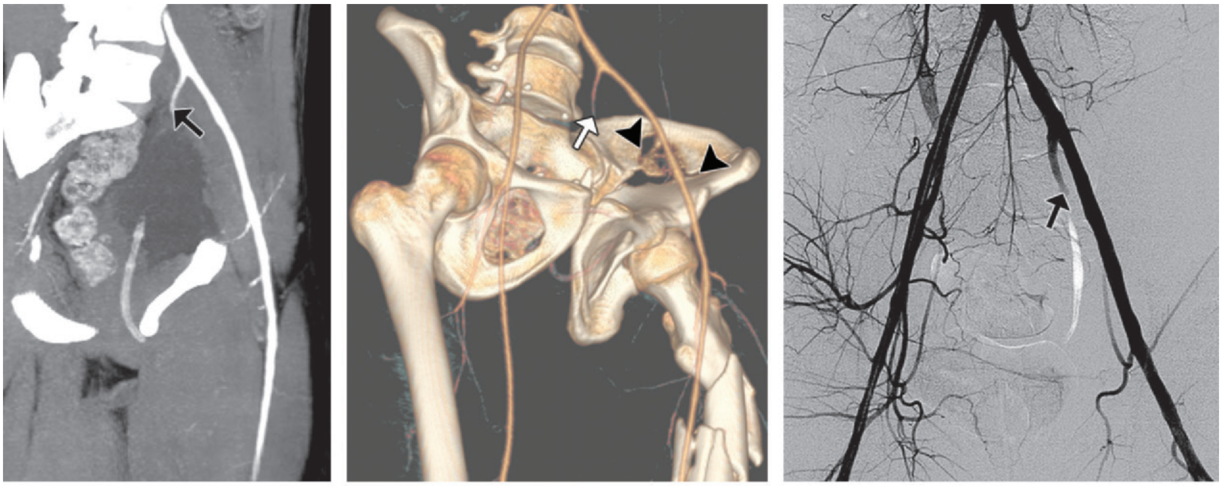
Vascular Injuries in Trauma

The imaging findings related to vascular injury at CT may be classified as direct or indirect. Direct signs, which tend to be more specific but less sensitive in detection of vascular trauma, include abnormalities of the vessel wall such as laceration with active hemorrhage, intimal tear, dissection, intraluminal thrombosis, pseudoaneurysm, narrowing, and presence of arteriovenous fistulas (29). Indirect signs, which tend to be more sensitive but less specific, include abnormalities of the perivascular tissues or end organs and include presence of a perivascular hematoma or fat stranding and varying degrees of end-organ hypoenhancement (29).

Active Contrast Material Extravasation

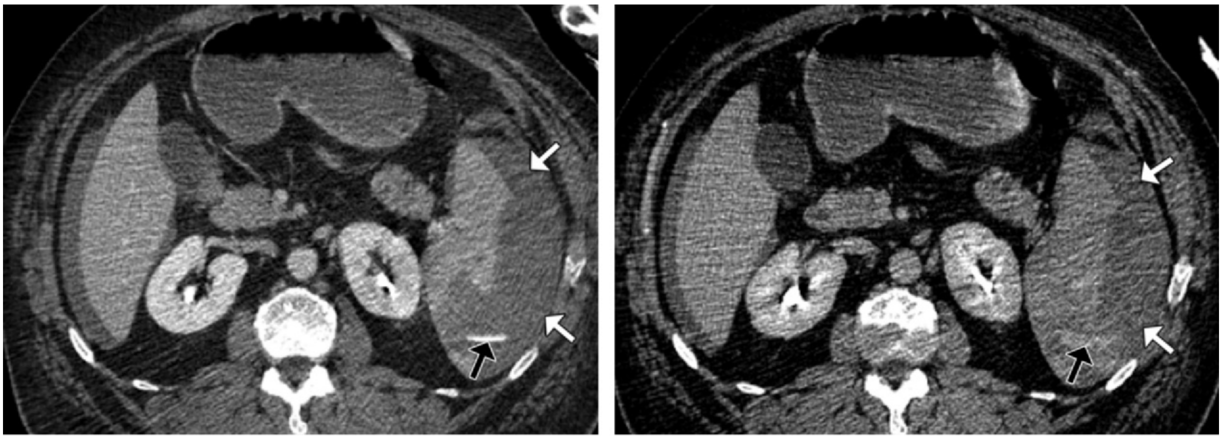
In cases of vascular injury with active hemorrhage, there is typically a defect in all three layers of the vessel wall (intima, media, and adventitia), resulting in contrast-enhanced blood extending beyond the vessel lumen. At imaging, an extravascular hyperattenuating focus or "blush" is seen, and this focus expands in subsequent more delayed phases of acquisition. Active extravasation can occur in both the intra- and extraperitoneal spaces, adjacent to the injured vessel, or as intraparenchymal or intraluminal bleeding when a solid or hollow viscus is injured (30,31).

In cases of active hemorrhage, it is important to distinguish between arterial and venous hemorrhage, given the potential differences in management (31–33). Arterial injury will commonly be visualized in the arterial phase as evidenced by extravascular pooling of contrast material, with attenuation similar to that of the aorta, and expansion in subsequently acquired portal venous or delayed phase datasets (Figs 6, 7). In contradistinction, venous injury is initially seen only in the portal venous phase as a focus of extravascular attenuation, also expanding on delayed phase images,



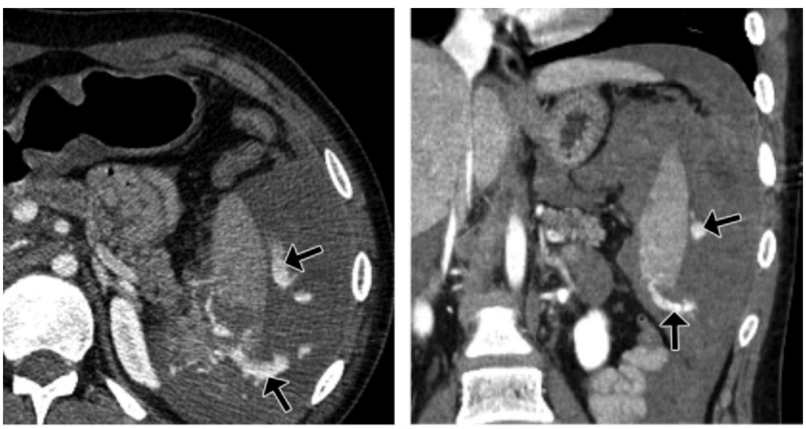
a. b. c.

Figure 5. Arterial occlusion in a 21-year-old man after a motor vehicle collision. **(a)** Left posterior oblique MIP CT angiogram shows occlusion of the left internal iliac artery (arrow). **(b)** Three-dimensional reformation CT image shows occlusion of the left internal iliac artery (arrow) and fractures of the left proximal femur and left iliac crest (arrowheads). **(c)** DSA image from catheter angiography performed to confirm the diagnosis shows occlusion of the left internal iliac artery (arrow).



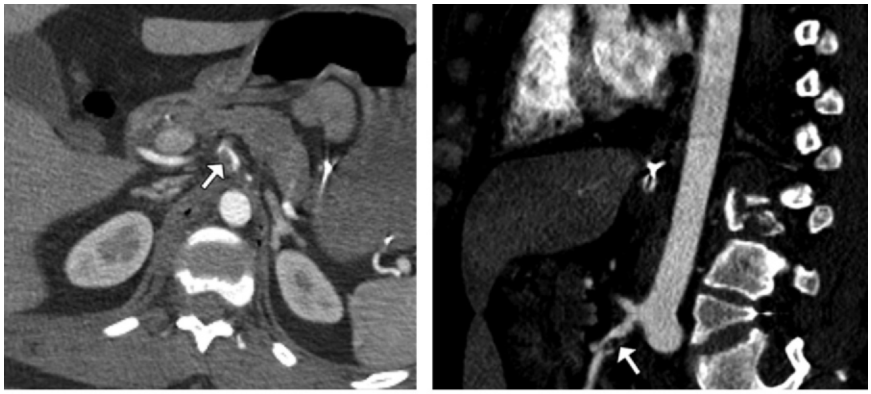
a. b.

Figure 6. Arterial extravasation in a 49-year-old man struck by a snowplow. He was shown to have a laceration of the segmental branches of the splenic artery. **(a)** Axial portal venous phase CT image shows a dense linear jet of contrast material extravasation (black arrow) and a splenic subcapsular hematoma (white arrows). **(b)** Corresponding delayed phase image shows continued extravasation (black arrow), as demonstrated by growth in size with decreased attenuation. White arrows = splenic subcapsular hematoma.



a. b.

Figure 7. Arterial extravasation in a 16-year-old boy involved in a motor vehicle collision (car vs boulder). Contrast-enhanced CT showed multiple splenic lacerations. Axial **(a)** and coronal **(b)** portal venous phase CT images show dense linear jets of arterial extravasation within the splenic parenchyma (arrows) and within a surrounding perisplenic hematoma. No delayed imaging was performed because the patient was hemodynamically unstable. He was rushed to the operating room, and splenectomy was performed.



a. b.

Figure 8. Intimal tear in a 33-year-old woman after a motor vehicle collision. **(a)** Axial contrast-enhanced CT image shows a filling defect (arrow) in the celiac artery, consistent with an intimal injury. **(b)** Sagittal oblique CT angiogram shows a curvilinear filling defect (arrow) causing partial occlusion of the celiac artery. There was no evidence of end-organ ischemia. Conservative management was chosen, and repeat CT 2 days later showed resolution of the finding.

when acquired. However, low-intensity arterial bleeding or arterial bleeding in a profoundly hypotensive patient may become initially apparent only in the portal venous or delayed phase (Fig 3).

Other Forms of Vascular Injury

While potentially more subtle at CT, major vasculature injuries may be present in the absence of active hemorrhage. In these cases, knowledge of the anatomy of the vessel wall allows a deeper understanding of the various forms of injury. The tunica intima is the innermost layer, followed by the tunica media and tunica adventitia. Vessel wall injury, with or without concomitant active hemorrhage, may have a spectrum of imaging findings ranging from irregular narrowing, beading, and outpouching to complete occlusion. It is important to accurately diagnose these vessel injuries, since they may be a source of emboli, progress to frank rupture or occlusion, or be the cause of subsequent end-organ ischemia.

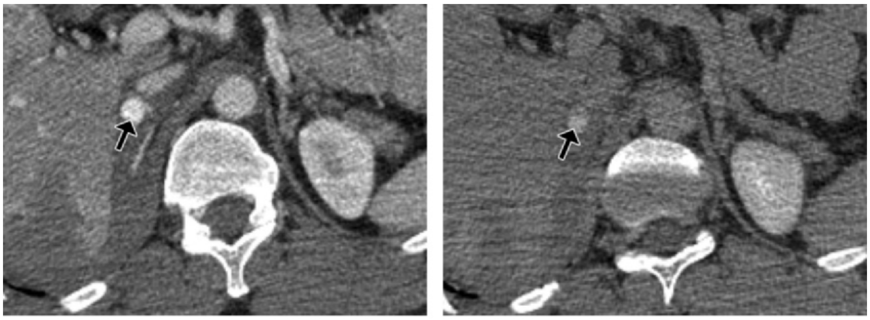
Intimal Tears.—Pathologically, intimal tears involve separation of the intima from the adjacent media. At imaging, this may appear as a linear or curvilinear hypoattenuating filling defect emanating from the vessel wall into the contrast-enhanced lumen (Figs 1a, 1d, 2, 8).

Vessel Dissection.—In the case of dissections, the injury results in interposition of blood between the intima/inner media and the outer media/adventitia. This leads to creation of true and false lumina, with potential for antegrade or retrograde propagation of blood in both lumina. At imaging, traumatic dissection may manifest in a variety of ways. A linear area of hypoattenuation, representing the intima and inner media (dissection flap), may project into the vessel lumen. Alternatively, with thrombosis of the false lumen, a dissection may appear at CT as a crescentic focal region of vessel narrowing.

Figure 9. Pseudoaneurysm in a 46-year-old woman struck by a motor vehicle. Axial arterial phase CT image shows an ovoid area of hyperattenuation (arrow) adjacent to the proximal splenic artery just distal to the celiac trifurcation, consistent with a pseudoaneurysm.

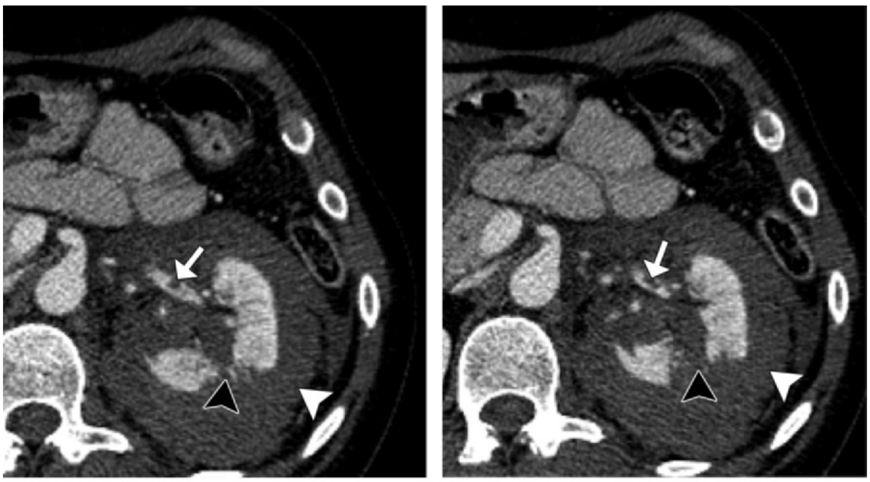
Pseudoaneurysm.—Pseudoaneurysms are contained vascular injuries that may occur when the arterial intima and media are injured and flowing blood is contained by the adventitia. Alternatively, pseudoaneurysms may occur when all three layers of the arterial vessel wall are injured and blood is contained only by the perivascular tissues through formation of a fibrous capsule (34). At imaging, a well-circumscribed outpouching/focal lobule is typically seen adjacent to the vessel, which mirrors the attenuation of the blood pool in all phases acquired and does not enlarge at delayed imaging (Figs 9, 10). Pseudoaneurysms can occur along a major vessel as well as within the parenchyma of a solid organ, most commonly the spleen (19,35). Inherently unstable, pseudoaneurysms are at increased risk for rupture as well as partial thrombosis, leading to the potential for emboli to distal organs (21,35).

Arteriovenous Fistula.—In addition to pseudoaneurysms, traumatic arteriovenous fistulas are another example of contained vascular injury.



a. b.

Figure 10. Pseudoaneurysm in a 38-year-old man who fell from a three-story building. **(a)** Axial portal venous phase CT image shows a well-defined circular area of hyperattenuation (arrow) that appears to arise from the right adrenal artery. **(b)** Axial delayed phase CT image shows the outpouching (arrow), which maintains its shape but diminishes in attenuation, consistent with an adrenal artery pseudoaneurysm.



a. b.

Figure 11. Partial occlusion in a 45-year-old woman after a motor vehicle collision (car vs telephone pole). Sequential axial contrast-enhanced CT images show a hypoattenuating intraluminal filling defect (arrow) in the left renal vein, enlarging in size at cranial-caudal imaging. A large parenchymal laceration is seen transecting the posterior kidney (black arrowhead), and a large surrounding perinephric hematoma (white arrowhead) is noted.

Although rare, awareness and prompt diagnosis of this injury are clinically important due to an increased risk for rupture (19). As there is direct communication between an artery and a vein, the finding at imaging of early filling of a major vein in the arterial phase may be diagnostic. If a contralateral anatomic equivalent is present for comparison (eg, the iliac or femoral veins), asymmetric early filling can also be diagnostic.

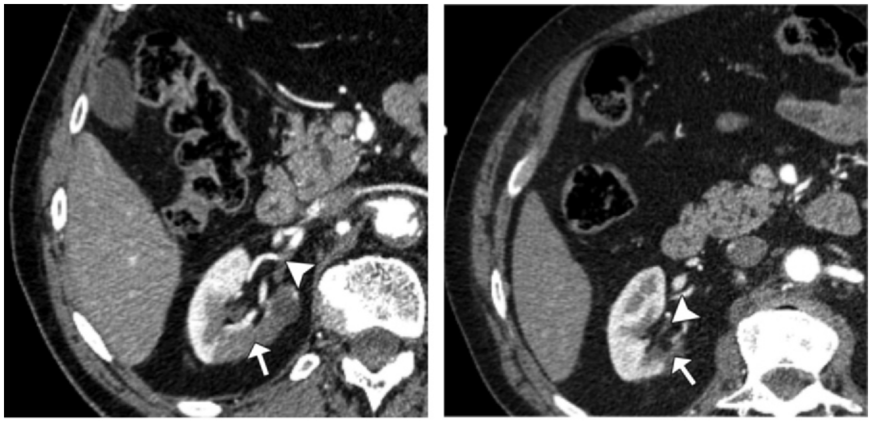
Intraluminal Thrombosis.—Most commonly, when occlusion of a major vessel is seen, there is intimal disruption with subsequent platelet aggregation at the site of injury, leading to thrombosis (36). At imaging, thrombosis appears as a hypoattenuating intraluminal filling defect, which may result in partial (Figs 8, 11) or complete (Figs 12, 13) occlusion, the latter resulting in abrupt cutoff of a contrast-enhanced vessel.

Vessel Contour Abnormalities.—In cases in which the vessel lumen is narrowed (Fig 14) or irregular in contour, the differential diagnosis includes dissection, intimal tear with partial thrombosis, vasospasm, and perivascular hematoma resulting in external compression. Vasospasm occurs when there is contraction of the smooth muscle fibers in the media as a hemostatic response to vessel injury induced by aggregating platelets. At imaging, there is diminished caliber with concentric narrowing adjacent or even distal to the site of injury (2,21). Vasospasm is a difficult diagnosis to make but should remain in the differential diagnosis since it can resolve spontaneously or masquerade as intraluminal thrombosis. Perivascular hematoma and narrowing associated with external compression are diagnoses that may be made when there is direct evidence that there is an extraluminal source for narrowing or occlusion.

Major Vascular Injury Sites

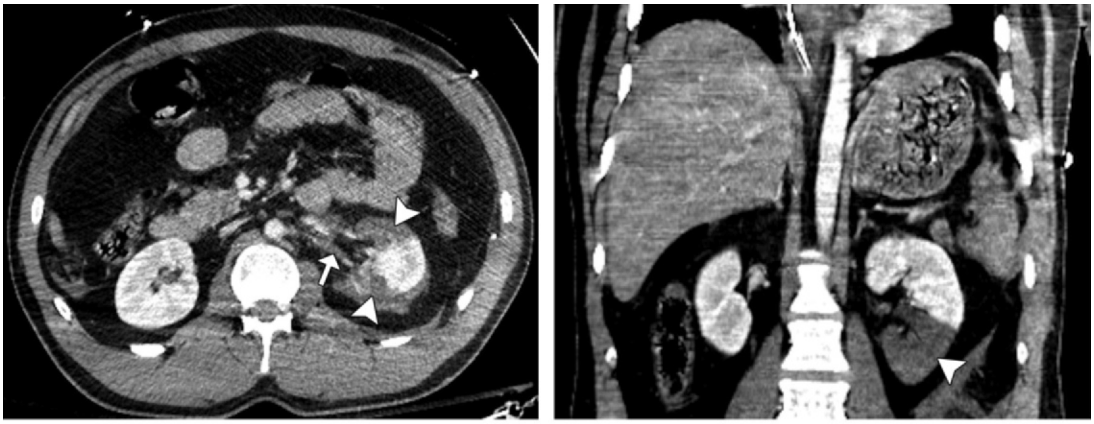
Aortic Injury

Given its high mortality rate, it is imperative to immediately diagnose aortic injury. Multidetector CT is 98% sensitive in detecting aortic injury. In



a. b.

Figure 12. Complete occlusion in a 76-year-old man who fell from a height. Contrast-enhanced CT showed injury to the right renal artery. **(a)** Axial contrast-enhanced CT image shows numerous intraluminal filling defects consistent with intraluminal thrombosis in segmental renal arterial branches (arrowhead), with resultant downstream segmental hypoperfusion in the posterior right kidney (arrow). **(b)** Axial contrast-enhanced CT image 1 year later shows parenchymal (arrow) and vessel (arrowhead) atrophy.



a. b.

Figure 13. Complete occlusion in a 25-year-old man after a high-speed motor vehicle collision. **(a)** Axial contrast-enhanced CT image shows occlusion of the distal left renal artery (arrow) with downstream segmental nonenhancement of the renal parenchyma (arrowheads). **(b)** Coronal reformatted CT image shows downstream segmental nonenhancement of the renal parenchyma (arrowhead). **(c)** DSA image shows abrupt cutoff of a segmental branch of the left renal artery (arrow) and absent perfusion of the inferior kidney.

c.

comparison with the thoracic aorta, abdominal aortic injuries are rare. Ninety percent of aortic injuries occur at the aortic isthmus where the aorta is attached to the ligamentum arteriosum (13,16). In a similar mechanism of injury, abdominal aortic injuries can occur near the diaphragmatic crus, associated with shear forces created by its fibrous attachments (16,27,37–40). In addition, lower thoracic and lumbar vertebral body fractures can also be associated with abdominal aortic injury, necessitating close scrutiny of the abdominal aorta (41). There is a broad spectrum of imaging findings associated with traumatic aortic injury, including intimal tear, dissection, pseudoaneurysm, intraluminal thrombosis, adventitial hematoma, and aortic transection.

Shalhub et al (42) analyzed 113 cases of blunt abdominal aortic injury and noted that 48% of cases led to open or endovascular repair while the overall mortality was 68%, the majority of which occurred within the first 24 hours. Classification of abdominal aortic injury may be considered with respect to three zones that can affect the surgeon's approach in the setting of open repair. Zone 1 extends from the diaphragmatic hiatus to the SMA. Zone 1 injuries require extensive open exposure at laparotomy; therefore, an endovascular approach is preferred in stable patients (42). Zone 2 extends from the SMA to the level of the renal arteries; the decision for endovascular repair depends on

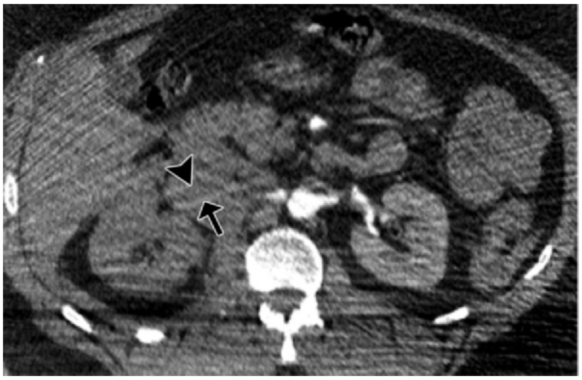


Figure 14. Vessel narrowing in a 45-year-old man after a motorcycle collision. Axial contrast-enhanced CT image shows a mixed-attenuation perivascular hematoma (arrowhead) from renal artery transection. There is near occlusion of the right renal artery, which is hypoenhancing and narrowed distally (arrow). There is diminished perfusion of the right renal parenchyma relative to the left.

involvement of the SMA or renal arteries (42). Zone 3 extends from the inferior aspect of the renal arteries to the aortic bifurcation and is the most common site of injury in blunt abdominopelvic aortic injury (42). Zone 3 injuries are amenable to an open or endovascular approach, with a preference for endovascular therapy when visceral injury is suspected, given that peritoneal spillage can cause complications after open repair (Fig 1a, 1d) (42,43).

Management of aortic injury is highly dependent on the imaging features. Shalhub et al (42) demonstrated that intimal tears less than 10 mm in length can be managed nonsurgically with blood pressure control and repeat imaging. Large intimal tears (considered to be >10 mm in length) are managed on a case-by-case basis, since there is a higher risk for large thrombus formation or downstream arterial insufficiency. Pseudoaneurysms of the aorta are typically directly managed with surgical or endovascular repair given their high risk for rupture (42,43).

Vascular Injury in the Pelvis

Vascular injury in pelvic trauma is associated with high morbidity and mortality. Up to 40% of blunt pelvic trauma is associated with significant pelvic bleeding (21). Pelvic fractures are also associated with vascular injury in blunt pelvic trauma (44). The pelvis is a bony ring composed of the sacrum along its posterior aspect and two lateral components (ilium, ischium, and pubis) that are fused along the anterior aspect at the pubic symphysis. The pelvic vessels include the common, internal, and external iliac arteries and their branches.

Pelvic ring disruption caused by blunt trauma can occur via three mechanisms, as described by the Young-Burgess classification system: lateral compression, anterior-posterior compression, and shear injury (45). These three force vectors are responsible for pelvic ring disruption/instability. Pelvic ring instability is directly related to the likelihood of vascular injury, given the close approximation of the pelvic vessels to the ligamentous and bony elements (Fig 15) (44). Ben-Menachem et al (44) demonstrated that the highest prevalence of arterial injury occurs with anterior-posterior compression, involving the superior gluteal and internal pudendal arteries, given their proximity to the sacroiliac joint and fascia of the piriformis muscle.

As stated earlier, pelvic CT angiography is integrated into our department's trauma multidetector CT protocols when there is clinical suspicion for pelvic hemorrhage, especially when there is evidence of pelvic ring disruption at admission radiography. A variety of arterial injuries may be identified in pelvic vascular trauma, most commonly active hemorrhage and vessel occlusion, although intimal injuries, dissection, arteriovenous fistula, and pseudoaneurysm formation may rarely be seen as well. Importantly, multiphasic multidetector CT of the pelvis also allows differentiation of arterial from venous injury and, in turn, determination of the need for endovascular treatment versus external fixation alone (Fig 15) (44–46).

Visceral Organ Vascular Injury

When evaluating the solid organs in the setting of blunt abdominopelvic trauma, vascular injury can manifest at contrast-enhanced CT as direct intraparenchymal vascular injury or indirectly as varying degrees of end-organ hypoenhancement.

Manifestations of direct intraparenchymal vascular injury include arteriovenous fistula, pseudoaneurysm, laceration, and hematoma (47). As discussed earlier, contained vascular injuries such as parenchymal arteriovenous fistulas and pseudoaneurysms (Figs 9, 10) can manifest as contrast material extravasation at initial or follow-up contrast-enhanced CT. Therefore, accurate diagnosis is pivotal for appropriate follow-up imaging or treatment (19,20,34,35,47,48). Lacerations can manifest as linear or irregular hypoattenuating parenchymal defects at contrast-enhanced CT (Fig 7) (19,20,34,35,48). Lacerations with adjacent contrast material extravasation may necessitate endovascular or surgical management in the appropriate clinical setting (Fig 7) (20).

Finally, hematomas can be subcapsular or intraparenchymal, manifesting as an elliptical/curvilinear low-attenuation collection of blood below the organ capsule or as intraparenchymal low attenuation with irregular borders (Fig 6) (34,47). Active contrast material extravasation can occur within a parenchymal hematoma in a

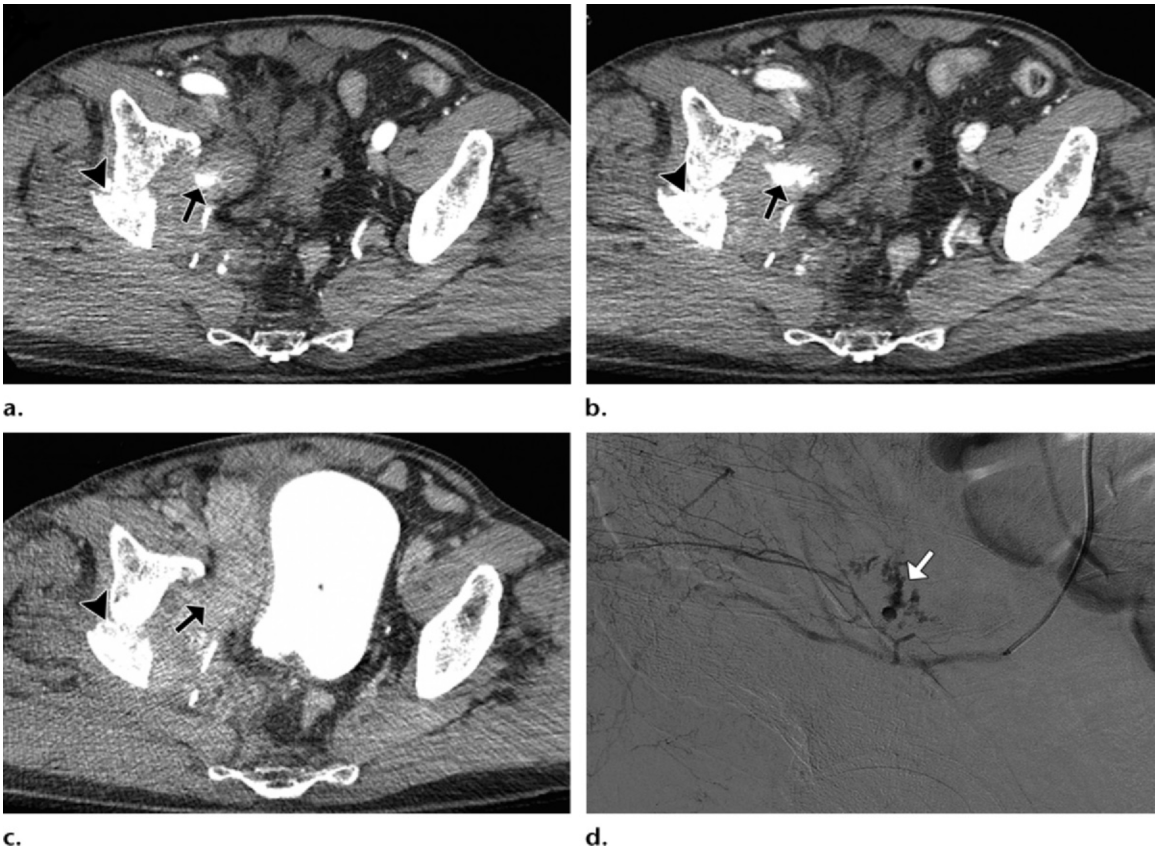


Figure 15. Acetabular fractures and vascular injury in a 66-year-old male pedestrian struck by a motor vehicle. **(a–c)** Arterial **(a)**, portal venous **(b)**, and delayed **(c)** phase CT angiograms show right acetabular fractures (arrowhead). A focus of contrast material extravasation in the arterial phase (arrow in **a**) expands in the portal venous phase (arrow in **b**) and fades into an enlarging hematoma in the delayed phase (arrow in **c**). CT cystography was performed during the delayed phase to assess for bladder rupture; note the contrast material–opacified bladder in **c**. **(d)** DSA image shows active extravasation (arrow), which was embolized.

diffuse or more focal pattern, depending on the amount of clotted blood in the hematoma (47). Subcapsular hematomas can expand at delayed contrast-enhanced CT, indicative of active hemorrhage. Finally, major vessel injury can manifest as complete nonenhancement of an end organ or as segmental or wedge-shaped infarction (Figs 12–14) (20,34).

In addition, when evaluating the solid organs, careful assessment for imaging findings commonly associated with vascular injuries is imperative to avoid overlooking them. For example, chest wall injury can lead to rib fractures or transverse process fractures, which can lacerate and cause active extravasation from solid organs (2,21,49).

Liver.—The spectrum of solid organ vascular injuries described earlier is commonly seen in liver injury; however, vascular injuries in the liver may be more complex given its dual blood supply. In a portal venous injury, the affected liver segment may appear relatively hyperattenuating in the arterial phase due to compensatory increased arterial inflow. Subsequently, the affected liver segment may appear relatively hypoattenuating in the portal venous phase with respect to the adjacent liver parenchyma due to the venous injury (Fig 16) (50).

In addition to portal vein injuries, hepatic vein injuries are also a source of major hemorrhage and typically require open repair (Fig 17) (51,52). Poletti et al (48) demonstrated that hepatic vein involvement leads to surgery 6.5 times more frequently than when a hepatic laceration does not extend to the veins. Poletti et al (48) also showed that hepatic vein injury is 3.5 times more likely to be associated with arterial injury in comparison with lacerations where the hepatic veins are intact (53).

Hepatic artery injuries may manifest at CT as active hemorrhage or formation of a pseudoaneurysm. Pseudoaneurysms may have an acute or delayed presentation, the latter resulting from formation of a fibrous capsule surrounding the site of injury during the healing process. Hemobilia due to hepatic vascular injury with extension into an adjacent injured bile duct may result in flow of blood products into the biliary system and eventu-

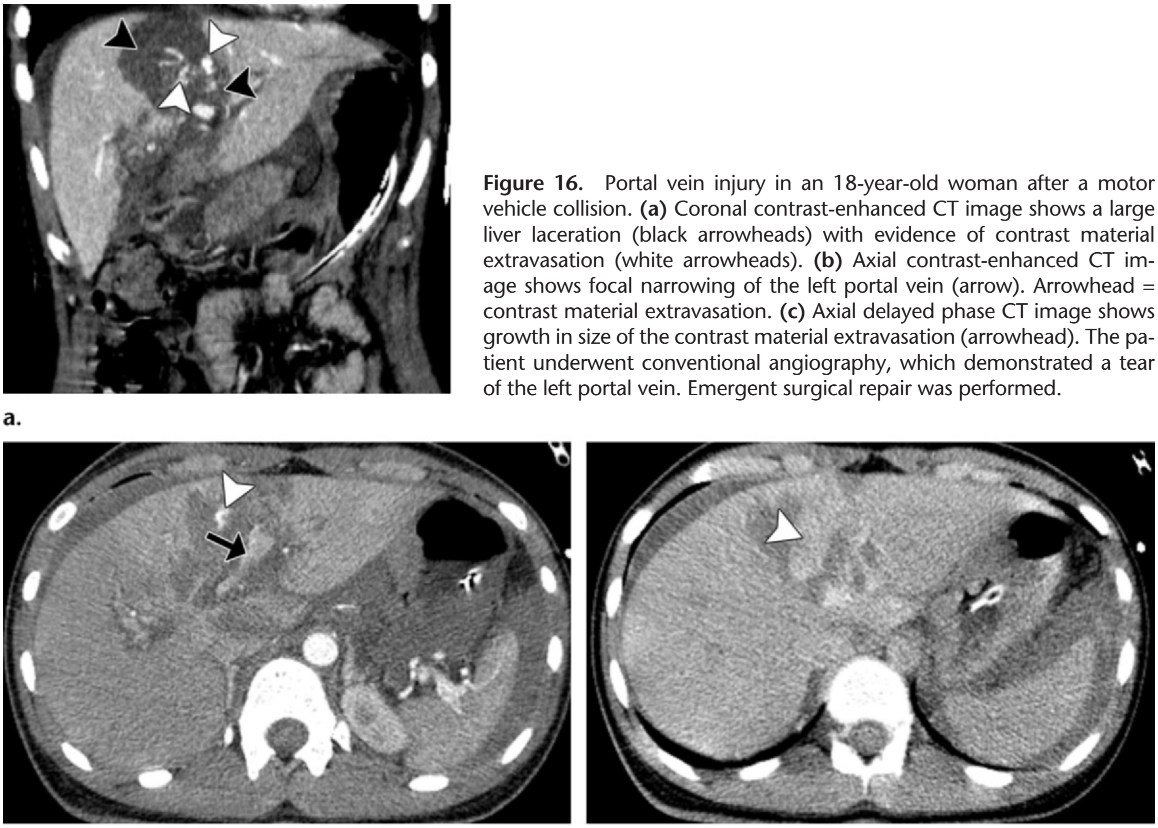

a. b. c.

Figure 16. Portal vein injury in an 18-year-old woman after a motor vehicle collision. **(a)** Coronal contrast-enhanced CT image shows a large liver laceration (black arrowheads) with evidence of contrast material extravasation (white arrowheads). **(b)** Axial contrast-enhanced CT image shows focal narrowing of the left portal vein (arrow). Arrowhead = contrast material extravasation. **(c)** Axial delayed phase CT image shows growth in size of the contrast material extravasation (arrowhead). The patient underwent conventional angiography, which demonstrated a tear of the left portal vein. Emergent surgical repair was performed.

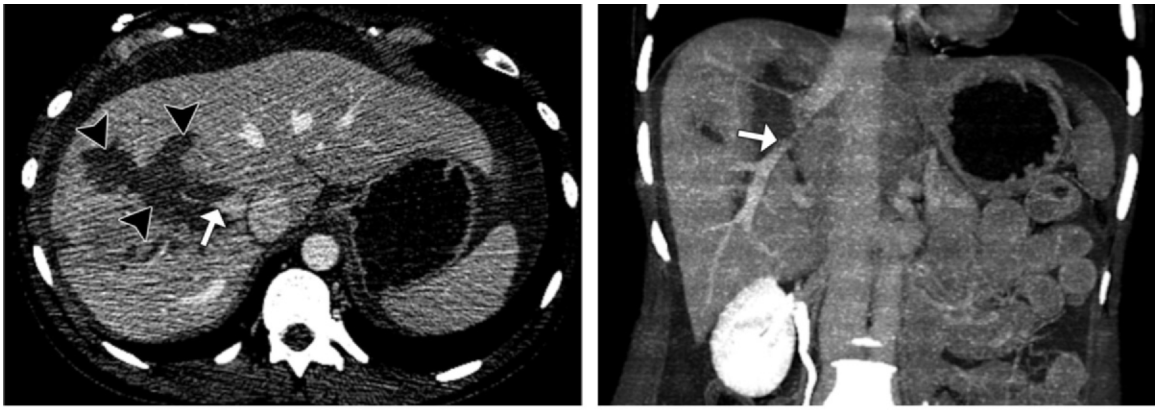
ally the duodenum, which may clinically manifest as gastrointestinal bleeding (54,55). In major liver trauma, repeat imaging should be considered in cases of hepatic artery injury to assess for evolution of the injury, including posttraumatic pseudoaneurysm, biloma formation, or hemobilia (34).

Spleen.—In blunt abdominal trauma, the spleen is the most commonly injured organ. The spleen is a highly vascular organ that is surrounded by a thin fibroelastic capsule. Its delicate capsule is advantageous in settings such as portal hypertension to accommodate expansion in elevated portal venous pressures. However, this sinusoidal organ is essentially a blood reservoir that lacks a thick fibrous capsule, reducing its ability to increase intraorgan pressures to tamponade parenchymal bleeding.

Splenic vascular injuries have various forms of presentation, including splenic artery or vein laceration, intraparenchymal hematoma, subcapsular hematoma, and contained vascular injuries (pseudoaneurysms and arteriovenous fistulas). The sinusoidal architecture of the splenic parenchyma causes it to have heterogeneous enhancement in the arterial phase, limiting the ability to detect parenchymal defects. As discussed earlier, lacerations of the solid organs, commonly the spleen, can lead to linear or irregular parenchymal hypoenhancement with associated active contrast material extravasation (Figs 6, 7). Active extravasation has an increased likelihood of requiring splenectomy in comparison with patients who have no vascular injury or contained vascular injuries only (19).

As discussed earlier, our institutional CT protocol extends CT angiography of the thorax to include the spleen. The arterial phase increases sensitivity in detecting contained vascular injuries, such as pseudoaneurysms and arteriovenous fistulas, which can be overlooked when only portal venous and delayed phase images are acquired (19,35,56). It is important to identify contained vascular injuries given their increased risk for rupture, leading to uncontained active hemorrhage (57). In addition, early identification of pseudoaneurysms increases the success rate of embolization, avoiding more invasive surgical management (58). Portal venous phase enhancement of the spleen allows one to accurately assess the parenchyma for lacerations as well as to discern suspicious foci of hyperenhancement that may represent arterial extravasation or contained vascular injury (59). Therefore, inclusion of dual-phase CT is imperative to achieve an accurate diagnosis.

Kidneys.—In the kidneys, major vascular injury may also have various presentations. When the kidney is lacerated into multiple distinct portions,



a. b.

Figure 17. Hepatic vein injury in a 29-year-old man after a motorcycle collision. **(a)** Axial portal venous phase CT image shows a large liver laceration (arrowheads) with irregularity and decreased enhancement of the right hepatic vein (arrow). **(b)** Coronal portal venous phase MIP CT image shows focal narrowing and thrombus of the right hepatic vein (arrow).

it is considered "shattered." A shattered kidney will typically manifest as active hemorrhage that usually requires surgery or endovascular repair (60). Renal vein injury can have obvious imaging findings such as transection or thrombosis. Secondary findings include changes related to acute venous hypertension of the affected kidney, including nephromegaly, delayed nephrogram, and decreased excretion of contrast material at delayed phase imaging (60).

Renal artery occlusion can occur as a result of a dissection or intimal tear caused by rapid deceleration and stretching of the renal artery across a vertebral body or transverse process (60,61). At CT, renal artery occlusion results in distal nonenhancement and ischemia of the affected segment of the kidney (Figs 12–14). Occasionally, renal artery occlusion can cause reflux of contrast material into the renal vein from the inferior vena cava, owing to lack of forward flow of blood in the affected renal vein (60).

Major renal artery injuries with occlusion are usually treated conservatively in appropriately selected patients. As Jawas and Abu-Zidan (61) described, surgical or endovascular revascularization is unlikely to succeed when the kidney has been ischemic for more than 2 hours. Thus, intervention is usually considered only when there is bilateral injury or if the unilateral arterial occlusion is discovered within a 3-hour window from the time of trauma (61).

Bowel and Mesentery.—In the mesentery and bowel, major vascular injury can have variable imaging manifestations that include active extravasation, mesenteric vessel vasoconstriction, mesenteric vessel beading, and abrupt termination of the mesenteric vasculature at sites of injury (Figs 1b, 1c, 18, 19). Brofman et al (15) retrospectively reviewed CT studies of patients with surgically proven bowel injury, mesenteric injury, or both. Their study demonstrated that active mesenteric extravasation (17%), mesenteric vascular beading (35%), and abrupt termination of the mesenteric vessels (39%) are vascular injury imaging findings highly suggestive as direct signs of potential mesenteric and/or bowel injury (15).

Hemoperitoneum in the absence of solid organ injury should also be viewed as suspicious for potential mesenteric or bowel vascular injury (62). A mesenteric hematoma is another sign of mesenteric vascular injury and at CT appears as a more focal area of hyperattenuation in the mesenteric fat (Fig 19a) (15). Ideally, when evaluating the mesenteric vessels, an important imaging feature to appreciate is the hypoattenuating mesenteric fat surrounding the contrast-opacified mesenteric vessels. Any disruption of the surrounding vascular fat by hyperattenuating fluid or fat stranding in the mesentery should raise suspicion for mesenteric injury.

In hypotension, the mesenteric vessels may demonstrate diffuse "reflex" vasoconstriction (Fig 4), leading to bowel ischemia from a nonocclusive cause that can easily be missed at imaging (63). End-organ effects of mesenteric vascular injury initially manifest as bowel wall hyperenhancement, which is caused by decreased perfusion leading to capillary leakage of contrast material in the mucosa, resulting in the hyperenhanced appearance (Fig 18d) (64). As ischemia progresses, the bowel wall becomes hypoenhancing, highly suggestive of ischemia/infarction (64). Therefore, although major vascular injury in the mesentery can have a more obvious imaging manifestation such as active extravasation, careful scrutiny of the mesenteric vessels is important to find additional signs that can be associated with bowel ischemia.

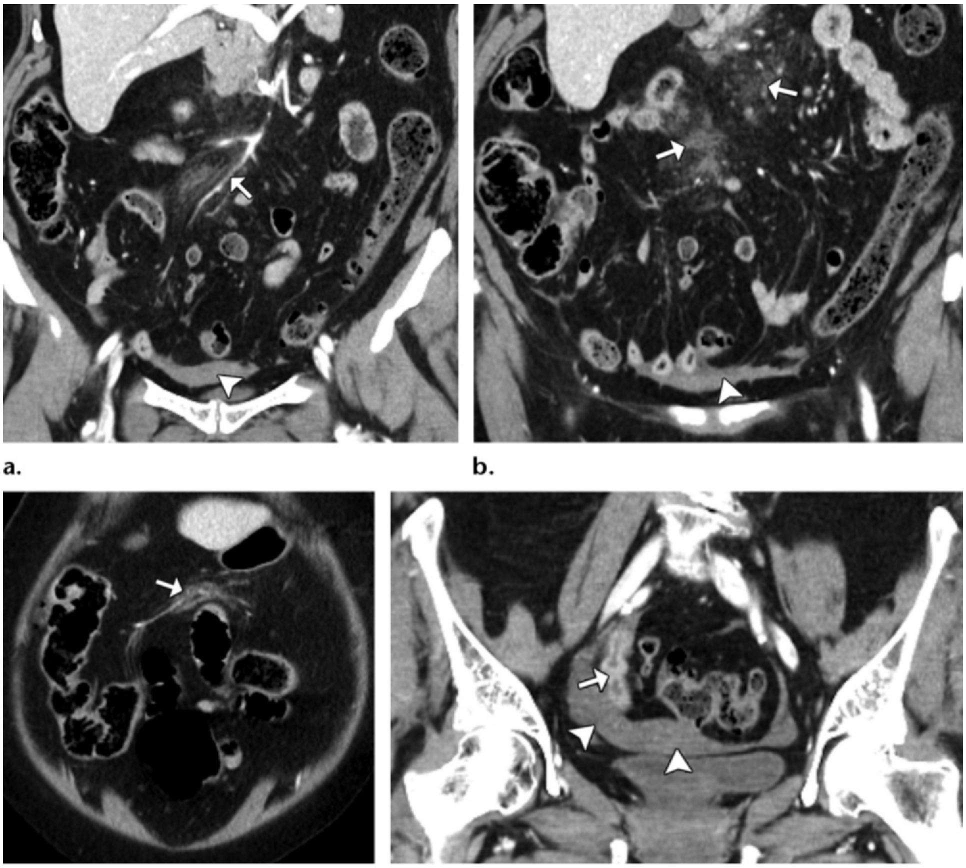


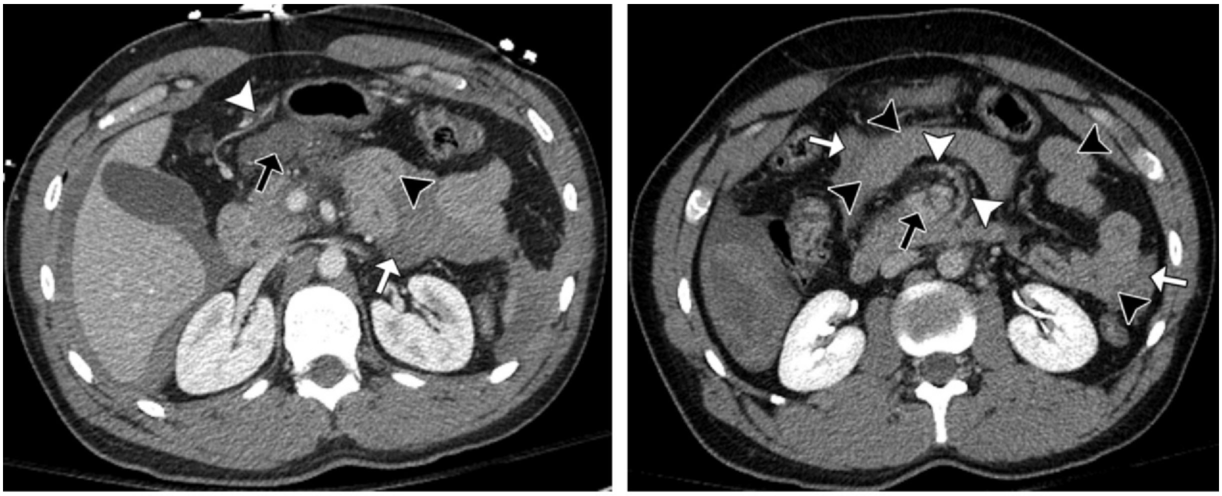
Figure 18. Bowel and mesenteric injuries in a 75-year-old woman with right lower quadrant pain after a high-speed motor vehicle collision. Coronal contrast-enhanced CT was performed. **(a)** Image shows irregular beading of a branch of the SMA (arrow) as well as hyperattenuation in surrounding mesenteric fat. **(b)** Multiple sites of mesenteric hyperattenuation (arrows) increase suspicion for mesenteric injury. **(c)** Irregular vascular beading with adjacent hyperattentuation (arrow) is also seen in the region of the transverse mesocolon. **(d)** Hyperattenuating fluid is seen layering in the lower pelvis (arrowheads) adjacent to a segment of ileum with mucosal hyperenhancement and thickening (arrow). The patient was taken to the operating room and noted to have multiple small bowel mesenteric tears, serosal tears of the mid transverse colon, and a devascularized 4-cm segment of small bowel 10 cm from the ileocecal valve.

Organ Injury Grading Systems

Discussion of vascular injury in the visceral organs necessitates an understanding of both the history and current trends in organ injury grading scales. In 1987, the Organ Injury Scaling (OIS) Committee of the American Association for the Surgery of Trauma (AAST) devised injury severity grades for individual organs for the purposes of having a common nomenclature in trauma as well as for future clinical research. AAST organ injury grading scales are based on the gross anatomic appearance of injured organs seen during surgery, with increasing severity from grade 1 to grade 6 (65). The different AAST organ injury grading scales share certain features of traumatic injury such as size of lacerations, major vessel injury, segmental or complete infarction, and organ shattering. Each AAST OIS grade is assigned an abbreviated injury severity score (AIS), which is used to calculate the injury severity score (ISS), a predictor of patient survival (65,66).

Commonly, radiologists will assign an AAST injury grade based on CT findings. Over 2 decades, there has been no revision to the AAST OISs despite advances in imaging and treatment, with the most recent revision for the spleen and liver done in 1994 (66,67). Although the AAST OIS is a familiar lexicon to facilitate radiologist communication of the type of organ injury to the clinician, it lacks important CT findings in vascular injury that can significantly alter clinical management decisions. In traumatic vascular injury, active contrast material extravasation and contained vascular injury are not included in the AAST grading scales, resulting in low grades, and in turn lower AISs, for injuries that may require endovascular or surgical intervention (25,68).

As Moore et al (67) describe in the 1994 AAST OIS revision, “Despite this extensive



a. b.

c.

Figure 19. Bowel and mesenteric injuries in a 28-year-old man who crashed into a tree while driving an all-terrain vehicle (ATV) at high speed. Axial **(a, b)** and sagittal **(c)** contrast-enhanced CT images show a mesenteric hematoma (black arrow) in the transverse mesocolon. There is irregular beading of the mesenteric vessels (white arrowheads) and hyperattenuating fluid (white arrows) layering along thickened small bowel loops (black arrowheads) in the left upper quadrant. The patient was taken for emergent laparotomy given the increased radiologic suspicion for mesenteric laceration and bowel injury. Laparotomy demonstrated a small bowel mesenteric tear as well as perforation of the jejunum just 1 cm distal to the ligament of Treitz. In addition, a 10-cm tear of the transverse mesocolon and bleeding of the middle colic artery were repaired.

preparation process, OISs are inherently limited by design as ordinal rather than interval scales. For example, the difference between a grade I versus II injury is generally less significant clinically than a grade IV versus V. The fundamental objective of the OIS, however, is not to assign prognostic value to a specific injury, but rather to provide a clearer description to facilitate comparison of an equivalent injury managed in one fashion versus another." Therefore, CT grading of organ injury using the AAST OISs will provide clinicians with a familiar lexicon; however, it is important to realize its limitations with regard to severity of vascular injury and patient management, necessitating a paradigm shift to CT-based grading systems with potentially more accurate prognostic values.

Pitfalls

Awareness of the various imaging pitfalls is important to avoid misdiagnosis and allow accurate, timely interpretation in the trauma setting. Potential pitfalls in the case of pelvic trauma include streak artifact from a hip prosthesis, which may mask adjacent sites of vascular injury. If there is high clinical suspicion for pelvic vascular injury, delayed phase images may be useful to assess for enlarging areas of active extravasation. An additional pitfall in cases of vascular trauma includes vessel narrowing caused by preexisting noncalcified atherosclerotic plaque, which may be mistaken for traumatically induced acute intraluminal thrombosis (69). In these cases, a review of prior imaging, if available, may be useful in determining whether a region of focal narrowing is acute or chronic.

In addition, repeat CT may be useful to ensure stability/resolution of a region of focal vessel narrowing. A common pitfall is the penile bulbar blush seen at contrast-enhanced CT, which may erroneously be characterized as vascular injury. However, its location as well as bilateral nature should provide confidence that this is normal enhancement and unrelated to trauma (Fig 20). Another potential source of pitfalls is a deficient CT technique, especially the lack of multiphasic imaging in cases of vascular injuries that require several time points

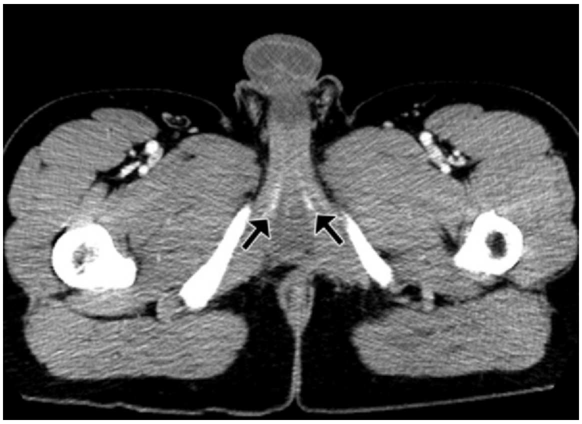


Figure 20. Axial contrast-enhanced CT image shows a penile blush (arrows). This imaging feature will typically be bilateral as well as at the base of the bulbar penis. Variable appearances can occur; therefore, knowledge of this imaging finding will prevent potential error in interpretation.

for accurate diagnosis and complete characterization, such as differentiating between active hemorrhage and contained injuries. Finally, a thorough evaluation of major vessels is important to avoid rare but clinically significant injuries, such as partial thrombosis (2).

Conclusion

Vascular injury in blunt abdominopelvic trauma may present with a variety of imaging features that can be highlighted by appropriately protocoled studies. Multiphasic acquisitions facilitate diagnosis and characterization of the complete range of vascular injuries. Accurate diagnosis of major vascular injury, through an understanding of its relevant imaging features, is fundamental to optimizing clinical outcomes in the trauma population.

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