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PICTORIAL REVIEW

Pearls and pitfalls in imaging of blunt traumatic thoracic aortic injury: a pictorial review

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ABSTRACT

Blunt thoracic aortic injury (TAI) occurs most frequently as a sequelae of high impact deceleration such as high-velocity road traffic accidents and falls from height. The burden of mortality and morbidity is high, however advances in pre-hospital care, diagnostic imaging and endovascular therapies have improved outcomes in this group of patients. Emergent treatment depends on accurate, early diagnosis by the radiologist. It is therefore of paramount importance that radiologists are familiar with both the direct (intimal flap, pseudoaneurysm, aortic contour irregularity and contrast extravasation) and indirect (periaortic haematoma) imaging findings of TAI. Furthermore, it is critical that technical (breathing artefact and cardiac motion artefact) as well as anatomical (ductus diverticulum, aortic spindle and mediastinal structures which imitate periaortic haematoma) pitfalls are recognised to avoid misdiagnosis. This pictorial review will help the diagnostic radiologist to recognise the patterns of injury and imaging features associated with TAI, as well as highlighting potential mimics when interrogating CT angiography (CTA) in major trauma.

INTRODUCTION

Blunt thoracic aortic injury (TAI) carries a significant burden of mortality and morbidity, with a substantial fatal outcome; up to 80% in the pre-hospital population.¹ The advent of the United Kingdom national trauma network has improved pre-hospital survival.² Concurrent advances in CT angiography (CTA) and the use of minimally-invasive endovascular techniques have improved outcomes in this group of patients. The importance of timely and precise diagnosis, followed by prompt treatment cannot therefore be understated.

TERMINOLOGY

The terminology used by radiologists in TAI can be confusing and inconsistent. A useful approach in considering the spectrum of TAI is the classification proposed by Starnes and colleagues, who describe four categories related to aortic injury: intimal tear, large intimal flap, pseudoaneurysm and rupture (Table 1).³

ANATOMY AND MECHANISM OF INJURY

The vast majority of TAIs occur just distal to the left subclavian artery at the site of the aortic isthmus. The most

common preceding high velocity traumatic mechanisms include road traffic accidents and falls from height, which produce both deceleration as well as a combination of shearing and crushing forces.

A number of hypotheses have been proposed in relation to the mechanisms which result in TAI.⁴ The aortic isthmus is relatively immobile due to its attachment to the ligamentum arteriosum; high velocity trauma imposes shearing forces at this point resulting in TAI.⁵ The osseous pinch theory describes the impingement of the aorta in between anterior osseous structures of the thorax and posterior vertebral bodies. Furthermore, a displaced vertebral fracture can cause direct trauma to the aorta. A sudden increase in intra-aortic pressure (water-hammer effect) can also lead to injury of the aortic root and ascending aorta. These effects likely occur in combination to cause synchronous injury to the thoracic aorta.

IMAGING FEATURES

Plain chest radiography

Plain chest radiographs are an integral part of the "ABC" component of the primary assessment. A number of signs

Table 1. Classification for thoracic aortic injury (TAI) proposed by Starnes et al based on imaging characteristics on CT angiography (CTA)

Category	Features	Example
Grade 1: Intimal tear	<ul style="list-style-type: none"> No external change to the aortic contour Small tear with less than 10 mm of thrombus Rarely, can be treated conservatively
Grade 2: Large intimal flap	<ul style="list-style-type: none"> No external change to the contour of the aorta >10 mm thrombus visible
Grade 3: Pseudoaneurysm	<ul style="list-style-type: none"> Bulbar appearance with change in the contour of the aorta Contained rupture
Grade 4: Rupture	<ul style="list-style-type: none"> The patient is rarely stable enough for imaging Extravasated contrast beyond the aortic contour

Figure 1. 45-year-old male patient involved in road traffic accident. There is increased density at the right apex in keeping with a right apical pleural cap.

have been described which may suggest the presence of an underlying aortic injury, including widening of the mediastinum, apical pleural capping, an abnormal aortic contour and deviation of an endotracheal or nasogastric tube to the right. The pleural cap is an extrapleural collection of fluid, in this case blood, extending around the lateral aspect of the mediastinum and into the extrapleural space (Figure 1). Plain chest radiographs' interpretation is hindered by the fact that the radiograph is performed in the anteroposterior supine position. Furthermore, chest radiography can be normal in up to 7% of cases.¹ Therefore, although chest radiographs can be helpful, we recommend that interrogation of the radiograph should not delay cross-sectional imaging if clinically warranted. Rather, in the trauma setting, chest radiography is better utilised to assess for life-threatening injuries, such as tension pneumothorax and large haemothorax that may require immediate drainage.

Figure 2. 46-year-old female involved in a road traffic accident. There is an intimal flap (a; arrows) as evidenced by a thin, linear filling defect at the level of the aortic isthmus. Associated traumatic injuries including left first rib (b; solid arrow) and left scapula fracture (b; dashed arrow) are indicative of a high velocity trauma which should prompt closer assessment for thoracic aortic injury (TAI).

Figure 3. 32-year-old female cyclist involved in a road traffic accident with a high-speed car. There is an intimal flap (a; arrow) at the level of the aortic isthmus in keeping with aortic injury. Axial image (b) demonstrates high density periaortic haematoma (b; dashed arrows) within the mediastinum. The sagittal view is more definitive in comparison with the axial image for the visualisation of TAI. TAI, thoracic aortic injury.

CT angiography

CTA has a sensitivity of 98% and specificity of 100% in the assessment for TAI⁶ and is indicated in all high velocity trauma. At our institution, we have adopted the use of biphasic “combi” CT in cases of blunt trauma, the protocol for which was developed and refined on the battlefield in Camp Bastion, Afghanistan.^{7,8} The biphasic CT provides cross-sectional imaging in both arterial and portal venous phases due to two contrast bolus injections. This reduces the time patient spends in the scanner as well as reducing the radiation dose to the patient while preserving high image quality.

The use of CTA is key in both diagnosing and planning the treatment of TAI including assessing endovascular stent-grafts

Figure 4. 40-year-old male who fell from a height. A 7 mm wide-necked thoracic aortic pseudoaneurysm arises distal to the left subclavian artery at the level of the aortic isthmus (arrow).

Figure 5. Cyclist hit by car on a main road. There is a right rib fracture (a; arrow) and sternal fracture (b; arrow head) indicating a high velocity trauma. In the coronal plane a pseudoaneurysm is appreciated (b; dashed arrow). The patient went on to digital subtraction angiography (c) and subsequent stent insertion (d).

and assessing the aortic arch type which can predetermine the required coverage of the left subclavian artery in order to create a “seal” of the transection.

Once the examination has been completed, the aorta should be interrogated at a workstation with multiplanar reformat capabilities: the visualisation of the aorta in multiple planes is essential. In particular, the thoracic aorta is best visualised in the sagittal-oblique plane (left anterior oblique; 20–90 degrees) to increase conspicuity of TAI which can be subtle in the axial

Figure 6. Restrained passenger with seatbelt involved in road traffic accident. CT reveals a large pseudoaneurysm (a) at the level of the aortic isthmus. Extensive haemomediastinum is appreciated in the coronal plane (b; dashed arrows). Note is also made of splenic injury (b; solid arrow).

Figure 7. 65-year-old male involved in road traffic accident 30 years previously. The patient presented with chest pain. There is a large pseudoaneurysm (*) at the level of aortic isthmus. The aneurysm demonstrates peripheral calcification in keeping with its chronicity.

plane. The radiological features of TAI can be classified as either indirect or direct signs of vascular injury.

Direct signs

TAIs involve alterations to the aortic wall which can affect the inner (intimal), middle (medial), or outer (advential) layer and manifests in different radiological appearances: Grades 1 and 2 (intimal flap) and Grades 3 and 4 (pseudoaneurysm, contour irregularity and/or contrast extravasation).

Intimal flap (Figures 2 and 3) is reflective of a tear involving the intimal lining of the aortic wall and is classed as a minimal injury. On CTA intimal flaps are characterised by linear filling defects within the lumen of the aorta.

Figure 8. 30-year-old male involved in a head-on collision with a lorry. Sagittal-oblique (a) and axial (b) images demonstrate a linear filling defect (arrows) which extends across the width of the aortic lumen (arrows) consistent with transection. There is high density periaortic haematoma as well as pseudoaneurysm formation just inferior to the transection (*).

Figure 9. 35-year-old male involved in fall from height. There is an aortic transection (a; solid arrow) involving the thoracic aorta at the aortic isthmus. There is arterial blush of contrast in keeping with active haemorrhage at the left lateral aspect of the aortic arch (b; dashed arrow) as well as large volume mediastinal haematoma.

Focal damage to both the tunica intima and media layers of the aorta results in the adventitia being the only lining retaining blood. The adventitia is highly compliant, and hence results in pseudoaneurysm formation (Figures 4–6) which risks rupture if not treated. Chronic pseudoaneurysms (Figure 7) can develop in cases where aortic injury has been untreated or undiagnosed. These tend to have dense peripheral calcification and may contain thrombus.

A full thickness tear or complete aortic transection (Figure 8) involves all three layers of the aortic wall. This can result in contrast extravasation (Figure 9). TAI may also precipitate intraluminal thrombus formation.

Indirect signs

Periaortic mediastinal haematoma (Figure 10) displaces the periaortic fat plane and abuts the adjacent aorta. This is a key indirect sign for TAI and should prompt the radiologist to inspect the aorta for direct signs of injury.

Periaortic haematoma does not reflect extravasated blood from the aortic lumen but rather damage to the arterial vasovorum or perivascular veins.⁴ The absence of direct signs

Figure 10. 60-year-old male patient involved in high-speed road traffic accident. Axial CT images (a; arrows) demonstrate periaortic haematoma which is adherent to the aortic arch. This is an indirect sign prompting further evaluation of the thoracic aorta. Left anterior oblique reformatted image (b; arrow) demonstrates intimal flap and small pseudoaneurysm in the aortic arch distal to the origin of the left subclavian artery consistent with traumatic aortic injury.

Figure 11. Type I Arch. The great vessels originate at the same level of the arch peak.

Figure 12. Type II arch. The distance between the aortic arch peak (superior white line) and the brachiocephalic artery origin (inferior white line) is approximately two to three times the diameter of the left common carotid artery (black line).

Figure 13. Angiographic image demonstrating a pseudoaneurysm at the level of the aortic isthmus (a). A 21 mm Gore thoracic aortic stent (Gore Medical, Flagstaff, AZ) is subsequently deployed (b) via a right femoral approach with immediate exclusion of the pseudoaneurysm.

on CTA in the context of periaortic haematoma should urge the radiologist to recommend formal angiographic imaging to further assess for TAI.

The presence of pleural effusions and haemothorax can also be a sign of recent TAI, which develop more frequently within the left hemithorax.

Non-vascular pertinent findings

Any signs or findings of high impact injury, should raise suspicion for TAI, including scapular, sternal, first/second rib fractures as well as high thoracic vertebral fractures.

Arch types

Arch anatomy is important in relation to procedure planning for endovascular stent insertion and the interventionalist will measure all distances required. The reporting radiologist should be aware of the spectrum:

Figure 14. Gated (a) vs non-gated (b) CT angiographic studies. On the sagittal sections of the aorta, the fenestrations are more difficult to appreciate on the non-gated images.

Figure 15. 30-year-old cyclist vs car. There is a smooth out-pouching along the inferior margin of the aorta at the level of the isthmus, which forms obtuse margins. Features are classical for a ductus diverticulum.

- (1) Type I arch (Figure 11): The craniocaudal distance (CCD) between the aortic arch peak and the brachiocephalic artery (BCA) origin is less than the diameter of the left common carotid artery (LCCA).
- (2) Type II arch (Figure 12): The CCD distance between the aortic arch peak and the BCA origin is approximately one to three times the diameter of the LCCA.
- (3) Type III arch: The CCD between the aortic arch peak and the BCA origin is $> \times 3$ of the diameter of the LCCA.

Figure 16. 47-year-old male patient involved in a high-speed road traffic accident. There is a haematoma in the left supraclavicular fossa (a; arrow heads) which was subsequently determined to be a transected left dorsal scapular artery. On further assessment of the thoracic aorta there is a smooth bulge distal to the left subclavian artery in the region of the aortic infundibulum (b; arrows) with no periaortic haematoma. Features are of an incidental ductus diverticulum.

Table 2. A summary of the imaging findings which should be interrogated on CT angiography when traumatic aortic injury is suspected. Additional imaging findings which aid further management planning are also described

Radiologists' checklist for reporting CTA in the context of traumatic aortic injury
<ul style="list-style-type: none"> Interrogate aorta at a workstation using multiplanar reformatting (aortic injury is most conspicuous in the sagittal-oblique plane (left anterior oblique; 20-90 degrees)) Lower curvature contour of the aortic arch Intimal tear/flap Pseudoaneurysm formation Mediastinal haematoma Periaortic haematoma Presence of haemothorax Additional injuries, e.g. fractures (vertebral, scapula, first/second ribs)
Additional information needed by the image-guided/endovascular surgeon
<ul style="list-style-type: none"> Arch type: I, II, III, "gothic arch" External and common iliac artery diameters Tortuosity of vessels Arch anatomy variants: direct vertebral artery origin, aberrant subclavian artery

Digital subtraction angiography

Historically, digital subtraction angiography (DSA) was considered the gold standard for diagnosing TAI by the Advanced Trauma Life Support guidelines.⁹ However, multidetector CT, has superseded DSA due to the high sensitivity and specificity for TAI. In current practice, DSA is reserved for endovascular stent insertion or in patients who have evidence of lateralising signs of an aortic injury but no definitive lesion is identified on CT. (Figure 13).

NORMAL VARIANTS AND PITFALLS

Radiologists need to be aware of both technical and anatomical pitfalls to avoid reporting false-positive findings. Technical artefacts can lead to an incorrect impression of discontinuities in the walls of vessels. This includes breathing artefact in the critically ill patient, which can be confirmed by assessing the lung windows.

Most trauma CT scans are non-cardiac gated which can lead to artefact from cardiac motion mimicking an intimal flap or transection (Figure 14). The aortic root and ascending aorta are particularly susceptible. Pulsation artefact can be distinguished from pathology by the lack of periaortic haematoma as well as the margin between the apparent filling defect and contrast within the lumen being blurred, as opposed to a true intimal flap which would appear sharp.⁴ If there is any clinical doubt as to whether an apparent defect has arisen secondary to artefact, a cardiac-gated study could be considered.

A number of anatomical variants can also complicate evaluation of TAI on CTA, the most common of which is the ductus diverticulum (Figures 15–16), a remnant of the embryonic ductus arteriosus. It most commonly presents itself as a smooth bulge

within the inferior aortic arch at the level of the aortic isthmus. By sharing its typical location with that of most TAIs, it can be a cause of considerable radiological uncertainty. Typically, the ductus diverticulum will form obtuse angles with the aorta. Rarely, however, acute angles may be formed imitating a pseudoaneurysm. Once again, the absence of periaortic haematoma can aid the radiologist in distinguishing artefact from pathology. It is important to note however that the absence of mediastinal blood does not completely exclude the presence of TAI.

Other normal structures that can cause confusion include the aortic spindle and thymus. The aortic spindle is identified as an area of fusiform dilatation of the descending aorta distal to the aortic isthmus. It is thought to represent a remnant of the foetal aorta. Similar to the ductus diverticulum, it is distinguished from pathology by its smooth margin and absence of periaortic haematoma. Thymic tissue in young adults may be mistaken for mediastinal haematoma. In contrast to mediastinal haematoma in TAI, thymic tissue is nodular in its appearance due to interspersed fat and is located in the anterior mediastinal compartment.

CONCLUSION

The ability to make a confident, rapid and accurate diagnosis of TAI in critically ill trauma patients reduces mortality and is a vital skill for all radiologists. Identifying subtle imaging findings in TAI can only be achieved by systematically interrogating the thoracic aorta and reformatting images in multiple planes (Table 2). Understanding the spectrum of imaging findings as well as potential technical and anatomical mimics will improve both sensitivity and diagnostic precision in patients with TAI.

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