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Traumatic abdominal aortic injury: clinical considerations for the diagnostic radiologist

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Abstract

Traumatic abdominal aortic injury (TAAI) is a severe complication of penetrating and blunt trauma with significant morbidity and mortality, particularly if diagnosis is delayed. In patients with life-threatening injuries, accurate and prompt diagnosis of TAAI can be made with computed tomography (CT). Once the diagnosis of TAAI is made, the radiologist should provide an accurate description of the aortic lesion and the extent of injury in order to guide management whether it be non-operative, open aortic repair, or endoluminal stent repair. The purpose of this article is to review the key imaging aspects of TAAI and to discuss how the key CT imaging findings affect clinical management.

Key words: Emergency radiology—Trauma—Aortic injury—Abdominal aorta

Traumatic abdominal aortic injury (TAAI) is a rare life-threatening complication of penetrating and blunt trauma and comprises 5% of all aortic injuries [1]. The reported incidence of penetrating abdominal aortic injury (PAAI) is 2% for gunshot and 1% for knife injuries [2]. Blunt abdominal aortic injury (BAAI) is rarer, comprising less than 1% of all blunt trauma injuries [3–5].

Despite their low incidence, both blunt and penetrating traumatic injuries to the abdominal aorta carry a poor prognosis. TAAI carries an extremely high mortality rate of 75% when managed conservatively, and even in-hospital mortality rates have been estimated at 32% [5–9]. The clinical symptoms of TAAI are non-specific; patients may present with acute abdominal pain, hypotension, back pain, neurologic deficits, end organ damage, or may be asymptomatic [10]. Because computed tomography (CT) can provide a rapid, accurate diagnosis in the evaluation of trauma, CT has become the standard method for evaluating the trauma patient and is able to accurately delineate aortic injuries [11].

The initial diagnosis of TAAI relies heavily on imaging, with the radiologist playing a crucial role in the evaluation and care of these patients. The purpose of this article is to review the key imaging aspects of TAAI and to discuss how the key CT imaging findings affect clinical management.

The abdominal aorta

The abdominal aorta enters the abdomen through the diaphragmatic hiatus at the level of the twelfth thoracic vertebral body and extends to the aortic bifurcation at the level of the fourth lumbar vertebra [12]. The peri-hiatal aortic segment extends from the diaphragmatic hiatus to the celiac axis. The juxta-renal aortic segment extends from the celiac axis to the renal arteries, and the infrarenal segment extends from renal arteries to the aortic bifurcation [13]. The position of the abdominal aorta within the retroperitoneum allows direct forces from adjacent vertebral body fractures to injure the abdominal aorta (Fig. 1). The abdominal aorta is relatively fixed against the vertebral column, and both shearing forces and transmission of pressure through adjacent organs with compression of the aorta against the vertebral column can result in TAAI [14–16] (Fig. 2). The most common segments of the abdominal aorta to be injured by trauma are in descending order infrarenal (67%), suprarenal (33%), and extension from a thoracic aortic injury (25%) [13].

Computed tomography technique

Multidetector row CT (MDCT) has replaced catheter angiography as the primary diagnostic tool for the evaluation of TAAI in stable trauma patients [2, 5, 7, 9, 17, 18]. Some institutions perform CT with acquisitions in the arterial and portal venous phase when evaluating for TAAI. At our institution, one set of images through

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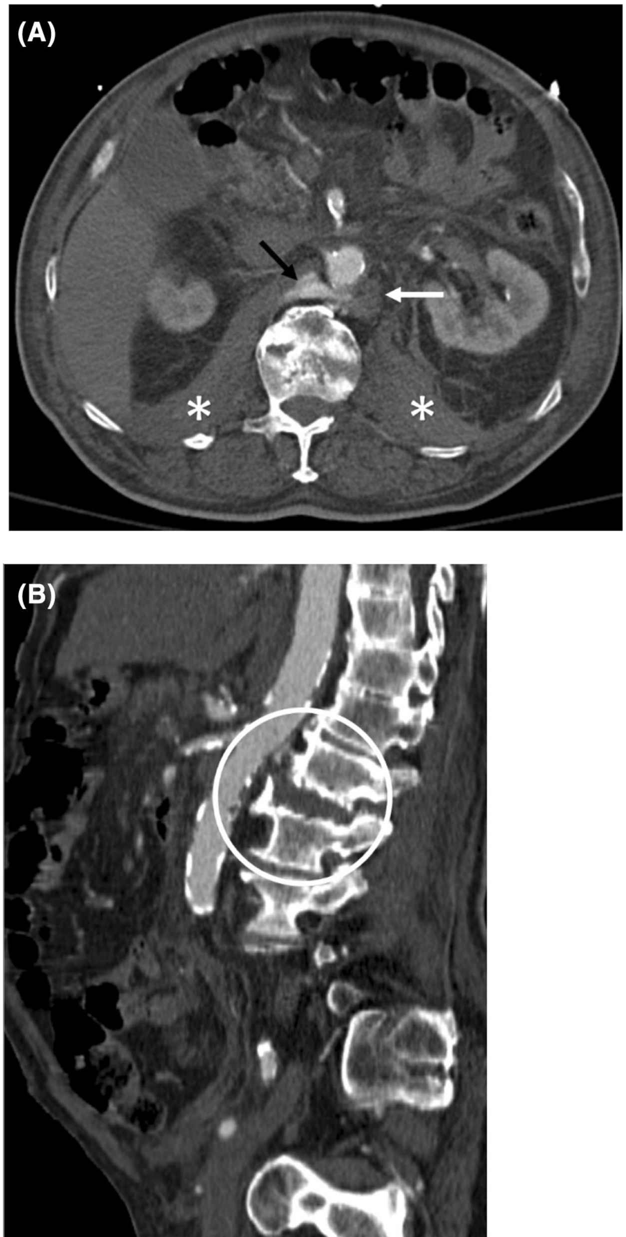


Fig. 1. An 80-year-old man status post fall. **A** Transaxial image demonstrates high-attenuation fluid (white arrow) adjacent to and obscuring the fat plane with the aorta with adjacent high-attenuation contrast material representing a traumatic fistula to the azygous vein (black arrow). There is associated irregularity of the posterior aspect of the aorta. The periaortic hematoma is an indirect sign for aortic injury, whereas the irregular contour of the posterior aspect of the aorta is a direct sign of aortic injury. Extensive hematoma is also seen within the retroperitoneum (asterisks). **B** Sagittal image shows a distraction injury of L2–L3 (circle) at the level of the presumed aortic injury. Traumatic injury to vertebral bodies has a high association with adjacent aortic injury.

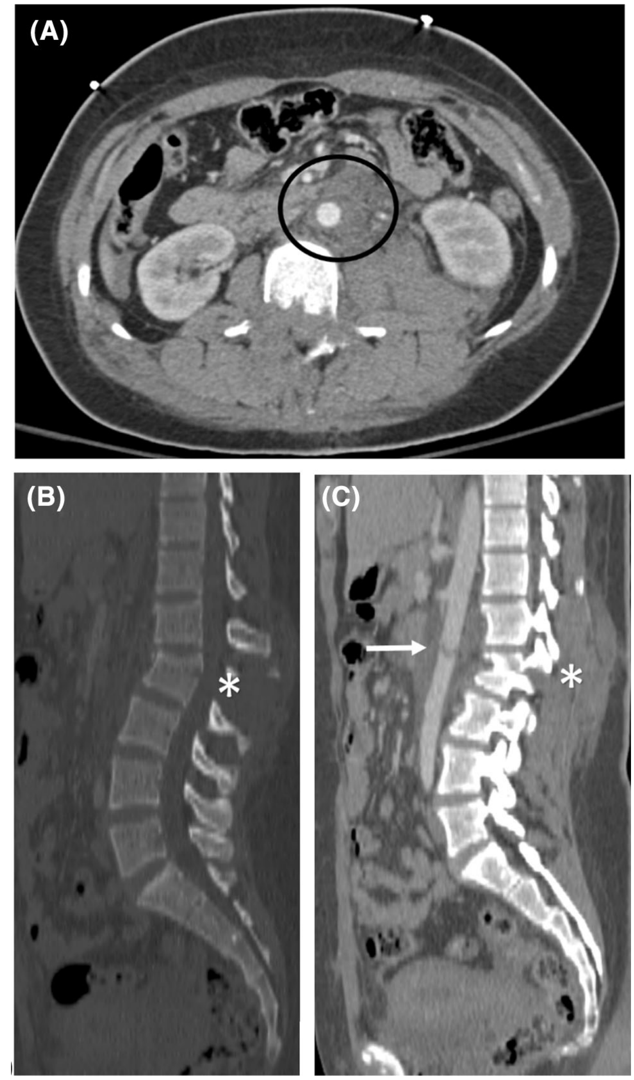


Fig. 2. A 21-year-old patient involved in a high-speed motor collision. **A** Transaxial image of the aorta demonstrates extensive periaortic hematoma (circle). **B** and **C** Sagittal images show a hyperflexion injury of the L2 vertebral body (asterisk) with an associated aortic injury (white arrow) at the same level. Note the transected aorta and surrounding hematoma without intervening fat plane.

the abdomen and pelvis is obtained with a fixed delay of 70 s after intravenous contrast administration. We believe that this allows for optimal scanning of the solid organs and bowel while also allowing for the diagnosis of vascular injuries [19]. All trauma examinations at our institution are performed with 3-mm-thick slices and 2-mm spacing. The overlap of 1 mm allows for adequate multiplanar reconstructions. Level 1 trauma scans are reviewed at the scanner by the radiologist. The fixed delay of 70 s often provides adequate enhancement of the aorta for the evaluation of aortic injury. Because we do not use bolus tracking in evaluation of TAAI, suboptimal opacification of the aorta may occur in those patients with poor cardiac output. In this small subset of cases, we have found that an immediate rescan provides images adequate to evaluate for an aortic lesion. Having

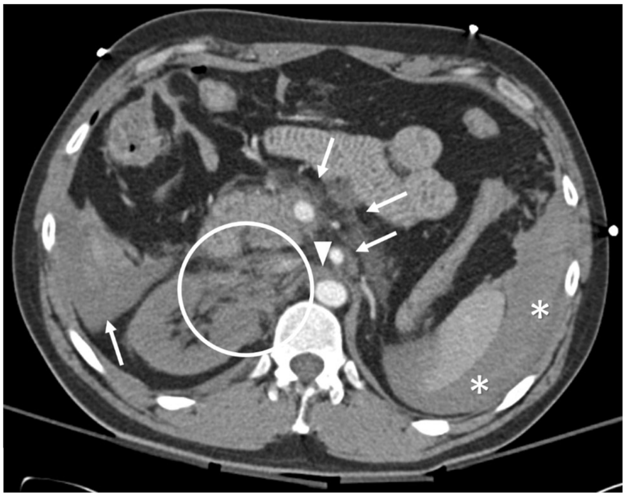


Fig. 3. A 52-year-old man involved in a motor vehicle accident with aortic injury. Transaxial CT image demonstrate periaortic hematoma (white arrowhead), retroperitoneal hematoma (asterisks), and an associated traumatic renal vein avulsion (white circle). Hematoma is also seen within the mesentery extending along the mesenteric vasculature and surrounding the liver (white arrows).

a radiologist at the scanner also allows rescanning in cases where it is unclear if the aortic lesion represents a traumatic pseudoaneurysm or active extravasation.

The advent of dual-energy computed tomography (DECT) has been shown to have many benefits in the evaluation of a patient presenting to the emergency department [20]. The utilization of DECT in the evaluation of TAAI has not been as well investigated, but many potential benefits can be obtained by acquiring attenuation datasets from multiple energy spectrums. One possible advantage of DECT would be to allow reconstruction of a virtual non-contrast image to better asses for aortic intramural hematomas in addition to lowering radiation dose. Using a virtual monoenergetic image can decrease beam hardening artifact, increasing the radiologist's confidence in diagnosing an aortic lesion adjacent to spinal instrumentation. The ability to acquire a single mixed image from two photopeaks also allows for an angiographic phase with better signal-to-noise characteristics, especially in the obese patient. By increasing iodine conspicuity through material decomposition, improved vessel enhancement can be achieved with the same or less iodinated contrast material [21–26]. Nevertheless, we have found that single energy MDCT has been sufficient to diagnose and accurately describe TAAI.

Computed tomographic appearance and grading of aortic lesions

The diagnostic sensitivity of MDCT has not been as well studied for abdominal aortic injury as for thoracic aortic injury, but studies have shown sensitivity approaching 100% for detecting thoracic aortic injuries with MDCT [27–30]. When evaluating the aorta for TAAI, it is important to recognize both direct and indirect signs. Indirect CT signs of TAAI are extremely important as they often help focus evaluation to a particular segment of the aorta. The indirect signs of TAAI include the presence of a retroperitoneal hematoma and/or fat stranding about the aorta (Fig. 3). Retroperitoneal hematoma appears on CT as a collection of fluid ranging in attenuation value from 30 to 70 Hounsfield units (HU). The presence of a retroperitoneal hematoma is sensitive (92% in one study), but not specific for TAAI and can be seen with injury to the surrounding small, periaortic vessels, often veins [13, 19]. Because injuries to vertebral bodies and retroperitoneal organs can lead to a retroperitoneal hematoma, it is imperative to scrutinize the relationship of any retroperitoneal hematoma to the

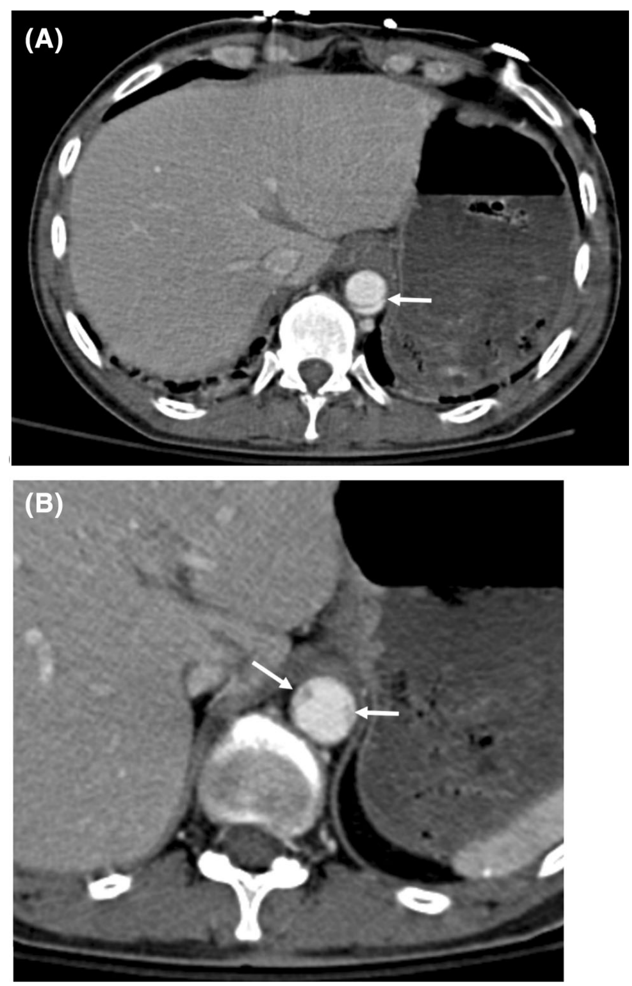


Fig. 4. A 65-year-old man who was struck by a car. **A** Transaxial image of the upper abdomen demonstrates a focal intimal flap (white arrow), a direct sign of aortic injury. **B** More inferiorly, intimal strands are seen within the aortic lumen in this patient with abdominal aortic injury.

abdominal aorta. A retroperitoneal hematoma that is not centered on the AA, or one that has a clear fat plane between the hematoma and the aorta, is unlikely to be secondary to aortic injury. It is important to note that TAAI often is associated with an injury to one or more retroperitoneal organs (Fig. 3B). A TAAI that appears to be isolated should prompt a careful evaluation of other abdominal and retroperitoneal organs and the spine for associated injuries.

In cases of penetrating injury, the projectile or weapon tract can serve as an indirect sign of injury. Any path that traverses or passes near the aorta should be highly suspicious for TAAI, particularly in the presence of a retroperitoneal hematoma surrounding the aorta. The projectile or weapon tract should be traced in all cases of penetrating injury, with multiplanar reconstructions used to depict the tract in multiple planes.

Detection of indirect signs of aortic injury should direct attention to the particular segment of aorta involved for direct signs of injury. Direct signs of TAAI are those that reflect injury to the abdominal aorta as graded by the Society of Vascular Surgery (SVS), including less severe injuries reflecting an intimal flap (grade I) or intramural hematoma (grade II), or more severe injuries such a pseudoaneurysm (grade III) and rupture (grade IV) [5, 31, 32]. It is important to note that the grading and management of aortic trauma is constantly evolving, with recent suggestions to revise the grading of traumatic aortic lesions. Heneghan et al. proposed three classifications for thoracic aorta injuries: minimal—those lesions with no external contour abnormality, intimal tear, and/or thrombus < 10 mm; moderate—external contour abnormality or intimal tear > 10 mm; severe—active extravasation or left subclavian hematoma > 15 mm [33]. Regardless of the current or potential future classifications, the crux of grading depends on the ability to detect, differentiate, and accurately describe aortic injuries.

Grade I injury manifests as a thin, curvilinear filling defect reflecting the intimal or intimomedial flap within the aortic lumen and can be described as large (> 10 mm) or focal (< 10 mm) (Figs. 4, 5, respectively). Intimal injury allows the exposed underlying media to initiate the coagulation cascade, and thus, eccentric thrombus along the aortic wall may be another direct sign of TAAI which reflects the underlying intimal flap (Fig. 6). In some cases of TAAI, less severe injury manifests in the form of an aortic intramural hematoma (grade II injury). Although intravascular contrast may decrease sensitivity for the detection of a high-attenua-

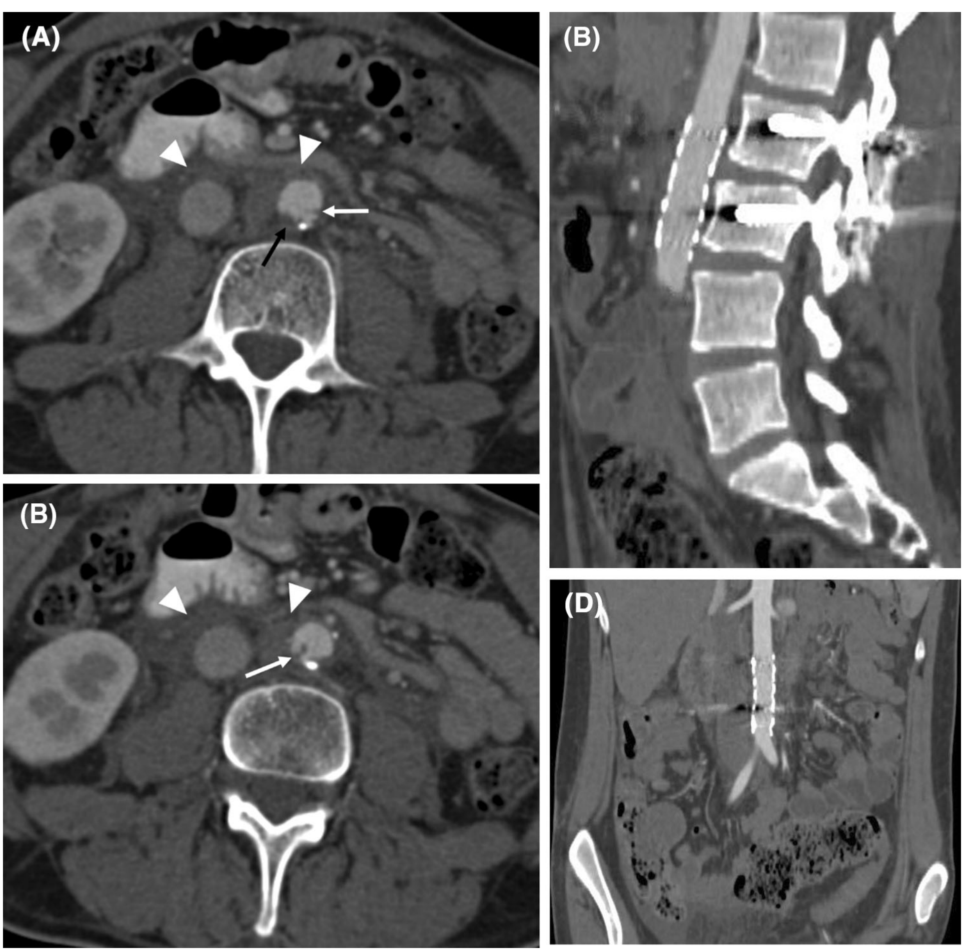
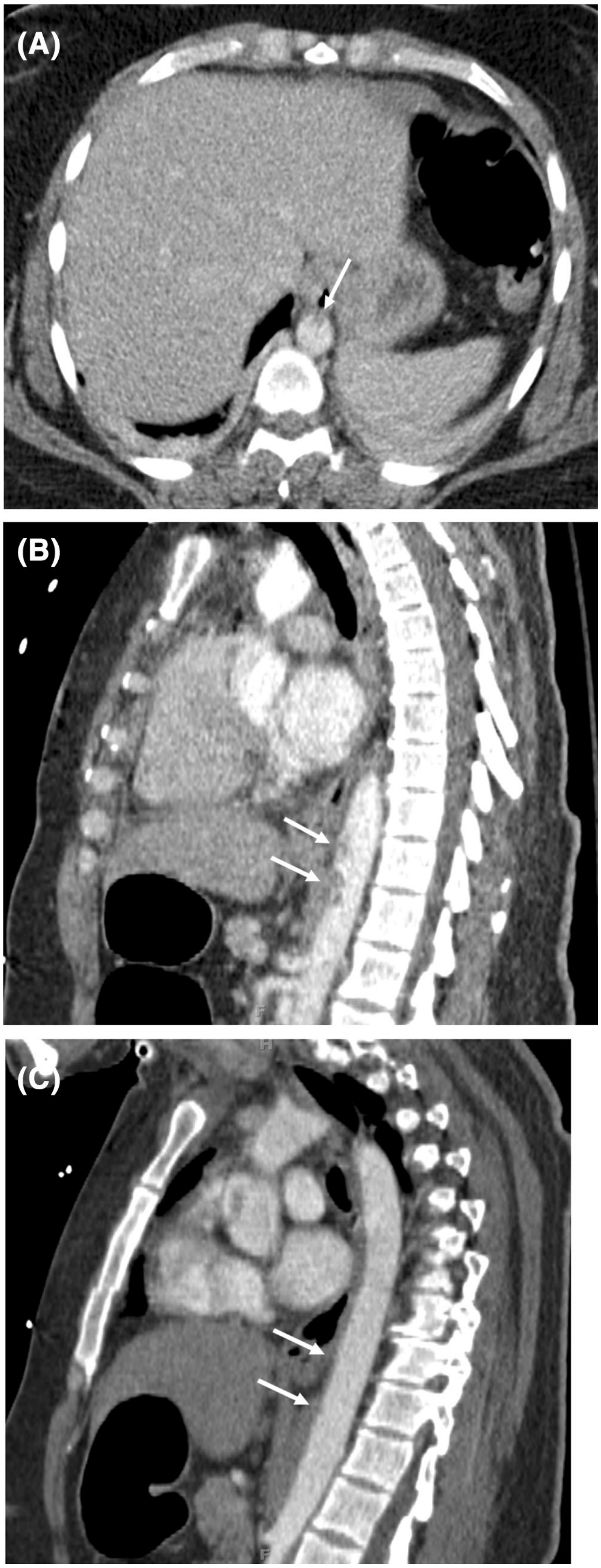


Fig. 5. A 70-year-old man with compression injury of the chest and resultant aortic injury. Unstable vertebral fracture is not shown. **A**, **B** Transaxial images demonstrating irregularity of the posterior wall of the aorta (black arrow), retroperitoneal hematoma (arrowheads), and focal intraluminal strand of tissue (white arrow). He was subsequently managed with an endoluminal stent placement. **C** Sagittal and **D** oblique coronal images demonstrate placement of an endoluminal stent for management of zone III injury.



◀ **Fig. 6.** A 49-year-old woman in a motor vehicle collision. **A** Transaxial and **B** sagittal images at the diaphragmatic hiatus demonstrate a focal area of eccentric thrombus (white arrow) within the aorta. **C** Follow-up imaging demonstrates resolution of the findings seen at the time of trauma.

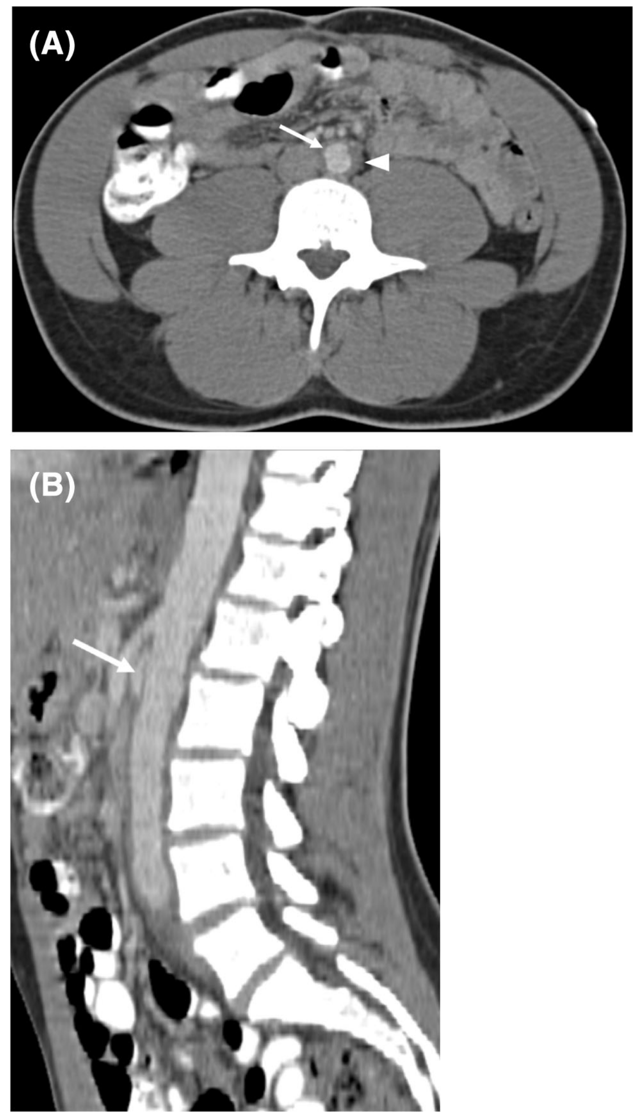


Fig. 7. A 44-year-old man in a motor vehicle collision resulting in abdominal aortic injury. **A** Transaxial image demonstrates periaortic hematoma (arrowheads) with a focal outpouching/pseudoaneurysm (white arrows) of the aorta. **B** Sagittal image shows the length of the focal outpouching of the aortic (white arrows).

tion intramural collection, careful scrutiny of the contour of the abdominal aorta wall should be performed. Any focal luminal narrowing may be secondary to a surrounding intramural hematoma and varying thickness of

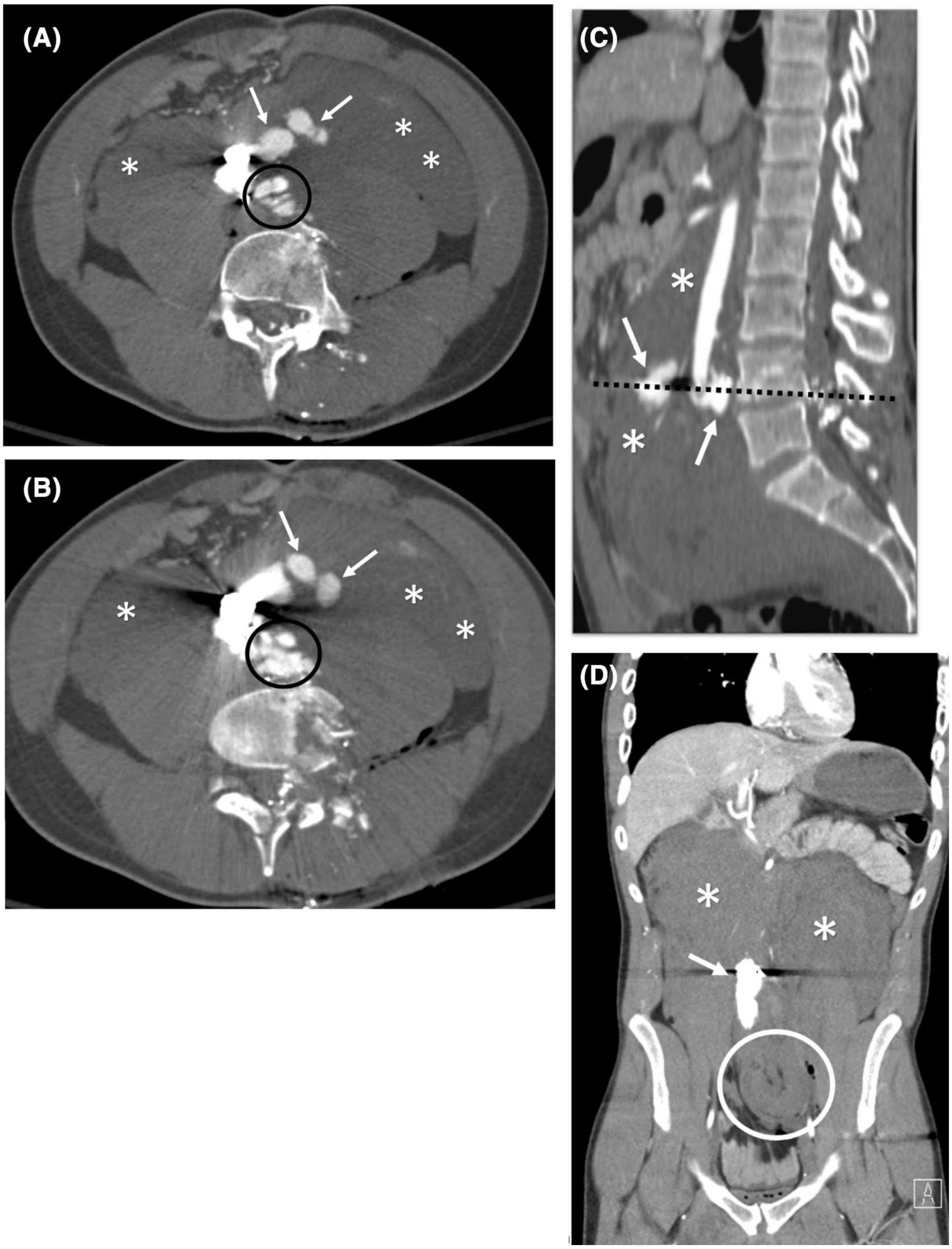


Fig. 8. A 25-year-old woman status post gunshot injury. **A**, **B** Transaxial images demonstrates penetrating aortic injury (circle) with extravasation of contrast (white arrows) and extensive surrounding hematoma (asterisk). **C** Sagittal image shows the transected aorta with adjacent extravasation of contrast (white arrow) and extensive adjacent hematoma (asterisks). The dashed line indicates the bullet path. **D** Coronal image demonstrates extensive extravasation of contrast (white arrows) and adjacent hematoma (asterisks). Note is made of an avulsed kidney seen within the pelvis (white circle).

the aortic wall should be viewed as highly suspicious for an intramural hematoma in the setting of trauma, particularly in a patient without substantial atherosclerotic disease. In a patient with a tortuous abdominal aorta, multiplanar reconstructions may be necessary to evaluate for changes in luminal contour. These less severe injuries (grades I and II) often are managed conservatively with follow-up imaging to document resolution (Fig. 6C) [34].

More severe aortic injuries result in partial or complete disruption of the aortic wall and lead to pseudoaneurysm or transection. A focal external contour abnormality may suggest traumatic pseudoaneurysm (Fig. 7), a grade III aortic injury. The most apparent direct finding is active extravasation of intravenously administered contrast representing a full thickness aortic rupture (grade IV) allowing contrast material to communicate freely with the retroperitoneal space (Fig. 8). This presentation is rare as such patients have high mortality and often are too hemodynamically unstable to undergo CT. Importantly, the absence of active extravasation does not preclude the diagnosis of an aortic transection, as contrast material within a completely transected aorta can still be contained within the confines of the periaortic connective tissue.

In our practice, we avoid using terms such as *traumatic pseudoaneurysm* or *traumatic dissection* as CT often underestimates the extent of aortic injury. By avoiding these terms, we also hope to circumvent any confusion between these traumatic entities with pseudoaneurysms or dissections not related to trauma, the latter of which

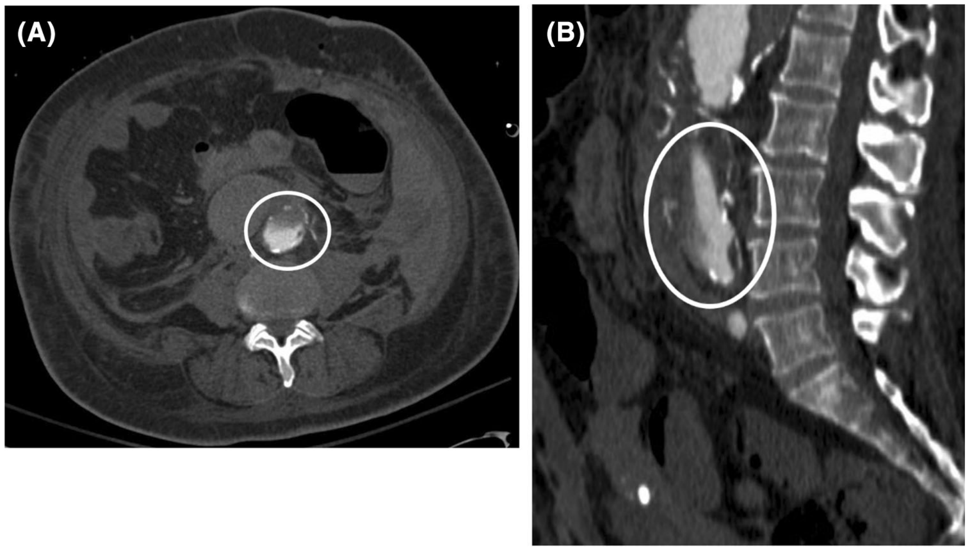


Fig. 9. A 68-year-old woman who received a CT scan to evaluate for aortic injury after fall. **A** Transaxial images demonstrate an area of low attenuation within the lumen of the aorta without a sharp border giving a ‘‘smoke-like’’ appearance. Note the absence of surrounding hematoma or signs of direct aortic injury. **B** Sagittal image demonstrates the ill-defined ‘‘smoke-like’’ appearance within the aorta and absence of signs of aortic injury. This is a flow artifact which can be seen in the setting of low cardiac output and can be a mimicker of aortic injury.

may be managed less urgently. Instead, we opt to describe the aortic lesion in context of the grades set forth by the SVS—curvilinear filling defect representing intimal flap; high-attenuation crescent representing an intramural hematoma; focal contour abnormality of the aorta representing traumatic injury; free extravasation of contrast due to aortic rupture.

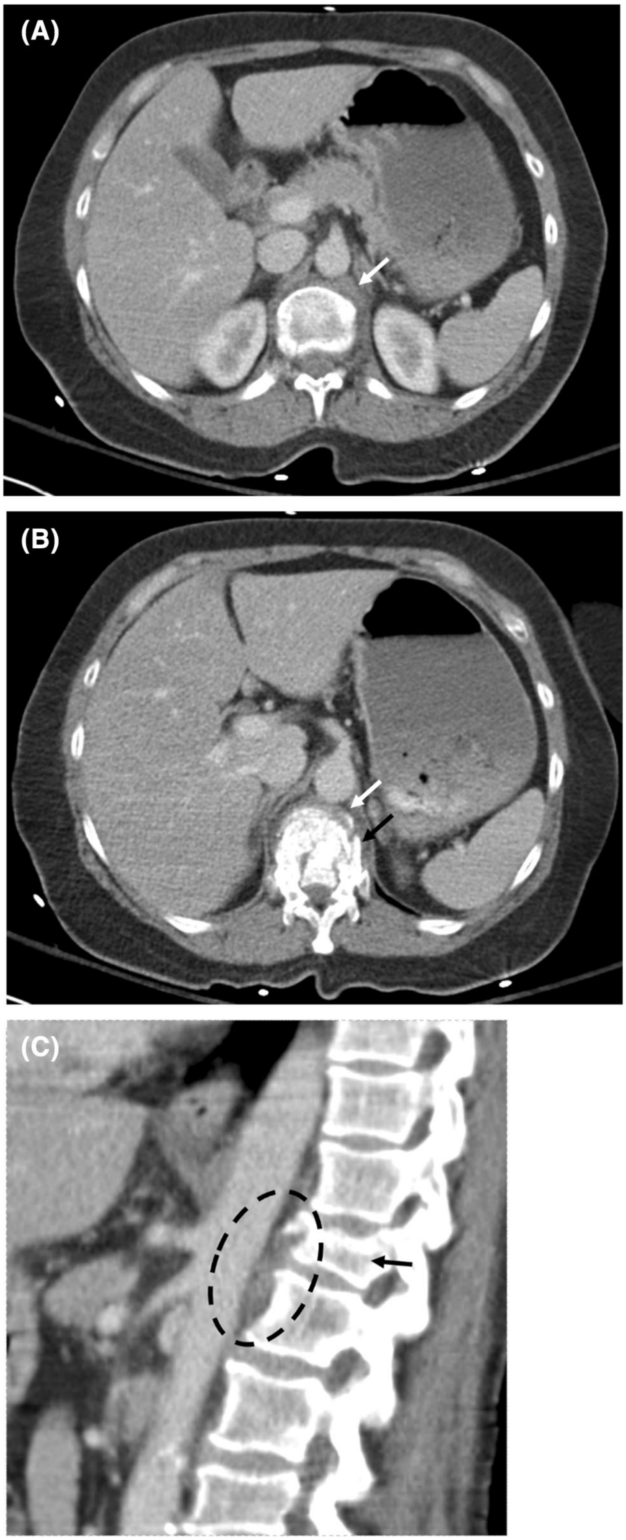
With the advent of MDCT, subtle aortic lesions after trauma are more frequently detected and have given rise to an entity known as ‘‘minimal aortic injury’’ [34, 35]. There is a wide range of definitions for ‘‘minimal aortic injury’’ including an intimal flap measuring < 1 cm without traumatic pseudoaneurysm or periaortic hematoma. Some definitions include flaps up to 2 cm, small traumatic pseudoaneurysms, and periaortic or aortic hematomas [35–40]. Regardless of the definition, it has been well documented that these less severe forms of aortic injury can be managed conservatively [36]. Consequently, we avoid the term ‘‘minimal aortic injury’’ when describing TAAI and instead choose to describe the findings and suggest that they may reflect ‘‘low-grade’’ aortic injury.

Patients who have direct MDCT signs of TAAI do not require any further imaging as this may delay appropriate management. In patients with indirect MDCT findings of TAAI and those with lower grade injuries, a follow-up CT examination in 48–72 h is recommended to document stability and/or resolution of these findings (Fig. 6C). Patients whom have indirect signs or low-grade aortic injuries and also a major contraindication to iodinated contrast material may be evaluated with a short-interval magnetic resonance examination. In our experience, the need for conventional angiography in these ‘‘borderline’’ cases is decreasing, a reflection of the ability of CT to detect lesions that are beyond the resolution of conventional angiography [41].

CT pitfalls

Accurate diagnosis of TAAI requires knowledge of the potential pitfalls of CT imaging of the abdominal aorta. Flow artifact can be especially confusing as it may mimic a flap or thrombus. In our experience, a true intimal flap or focal thrombus has a sharply demarcated border. A flow artifact tends to have an indistinct border giving a smoke-like appearance to this artifact (Fig. 9). The indistinct nature of a flow artifact often is best demonstrated by multiplanar reconstructions parallel to the long axis of the vessel. If a suspected flow artifact is identified at the time of examination, immediate repeat scan of the area of concern will allow complete opacification of the aorta; a flow related artifact should be eliminated and any remaining filling defect should be viewed with high suspicion.

A vertebral body fracture without abdominal aortic injury is much more common and can result in a significant retroperitoneal hematoma that surrounds or abuts the abdominal aorta [42–44]. Meticulous attention should be paid to the relationship between the retroperitoneal hematoma and the abdominal aorta. A fat plane between the retroperitoneal hematoma and the aorta indicates that the retroperitoneal hematoma is unlikely to be secondary to aortic injury (Fig. 10). Injury



◀ **Fig. 10.** A 35-year-old woman presenting after a motor vehicle collision with back and chest pain. **A** Transaxial image demonstrating hematoma (white arrow) along the posterior aspect of the aorta mimicks an aortic injury. **B** Transaxial image just superior to image A shows a vertebral body fracture (black arrow) at the level of the hematoma. Note the normal appearing contour of the aorta and normal fat plane surrounding the aorta. **C** Sagittal image demonstrates the vertebral body fracture (black arrow) accounting for the adjacent hematoma (black dashed circle). The contour of the aorta and adjacent fat plane are normal, and there are no imaging findings of aortic injury.

to the inferior vena cava and retroperitoneal organs also can produce a large retroperitoneal hematoma that may abut the aorta. Again, identifying a fat plane between the hematoma and the aorta may help in discerning the true focus of hemorrhage.

Normal structures also can be confused for aortic injury. Four paired lumbar arteries arise from the posterolateral aspects of the abdominal aorta from the level of L1 through L4. Care must be taken not to mistake these vessels for contour abnormalities or pseudoaneurysms (Fig. 11). The median sacral artery arises posterior to the abdominal aorta, just superior to the aortic bifurcation and at the time of CT also may be mistaken for a focal contour abnormality [45]. These branch vessel ostia usually can be distinguished from an aortic injury by the absence of an associated hematoma or fat infiltration. Knowledge of the locations of these vessels and examining sequential images should eliminate confusing these structures for aortic injury.

What the vascular surgeon wants to know

Aortic injury grading is based on the CT appearance of the aortic lesion, underlining the importance of using the correct descriptor when reporting an aortic lesion. Intimal tears and flaps have been shown to heal with conservative management and often are managed with beta blockers, aspirin, and interval follow-up CT examination [34]. Any evidence of progression at the time of follow-up imaging can be managed by operative repair of the intimal flap or endovascular stent graft placement [5].

The location and length of the lesion also can change clinical management. Vascular surgeons divide the abdominal aorta into three zones based on differences in surgical approach: from the diaphragmatic hiatus to the superior mesenteric artery (SMA) (zone I), from the SMA through the renal arteries (zone II), and from the renal arteries to the aortic bifurcation (zone III) [5, 46].

These three zones are critical in determining whether or not endovascular repair is possible. Zone I aortic lesions require extensive open exposure, but could be amenable to endovascular repair. Importantly, zone II lesions are not amenable to endovascular stent placement, as custom fenestrated grafts to accommodate the SMA and renal arteries are not well suited for use in the acute setting. Zone III lesions are amenable to open or endovascular repair [5]. It is crucial to report any sus-

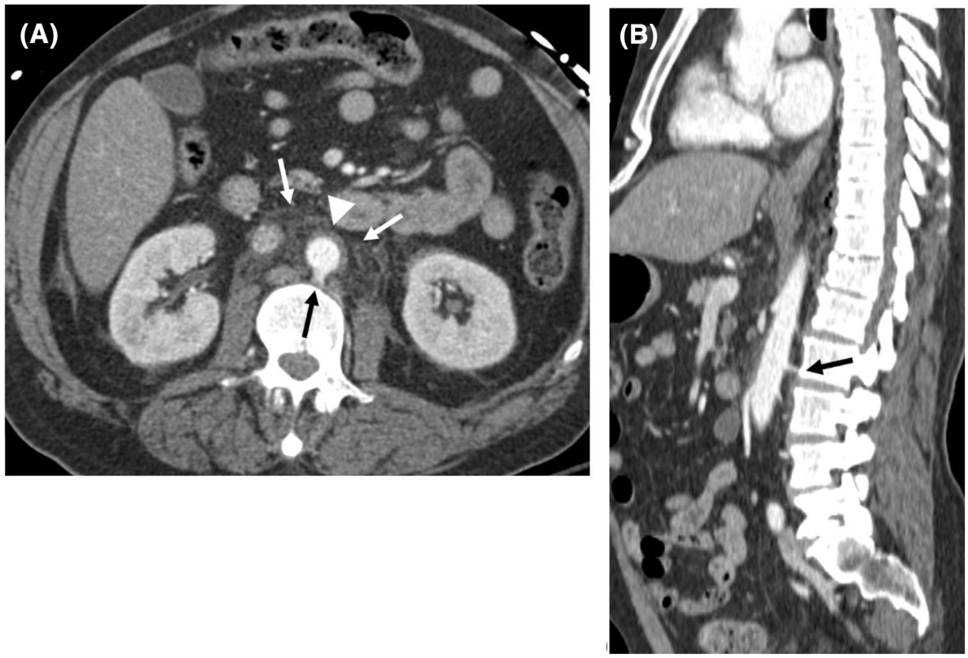


Fig. 11. A 56-year-old man with back pain after fall. **A** Transaxial CT image demonstrates a retroperitoneal hematoma (white arrow) that directly abuts the aorta. In addition, there is an intramural hematoma (white arrowhead) of the aorta. Along the posterior aspect of the abdominal aorta, there is a focal contour irregularity (black arrow) that could be mistaken for a traumatic pseudoaneurysm (grade III). **B** Sagittal reconstruction demonstrates that this focal outpouching correlates with lumbar arteries (black arrow). The patient was managed conservatively, and the intramural hematoma resolved on subsequent imaging (not provided).

pected bowel injury, as free succus or stool within the peritoneal cavity predisposes an open graft to infection and may be an indication for endovascular repair.

Patients undergoing endovascular repair for trauma should be followed in the same manner as those who undergo abdominal aortic repair for a non-traumatic abnormality. Follow-up CT angiogram should be performed 30 days, 6 months, and 1 year after repair, followed by annual CT angiograms [46].

Conclusion

TAAI is an uncommon, but potentially life-threatening manifestation of both penetrating and blunt trauma. Contrast-enhanced MDCT examination of the abdomen and pelvis is the gold standard diagnostic examination. Therefore, the radiologist plays a critical role in detecting TAAI and directing management. Indirect signs of retroperitoneal hematoma and fat stranding may help focus evaluation of a particular aortic segment. Direct findings of TAAI include an intimal flap, intramural hematoma, focal thrombus, contrast extravasation, pseudoaneurysm, or focal contour abnormality. The CT appearance of an aortic lesion is critical in injury grading and subsequent management. The radiologist should provide accurate descriptors of the aortic lesion and also report where the aortic lesion begins, the length of the aortic abnormality, and which aortic segment(s) the lesion involves to help with pre-operative planning. Communication with the clinical teams involved in the care at every possible step is critical in patient management.

Compliance with ethical standards

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Conflict of interest The authors declare that they have no conflicts of interest.

Ethical approval This is a review article and not a study involving procedures on human participants or animals performed by any of the authors.

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