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Imaging of thoracic aortic injury


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Abstract Isthmic aortic rupture or disruption should be systematically sought when there is high kinetic energy trauma to the thorax. This condition is extremely serious and life threatening. It needs to be diagnosed rapidly but diagnostic pitfalls must be avoided. CT angiography is the standard examination. The main CT signs of rupture or disruption of the thoracic aorta are peri-aortic hematoma, intimal flap, pseudo-aneurysm and contrast agent extravasation. There are three types of lesion: intimal, subadventitial or pseudo-aneurysmal, and complete rupture with lesion of the three tunicae, and it is important to grade them for better therapeutic management. The main diagnostic pitfalls of the CT scan are the presence of a ductus diverticulum and post-isthmic fusiform dilatation. Associated lesions must not be overlooked. The most common are ruptures of the aortic root and the thoracic aorta in the diaphragmatic hiatus.

Traumatic rupture or disruption to the thoracic aorta more frequently affects males, predominantly young men between 30 and 40 years of age. It is a serious condition with considerable morbi-mortality, with or without treatment. The percentage of deaths at the site of the accident is assessed at 80 to 90% [1]. Death in hospital without appropriate treatment is 30% within 6 hours, 40 to 50% within 24 hours and 90% within 4 months [1]. Following treatment, the mortality rate is still high, varying from 5 to 28% depending on the technique used and the extent of the associated lesions [2]. However, with modern therapeutic techniques, particularly endovascular repair, it is close to 9% according to more recent studies [2]. It is essential to make an extremely quick, precise and reliable diagnosis for rapid and effective treatment of the patient.

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Anatomy and anatomopathology

The thoracic aorta can be divided into four segments (Fig. 1). The first two segments, which are intrapericardial, are the Valsalva sinus (segment 0), where the coronary arteries originate, and the ascending aorta (segment 1), which originates 1 to 2 cm above the coronary ostia. The horizontal aorta (segment 2), which extends from the brachiocephalic arterial trunk to the subclavian artery, composes the third segment. Finally, the descending aorta (segment 3), situated beyond the subclavian artery and extending to the diaphragmatic orifice, is the last segment.

Lesions of the wall of the thoracic aorta are usually transverse, segmental (55%) or circular (45%). Spiral and irregular aortic lesions are very rare [1,3]. Goarin et al. classed aortic lesions in 3 grades [4]. The first two grades are composed of partial lesions and are found in 60 to 65% of cases. Grade 1 lesions are limited intimal lesions (intimal flap) or an isolated intramural hematoma (Fig. 2a). Grade 2, in which both the tunicae intima and media are involved, defines subadventitial tears (false aneurysm, hemomediastinum) (Fig. 2b and d). Grade 3 lesions, found in 40% of cases, are lesions involving all three tunicae (Fig. 2c), with rapid extravasation of blood. The neighboring mediastinal soft tissues may provide temporary buffering [1].

Special attention should be paid to diagnosing isolated intimal lesions, which make up 10% of the aortic lesions. CT angiography has been shown to be decidedly superior in this situation to arteriography, which only finds one lesion in two.

Therapeutic management is multidisciplinary. Some centers use intravascular ultrasound to confirm the diagnosis. In the majority of cases, simple scan monitoring 24—48 hours later is enough; it can show stability or spontaneous resorption.

Location of thoracic aortic lesions

The sites of attachment of the thoracic aorta determine the severity of lesions (Fig. 3). Lesions of the aortic isthmus can be differentiated from lesions of the root of the aorta or the descending thoracic aorta. In 10% of the cases, there are several lesion sites.

The isthmus is the commonest location for lesions (approximately 90% of all cases of patients who have been subjected to thoracic trauma) [1,5]. Its relatively immobile position in the thorax due to its attachment by the ligamentum arteriosum explains the reason for this site being involved in many injuries [1,3].

Lesions of the root of the aorta are sometimes associated with damage to the aortic valve. Lesions of the ascending aorta are rare (between 5 and 8% of the cases) according to data in the literature [3]. These two types of lesions are sometimes associated with hemomediastinum.

Involvement of the aortic arch and its branches is not so common. While involvement of the aortic arch itself is rare (about 2% of the cases) [3], the incidence of aortic arch branch involvement varies considerably in the literature. It is important to look for damage to the branches of the aorta if there is a mediastinal hematoma without any aortic damage.

In 1 to 12% of the cases, there is trauma to the descending thoracic aorta [3]. The distal descending aorta is attached to the adjacent vertebral column by the diaphragm. When there is a shock to the thorax, the resulting shear forces are responsible for lesions at this site.

Pathophysiology and lesion mechanism

There are several causes of the aorta rupturing, but the common factor is the violence of the shock. Road accidents make up 75 to 80% of the cases [6]. Other causes are, for example, accidental crushing and more rarely, falls. In 90% of the cases, there is multiple trauma.

There are several mechanisms that act either in isolation or together, one of the main ones being deceleration. This particularly concerns the front seat passenger of a vehicle going at speeds faster than 50 km/h subjected to frontal or lateral shock. This mechanism causes displacement of the heart, with torsion and shearing forces being exerted on the immobile areas of the aorta, i.e. the isthmus (ligamentum arteriosum), aortic root and at the diaphragm [3]. Moreover, intravascular pressure increase, secondary to aortic
Fig. 2. Types of lesion: a: intimal lesion; b: sub-adventitious tear (pseudo-aneurysm); c: complete rupture (lesion crossing the three tunicae); d: intraoperative view of an aortotomy showing an intimo-medial tear. Color code of the aortic tunicae: intima (green), media (blue), adventitia (red).

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Compression, can cause isthmic disruption by traction (the water hammer effect). The root of the aorta may also be affected due to the pressure of the retrograde flow [6].

Finally, crushing, generally anteroposterior is directly responsible for mediastinal, particularly aortic, lesions, due to direct compression of the aorta between the anterior thoracic wall (in particular, the manubrium sterni and the clavicle) and the thoracic spine [6].

**Clinical examination**

Clinical examination contributes little because it is non-specific and not very sensitive. There are no warning signs in a third of cases. Functional signs that might be found are thoracic pain (deep, retrosternal and interscapular), dyspnea and cough.

Physical signs are arterial hypertension of the arms with no femoral pulse or a reduction in it, secondary to pseudo-coarctation of the aorta (a severity factor), precordial or interscapular systolic murmur, paraplegia or paraparesis and significant hemothorax.

In practice, considering the context of multiple trauma, pseudo-coarctation seems to be the only differentiating sign.

**Standard X-ray**

The signs are not very specific and the X-ray image is normal in 7% of the cases [7].

The main purpose of an X-ray is to detect a mediastinal hematoma that would indicate considerable aortic trauma. Mediastinal enlargement of more than 8 cm and/or 25% of the width of the thorax (Fig. 4a) is most frequently observed, but is not the most sensitive sign [7]. The diagnosis must be suspected if there is any abnormality whatsoever of the aortic arch or opacification of the space between the aorta and the pulmonary artery (Fig. 4a).

The other signs found are deviation of the trachea towards the right, deviation of the nasogastric catheter towards the right, lowering of the left main bronchus
CT angiography

CT angiography is the standard examination for this condition with sensitivity of 98% and specificity of 100% [8]. It provides initial evaluation and the precise diagnosis of aortic lesions. It is indicated in high speed or violent trauma, death of a passenger at the site of the accident, doubt concerning the nature of the trauma (unconscious patient), strong clinical suspicion and chest X-ray abnormality.

Protocol and examination technique

We use a standard protocol for cases of multiple trauma: non-enhanced cerebral and abdominal CT scan, a cervical thoracic abdominal and pelvic scan in the arterial phase (including the ilio-femoral axes) and an abdominopelvic scan in the portal phase, after injection of 140 mL of iodinated contrast agent at a rate of 3–4 mL/s. Cardiac gating, which avoids heartbeat artifacts for better analysis of the ascending aorta, is not used in an emergency situation because it requires qualified staff, patient preparation time and slower acquisition time, exposing to breathing artifacts. It is reserved for difficult cases, when surgery has been differed.

There are several methods of reconstruction: MultiPlanar Reconstruction (MPR), Maximum Intensity Projection (MIP), curved MPR and volume rendering 3D reconstruction, or even the endovascular view. MIP reconstruction, particularly in the sagittal oblique plane, is essential for guiding the therapeutic procedure. It simulates the standard projection obtained during angiography and shows the thoracic aorta in its long axis. The examination including the native slices must be burnt onto a CD in case the patient is transferred to a specialized center, so that the operator can reproduce the reconstructions he considers necessary.

CT signs

With a CT scan, the direct signs of traumatic aortic lesions can be visualized. The appearance can vary considerably, from simple irregularity of the margin of the aortic wall to a true tear.
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A grade 1 disruption appears as an intimal flap and corresponds to the rupture of the tunica intima, a very thin layer which is not visible radiologically and a part of the tunica media, a thicker layer. On a CT scan, it is seen as a hypodense line within the lumen (Fig. 5a and b).

Grade 2 is a sub-adventitious disruption, i.e. damage to the whole of the tunica intima and media. Only the tunica adventitia, a distensible and watertight structure, retains the blood, thus, forming a false aneurysm (Fig. 6a–c).

Slowing of the blood flow inside the false aneurysm contributes to the formation of endoluminal mural thrombi. Rarely, a true dissection may be seen, the blood under pressure forces its way into the aortic wall through the tear (entry point) and produces a longitudinal and circumferential split in the media, individualizing the true and false lumens.

In a grade 3 lesion, all three tunicae layers are ruptured. There is therefore extravasation of contrast agent,

Figure 5. CT image of an intimal flap: a: axial slice (white arrow); b: coronal slice after MPR (arrow black).

Figure 6. Multi-trauma patient brought in by the emergency service. The whole body CT scan showed sub-adventitious aortic disruption with the appearance of a pseudo-aneurysm: a: volume rendering 3D reconstruction (white arrow); b: pseudo-aneurysm followed by a pseudo-coarctation on the MPRs (white arrow); c: intraoperative view of the pseudo-aneurysm of the aortic isthmus (white arrow).
the blood only being retained by the mediastinal fat (Fig. 7).

When these pathognomonic signs are present, no other examination is necessary.

A CT scan can also reveal indirect signs of aortic disruption, principally mediastinal hematoma and aortic parietal hematoma. A mediastinal hematoma does not affect the periaortic fat plane. In contrast, an aortic parietal hematoma is directly continuous with the aortic wall (Fig. 8). However, these two signs are not specific: a mediastinal hematoma is also visible in lesions of the azygos vein, intercostal arteries and internal thoracic arteries, and an aortic parietal hematoma may be related to a lesion of the vasa vasorum without an aortic wall rupture. This latter hematoma is sometimes visible without direct signs or lesions on the arteriogram. In this case, if the patients are stable, simple CT monitoring at 48–72 hours is recommended.

In multiple trauma, other lesions are often seen and CT is again the best means of looking for them. Damage may be found to the pleura (pneumothorax and/or hemothorax), lungs (contusions, tears, ventilation disorders), trachea and bronchi, esophagus, diaphragm and skeleton. Particular attention must be paid to looking for fractures of the sternum and first and second ribs, because these are markers of serious trauma and hence of a high risk of an aortic lesion; however, their absence does not eliminate the possibility.

Pitfalls of CT angiography

CT angiography pitfalls are anatomical or technical in origin.

The anatomical pitfalls may be venous, arterial or pulmonary, the ductus diverticulum (Fig. 9) being one of the main ones. It is a remnant of the embryonic ductus arteriosus, found in 9% of the arteriograms in the adult. It appears as a rounded (obtuse angle with the aortic wall) or spicular (acute angle with the aortic wall) bulge located on the anterior inferior surface of the isthmus. When its angle is obtuse and it is calcified, it does not pose much of a diagnostic problem. On the other hand, if it makes an acute angle with the aortic wall and there is no intimal flap, the diagnosis is less obvious and certain teams propose an endovascular ultrasound examination to remove the doubt.

Occasionally, post-isthmic aortic dilatation of a non-pathological nature can be confused with an aortic lesion. In some cases, the simultaneous opacification of the aorta and adjacent veins (azygos, intercostal or bronchial veins) by the contrast agent may give the false appearance of an intimal flap. Sometimes, a non-pathological dilatation of the ostium of the bronchial and intercostal arteries may simulate a small pseudo-aneurysm, but its conical shape and the artery, seen at its distal end, helps diagnosis. Finally, a small periaortic pulmonary atelectasis can simulate an intimal flap (Fig. 10). With careful examination, the pulmonary vessels and the bronchi entering the atelectasis can be found.

The technical pitfalls are essentially heartbeat artifacts (Fig. 11), which are particularly present at the root of the aorta and in the ascending aorta, and simulate an intimal pseudo-flap. This image continues in the mediastinal fat giving a blurred interface with the hyperdense lumen of the aorta, which can help with diagnosis. Otherwise, these artifacts can be removed by ECG-gated CT.

Breathing and patient movement artifacts can also be found. They are revealed by visualizing the thorax in the lung parenchymal window.

If there is no mediastinal hemorrhage, all these diagnostic pitfalls can be identified without difficulty. However, where traumatic disruption of the thoracic aorta is suspected in a stable patient, it is sensible to reassess the patient after 24–48 hours by performing a control ECG-gated CT scan.

Arteriography

With good sensitivity and good specificity (higher than 90%) for grade 2 and 3 lesions, arteriography was considered to be the best diagnostic examination for aortic lesions before the advent of the multi-detector scanner [9]. The arteriographic signs are irregularity of the vascular wall up to a break in its continuity, extravasation of contrast agent where there is complete rupture, fusiform enlargement of the aorta, sack-like false aneurysm and pseudo-coarctation (Fig. 12).

Arteriography is currently reserved for detection of damage to branches of the aorta and to pre-therapeutic situations before implanting an endoprosthesis via the endovascular route. It can also be performed at the end of
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Figure 9. A 48-year-old female car accident patient, with no traumatology finding, hospitalized in the cardiology department because of ventricular extrasystole. The various reconstructions show a calcified ductus diverticulum with an aortic swelling: a and c: volume rendering 3D reconstructions (white arrow and arrowhead); b: MIP oblique sagittal reconstruction (black arrow).

Pelvic embolization procedure, for example, and before a whole body CT scan, in order to eliminate an aortic lesion.

Echocardiography

Transparietal ultrasound is not good enough for detecting aortic lesions because there are many areas of shadow.

Figure 10. Pulmonary atelectasis (white arrow) along an aortic aneurysm, not to be confused with aortic fissionation.

Figure 11. Heartbeat artifact of the ascending thoracic aorta mimicking a traumatic lesion of the wall (black arrow).
Figure 12. A 37-year-old man subjected to violent trauma due to sudden deceleration. The arteriogram shows pseudo-coarctation of the aorta (black arrow).

MRI

The characteristics of MR imaging are excellent for detecting acute aortic trauma, but its use is limited in emergency situations, essentially because of the problem of accessibility. The examination time is also too long and it is not possible to introduce certain support systems into an MRI room. However, it is particularly relevant in monitoring minimal intimal lesions, in situations where surgery is delayed, and in young patients to reduce irradiation. The examination protocol consists of axial scout slices, kinetic sequences in the plane of the aorta, T1-weighted axial slices before and after injection of gadolinium and an MRA sequence of the aorta with injection of gadolinium.

Treatment

An aortic rupture is a life-threatening emergency. Rapid management by an experienced resuscitation team is necessary to provide the immediate treatment essential for the patient’s survival. One of the key points is strict control of the arterial pressure using beta-blockers and vasodilators aiming at systolic arterial pressure below 120 mmHg and mean arterial pressure below or equal to 80 mmHg. Next, the usefulness of immediate or deferred endovascular or surgical treatment is discussed.

Surgical treatment

After thoracotomy via the fourth left intercostal space, the surgeon most often sutures the lesions (Fig. 13a and b) after lowering the arch, or performs segmental resection with a prosthetic repair (Dacron graft) (Fig. 13c and d), with or

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Figure 13. The different operative techniques for aortic ruptures: simple suture as a diagram (a) and in an intraoperative view (b); prosthetic repair as a diagram (c) and in an intraoperative view (d).
without circulatory support. Associated lesions are treated in the same operation.

Studies report a mortality rate varying between 19 and 28% [2] and a rate of paraplegia of about 16% [2]. Other complications of surgical treatment are hemorrhage with heparin, CNS lesions, renal impairment, respiratory insufficiency, hemothorax, respiratory infections, prosthesis infections, etc.

**Endovascular treatment**

Immediate or deferred endovascular repair has become the first-line treatment. The radiologist inserts an endoprosthesis that does or does not cover the ostium of the left subclavian artery (Figs. 14 and 15). Transposition of the subclavian artery to the carotid may be necessary (Fig. 15).

**Figure 14.** Road accident victim. On diagnosis: a: thoracic aorta rupture (black arrow) on an axial CT slice. After endoprosthesis treatment: b: diagram of the endoprosthesis (black arrow); c: axial CT slice of the endoprosthesis (white arrow); d: endoprosthesis in its greater axis on an oblique sagittal reconstruction (white arrowhead); e: 3D view of the endoprosthesis.

**Figure 15.** Treatment with an endoprosthesis (white arrow) of a rupture of the aortic isthmus (black arrow) covering the ostium of the left subclavian artery (curved arrow) with reimplantation of the latter in the left common carotid artery (arrowhead): a and b: axial slice; c: volume rendering 3D reconstruction.
The success rate is good with a lower rate of complication than in open surgery. Morbidity relating to endovascular treatment is less than for surgical treatment, with less risk of spinal cord ischemia (3% versus 9%, respectively) and end stage renal disease (5% versus 8%, respectively) [2].

Mortality is also lower with endovascular treatment compared with an emergency thoracotomy (9% versus 19%, respectively) [2].

In the long term, few complications are found with endoprosthetic treatment of traumatic lesions of the aorta [2].

Conclusion

Traumatic rupture of the thoracic aorta is a diagnostic and therapeutic emergency. It should be suspected in any patient having had an accident involving high kinetic energy. CT angiography is the standard examination for diagnosis and post-therapeutic monitoring.

Beware of atypical locations, isolated small intimal lesions and false positives (heartbeat artifacts, ductus diverticulum, etc.). For rupture of the isthmus, the efficacy of endovascular treatment with an aortic endoprosthesis no longer needs to be demonstrated and there are few later complications.

Disclosure of interest

The authors declare that they have no conflicts of interest concerning this article.

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