Traumatic injuries of the thoracic aorta: The role of imaging in diagnosis and treatment

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Abstract Traumatic injury of the thoracic aorta remains the leading cause of death in multiple trauma patients and it requires urgent management. Computed tomography has a key diagnostic role and allows the clinician to choose an appropriate treatment strategy. The development of new classifications, based on a better understanding of the mechanisms of these injuries, has clarified the indications for treatment. Advances in techniques, especially in endovascular management, have contributed to improving prognosis for patients. Interventional radiology, which usually consists of endovascular placement of a covered stent, now constitutes the gold standard treatment in these injuries. Due to the potentially grave prognosis of these patients, it is crucial to know how to detect these injuries and to describe the imaging signs of serious damage.

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Road traffic accidents are the main cause of aortic trauma. Traumatic injury of the large vessels is being seen with increasing incidence in tertiary trauma units. While during the 20th century this rise could be attributed to an increase in numbers of road traffic accidents, today it is the improved initial management on the part of emergency care networks, at the head of which are emergency ambulance services, that is responsible for a fall in early deaths, and this explains why there is a growing number of patients who manage to survive until they are admitted to a hospital unit [1,2].

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Sites of predilection, mechanism and pathophysiology

The pathophysiology of thoracic aorta trauma injury is complex. The greater frequency of aortic isthmus damage is in part related to its anatomical position, which is relatively fixed within the rib cage [5]. In a high-velocity trauma, such as a road traffic accident, the thoracic aorta is subjected to rapid deceleration together with compression of the chest wall. Associated with this are complex torsion or stretching injuries to the aortic wall, especially at the points of fixation, which explains the increased frequency of injury to the aortic isthmus [5,6] (Fig. 1).

By contrast, injuries to the ascending thoracic aorta are probably just as common but they are seen less often because they are so serious that they are frequently the cause of immediate death [5,7].

The circumstances in which these injuries arise are, in decreasing order of frequency: road traffic accidents, crushing accidents, falls from a height and other deceleration accidents that occur during sports such as skiing [2–6].

Which examinations should be performed? A crucial role for CT angiography

The management of a patient with thoracic aorta trauma varies depending on their condition on arrival at hospital, as well as whether there are any associated injuries. A careful evaluation by the intensive care team allows the initial assessment to be made, and as part of this the factors that could worsen the prognosis must be clearly set out.

Although transoesophageal echocardiography used to be considered to be the first line technique for exploring a suspected traumatic aortic injury, recent data from the literature has confirmed that CT angiography should take the main role in the decision process when managing these

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Figure 1. Multiplanar CT angiography reconstructions of the thoracic aorta. Illustration of the preferential topographical distribution of traumatic injuries: a: accumulation of contrast material in a crevice in the ascending thoracic aorta wall, located at the aortic valve cusps (white arrow); b: presence of two trauma injuries: an injury to the aortic root, located immediately above the sinus of Valsalva (white circle); another injury to the descending thoracic aorta at its junction with the isthmus (black arrow); c: traumatic pseudoaneurysm (white circle) of the aortic arch, originating between the left carotid artery (black arrow head) and left subclavian artery (white arrow head); d: traumatic rupture of the descending thoracic aorta with significant extravasation of contrast material in the arterial phase (white circle), explaining the abundant mediastinal haematoma (white star).
injuries [8]. Initial investigations must therefore be carried out by CT angiography as soon as the patient’s condition allows [9].

This examination leads to both an accurate diagnosis of traumatic aorta injuries and allows for a full investigation of the patient in order to look for any associated injuries.

Given how computed tomography has advanced technologically and become more widespread, it is possible to achieve a high quality exploration of the whole body in the minutes that follow the patient’s arrival at the tertiary trauma centre, and this is the case 24 hours a day.

The protocol that is classically followed is that of the multiple trauma patient. This consists of a pre-contrast acquisition of the head and neck, followed by an arterial phase acquisition covering the neck, chest, abdomen and pelvis. This is usually followed by a portal phase acquisition of the abdomen and pelvis, so that any injuries to wholly intra-abdominal organs can be better studied [10].

ECG-gated CT can only be considered when the team has received training and the patient is haemodynamically stable. Nonetheless, this technique, which overcomes the issue of artifacts related to movements caused by the patient’s heartbeat, can prove to be very useful in some cases by removing doubts over diagnosis.

A new protocol for computed tomography exploration in multiple trauma patients has been put forward by Yaniv et al. [11]. It allows for a single acquisition of the chest, abdomen and pelvis with a triphasic contrast material injection. The advantages of this protocol are on the one hand it entails lower doses of radiation for a population that consists mainly of young people, and on the other there is a clear reduction in beam-hardening artifacts caused by the bolus of contrast material. These artifacts occur when the contrast material stagnates in the superior vena cava, and they can sometimes be a significant barrier to the accurate assessment of the aortic arch (Fig. 2).

MRI combines safety with an acceptable diagnostic performance [9]. Nonetheless, this technique is not at present used in emergency situations. The duration of acquisitions and the immobility required of the patient prohibit the use of this modality. In addition, the availability of MRI equipment means that it cannot be considered for first line imaging investigations.

Finally, standard radiography is only of value for diagnosing associated chest trauma injuries. Angiography must only be used prior to the placement of a thoracic endoprosthesis.

How should trauma injury to the thoracic aorta be classified?

Identifying the class of trauma injury to the thoracic aorta is the principal purpose of CT angiography. This is because this classification involves a morphological description of the injuries that allows a suitable treatment to be chosen, whether emergent or deferred.

Starnes et al. [12] have proposed a classification based on the CT angiography images, allowing a distinction to be made from the outset between two clear groups (Figs. 3 and 4):

- patients with no abnormality to the external contours of the aorta (grades I and II);
- patients with an external contour abnormality to the thoracic aorta (grades III and VI).

This classification looks at how serious the injuries are, meaning it can assist in making decisions about treatment.

Rabin et al. suggested incorporating into this classification the following criteria for serious injury: significant mediastinal haematoma, extent of left haemothorax and the presence of pseudocoarctation (Figs. 5 and 6) [13].

It is crucial to look for these features that point to a poor prognosis on CT angiography because they require
emergency treatment. Multiplanar reconstructions are sensitive for the detection of small grade I or II lesions, which are sometimes difficult to see on standard axial images. They also allow the lesions and their extent to be better understood. Finally, they are an essential tool for assessing the required dimensions of an endoprosthesis when endovascular treatment is planned [14].

The treatment choice must take into account the rest of the assessment and other trauma injuries: brain, spine, abdomen and pelvis, as well as other chest injuries (Fig. 7). This assessment of injuries will allow therapeutic management to be ordered in terms of priority, as some injuries of the thoracic aorta are less urgent to manage than chest or abdominal injuries.

What are the imaging pitfalls?

A number of artifacts can mimic a traumatic injury of the thoracic aorta. The classic example is that of the cardiac pulsation artifact, especially in the ascending aorta (Fig. 8). If there is any doubt, CT angiography with ECG-gating or a transoesophageal echocardiogram will allow this pathology to be excluded in stable patients [8–15].

Nonetheless, there remain a number of pitfalls that require particular attention:

- pseudo ruptures: on lateral aortic imaging there is an accumulation of contrast material in a wall crevice, and this finding varies in terms of whether or not it points to...
a pathology. It is usually a congenital abnormality, such as a dilation at the aortic insertion into an arterial canal, known as ductus diverticulum. Sometimes these images correspond to acquired conditions, such as aneurysms or simple or complicated plaques of atherosclerosis (Fig. 9);

- mediastinal haematoma of venous origin: not all mediastinal bleeding corresponds to aortic injury. The literature

Figure 6. Criteria for serious injury: mediastinal haematoma and haemothorax. MIP reconstruction of CT angiography of the chest—axial plane (a and b), sagittal plane (c) and angiogram image (d). Significant pseudoaneurysm affecting over 50% of the aortic circumference, causing aortic transection (white arrow); there is also abundant mediastinal haematoma (white stars) and left haemothorax with extravasation of contrast material into the pleura (white arrow head).

Figure 7. Associated injuries: a: standard anteroposterior radiograph demonstrating a complete opacity of the right thoracic hemifield (black star), associated with an over-elevated homolateral diaphragmatic cupola (black arrow); b—d: portal phase chest and abdomen CT angiography; b: sagittal reconstruction; c: coronal reconstruction and d: original axial image. Diaphragmatic rupture, the anterior (black arrow) and posterior insertions encompass the apparently contused liver where it is displaced upwards into the chest (white stars).
describes trauma injuries to the great veins like the superior vena cava. These injuries are rare but they can be life-threatening;
• mediastinal haematoma secondary to an extra-aortic injury. It is important to know how to detect abnormalities of the supra-aortic vessels, possibly using 3D reconstructions. These dangerous lesions are a therapeutic challenge. They are often associated with aortic injuries although they can sometimes be isolated (Fig. 10).

Which injuries must be treated and within what timeframe?

An assessment of how serious the injuries are is a crucial factor for choosing treatment.

Many studies have shown that not all traumatic injuries of the thoracic aorta require emergency treatment and that some can be treated medically (Figs. 11 and 12) [13]. Aside from patients presenting signs of complications (significant left haemothorax, pseudocoarctation or extensive mediastinal haematoma), trauma injuries can be classified into two distinct groups according to their course:
• injuries in which the external wall of the aorta is spared: these are grade I and II injuries and they can be treated medically, combined with close monitoring (Fig. 13). Grade III injuries with no signs of serious damage must undergo invasive treatment, but this can sometimes be deferred depending on the relative priority of treating other trauma injuries. It is, however, reasonable in these cases to treat with placement of a stent graft in
the 24 hours following the patient becoming haemodynamically stable and surgical conditions being optimal. Nonetheless, the intervention must not be delayed for too long in order to avoid a secondary rupture;

- grade III injuries with signs of serious damage must be treated as grade IV injuries (Fig. 14) meaning that they must be treated as an emergency. These injuries cause increased mortality (Fig. 15).

This treatment decision tree is based on the natural history of thoracic aorta trauma. Indeed, over half of grade I and II injuries will resolve spontaneously with medical treatment only. Just 5% of grade I and II injuries deteriorate [16].

Furthermore, Harris et al. recently demonstrated that a lactate level on admission exceeding 4 mmol/L, a posterior mediastinal haematoma of over 10 mm in size, and a ratio between lesion size and normal aortic diameter
Figure 13. Follow-up of grade I and II injuries: a: CT angiography of the thoracic aorta demonstrating a small grade I injury to the thoracic aorta (black arrow); medical treatment and close monitoring was chosen; b: MIP reconstruction of repeat axial CT angiography images four months after the accident. The injury has deteriorated and pseudoaneurysm has worsened (white arrow). Placement of a thoracic endovascular stent is chosen; c and d: MR angiography of the chest with volume reconstruction (left) and MIP reconstruction (right) of sagittal views seven years after the treatment. The stent has expanded well and there is no leakage of note.

exceeding 1:4 are prognostic factors for aortic rupture [16].

Once again, CT angiography finds its place in the pre-treatment assessment. The various multiplanar reconstructions allow the calibre of the aorta to be assessed, which assists in the choice of aortic endoprosthesis. Abdominal and pelvic images also mean that the various femoral or brachial access routes can be assessed.

Which invasive treatment should be offered?

The approach to treatment varies from one unit to another, in spite of several attempts to bring practices in line [17].

However, over the last decade endovascular treatment has clearly become the first line treatment over open surgery, as long as it is technically possible in view of the topography and extent of the injuries. This is because the placement of an endovascular stent often leads to effective repair of traumatic aortic injury, with a fall in morbidity and mortality [18,19].

Indeed, the various studies from the literature all report the same positive results where endovascular treatment is concerned. The technical success rate often reaches 100%, with cause-specific mortality at 30 days hovering around 2.1%, and a two-year survival rate of 93.7%, and this comes with no neurological deficits linked to the intervention [20,21].

Nonetheless, as with any endovascular procedure, placement of an aortic endoprosthesis is not devoid of risk, with mortality during the intervention of around 4% and periprocedural mortality of around 16%. This mortality rate is of course more often attributable to the traumatic injury itself rather than to an iatrogenic complication. Spinal cord ischaemia remains a very rare complication in this condition, estimated to arise in fewer than 1% of cases [22,23].
While this technique is promising, there is a lack of retrospective information meaning that its reliability in the long-term cannot be assessed, especially in young patients, so patients will require regular follow-up.

**Technical aspects: what special precautions should be taken?**

When imaging examinations are carried out, the patient’s state of haemodynamic shock associated with hypovolaemia and vasoconstriction gives rise to the risk that the diameters for the endoprosthesis may be underestimated. Because of this, it is important to overestimate the size of the stent by at least 15% in order to avoid the risk of secondary leakage. Nonetheless, the data from the literature are not consistent, and this remains an issue at present [24].

The existence of any anatomical variants must be noted in the pre-treatment CT angiogram report. For example, an arteria lusoria may need to be occluded before an endoprosthesis can be placed in the descending thoracic aorta (Fig. 16). Angiography of the supra-aortic vessels is also indispensable in order to check whether the circle of Willis is complete, especially before the intentional occlusion of the left subclavian artery, without prior stenting.

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**Figure 14.** Endovascular treatment. Same patient as in Fig. 5: a: angiography image after placement of the endovascular stent and occlusion of the left subclavian artery (black arrow); b and c: repeat CT angiography seven years after the intervention, sagittal and axial reconstructions. Optimum expansion of the endovascular stent, with retrograde circulation the left subclavian artery (white arrow).

**Figure 15.** Endovascular treatment of a grade IV injury; a: arterial phase MIP reconstruction of coronal CT angiogram images of the chest demonstrating a significant aortic dissection in the descending thoracic section, with massive extravasation of contrast material; b: anteroposterior aortography demonstrating extravasation of contrast material; c: oblique aortography after placement of a thoracic endovascular stent. Contrast material extravasation resolves confirming that the endovascular stent is positioned correctly.
Anatomical variant and aortic trauma. Arterial phase CT angiography of the chest—axial images (a and b) and MIP reconstruction of coronal images (c). Grade III traumatic thoracic aorta injury (white arrow heads) associated with a mediastinal haematoma (white arrows). Presence of retroesophageal right subclavian artery (black arrow).

How should traumatic injury of the thoracic aorta be monitored?

A traumatic injury of the thoracic aorta must be monitored closely in the period immediately after the trauma, especially when it is a lower grade injury that has been treated medically. This follow-up should preferably be performed using CT angiography (Fig. 17).

Later on, it is recommended that MR angiography should be performed for follow-up. This is because MRI

CT angiography before and after treatment. Arterial phase CT angiography of the chest in the axial (a) and oblique sagittal planes (b) demonstrating a grade III thoracic aorta injury (white arrows) with mediastinal haematoma (white star). Emergency endovascular treatment is chosen. c-d: repeat CT angiography of the chest three years after endovascular stent placement: axial view (c) and MIP reconstruction of oblique sagittal images (d) confirm that the stent has expanded correctly and there is no leakage.
Traumatic injuries of the thoracic aorta

offers acceptable sensitivity and specificity while avoiding recourse to irradiating examinations.

**Conclusion**

Traumatic pathologies of the thoracic aorta are serious and associated with significant mortality. CT angiography of the chest is the first line examination to carry out in stable patients. An improved understanding of the pathophysiology of these injuries today allows endovascular treatment to be offered only to patients with serious (grades III and IV) or complicated injuries.

Grade I and II injuries can be treated medically combined with close monitoring.

Later follow-up of these injuries should preferably use MR angiography.

**Take-home messages**

**Diagnosis**
- Thoracic aorta trauma injuries are a diagnostic emergency.
- CT angiography of the chest is the examination of choice if there is any suspicion of traumatic injury to the thoracic aorta in a haemodynamically stabilised patient.
- CT angiography allows a positive diagnosis of traumatic injury to the thoracic aorta to be made, as well as an exhaustive assessment of other associated trauma injuries.
- Modern imaging modalities usually allow imaging pitfalls to be overcome, whether these are artifacts or other issues.
- If there is any doubt over diagnosis, a transoesophageal echocardiogram (as an emergency) or ECG-gated CT angiography (deferred) can resolve this.

**Management**
- It is important to accurately describe the traumatic injuries in their entirety so that the overall therapeutic management can be ordered in terms of priority.
- Classifying traumatic injuries to the thoracic aorta means that they can be assessed in terms of how serious they are, allowing appropriately emergent treatment to be offered and possibly deferring treatment.
- Trauma injuries that spare the external wall of the aorta (grades I and II) can be managed with medical treatment only, as long as there are no signs of serious injury.
- Signs pointing to a serious aortic trauma injury are: abundant left haemothorax, extensive mediastinal haematoma and pseudocoarctation.
- Trauma injuries involving the external wall of the aorta (grades III and IV) constitute an indication for endovascular treatment.
- In grade III injuries, deferring treatment is possible (for 24 hours), as long as there are no associated signs of serious damage.

- Grade IV injuries, and any other injury in which there are signs of serious damage, require emergency invasive management.
- Endovascular stents are the gold standard treatment for traumatic injuries to the thoracic aorta.
- CT angiography prior to the procedure allows the appropriate material to be chosen, the approach routes to be assessed and the measurements for the endoprosthesis to be made.
- It is important to overestimate the stent measurements by at least 15%.

**Follow-up**
- Whether injuries are untreated (grades I and II with no signs of complications) or treated (grades III and IV with or without complications), they need close follow-up at extremely regular intervals in the acute phase.
- Later on, aortic endovascular stents will need regular annual monitoring.
- In view of the young age of the target population and the repeated examinations envisaged for follow-up, it is desirable that these should be performed using MR angiography.

**Clinical case study**

This 30-year-old male was brought to the emergency department following multiple injuries due to a road traffic accident. The angiogram images showing a grade III rupture to the thoracic aorta and the outcome of the intervention (stent graft) are provided (Fig. 18).

**Questions**

1) 12 hours after the stent graft has been inserted, an emergent repeat CT scan is carried out due to persistence of a state of shock. Based on the imaging you receive (Fig. 19), what is your diagnosis? What management would you suggest?

2) Angiography imaging is performed (Fig. 20). Describe the abnormalities. What precautions would you take prior to any intervention?

3) Repeat CT imaging is provided (Fig. 21). Describe the abnormalities. How often would you continue with follow-up imaging and using which modality?

**Answers**

1) Leakage from around the stent fed by the left subclavian artery.

2) Action to take: emergency embolisation of the left subclavian artery.

2) Confirmation that the leakage originates from the left subclavian artery.
Figure 18. Initial treatment. Left: pseudoaneurysm deforming the external contours of the aorta, affecting over 50% of the arterial circumference (classified as grade III), straddling the origin of the supra-aortic vessels. Right: Repeat imaging at the end of treatment. The covered endovascular stent placed in the horizontal and descending portions of the thoracic aorta leads to exclusion of the pseudoaneurysm and recovery of a normal calibre, all the while sparing the vasculature of the left brachiocephalic and common carotid arteries. This result is achieved through the intentional exclusion of the left subclavian artery, after having checked that the right vertebral artery was patent.

- Check that the rupture does indeed concern the aorta rather than other vascular segments (supra-aortic vessels, mediastinal veins).
- Check the right vertebral artery and whether the circle of Willis is complete before embolisation of the left subclavian artery.

Figure 19. CT angiography of the chest performed 12 hours after placement of a stent graft, carried out because the patient deteriorated clinically. A bilateral pleural effusion of moderate abundance can be seen entailing collapse of the pulmonary parenchyma, and above all a type II endoleak fed by the left subclavian artery which is making the pseudoaneurysm patent once again.

Figure 20. Angiography. Contrast material administered via the brachial route to the left subclavian artery confirms the opacification of the pseudoaneurysm through a tear at the origin of this artery, as well as a slight traumatic dissection of the artery downstream (left internal thoracic artery protrudes over the lesion).

- The embolisation site must be before the vertebral artery.
- Complete occlusion of the left subclavian artery with exclusion of the leak originating from this artery, the


