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Max Wintermark
Stefan Wicky
Pierre Schnyder

Imaging of acute traumatic injuries of the thoracic aorta

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M. Wintermark · S. Wicky ·
P. Schnyder (✉)
Department of Diagnostic and
Interventional Radiology,
University Hospital, CHUV–BH10,
1011 Lausanne, Switzerland
E-mail: Pierre.Schnyder@chuv.hospvd.ch
Phone: +41-21-3144556
Fax: +41-21-3144554

Abstract Blunt traumatic aortic injuries are a major concern in the settings of high-speed deceleration accidents, since they are associated with a very high mortality rate; however, with prompt diagnosis and surgery, 70 % of the patients with a blunt aortic lesion who reach the hospital alive will survive. This statement challenges the emergency radiologist in charge to evaluate the admission radiological survey in a severe chest trauma patient. With a 95 % negative predictive value for the identification of blunt traumatic aortic lesions, plain chest film represents an adequate screening test. If aortography remains the gold standard, it tends, at least in hemodynamically stable trauma patients, to be replaced by spiral-CT angiography (SCTA), which demonstrates a 96.2 % sensitivity, a 99.8 % specificity, and a 99.7 % accuracy. In unstable patients, trans-esophageal echography (TEE) plays a major diagnostic role. Knowledge of advantages and pitfalls of these imaging techniques, as reviewed in this article, will help the emergency radiologist to choose the appropriate algorithm in the diagnosis of traumatic aortic injury, for each trauma patient.

Keywords Wounds and injuries · Thoracic injuries · Aortic rupture · Diagnostic imaging · X-ray CT · Emergency treatment

Epidemiology and biomechanics

Blunt injuries of the thoracic aorta are met in 0.5–2 % of chest trauma patients admitted in emergency rooms alive [1, 2]. Aortic lesions represent the most lethal condition among chest injuries and are responsible for up to 40 % of fatalities occurring in traffic accidents [2, 3]. Head-on and lateral motor vehicle accidents at speeds superior to 50 km/h, or associated with substantial car deformity, are the main cause (76 %) of blunt traumatic aortic injuries, followed by falls from heights – usually exceeding 3 m – and crush injuries [4, 5, 6, 7].

Four mechanisms are hypothesized to explain blunt lesions to the thoracic aorta [8, 9]. Sudden antero-posterior or lateral deceleration superior to 80 g induces anterior cardiac displacement, leading to shearing forces, and sometimes rupture, at the aortic isthmic level [3, 8]. Rapid vertical deceleration occurring in falls from height results in aortic arch compression against the anterior thoracic cage. Aortic injuries with such biomechanics are thus located on the ascending aorta [10]. The "water-hammer effect" relates to a low thoracic or abdominal compression. The resultant sudden increase of the intra-aortic pressure may be responsible for ascending aortic injuries immediately above the aortic valve. A pressure peak of 80–350 kPa (600–2500 mmHg) is required to rupture a normal aorta [5]. Finally, the "osseous pinch" hypothesis assumes a compression of the heart and the aorta between the sternum and vertebral column, for instance, under a violent frontal impact against the steering wheel. The resultant left posterior displacement of the heart generates an aortic torsion, which may result in a traumatic aortic lesion, sometimes associated with thoracic vertebral fractures [11].

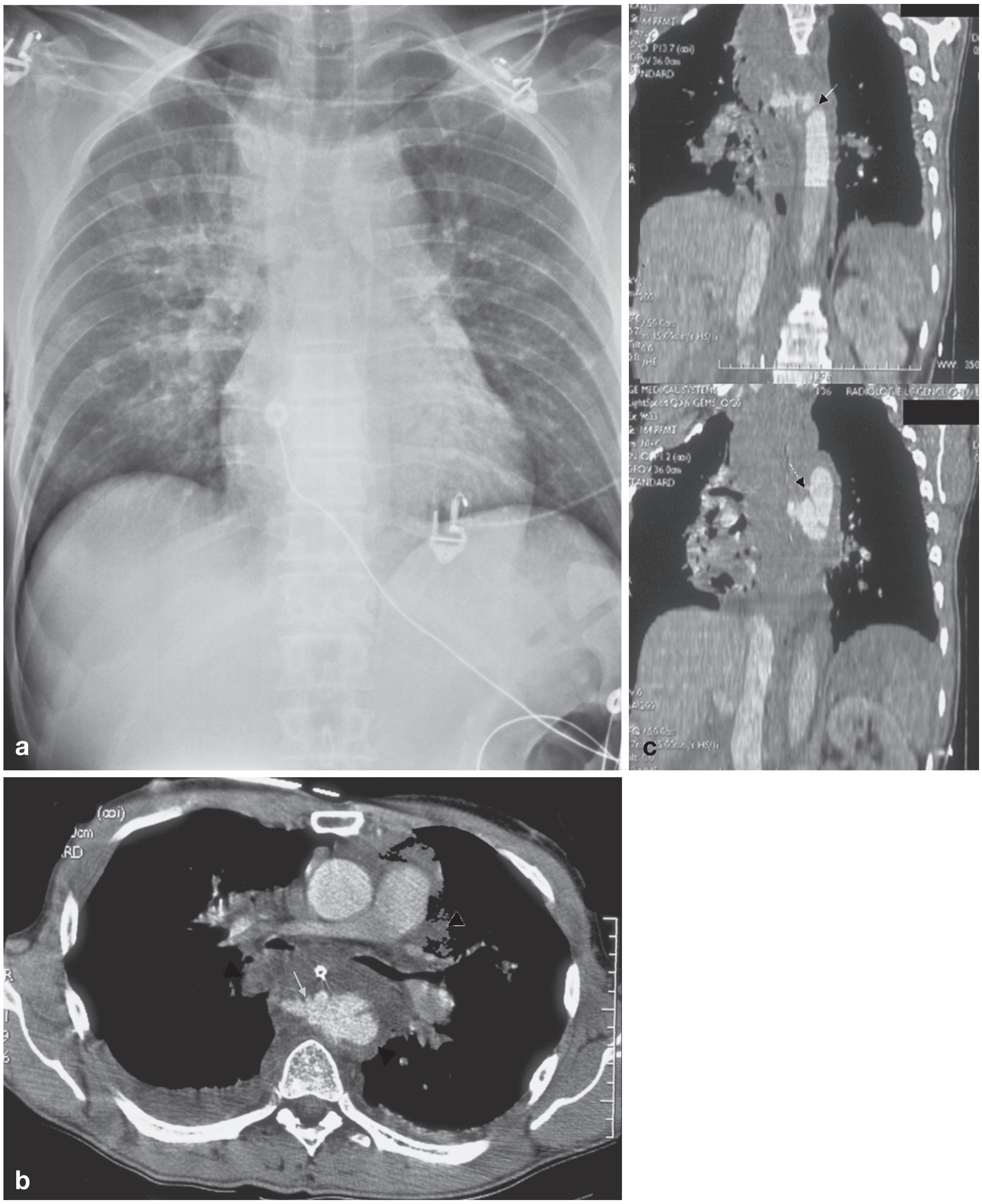


Fig. 1 a–c A 43-year-old male patient who threw himself through a window to commit suicide and fell from a 6-m height. **a** Admission chest X-ray shows a widening of the superior mediastinum, as well as an enlarged and blurred aortic knob. This radiological pattern justified spiral chest CT survey (2.5-mm thickness). **b** Axial CT section demonstrates an extensive mediastinal hematoma *(arrowheads)* originating at the site of a iodinated contrast material extravasation *(arrow)* on the medial aspect of the aortic isthmus. A right hemothorax is also present. **c** Two-dimensional reconstruction confirms this contrast material extravasation and relates it to a complete aortic transection *(arrows)* at the isthmic level

Clinical presentation and prognosis

Approximately 80 % of patients with blunt traumatic aortic injury die from exsanguination at the scene of the accident. In the remaining 20 %, the mortality rate of acute traumatic aortic injury in the absence of surgical treatment is high: 30 % die within 6 h; 50 % within 24 h; 90 % within 4 months. Chronic pseudo-aneurysms develop in 2 % of survivors with undiagnosed blunt traumatic aortic lesion [1, 5, 10, 12].

On the other hand, 70 % of the patients with blunt aortic lesion who reach the hospital alive will survive, if given appropriate treatment. Development of coordinated emergency medical services using ground and air support, setting of dedicated trauma centers and recent advances in diagnostic modalities may allow for a prompt and accurate diagnosis and thus improve blunt trauma patients' outcome [1, 13].

Possible aortic lesions should be suspected in case of high-speed deceleration trauma, even in the absence of clinical symptoms or signs. Indeed, the majority of traumatic aortic injuries are clinically silent until the onset of a sudden hemodynamic decompensation [10].

Mediastinal hematoma caused by transmural aortic lesions leads to compression and stretching of mediastinal tissues and may be responsible for retrosternal and interscapular referred chest pain, dyspnea, hoarseness, and coughing. Acute coarctation syndrome, relating to upper limb hypertension and lower limb decreased pulses and hypotension, as well as a precordial or interscapular systolic ejection murmur, is occasionally present. These symptoms and signs are neither sensitive nor specific [13, 14].

In young patients with elastic chest walls involved in deceleration accidents, kinetic energy is absorbed by the intrathoracic viscera rather than by the thoracic cage itself. Forty percent of patients with acute traumatic aortic injury show no external sign of chest wall trauma. Sternal, clavicular, scapular, or upper and paravertebral rib fractures are not specific for aortic injuries but hallmark the severity of trauma and should thus raise suspicion for blunt aortic injuries [3, 15, 16].

Pathology

Most blunt traumatic aortic injuries consist of transverse aortic lesions. They are rarely longitudinal, spiral, or ragged. They are segmental in 55% and circumferential in 45% of cases. Aortic lesions may either be partial (65%) or transmural (35%) [3, 13, 17].

Partial blunt aortic lesions may rarely be limited to intimal and/or medial hemorrhage with intact overlying adventitia or consist of traumatic aortic dissection or intramural hematoma, especially in young patients. More often, intima and media are completely disrupted and sometimes drawn apart over several centimeters, whereas the adventitia remains intact. Bleeding from the aorta or from intramural vasa vasora generates a pseudo-aneurysm, which features a saccular pulsating outpouching, separated from the aortic lumen by a collar and limited by a thin layer of adventitia and by neighboring tissues, usually surrounded by a hemomediastinum. It may rupture at any moment [3, 12, 13, 17].

In transmural blunt aortic lesions, the aortic wall is disrupted in its whole thickness (Fig. 1). Subsequent mediastinal hemorrhage rapidly extends cranially, creating a left apical extrapleural capping. It then ruptures into the pleural space and usually results in a left hemothorax. Massive mediastinal and pleural hemorrhage as well as exsanguination lead to immediate death [3, 13, 17, 18].

Ninety percent of blunt traumatic aortic injuries occur on the antero-medial aspect of the aortic isthmus. Since it lies between the relatively mobile aortic arch and the rigid descending thoracic aorta, which is fixed by the intercostal arteries and paravertebral connective tissues, the aortic isthmus represents the lowest-resistance point of the aorta in deceleration accidents [3, 12, 17].

Seven to 8% of blunt traumatic aortic lesions are located on the ascending aorta, above the aortic valve.

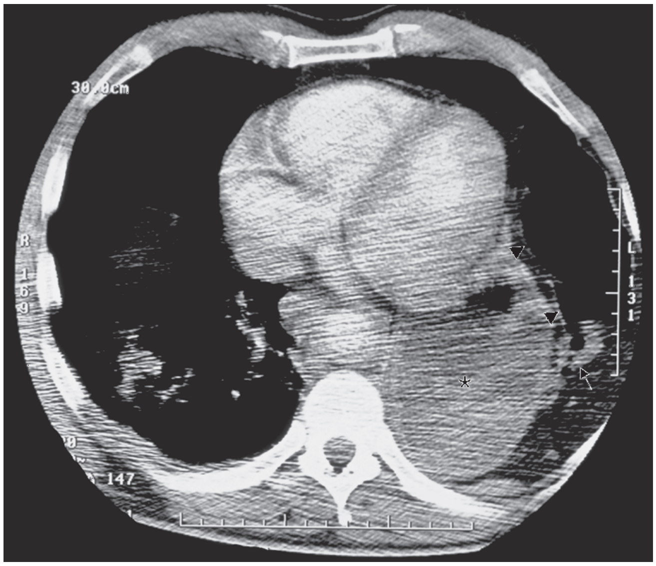


Fig. 2 Spiral chest CT pattern of combined blunt lesions of the diaphragm and diaphragmatic aorta in a 45-year-old male patient involved in a high-speed deceleration car crash. The blunt traumatic aortic injury features irregularity and blurring of the aortic contour, with surrounding mediastinal hematoma. The left diaphragm rupture allows for an intrathoracic herniation of the stomach *(asterisk)*, small *(arrow)* and large *(arrowheads)* bowel loops. Note the streak artifacts produced by the patient's arms left along his chest because of a humeral fracture

Such injuries are usually associated with aortic valve tears, cardiac contusions or ruptures, coronary artery tears, or hemopericardium with cardiac tamponade. They are almost always fatal [3, 13, 17, 19].

Blunt traumatic lesions of the descending aorta at the level of the diaphragm are observed in 2–3% of cases. In 10% of cases they occur simultaneously with diaphragmatic ruptures, both sharing similar biomechanics (Fig. 2) [3, 13, 17, 20].

Lesions of major mediastinal vessels, other than the aorta, are encountered in less than 1% of trauma patients who reach the hospital alive. They are multiple in 69% and associated with blunt aortic lesions in 20% of cases. Multiple blunt aortic lesions have also been reported [8, 21, 22].

Plain-film imaging of acute traumatic aortic injuries

The identification of blunt aortic injuries on chest plain films is based mainly on the radiological patterns associated with the presence of a mediastinal hematoma (Table 1) [8, 23, 24].

Mediastinal widening in the supine patient (Fig. 1a) is diagnosed if the mediastinum width to chest width ratio, at the level of the aortic arch, is superior to 0.25 or if its width at the level of the aortic arch is superior to

Table 1 Radiological findings in case of traumatic aortic rupture. *NA* not available. (From [8])

		Sensitivity (%)	Specificity (%)
Features directly related to the aortic injury:	Irregularity or blurring of the aortic knob contour	72	47
	Aortic knob enlargement	35	60
Features related to the presence of a mediastinal hematoma:	Mediastinal widening	90	19
	Aorto-pulmonic window opacification	42	83
	Displacement of the left lateral wall of the esophagus or of a naso-gastric tube	9	96
	Displacement of the left lateral wall of the trachea or of an endotracheal tube	20	92
	Trachea anterior displacement on lateral views	NA	NA
	Left mainstem bronchus downward displacement	3	99
	Cardiac silhouette enlargement and loss of definition	NA	NA
	Superior vena cava rightward displacement	7	96
	Azygos vein obscuration	NA	NA
Other features:	Left apical cap	5	95
	Opacification of the medial border of the left lung	12	95
	Left hemothorax	5	97
	Right paratracheal stripe thickening	30	99
	Right or left paraspinal stripe thickening	2	97

8 cm. Blunt traumatic aortic lesion is the cause of mediastinal hematoma in only 20% of cases. Mediastinal enlargement secondary to mediastinal hematoma may also arise from other major mediastinal vessel lesions or from small vessel injuries consecutive to sternal, clavicular, rib, or vertebral fractures (Fig. 3) [10, 23, 24, 25].

Pitfalls in the measurement of mediastinal width are well known. Some pitfalls are characteristic of trauma patients, such as vascular engorgement due to a large amount of fluid perfusion and magnification of the mediastinum in the supine antero-posterior chest X-ray, whereas other are fortuitous: thoracic aortic ectasia and tortuosity secondary to hypertension in the elderly; mediastinal lipomatosis; or lymphadenopathy [10, 13, 23, 24, 25, 26].

On front chest X-rays, hemomediastinum resulting from an aortic lesion at the level of the aortic isthmus may obscure the aorto-pulmonic window and displace mediastinal structures – trachea and left mainstem bronchus; or lines – endotracheal or naso-gastric tube [12, 13, 24, 25].

The blunt traumatic aortic injury itself may be responsible for various radiological patterns, such as enlargement, blurring, or irregularity of the aortic knob and descending aorta (Figs. 1a), or show a "broken halo" sign, related to a fractured calcified ring [24, 25, 27].

Finally, an apical extrapleural cap or a hemothorax, on the left side in 90% of cases, are radiological features classically associated with aortic lesions [12, 13, 18, 24, 25].

Aortic injury must be suspected in any patient with high-energy trauma to the chest. The violence and magnitude of the injuring forces are commonly unknown on admission and must be inferred from historical and clinical findings; thus, every high-speed trauma patient with suspected blunt traumatic aortic injury requires, as initial radiologic evaluation, a front chest X-ray. With a 90% sensitivity, a 25% specificity, and a 95% negative predictive value, the supine chest X-ray is a worthy screening tool for mediastinal hemorrhage, but affords little as far as definitive diagnosis is concerned [8, 10, 23, 24, 28].

Thoracic aortography as a gold standard in diagnosing acute traumatic aortic injuries

Thoracic aortography currently remains the definite tool to detect aortic injury, to define its location, and to determine its extent. It also defines the anatomy of the branches of the aortic arch and their possible involvement in the lesion [29, 30, 31].

Aortography is usually achieved with 40 cc of a nonionic iodinated contrast material at an injection rate of 18–20 cc/s. At least two sets of views are obtained, in the antero-posterior and left anterior oblique at 45° (see Fig. 3c) projections. Additional views in the right anterior oblique or lateral projections are sometimes required.

The aortographic diagnosis of blunt traumatic aortic injuries relies on the demonstration of an irregular or discontinued contour of the aortic lumen. An intimal flap, an aortic dissection, or a luminal outpouching relating to a pseudo-aneurysm are current aortographic patterns caused by blunt traumatic aortic lesions. A post-traumatic coarctation may occasionally be present.

A blunt traumatic aortic pseudo-aneurysm (Fig. 4e) has irregular or asymmetric contours and one or both

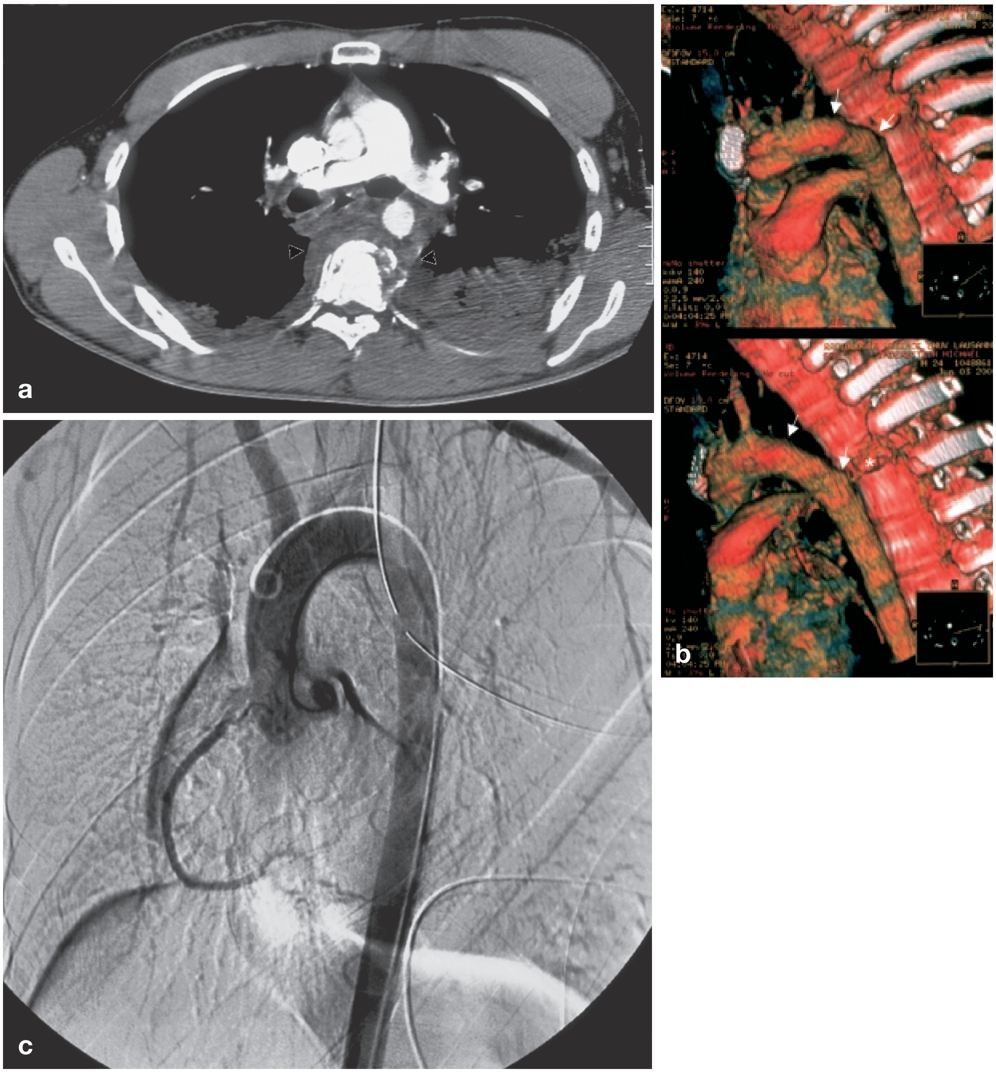


Fig. 3 a–c A 24-year-old female bicycle rider involved in a serious fall from a 5-m height. Admission chest X-ray was normal, except for an abnormal T6 vertebra. Neither obscuration of the aortic knob nor mediastinal enlargement were present; however, accident biomechanics and high-speed deceleration justified spiral chest CT survey to rule out an aortic injury. **a** Spiral chest CT section (2.5-mm thickness) obtained at the level of the aortic isthmus depicts a posterior hemomediastinum *(arrowheads)*, which is likely related to a T6-vertebra burst fracture. Altogether, an oblong aortic contour raised suspicion of a possible traumatic aortic lesion, reinforced by the presence of a left hemothorax. **b** The suspicion of a possible aortic injury could not be ruled out by 3D surface-shaded display (SSD) reconstructions, which both show two aortic outpouchings *(arrows)* distal to the left subclavian artery, as well as the T6-vertebra burst fracture *(open arrow)*. **c** This led to thoracic aortography (left anterior oblique projections), which was normal. Patient's follow-up over 1 year led to confirmation of the absence of blunt traumatic aortic pseudo-aneurysm

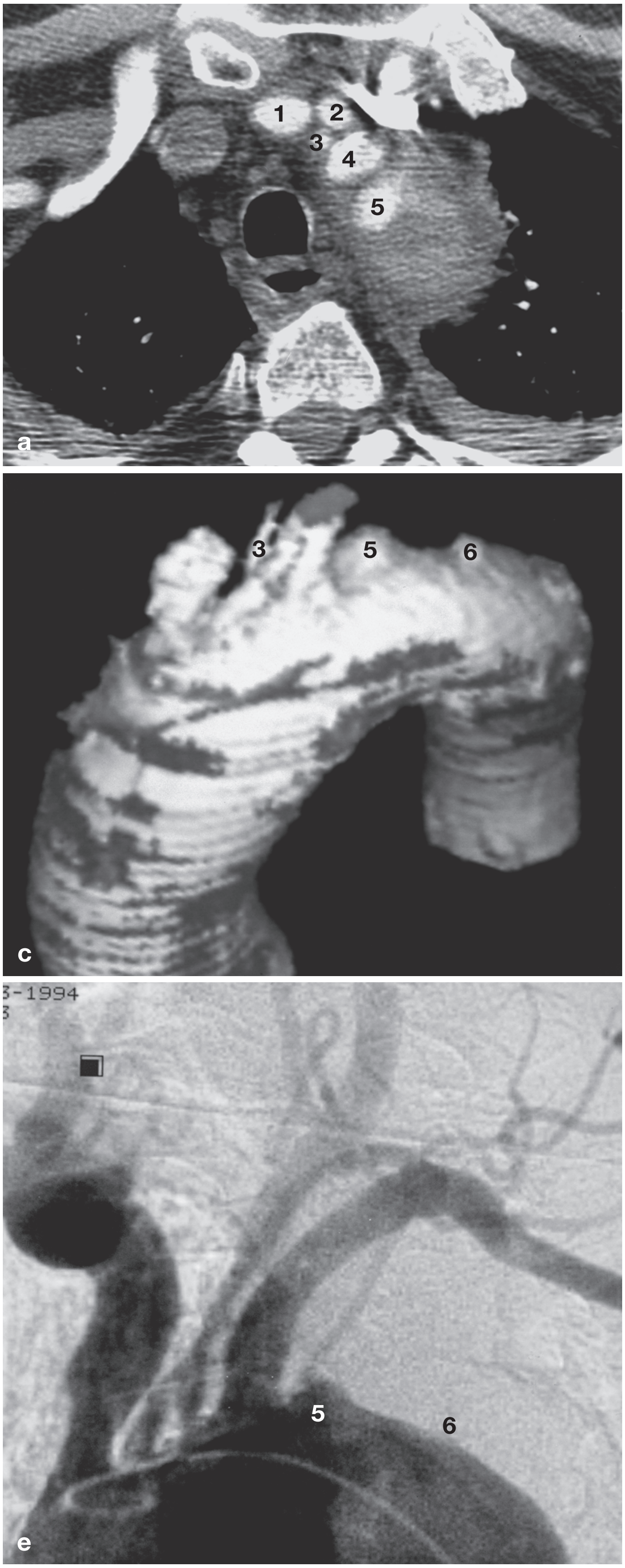
acute margins with the aortic lumen; it may retain contrast material after wash-out.

Intramural hematomas result in subtle abnormalities of the aortic luminal contour and their visualization usually requires more than the two classical aortographic projections [10, 13, 32].

Thoracic aortography can detect blunt traumatic aortic injuries with a 96 % sensitivity and a 98 % specificity [23, 31, 33].

False-negative examinations relate to incomplete series or inadequate injections [10, 21, 34]. The aortic study has to include the aortic root, as well as the distal descending thoracic aorta, since these locations are involved in, respectively, 8 and 2 % of all blunt aortic lesions [3, 13, 17, 19, 20].

False positives often relate to prominent ductus diverticulum or from ulcerated atheromas. A ductus diverticulum, which is seen in up to 9 % of thoracic aortograms, either relates to a remnant of the enlarged mouth of the ductus arteriosus or results from a traction by the ligamentum arteriosum and appears as a localized bulge of the anterior wall of the aorta. It has smooth, regular, and symmetrical contours and shapes obtuse angles with the aortic wall. Intimal flap is absent. The aortic lumen adjacent to the diverticulum shows no evidence of luminal narrowing. There is no contrast retention in the ductus diverticulum after the wash-out. Finally, an ulcerated atheroma (Fig. 4) features a small, isolated outpouching in the aortic wall with a collar-button appearance. It is located in the mid-descending aorta rather than at the aortic isthmus. It is associated with diffuse atherosclerotic disease [32, 35]. Other pitfalls of aortography in the blunt traumatic aortic lesion are the large infundibula of aortic arch branch vessels and of intercostal arteries – mainly the right bronchial–intercostal trunk, as well as unusual branching pat-



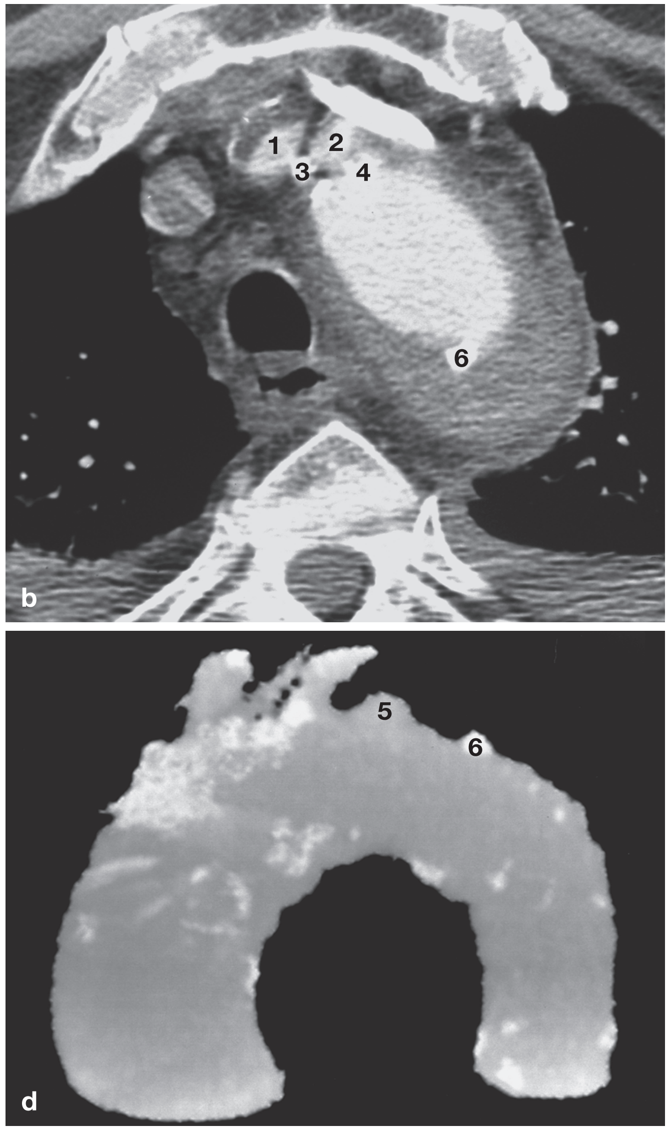


Fig. 4 a–e A 74-year-old male patient who fell from a 3-m height. **a, b** Spiral CT survey (3-mm thickness) demonstrates an extensive hemomediastinum, as well as six dense spots at the level of the aortic arch branching: *1* the innominate artery; *2* the left carotid artery; *3* an unidentified vessel; *4* the left subclavian artery; *5* an additional opacified spot; *6* a calcified atheroma. **c** A 3D SSD reconstruction identifies the vessel labeled *3* as an aberrant left vertebral artery originating directly from the aorta, as confirmed by aortography (**e**). **d** A maximum intensity projection reveals the distal outpouching of the aorta to be the calcified atheroma *(6)* seen in **b** and **c**. The proximal outpouching *(5)* relates to the blunt traumatic pseudo-aneurysm. **e** The thoracic aortography demonstrates the aberrant left vertebral artery *(3)* and the blunt traumatic pseudo-aneurysm *(5)* lying distally to the left subclavian artery, whereas the calcified atheroma has been digitally subtracted. (From [58]) terns of the aortic arch vessels [32, 35]. The aortic spindle, which is a congenital narrowing of the aorta at the ligamentous arteriosum, has also to be mentioned with distal fusiform dilatation. It usually regresses during embryonic development but may persist in up to 16 % of adults [32, 35].

Thoracic aortography can be achieved in most trauma patients but is time-consuming, and thus delays other diagnostic and therapeutic procedures such as craniotomy or laparotomy. In most institutions, angiographic teams are indeed on-call at night or during weekends, but a 30- to 45-min delay is usually required for them to reach the hospital and to bring the patient to the cath laboratory for the angiographic procedure [30, 31].

When thoracic aortography is performed on the basis of trauma mechanism, clinical data and chest X-ray findings, it has a low positive response ranging to less than 15 %. New imaging modalities, such as spiral CT (SCT) and transesophageal echography (TEE), are presently considered, not only as screening methods to select patients for thoracic aortography, but also as diagnostic procedures for the identification of blunt traumatic aortic injuries [10, 29, 36, 37].

Spiral-CT aortography as an accurate screening test

At our institution, spiral CT aortography (SCTA) is obtained when accident biomechanics or chest X-ray findings are compatible with a blunt traumatic aortic lesion. Patients with SCTA diagnosis of aortic lesion are thus immediately referred to cardiovascular surgeons, without performing a thoracic aortography. On the other hand, a normal SCTA, with no aortic abnormality and no mediastinal hematoma, is considered as definitely ruling out a blunt traumatic aortic injury. Thoracic aortography is finally only performed when SCTA displays a hemomediastinum without pathognomonic features of aortic lesion. Such conditions account for less than 5 % of screened patients.

Our protocol for multidetector-array spiral-CT survey of the blunt chest trauma (available at our web address: http://www.hospvd.ch/public/chuv/rad/en/rad_en_tra_med_prot.htm) includes acquisition of 2.5-mm CT slices at 2-mm intervals, with a pitch of 1.5:1 (The pitch designates the ratio of the patient couch travel per rotation by the product of the number of tomographic sections produced by a single rotation of the X-ray tube times the nominal tomographic slice thickness, according the Commission of the European Communities. European Guidelines on Quality Criteria for Computed Tomography, EUR 16262 EN, 1999, available from URL:http://www.drs.dk/guidelines/ct/quality/) and acquisition parameters of 140 kVp and 200 mAs. The scanning direction is caudo-cranial, from the diaphragm up to the thoracic outlet. The CT acquisition is obtained during and after intravenous administration of 100 cc of non-ionic iodinated contrast material at a rate of 3 cc/s. The scanning delay is automatically determined with the help of a software (SmartPrep, General Electric, Milwaukee, Wis.) which monitors the contrast material enhancement online. When possible, the patient's arms are raised over the head and images are obtained during suspended respiration or superficial breathing. This chest CT survey is usually obtained after unenhanced cerebral CT and before abdomino(-pelvic) CT.

With spiral-CT scanning, 2D (Figs. 1b, 5b, c) and 3D reconstruction algorithms, e.g., surface-shaded display (SSD) reconstruction (Figs. 3b, 4c, 5c) and maximum intensity projection (MIP; Fig. 4d), allow for the aorta to be viewed as multiplanar displays or generate images very close to those obtained by aortography. In these cases the modality is referred to as SCTA. These 2D and 3D reconstructions are processed quickly and constitute an additional diagnostic tool for the radiologist, but mostly provide the cardiovascular surgeon with precious anatomic information [2, 10, 38, 39, 40].

Direct SCTA signs of blunt traumatic aortic lesions include curvilinear intimal flap, intramural hematoma or dissection, irregularity of the aortic wall or contour, pseudo-aneurysm, and pseudo-coarctation (Figs. 1b, 2, 5b). Intimal flap allows for a precise location of the primary site of the aortic injury, whereas the pseudo-aneurysm features a focal saccular outpouching of the aortic wall [2, 10, 38, 39, 40].

The SCTA technique accurately displays hemomediastinum, an indirect sign of blunt traumatic aortic lesion. Mediastinal hematoma portrays a focal or diffuse soft tissue attenuation infiltrate (Figs. 1b, 2, 3a, 4a, b, 5a). The location of the hemomediastinum has a diagnostic significance: hemorrhage surrounding the aorta and other vascular structures is more suggestive of vascular injury than blood confined, for instance, to the retrosternal space adjacent to a sternal fracture [2, 10, 38, 39, 40].

Use of intravenous contrast material is not necessary to depict mediastinal hematoma but is mandatory to display aortic lesions themselves.

From October 1992 to December 2000, all patients admitted at our institution for blunt chest trauma had a chest X-ray. According to the accident biomechanics and the plain-film chest findings, 950 SCTA examinations were performed, among which 27 traumatic aortic injuries (2.8 %) could be identified. Twenty-two subjects underwent surgical repair of the thoracic aorta, which confirmed the aortic injury in all but 2 cases. Five patients died before surgery from severe associated trauma lesions. The blunt traumatic aortic lesions were then confirmed at autopsy. The follow-up of the other 923 patients revealed one false-negative SCT examination [4, 8, 28, 41].

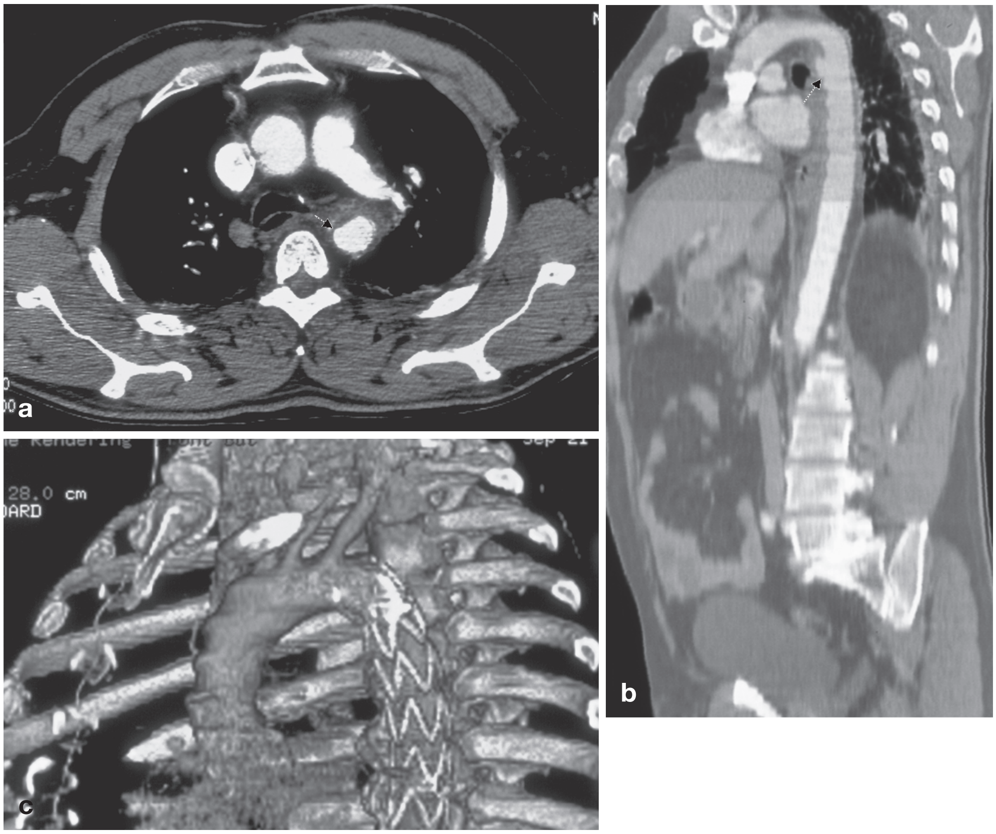


Fig. 5 a–c A 55-year-old male truck driver involved in a high-speed head-on crash with another truck. **a** Spiral chest CT section (2.5-mm thickness) obtained at the isthmic level demonstrates an intimal flap separating the aortic lumen from the blunt traumatic pseudo-aneurysm. The latter features a small contrast-filled outpouching *(arrow)* on the antero-medial contour of the descending aorta, which is surrounded by a very localized mediastinal hematoma. **b** Two-dimensional reconstruction clearly discloses the blunt traumatic aortic pseudo-aneurysm *(arrow)* on the antero-medial aortic aspect at the isthmic level, lying immediately distally to the left subclavian artery. **c** Considering the very localized extent of the mediastinal hematoma, this blunt traumatic aortic lesion was treated by endovascular balloon-expandable stent placement, as shown in a 3D SSD reconstruction

In our experience, all diagnostic information regarding the extent of aortic injury is almost always present on the initial axial CT images. Two-dimensional models show proximal and distal ends of small thoracic aortic injuries better than 3D reconstructions, because 2D models can be uniquely manipulated with curved, nonlinear reconstructions that use single or thin-slab multiplanar reconstructions to minimize artifacts of volume averaging or motion (Figs. 1c, 5b, c) [2, 10, 38, 39, 40].

False-negative diagnosis in our series was consecutive to poor contrast enhancement and partial-volume averaging within the CT section thickness. Axial CT sections may occasionally fail to display blunt traumatic aortic lesions located at the convexity of the aortic arch because of their transverse orientation and the vicinity of aortic arch branch vessels, which may lead to confusion. Finally, SCTA often fails in the detection of blunt traumatic lesions of aortic arch branch vessels [2, 10, 38, 39, 40].

In our series, false-positive cases were demonstrated both by SCTA and by aortography as a small outpouching of the medial aspect of the aortic isthmus. In 1 case the SCTA examination was spoiled by marked streak artifacts over the mediastinum due to a fractured right upper limb that did not allow for its upward positioning along his head. At surgery, both false-positive examinations were related to a ductus diverticulum. The SCTA characteristics of ductus diverticulum and ulcerated atheroma are the same as those described in the Thoracic aortography section. Moreover, a blunt traumatic pseudo-aneurysm is surrounded by mediastinal blood (Fig. 6), whereas ductus diverticulum and ulcerated atheroma are not. An ulcerated atheroma may be partially calcified (Fig. 4) and, in such instances, may be identified by applying MIP processing (Fig. 4). Other pitfalls in the interpretation of SCTA relate to variant branching patterns of the aortic arch (Fig. 4), as described above, as well as to streak artifacts [2, 10, 38, 39, 40, 42].

According to our results and in agreement with other studies [2, 4, 8, 10, 28, 38, 39, 41], the use of SCTA in the identification of blunt traumatic aortic lesions shows sensitivity, specificity, and accuracy of 96.2, 99.8, and 99.7 %, respectively.

An unequivocally normal mediastinum on SCTA, with no mediastinal hematoma and a regular aorta surrounded by normal fat, has a 99.9 % negative predictive value for aortic injury [2, 4, 8, 10, 28, 38, 39, 40, 41].

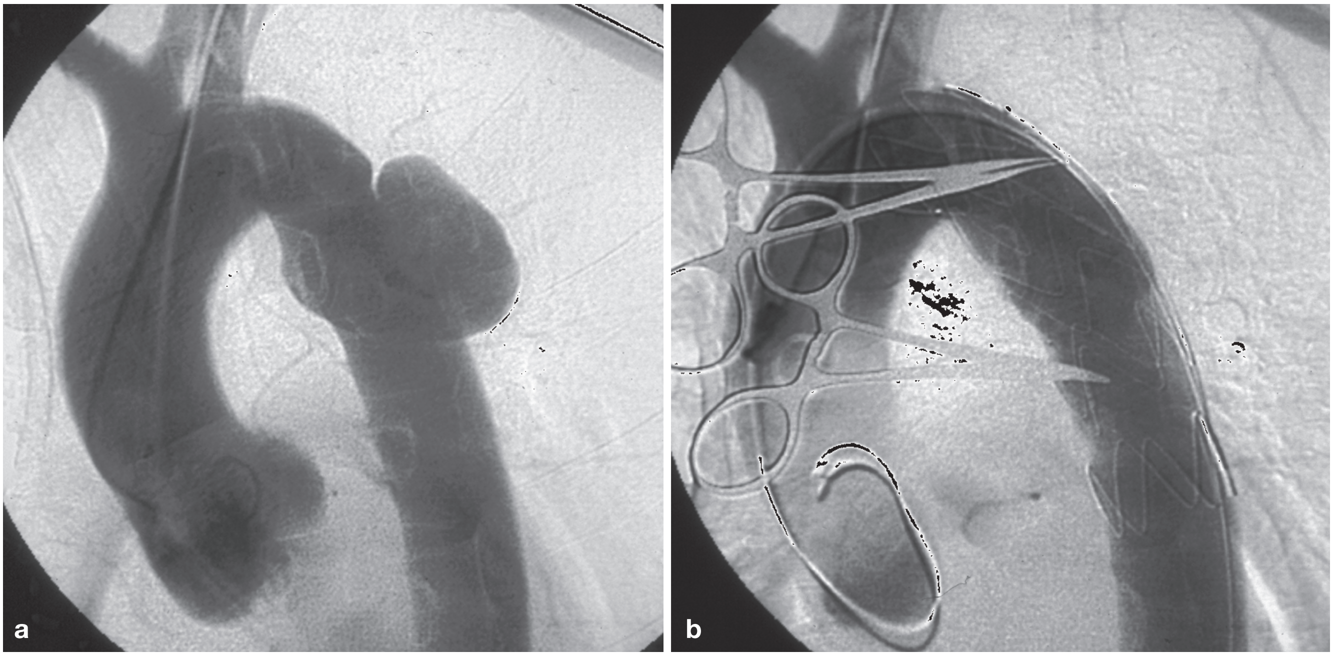


Fig. 6 Another example of endovascular treatment of a large blunt traumatic pseudo-aneurysm *(arrow)* of the aortic isthmus, with angiographic views **a** before and **b** after stenting

Other imaging modalities

Trans-thoracic echography (TTE) cannot be used to reliably assess a possible blunt traumatic lesion of the thoracic aorta. High-frequency transducers are required to achieve the spatial resolution mandatory to display anatomic details, such as intimal tears, but they cannot provide the necessary depth of penetration. Moreover, TTE is usually suboptimal in the evaluation of severe chest trauma patients, with their possible chest wall hematomas, subcutaneous emphysema, pneumothorax, pulmonary contusion, and/or mediastinal emphysema [10].

Trans-esophageal echography is a semi-invasive imaging modality that yields high-resolution, real-time axial and longitudinal images of the aorta and can accurately demonstrate blunt traumatic isthmic aortic lesion, with sensitivity and specificity of 91 and 98 %, respectively [43].

Direct TEE signs of blunt traumatic aortic injury include intraluminal intimal flap, aortic wall hematoma, pseudo-aneurysm and aortic occlusion (pseudo-coarctation), or complete transection. The mediastinal hematoma may be responsible for an increased distance (over 3 mm) between the esophageal probe and the descending thoracic aorta, as well as for an ultrasound signal between the aortic wall and visceral pleura. A double contour of the aortic wall features the presence of an intramural or peri-aortic hematoma [43, 44, 45].

Trans-esophageal echography, combined with color Doppler flow mapping, provides an accurate demonstration, notably of the aortic isthmus, the site of 90 % of blunt traumatic aortic injuries. New multiplanar probes offer excellent visualization of the aortic arch, despite the interposition of the left mainstem bronchus air between the esophagus and the aorta.

Trans-esophageal echography can be performed at bedside in less than 20 min. It does not delay other diagnostic and therapeutic procedures, such as mechanical ventilation or laparotomy, since it can be realized simultaneously [43, 45, 46].

However, TEE is inappropriate in cases of massive facial trauma, unstable cervical spine fractures, possible injury to the brachiocephalic arteries, combative behavior, acute or chronic esophageal disease, severe coagulopathy, or history of previous radiation therapy in the chest. Nevertheless, its rate of complications, such as aspiration or esophageal perforation, is low [42, 45].

Trans-esophageal echography does not depict the entire circumference of the aorta in 30 % of cases, depending on the quantity of mediastinal hematoma present. Pitfalls include strong reflections with distal acoustic shadowing, which represent aortic calcifications, as well as hypoechoic regions within an atheroma that may represent either hemorrhage or fatty deposit [43, 44, 45].

Finally, the quality of TEE is operator dependent [45, 46].

Magnetic resonance imaging is a valuable tool for the evaluation of the aorta. Angio-MR with 3D fast low-angle shot gradient-echo sequences are classically obtained before and during intravenous administration of

20 cc Gd-DTPA-dimeglumine with an injection rate of 2 cc/s, after a test bolus. Subtraction images are calculated along the aortic axis. They allow for an adequate spatial resolution of 1.5 × 0.8 mm and provide multiplanar imaging of the aorta.

The MR findings of blunt aortic lesions are very close to those of CT and conventional aortography; however, in many medical centers, the MRI unit is distant from the emergency department. The time spent on transferring the patient and completing the study, as well as the inaccessibility of the patient during the examination, are two of many limitations. These limitations preclude the routine use and widespread acceptance of MRI in trauma patients [10, 47].

Intravascular ultrasound imaging provides high-resolution, real-time cross-sectional axial images of the aorta. It might be used as a complementary tool to aortography, useful to clarify subtle focal aortic abnormalities, since it allows screening of the aortic wall, not detectable by thoracic aortography [48, 49, 50].

Intravascular ultrasound imaging is performed with a 7- to 10-F disposable catheter enclosing a 20- to 30-MHz transducer. It is introduced through a femoral artery sheath and advanced over a guidewire, under fluoroscopic guidance [48, 49, 50].

Direct intravascular ultrasound findings of blunt traumatic aortic injuries are almost the same as in TEE [48, 49, 50]; however, for the time being, intravascular ultrasound imaging shows several limitations, the first one relating to the price of the probes, which ranges up to 800 Euros. Furthermore, the current generation of intravascular ultrasound transducers only provides transverse views, whereas longitudinal views would demonstrate the most frequent transverse blunt traumatic aortic injuries at their best. Moreover, the ascending aorta is poorly depicted. The entire circumference of the aorta can often not be evaluated, especially very tortuous or ulcerated regions, since the probes cannot be orientated. Finally, an assessment of the aortic arch branch vessels would require time-consuming separate catheterization of each branch of interest [48, 49, 50].

Treatment of acute traumatic aortic injuries

Blunt traumatic aortic lesions require surgical operation as soon as diagnosed. For the cardiovascular surgeon, the admission imaging survey of blunt chest patients with aortic injuries must provide essential guidance regarding:

1. The urgency for repair, with respect to possible associated lesions
2. The surgical approach, which is dictated by the anatomic location of the injury (isthmic lesions are approached through fourth or fifth interspace left posterolateral thoracotomy, ascendant lesions through median sternotomy; extended incisions such as thoraco-abdominal incisions are rarely needed, usually only in cases of multiple or extended lesions)
3. The anatomic characteristics affecting intraoperative vascular control, the access to aorta being sometimes compromised by an extensive mediastinal hematoma
4. The need for extracorporeal circulatory support
5. The type of repair [10, 39, 54, 55]

Percutaneous sutureless positioning of an endovascular stainless balloon-expandable stent or prosthesis at the level of the lesion, under angiographic guidance, has recently been proposed as a new and promising therapeutic tool for selected blunt traumatic aortic injuries. We performed such a procedure in 2 patients of our series, in collaboration with the cardiovascular surgical team. No complication occurred during their follow-up, which is now 23 and 3 months, respectively (Figs. 5 and 6) [56, 57].

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