

Acute Traumatic Aortic Injury: Imaging Evaluation and Management¹

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Despite recent advances in prehospital care, multidetector computed tomographic (CT) technology, and rapid definitive therapy, trauma to the aorta continues to be a substantial source of morbidity and mortality in patients with blunt trauma. The imaging evaluation of acute aortic injuries has undergone radical change over the past decade, mostly due to the advent of multidetector CT. Regardless of recent technologic advances, imaging of the aorta in the trauma setting remains a multimodality imaging practice, and thus broad knowledge by the radiologist is essential. Likewise, the therapy for acute aortic injuries has changed substantially. Though open surgical repair continues to be the mainstay of therapy, percutaneous endovascular repair is becoming commonplace in many trauma centers. Here, the historical and current status of imaging and therapy of acute traumatic aortic injuries will be reviewed.

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Traumatic aortic rupture was first described in 1557 by Vesalius (1).

However, acute traumatic aortic injuries (ATAIs) remained rare until the advent of high-speed motor vehicles in the mid 1900s. Of all cases of blunt trauma resulting in substantial injury to the thorax, motor vehicle collisions account for a majority, followed by falls from height, pedestrian-automobile collisions, and crush injuries. ATAI from blunt trauma is a substantial cause of morbidity and mortality, occurring in approximately 0.5%–2% of all nonlethal motor vehicle collisions (2,3) and 10%–20% of all high-speed deceleration fatalities (3–10). An overwhelming majority of major trauma patients are young, and if they survive, face a life-time of morbidity (11).

The morbidity and mortality of this injury are high, and injury is immediately lethal in 80%–90% of cases (3,4). With improved in-field care and rapid detection and treatment of ATAI, the morbidity and mortality have improved, and patients who initially survive are more likely than ever to undergo successful repair (2,5,12,13). It is thus paramount that the radiologist be aware of the wide range of presentations and the various imaging findings of ATAI. This

review will be broad in scope, focusing on the pathophysiologic, clinical, radiologic, and surgical perspectives. The importance of recent diagnostic and therapeutic advances will be emphasized.

Motor Vehicle Collision Profile

It is estimated that 75%–80% of thoracic aortic injuries are a result of high-speed motor vehicle collisions, with most ATAIs occurring after rapid deceleration as a result of head-on or side-impact collisions above 50 km/h (14–16). Head-on collisions have historically been thought to play a predominant role in the mechanism of ATAI (4,6). Such studies have led to vehicle modifications and improved traffic laws, such as seat belt requirements, airbags, collapsible steering columns, and energy-absorbing bumpers. There has only been recent attention to vehicle safety modifications to protect occupants from lateral impact collisions.

Interestingly, case studies detailing the motor vehicle collision profile that results in thoracic trauma and ATAI suggest that only about 50% are due to head-on collisions (16–18). In reality, side-impact collisions are associated with a substantially higher mortality rate than head-on collisions, regardless of the injury severity score (17). In fact, mounting evidence suggests that victims of serious lateral impact crashes may be at greater risk of ATAI than those of nonlateral impact collisions, with one study (7) showing that 73% of all aortic isthmus injuries resulted from side-impact collisions. Evidence also suggests that occupant restraint mechanisms (excluding side airbags) are largely ineffective in curtailing ATAI in side-impact collisions (19). It remains to be seen if side curtain airbags will decrease the prevalence of serious thoracic trauma and aortic injuries.

Pathophysiology and Mechanism of Injury

The extent and morphology of aortic injuries vary widely, ranging from minimal hemorrhage to complete transection. Aortic injury most commonly

results from transverse tears and can be segmental (55%) or circumferential (45%) and may be partial (65%) or transmural (35%). Spiral and irregular tears are very rare (4,7). Partial lacerations usually involve only the inner two vessel wall layers, resulting in a contained rupture. The adventitia may be injured in up to 40% of cases, and adventitial injury is almost universally fatal because of rapid exsanguination. Temporary tamponade may be achieved by surrounding mediastinal soft tissues (4).

Despite extensive research, the exact mechanism of ATAI has not been precisely determined. A majority of ATAIs result from violent deceleration, most commonly as a result of a motor vehicle collision, especially head-on and side-impact collisions. Proposed mechanisms contributing to ATAI include shearing forces, rapid deceleration, hydrostatic forces, and the osseous pinch (Fig 1) (7820–23).

Rapid deceleration in the anteroposterior and lateral directions has been shown to be sufficient to result in cardiac displacement, resulting in torsion and shearing forces against the aorta at levels of relative immobility, mainly the ligamentum arteriosum, aortic root, and diaphragm (7,8). A combination of compression and upward thrust of the heart, which also involve shear and torsion, has been suggested (14). Lateral compression can result in severe internal chest deformation, resulting in anterior displacement of the heart and thus shearing forces at the aortic isthmus (16,17).

Increased intravascular pressure can exceed 2000 mm Hg following direct compression of the aorta and has been termed the *water-hammer effect*. The pressures that can be created by

Essentials

- With improvements in prehospital care, more survivors with acute traumatic aortic injury (ATAI) will reach trauma centers.
- Rapid diagnosis and treatment of ATAI is the standard of care.
- Multidetector CT is the diagnostic test of choice for detection of ATAI in the stable patient; when unequivocal findings are present, no further imaging is necessary.
- Transesophageal echoaortography is well suited for evaluation of the unstable patient who must proceed to the operating room prior to multidetector CT imaging.
- Conventional angiography, intravascular US, and transesophageal echoaortography are valuable adjuncts in the evaluation of equivocal multidetector CT cases.

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Abbreviations:

ATAI = acute traumatic aortic injury
TEA = transesophageal echoaortography

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this mechanism have been shown to result in mainly transverse tears at the level of the isthmus (23), but can also travel retrograde resulting in injury at the aortic root (22).

The osseous pinch results from direct compression of the aorta between the anterior chest wall and the thoracic spine (20,21). An animal model study by Crass et al (21) showed that anteroposterior compression of the chest consistently results in transverse lacerations to the aortic isthmus when compressed between the anterior chest (particularly the manubrium and medial clavicles) posteriorly against the thoracic spine. This is supported with in

vivo data (20). These studies also explain the predilection for concomitant injuries to the branch vessels (20,21). Direct injury of the thoracic aorta may also occur due to penetrating injury from rib and thoracic vertebral body fractures (24,25).

Whatever the dominant mechanism, it is safe to say that the pathophysiology of aortic injury appears complex and is likely due to interplay of a combination of the above mechanisms. Computer models and cadaveric simulations have been proposed and will likely be helpful in the future (26,27).

Signs, Symptoms, and Clinical Presentation

Clinical signs and symptoms are non-specific and insensitive for the diagnosis and exclusion of ATAI. A majority of patients with ATAI have no clinical signs of aortic injury until the sudden onset of hemodynamic instability (10,28,29). Symptoms of ATAI are thought to be due to stretching of the mediastinal connective tissues by mediastinal blood and include retroster-

nal pain, referred interscapular pain, dyspnea, hoarseness, and cough (10,30). Clinical signs of ATAI are absent in up to one-third of patients but when present include upper limb hypertension and lower limb hypotension with diminished femoral pulses due to "pseudocoarctation syndrome," systolic murmur, external chest wall injuries, paraplegia, and initial chest tube output greater than 750 mL (31).

On the basis of the presence of certain clinical variables, a risk assessment for aortic injury can also be made. Blackmore et al (32) found that seven criteria were predictors of ATAI. These include age older than 50 years, being unrestrained, hypotension with systolic blood pressure of less than 90 mm Hg, thoracic injury, abdominopelvic injury requiring emergent laparotomy or with fractures of the lumbar spine and pelvis, long bone fractures, and major head injury. Not surprisingly, patients meeting more criteria had a greater chance of having ATAI and those meeting four criteria or more had a 30% chance of sustaining ATAI in that study (32). In a more recent re-evaluation (33) of these

Figure 1

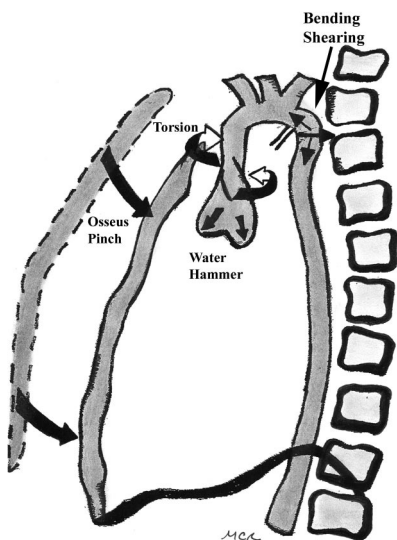


Figure 1: Schematic depicts various mechanisms of injury resulting in ATAI. The osseous pinch is shown by posterior translation of the sternum (large arrows), which traps the aorta at the narrowest point of the thorax. Torsion is depicted in the ascending aorta (curved arrows) resulting in twisting above the fixed aortic valve. Compression of lumen forces blood inferiorly toward the aortic valve resulting in the water hammer effect (arrows in aortic root). At ligamentum arteriosum, the aorta is affected by both bending and shearing stresses (small arrows) augmented by the anatomic changes from the osseous pinch against the thoracic spine and pressure changes from the water hammer effect. The combination of forces is concentrated at the fixed point of the descending thoracic aorta, the ligamentum arteriosum (parallel lines inferior to transverse aortic arch).

Figure 2

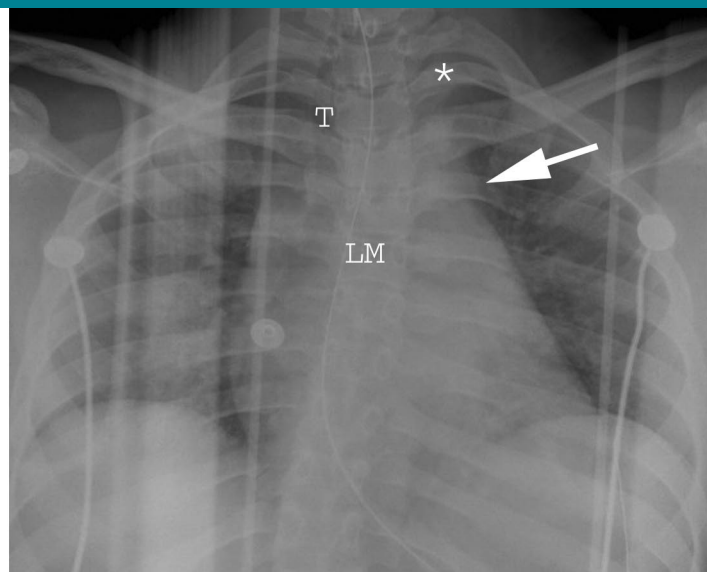


Figure 2: Findings of ATAI. Supine anteroposterior chest radiograph following motor vehicle collision shows widening of the mediastinum with deviation of the trachea (*T*) to the right, depression of the left mainstem bronchus (*LM*), convexity in the aortopulmonary window (arrow), and left apical cap (*) due to mediastinal hematoma from ATAI.

clinical predictors, only four factors (abdominopelvic injury, thoracic injury, hypotension, and being unrestrained) were found to be predictive. Moreover,

the combination of three or four factors resulted in a 2% chance of ATAI (33). The differences presumably reflect changes in patient populations and in-

jury detection over the years. In that study, chest radiographs were only marginally efficient in increasing diagnostic yield.

Figure 3

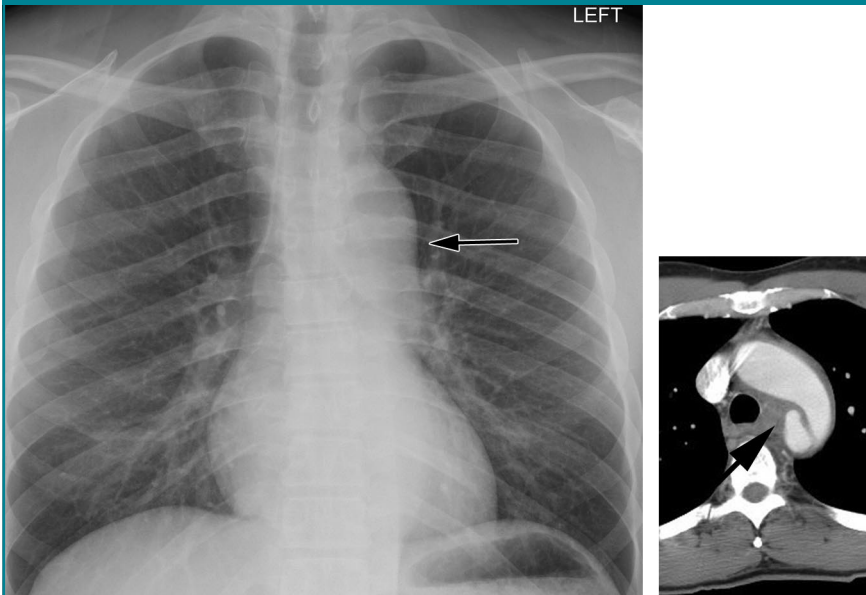


Figure 3: (a) Upright posteroanterior chest radiograph in young male patient following high-velocity motor vehicle collision initially interpreted as normal. While the mediastinum is not wide, the usual concavity is absent in the aortopulmonary window (arrow). (b) Transverse contrast-enhanced multidetector CT scan shows traumatic disruption of the aorta (arrow).

Figure 4

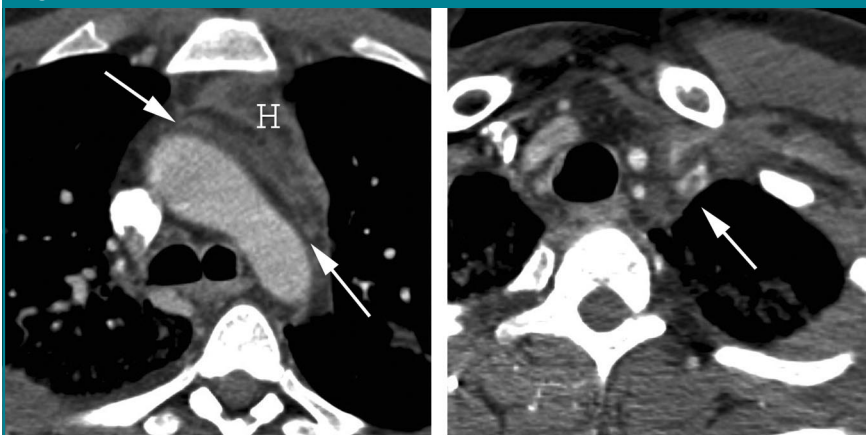


Figure 4: Mediastinal hematoma with preserved fat plane around aorta at transverse contrast-enhanced multidetector CT. (a) Image at the level of aortic arch shows hemorrhage in the anterior mediastinum (H) with intervening fat plane between hemorrhage and aortic wall (arrows). (b) Image at the level of thoracic inlet reveals intimal tear in left subclavian artery (arrow) accounting for source of hemorrhage.

Morbidity, Mortality, and Outcome

Aortic injuries carry a high mortality rate and are immediately fatal in an estimated 80%–90% of all cases (4,7,8,15). In Parmley et al classic series (4), only 20% of patients with ATAI initially survived more than 1 hour. Of those, there is an estimated mortality of 30% within the first 6 hours, 49% within the first 24 hours, 72% by 8 days, and 90% at 4 months if undetected and untreated. Williams et al (14) suggested an even more dismal outcome, with 94% mortality within 1 hour and up to 99% mortality at 24 hours if untreated. Blunt aortic injury rarely occurs in isolation (only 3.2% of autopsy cases) (15), and there is a substantial increase in mortality following ATAI in patients with co-existing head, thoracic, and abdominal injuries (34–36). Overall mortality following ATAI therefore depends on several factors, including high injury severity score, prolonged transport to trauma center, and hemodynamic instability at presentation (2,13,35,36). Overall survival is worse with increasing age, with mortality in excess of 80% in

Figure 5



Figure 5: Periaortic hematoma without direct injury. Transverse contrast-enhanced multidetector CT scan reveals hemorrhage in the mediastinum adjacent to the medial wall of descending thoracic aorta (*) due to traumatic tear of azygous vein (AZ, arrow).

patients older than 55 years (36). If detected in a timely manner, it is estimated that 60%–80% of patients with ATAI who reach the hospital alive will survive following definitive therapy (13,37,38). Therefore, prompt recognition and treatment of these injuries are critical for long-term survival.

Radiographic Findings in ATAI

Chest Radiography

In the acute trauma setting, the supine chest radiograph is still frequently obtained. While the predominant rationale is the inclusion or exclusion of immediate life-threatening lesions requiring immediate treatment (massive hemothorax or tension pneumothorax), it also provides some data to guide suspicion of ATAI. Evaluation for mediastinal hematoma, and by inference a major vascular injury, is the main goal of the initial chest radiograph (Fig 2). While mediastinal widening greater than 8 cm and/or 25% of the width of the thorax is the most frequent observation, it is not necessarily the most sensitive finding (39–41). More discriminating findings include any abnormality of the transverse aortic arch or loss of the aortopulmonary window (42,43). Therefore, even in those cases where the mediastinum is not widened, obscuration of the lung interface with the transverse or descending thoracic aorta should still be viewed with suspicion. It should also be noted that in up to 7% of ATAI cases, the chest radiograph may be normal or deceptively underwhelming (Fig 3). Other signs of ATAI on chest radiographs include rightward tracheal, esophageal, and/or nasogastric tube deviation; left mainstem bronchus depression; and a left apical cap (41–50).

Given that disruption of the aorta requires high-force trauma, other injuries are often present in the lung (pulmonary contusion), pleura (hemothorax and pneumothorax), diaphragm, and bony thorax. Although fractures of the first and second

Figure 6

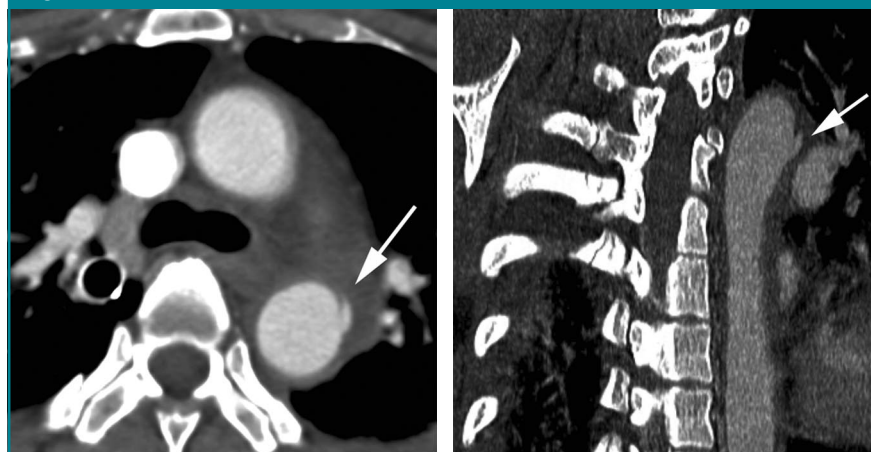


a.

b.

Figure 6: Retrocrural hematoma secondary to ATAI at transverse contrast-enhanced multidetector CT. (a) Image at aortic hiatus shows periaortic hematoma (arrow). (b) Image at the level of aortic isthmus shows ATAI (arrow) with extensive mediastinal hematoma.

Figure 7



a.

b.

Figure 7: Small tear as manifestation of ATAI. (a) Transverse contrast-enhanced multidetector CT scan shows a small intimal tear along lateral border of proximal descending aorta (arrow). (b) Sagittal oblique contrast-enhanced multidetector CT reformation shows craniocaudal extent of the tear (arrow).

ribs are clearly markers of severe blunt force trauma, they are not by themselves independent predictors of ATAI, nor should the absence of skeletal abnormalities be taken as a reassuring sign (44). Regardless, the greater the degree of manifestation of blunt force trauma, the higher the suspicion should be for ATAI.

The abnormal (even minimally so) supine anteroposterior radiograph in trauma should always be evaluated with

further imaging. In cases where the risk based on the mechanism of injury is low, this can be done with an upright radiograph (preferably a posteroanterior view), which is best suited for level 2 or 3 trauma patients. It should be emphasized that the most important observation is a clear visualization of the aortic arch, not absence of mediastinal widening, as a discriminating feature. However, if the force vector or mechanism of injury is suffi-

cient, if the patient is unconscious or intoxicated, or if the patient is already undergoing a contrast material-enhanced multidetector CT of the abdomen and pelvis then multidetector CT with contrast material is the most appropriate examination. If the patient must go to the operating room immediately because of life-threatening abdominal or neurologic

injuries, intraoperative transesophageal echocardiography may be used in some institutions to evaluate the aorta.

CT Scanning

Beginning in the early to mid 1990s, CT has gained an increasingly important role, first in screening and now in diagnosis of ATAI, such that multidetector

CT is the diagnostic test of choice for ATAI (45–48). The diagnostic sensitivity routinely exceeds 98% for ATAI, while specificity depends on the definition of a positive result (46–49). When the presence of mediastinal hematoma alone is included as a diagnostic criterion, false-positive findings are high and therefore should not be used as a criterion for definitive injury, while if only direct signs are used specificity approaches 100% (46,49,50). In many institutions, multidetector CT has replaced the need for conventional angiography prior to surgery in the majority of cases. It should be noted that this practice, even today, is not universally held (51).

Indirect findings of ATAI generally consist of the presence of mediastinal hematoma. The importance of hematoma depends on the location. Blood within the mediastinum with a preserved fat plane around the thoracic aorta is not from ATAI (Fig 4). The source is usually small veins within the mediastinum and generally does not require further evaluation for ATAI (52–54). Depending on location, careful attention should be paid to intercostal arteries, internal mammary arteries, and arch branch vessels as they may be the source of bleeding. On the other hand, periaortic hematoma is in direct continuity with the aortic wall (Fig 5). The bleeding presumably originates from either small veins immediately adjacent to the aorta or from the vasa vasorum (41). From this standpoint, periaortic hematoma may represent an occult intimal injury requiring further evaluation with intravascular ultrasonography (US) or transesophageal echoaortography (TEA). In these cases, the role of conventional angiography alone is limited. Authors of a recent study (55) found that none of 24 cases (albeit with a relatively wide confidence interval of 0% to 10.8%) with periaortic hematoma without direct signs were found to have ATAI at conventional angiography. In stable patients with low clinical suspicion, it may be appropriate to follow up with multidetector CT in 48–72 hours. In patients who have undergone abdominal multidetector CT alone, the pres-

Figure 8

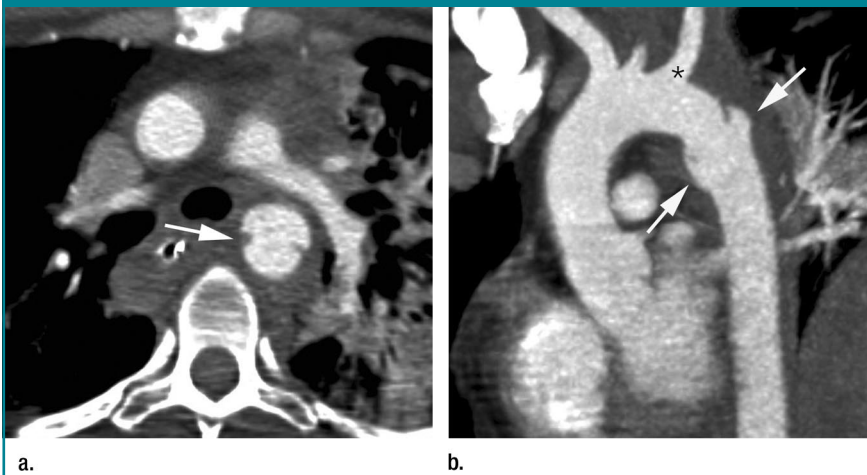


Figure 8: Aortic transection with contained pseudoaneurysm. (a) Transverse contrast-enhanced multidetector CT scan shows focal outpouching at the level of ligamentum arteriosum (arrow). (b) Left anterior oblique reformation reveals circumferential nature of the tear (arrows). * = left subclavian artery.

Figure 9

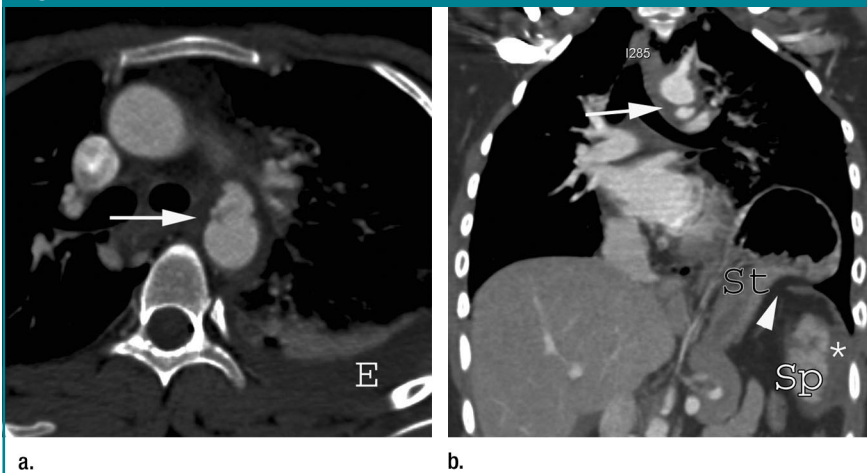


Figure 9: Aortic transection with associated injuries. (a) Transverse contrast-enhanced multidetector CT scan reveals aortic transection at the level of ligamentum arteriosum (arrow). *E* = pleural effusion. (b) Coronal reformation shows aortic injury (arrow) in association with left diaphragmatic rupture (arrowhead) containing herniated stomach (*St*) and splenic laceration (*Sp*) with perisplenic hematoma (*).

ence of a retrocrural hematoma (56) (Fig 6) or a small caliber aorta may be an indication of thoracic aortic injury. These findings should be followed with either multidetector CT of the chest or TEA, depending on the patient's clinical status and need for surgical intervention.

Direct signs of ATAI include presence of an intimal flap, traumatic pseudoaneurysm, contained rupture, intraluminal mural thrombus, abnormal aortic contour, and sudden change in aortic caliber (aortic "pseudocoarctation") (Figs 7–9). These should be interpreted as definitive positive findings, and unless there are extenuating circumstances, no additional imaging is necessary. Active extravasation of contrast material in practice is exceedingly rare as it often portends impending exsanguination (Fig 10). Rarely, a true dissection may occur. In the setting of direct signs and an unstable patient, surgery should be performed expeditiously and confirmation with conventional angiography can be a dangerous, if not fatal, waste of time.

Multidetector CT

It is clear that multidetector CT is the diagnostic modality for the initial evaluation and accurate diagnosis of thoracic trauma. However, protocols need to be optimized to generate the greatest amount of data in the least amount of time. We use a standardized trauma protocol for contrast-enhanced multidetector CT of the chest, abdomen, and pelvis in a single scan with injection of approximately 140 mL of contrast media at 3–4 mL/sec with a 75-second prescan delay. Images are acquired at thinnest possible multidetector array and are generally reconstructed at a transverse section thickness of 2–2.5 mm, with sagittal and coronal reformations for review at a picture archiving and communication system station. We have found this to be a good compromise between speed, data, and the need for imaging various organs. Despite not using a classic CT angiographic technique, we have found that our technique produces reasonable three-dimensional images when needed. In difficult cases,

Figure 10

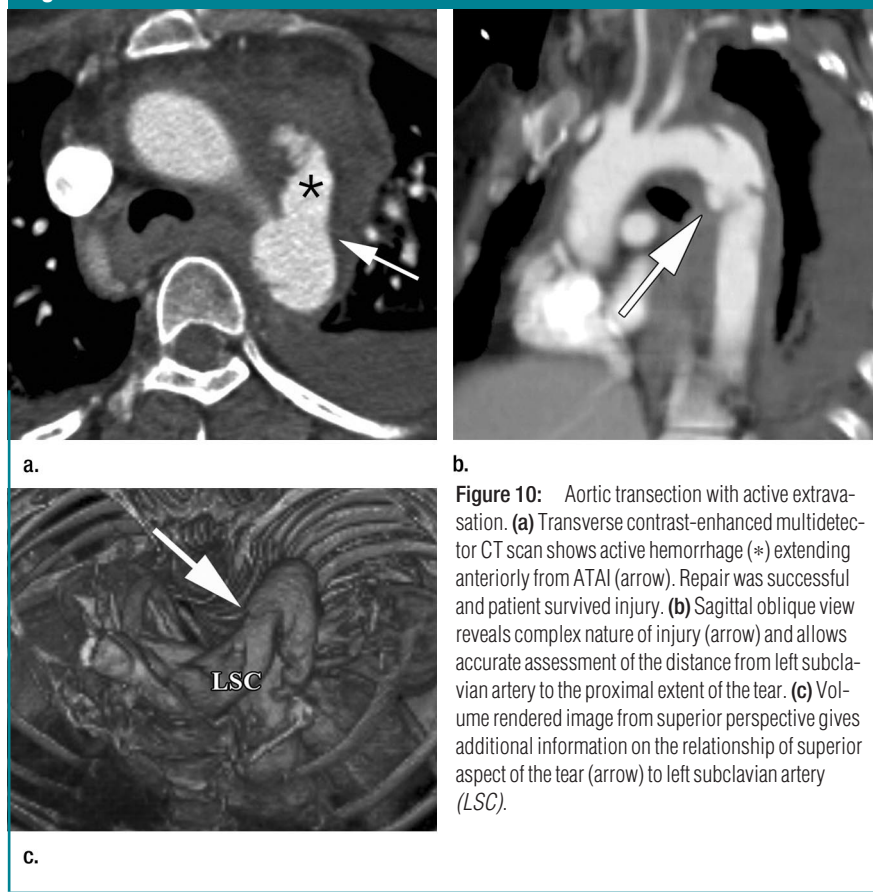


Figure 10: Aortic transection with active extravasation. **(a)** Transverse contrast-enhanced multidetector CT scan shows active hemorrhage (*) extending anteriorly from ATAI (arrow). Repair was successful and patient survived injury. **(b)** Sagittal oblique view reveals complex nature of injury (arrow) and allows accurate assessment of the distance from left subclavian artery to the proximal extent of the tear. **(c)** Volume rendered image from superior perspective gives additional information on the relationship of superior aspect of the tear (arrow) to left subclavian artery (LSC).

we will also use interactive manipulation and interpretation of the data set to generate multiplanar reformations in various obliquities of the coronal and sagittal plane for optimal display of vascular injuries and morphology and location with respect to adjacent vascular structures, such as the left subclavian artery.

While it is true that direct and indirect findings of ATAI are usually immediately apparent on conventional transverse images, the exact morphology and extent of vascular injury, particularly at the aortic isthmus, may not be fully appreciated until viewed in another plane (Fig 11). The isotropic data sets acquired with multidetector CT can be used to generate multiplanar reformations, which can be used to aid in surgical planning. It is our experience that the sagittal oblique plane (which simulates the standard projection obtained during angiography of the aorta) best

displays the thoracic aorta along its long axis. Three-dimensional volume-rendered images are also useful to the surgeon, as these images display the in vivo anatomy with its relationship to the adjacent structures, show the distance of the isthmus injury from the subclavian artery, and display the exact morphology of the injury (Fig 12). Some authors advocate the use of endovascular views for the evaluation of intimal morphology in difficult cases (57). In equivocal cases, it is often on these postprocessed images that the diagnosis is established.

Isthmus injuries.—The aortic isthmus, within 2 cm of the origin of the left subclavian artery, is the most common location for ATAI as established by many large autopsy series (4,7,8,15). The predilection of this injury for this location is thought to be due to its relatively immobile position within the thorax, being tethered by the ligamentum arteriosum (4,7,8,15). The severity

of injury at this location may range from minimal intimal injury (see below) to frank rupture with active extravasation. On axial images, these isthmus injuries are seen most commonly along the medial curvature of the arch at the level of the left pulmonary artery and left mainstem bronchus and should be the first location the radiologist looks at when encountering a large mediastinal hematoma. However, it must be noted that aortic injuries may occur at any location along the aorta.

Minimal aortic injuries.—Minimal aortic injuries, only affecting the intima of the vessel wall (Fig 13), are estimated to occur in 10% of patients with ATAI (58). These lesions pose a substantial problem because (a) they are being encountered at an increased frequency and (b) very little data exist on the optimal management. The apparent increased incidence is likely secondary to the improved spatial resolution of multidetector CT (58). Confirmation with direct conventional angiography may not be possible, as nearly half of the cases show no demonstrable abnormality at angiography, and intravascular US may be required to confirm the diagnosis (58). Some suggest that these minimal aortic injuries may not need any intervention, as with imaging follow-up the majority remain stable or resolve (58).

Aortic root and ascending aorta.—Traumatic injuries to the ascending aorta were seen in approximately 5%–14% of ATAIs in several large autopsy series (7,8); however, at multidetector CT, these lesions are extremely rare presumably because of their intrinsically lethal nature (59–61). There are three main patterns of injuries to the ascending aorta: (a) a laceration of the ascending aorta between the aortic root and the brachiocephalic artery, (b) injuries to the aortic root that involves the aortic valve, and (c) injuries to the aortic root that do not involve the aortic valve (Fig 14). It is intuitive that injuries to the aortic root should be associated with hemopericardium, but it has been shown to be an inconsistent finding in ascending aortic injuries (60,61). Therefore, the absence of hemopericardium should not be used to exclude ascending aortic injury. Injuries of the aortic root may also co-exist with injuries at the isthmus. Problem solving with cardiac-gated acquisition can be performed if there are equivocal abnormalities of the ascending aorta at routine contrast-enhanced chest multidetector CT, but the efficacy of this has not been objectively evaluated.

Aortic arch and branch vessel injuries.—Injuries to the aortic arch and branch vessels are less common but po-

tentially fatal. The incidence of aortic arch injuries is rare, estimated to occur in less than 4% of blunt chest trauma patients, as seen in a large, multi-center prospective evaluation of 274 patients with aortic injuries (39). The incidence of aortic branch vessel injuries varies widely in the radiologic and surgical literature. Isolated aortic branch injuries are most common, but may be seen combined with blunt ATAI in 0%–45% of patients (62–66). The brachiocephalic and common carotid arteries are most commonly injured, seen in 66%–90% of patients with branch vessel injuries (63,64). The extent of branch vessel injuries, like aortic injuries, ranges from subtle intimal injuries to complete transection and contained rupture (63,64).

At multidetector CT, a careful search for a branch vessel injury should be performed in the presence of mediastinal hematoma when there is no direct sign of aortic injury as well as in cases of ATAI. This has important implications for surgical approach, as brachiocephalic artery and proximal common carotid artery injuries require median sternotomy for proper exposure. It is intuitive that the volumetric data acquired at multidetector CT should make the diagnosis less problematic.

Mid and distal descending thoracic

Figure 11



Figure 11: Segmental ATAI. (a) Transverse contrast-enhanced CT image reveals periaortic hematoma and contour abnormality of the proximal descending thoracic aorta (arrows). (b) Transverse CT image inferior to a reveals continued periaortic hematoma and intimal flap projecting into the lumen (arrow). (c) Sagittal oblique view shows segmental nature of injury (arrows) and relationship to left subclavian artery.

aorta.—Trauma to the mid and distal descending aorta (Fig 15) is discovered in approximately 1%–12% of autopsies with aortic injuries (7,8). The distal descending aorta is tethered to the adjacent spine by the crux of the diaphragm and therefore injuries here are thought to occur as a result of shear forces applied at this location. Injuries to this segment of the thoracic aorta can be associated with diaphragm injury in 10% of cases and with adjacent compression fractures of the thoracic spine (25,67).

Imaging pitfalls.—Diagnostic pitfalls can be divided into two categories, anatomic and technical. Anatomic pitfalls include venous, arterial, and pulmonary (68). The left superior intercostal vein runs adjacent to the transverse aortic arch, and the hemiazygous vein may be seen posterolateral to the descending aorta (Fig 16). With both the aorta and the vein opacified with contrast material, the adjacent vessel walls can approximate the appearance of an intimal flap. This is usually not a diagnostic dilemma by scrolling images up and down and tracing out the vein back to its insertion into the left subclavian vein. Occasionally, the take-off of bronchial and intercostal arteries can have small infundibula that may give the impression of a small pseudoaneurysm. Infundibula are typically conical in shape and the artery can be seen at the apex of the outpouching. Ductus remnants may present as either bumps or diverticula (Figs 17, 18). Similar to infundibula, these may simulate injury and can be vexing due to their location, particularly when mediastinal hematoma is present. Clues to the diagnosis include continuity with the aortic wall, with obtuse margins and occasionally calcification. When a more acute angle is present, it can present a substantial diagnostic dilemma. It has been suggested that endoluminal views may be helpful by showing the absence of an intimal flap (57). Finally, enhancement of the collapsed lung adjacent to the aorta may also simulate an intimal flap. Careful analysis often reveals pulmonary vessels and bronchi entering the collapsed lung and confirms the diagnosis. Occasion-

Figure 12

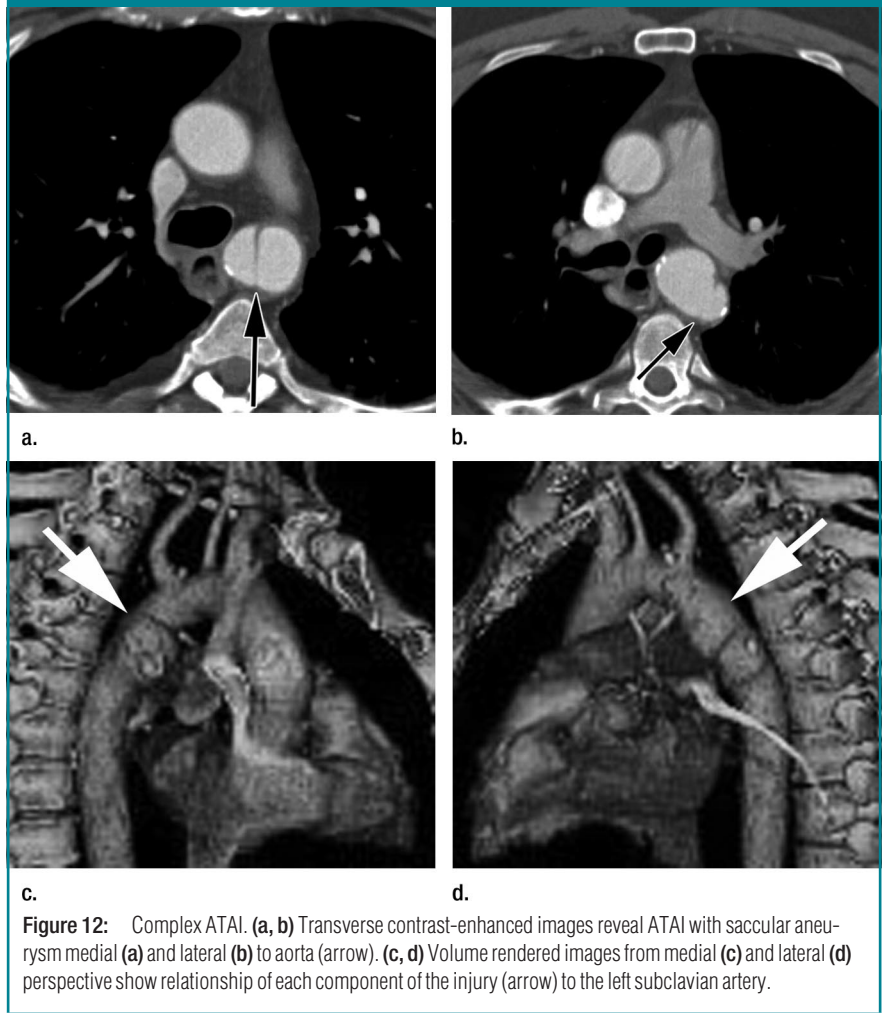


Figure 12: Complex ATAI. (a, b) Transverse contrast-enhanced images reveal ATAI with saccular aneurysm medial (a) and lateral (b) to aorta (arrow). (c, d) Volume rendered images from medial (c) and lateral (d) perspective show relationship of each component of the injury (arrow) to the left subclavian artery.

ally, normal postisthmic aortic dilatation (or aortic spindle) may be seen when viewed in the sagittal oblique plane. This contour change is a normal finding and should not be misinterpreted as an aortic injury.

Technical issues may arise from patient motion, breathing, and cardiac pulsation. In the absence of mediastinal hemorrhage, these can often be reliably dismissed. In the presence of hemorrhage, evaluation of lung windows can often delineate the presence of breathing artifact as motion within the lung parenchyma. Depending on the location, the artifact can either be dismissed or reimaged with either multidetector CT or conventional angiography. Cardiac pulsation is most prevalent at the aortic root and ascending aorta. The best clue to cardiac pulsation is

that the apparent intimal flap projects across the lumen and into the mediastinal fat (Fig 16). Cardiac pulsation artifacts can sometimes be distinguished from true intimal flaps by evaluating the sharpness of their interface with the high-density contrast material in the aortic lumen. Typically vascular flaps have a distinct interface, whereas a pulsation artifact is usually fuzzy. Care should be used with this rule when other artifacts, such as motion artifact, are present as well. If the area remains questionable, alternative strategies include performing a 180° reconstruction of data that may reveal a change in orientation of the artifact or rescanning, preferably using cardiac gating to suppress motion. For stable patients, it is reasonable to rescan in 24–48 hours for reassessment.

MR Imaging

While magnetic resonance (MR) angiography has excellent test characteristics for the detection of ATAI (69), its utility in the trauma patient is limited due to location remote from the trauma bay, scan time, room in the bore of the magnet for support devices, and a myriad of other logistical issues. MR imaging, however, may have a role in the follow-up when delayed surgery is con-

templated and minimal or equivocal intimal injuries are present, particularly as a strategy for radiation dose reduction in young trauma victims (69,70).

Conventional Angiography

The value of conventional aortography for the evaluation of ATAI is well established, with sensitivity of nearly 100%, specificity of more than 98%, and accuracy of more than 99%, and thus for

decades it has been considered the “gold standard” examination (28). The imaging findings of ATAI may range from subtle contour irregularity to frank contrast material extravasation (10,29,

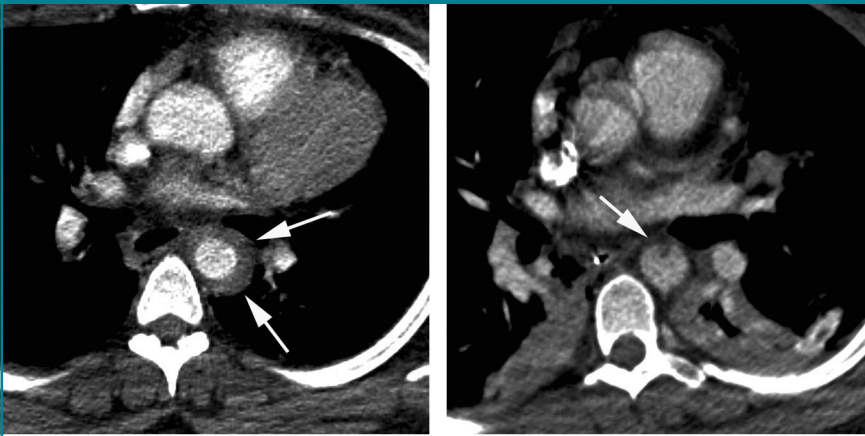
Figure 13

Figure 13: “Minimal” aortic injury at transverse contrast-enhanced multidetector CT. (a) Image shows periaortic hematoma surrounding mid descending thoracic aorta (arrows). (b) Image obtained 72 hours later reveals small thrombus at site of previously occult intimal injury (arrow).

Figure 15

Figure 15: Complex traumatic aortic injury with tears in proximal and mid descending aorta at transverse contrast-enhanced multidetector CT. (a) Image at the level of left pulmonary artery shows contour abnormality (arrow) and periaortic hematoma (H). (b) Image at the level of left atrium shows second tear (arrow) and more extensive periaortic and mediastinal hematoma.

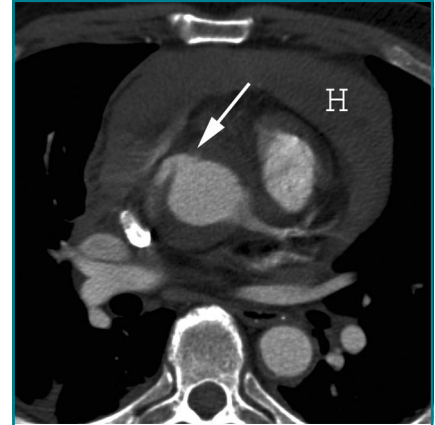
Figure 14

Figure 14: Ascending aorta ATAI. Transverse contrast-enhanced CT scan at the level of left main coronary artery shows aortic injury just above the right coronary cusp (arrow) with associated hemo-pericardium (H).

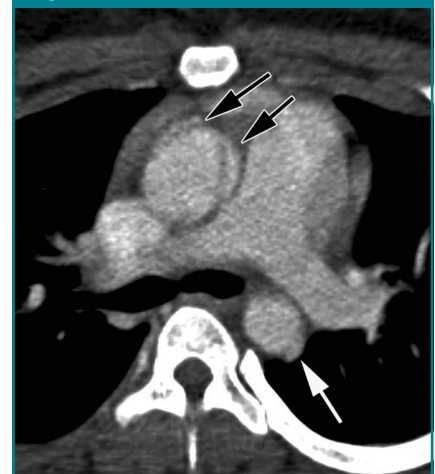
Figure 16

Figure 16: Artifacts that may mimic ATAI. Transverse contrast-enhanced multidetector CT scan shows pulsation artifact at the ascending aorta (black arrows). The linear hypodensity continuum into mediastinal fat. The hemiazygous vein mimics a contour abnormality along the posterolateral surface of descending thoracic aorta (white arrow).

Figure 17

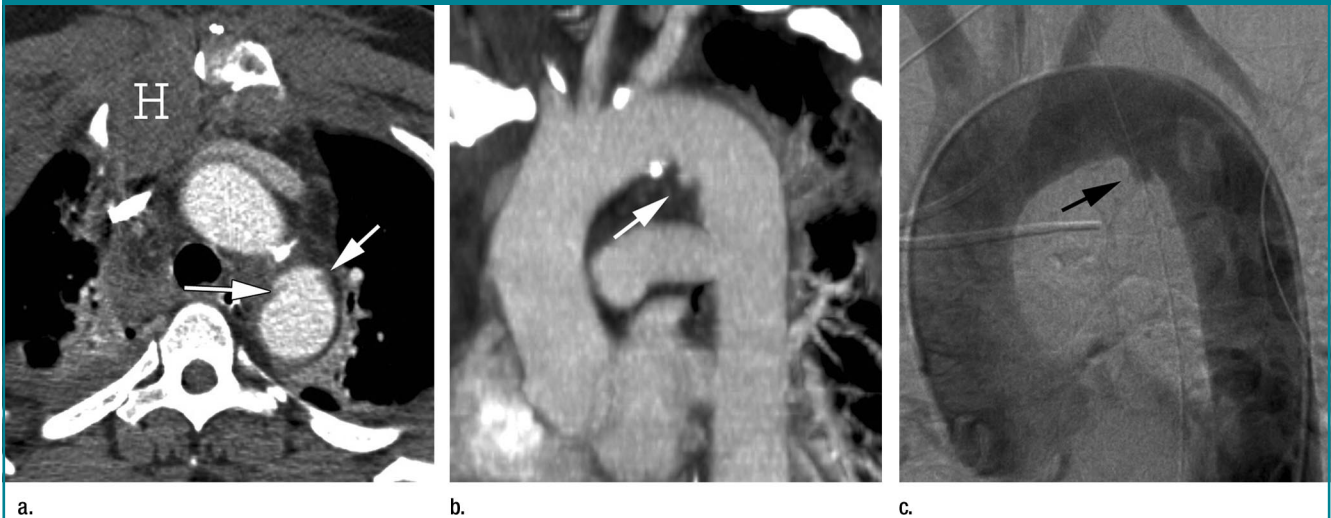


Figure 17: Atypical ductus bump. (a) Transverse contrast-enhanced multidetector CT scan shows apparent intimal flap at the level of ligamentum arteriosum (arrows). There is no periaortic hematoma. Note also anterior mediastinal hematoma (*H*) due to rib fractures. (b) Left anterior oblique maximum intensity projection shows small outpouching at the level of ligamentum arteriosum with obtuse angle superiorly and acute angle inferiorly (arrow). (c) Conventional angiogram in left anterior oblique projection shows similar finding (arrow) to b.

71). Pseudoaneurysm formation, intraluminal filling defect, and intimal irregularity are common findings in vessel wall injury.

Historically, the role of aortography was to (a) identify or exclude ATAI and, if present, (b) determine the exact location of the injury with respect to the branch vessels and (c) evaluate for co-existing branch vessel injuries (72–74). In the pre-CT era, approximately 80%–90% of aortograms obtained for suspected ATAI based on the mechanism and initial chest radiograph were normal (30,74). Conventional angiography for the diagnosis of ATAI has taken on a substantially limited role in the multidetector CT era. Additionally, disruption or delay in definitive care to perform angiography can be a critical indirect cause of patient morbidity and mortality. Despite this, the value of conventional aortography remains an important problem-solving tool in the stable patient, for planning prior to endovascular stent graft therapy, and in some cases for detection of branch vessel injury.

Intravascular US

Endoluminal or intravascular US is another useful adjunctive imaging modality that can be used to provide high-resolution cross-sectional images of

Figure 18

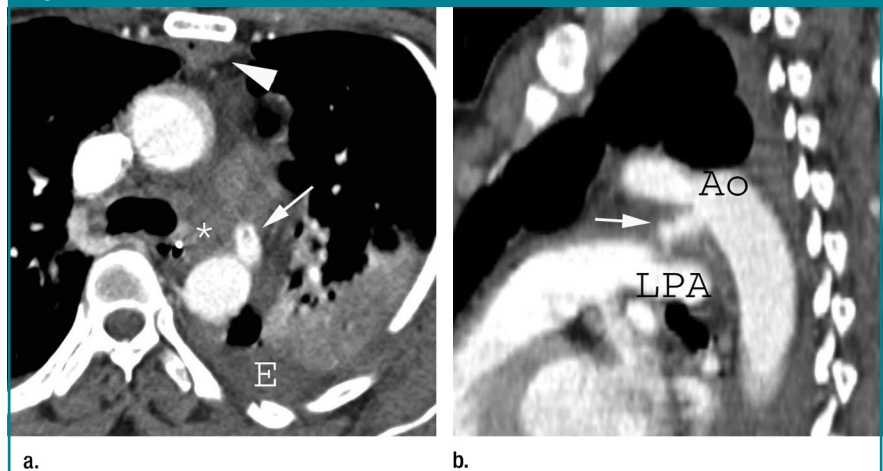


Figure 18: Ductus diverticulum. (a) Transverse contrast-enhanced multidetector CT scan at the level of ligamentum arteriosum shows well-defined contrast material-containing structure extending toward left pulmonary artery (arrow). Note anterior mediastinal hematoma (arrowhead) due to sternal fracture. *E* = effusion, * = mediastinal hematoma. (b) Left anterior oblique reformation shows extension from aorta (*Ao*) toward left pulmonary artery (*LPA*) along typical course of ductus arteriosus (arrow). Conventional angiography (not shown) performed because of mediastinal hematoma confirmed finding of ductus diverticulum.

the vessel wall and the surrounding tissues. The findings of aortic injury at intravascular US include vessel wall disruption, intimal flap, focal pseudoaneurysm, intramural and periaortic

hematoma, and complete transection (Fig 19) (75). Although these findings are considered to be specific for ATAI, false-positive results have been described (10,75).

The advantages of intravascular US mainly involve its problem-solving capabilities. It can be performed concurrently with conventional aortography and has been shown to be a useful complementary modality (10). Intravascular US is an operator- and experience-dependent invasive procedure, requiring arterial puncture, and complete evaluation of the aorta can be time-consuming and may not allow complete visualization of the brachiocephalic artery (10). Technical limitations of intravascular US, such as depth of penetration, also exist and are inherent in the size and frequency of the ultrasound transducer (75).

TEA Examination

Though TEA is usually performed by an anesthesiologist, a cardiologist, or a thoracic surgeon, radiologists may be asked to offer alternative examinations for the evaluation of the aorta in equivocal multidetector CT cases or in critically ill and unstable patients. TEA has a limited role in routine screening for ATAI and should not be performed at the expense of evaluation for other comorbid injuries, which is best accomplished with multidetector CT. In a review of the literature (76), the sensitiv-

ity of TEA for evaluation of ATAI ranged 56%–99% and specificity ranged 89%–99%. In a single study (77) in which TEA was compared with helical CT in 95 patients, all surgical ATAI cases were detected with both techniques. In addition, TEA can be helpful in evaluating equivocal CT or conventional angiographic findings for both the inclusion and exclusion of ATAI (77).

TEA is widely available, relatively noninvasive, and can be performed quickly at the bedside or in the operating room, which are seen as its main advantages. Moreover, since imaging is performed in real-time, the aortic valve, sinotubular junction, and ascending aorta can be evaluated to a much better extent with TEA than with multidetector CT. Thus, unlike the other imaging techniques, TEA can be used intraoperatively to immediately affect surgical and anesthesia decisions. Finally, TEA can help evaluate the myocardium for wall motion abnormalities, as well as assess the physiologic consequence of any pericardial fluid. Disadvantages include variable skill and experience of the operator, lack of 24-hour availability, and relatively poor visualization of the distal ascending aorta and proximal arch (78).

Treatment of ATAI: The Surgeon's Perspective

Open Thoracotomy

Acute traumatic aortic injuries are considered to be surgical emergencies, and most patients should undergo repair immediately. In the current era of percutaneous intervention, however, these “higher risk” patients may perhaps be better served with endovascular stent-grafting than with open surgery.

For open repair of descending thoracic aortic tears, a generous left posterolateral thoracotomy is made at the fourth or fifth intercostal space. It is absolutely essential that complete proximal control of the aortic arch be obtained prior to placement of the cross-clamp. Decision-making with regard to the location of proximal clamp placement in order to avoid clamping across the tear has been greatly aided by using two-dimensional and three-dimensional reformations (Figs 10–12).

The two basic strategies for the repair of descending traumatic tears are no distal perfusion adjuncts (simple clamp and sew) and perfusion adjuncts (left heart bypass and cardiopulmonary bypass). The “clamp and sew” technique has been used successfully by many authors, but distal spinal cord ischemia and paraplegia rates become unacceptably high after more than 30 minutes of clamp time (79,80). Therefore, most authors will use some form of distal perfusion adjunct.

A meta-analysis of mortality and risk of paraplegia in the repair of traumatic aortic rupture in 1492 patients showed an overall postoperative paraplegia rate of 9.9%. Among patients treated with simple aortic cross-clamping, the hospital mortality was 16% and incidence of paraplegia was 19.2%; for passive shunts, mortality was 12.3% and paraplegia rate was 11.1%; and with active perfusion, paraplegia rate was 2.3% (79,80). In another study (5), the incidence of paraplegia was 3.2% with cardiopulmonary bypass, 29% with simple aortic cross-clamping, and none with nonheparinized bypass. These findings have swayed the weight of evi-

Figure 19

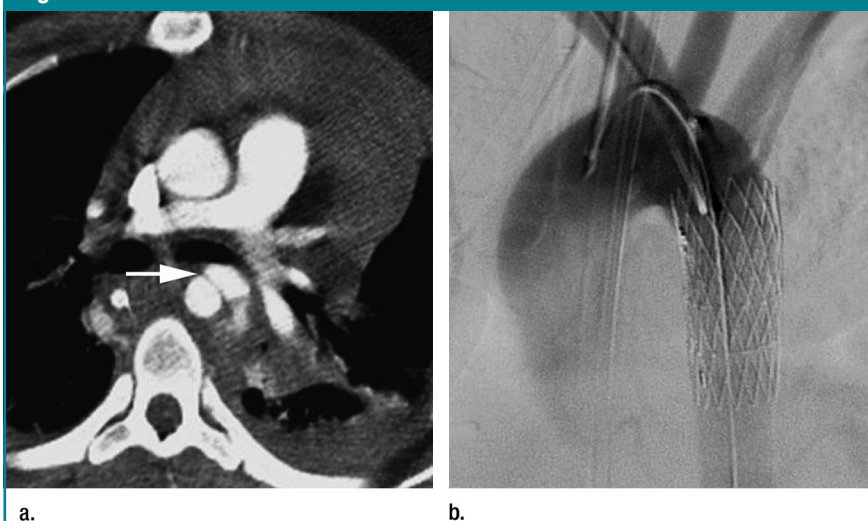


Figure 19: Stent-graft for treatment of ATAI. (a) Transverse contrast-enhanced multidetector CT scan shows complex tear (arrow) of proximal descending thoracic aorta. (b) Conventional angiogram in left anterior oblique projection following stent-graft deployment shows exclusion of transection from aortic lumen.

dence toward the use of perfusion adjuncts for these procedures. The actual reconstruction is usually performed with resection of the injured segment and placement of a Dacron graft.

Endovascular Stent-Graft Repair

Endovascular stent-grafting of nontraumatic thoracic and abdominal aortic aneurysms was first described, to our knowledge, in 1991 (81) and is now a well-established method of treatment. However, it was not until 1997 that this technique was adapted for the treatment of acute thoracic aortic injuries (82). There are now more than 500 documented cases of endovascular treatment of ATAI in the radiologic and surgical literature (83). The premise is to prevent further rupture of the vascular injury by exclusion from the systemic blood pressure of the thoracic aorta and thus reduce the risk of rupture (Fig 19). There are clear advantages of this method over open repair, including avoidance of single lung ventilation, aortic cross-clamping, cardiopulmonary bypass, systemic anticoagulation, reduced blood loss, and reduced surgical time (84). Endovascular repair may be performed in an immediate or delayed setting. Even in acutely injured patients with multiple co-morbid injuries, stent-grafting is feasible (85–87).

Endovascular stent-grafting planning with multidetector CT is critical for technical success. Dimensions to document are (a) the caliber of the aorta proximal and distal to the injury, (b) the distance from the left subclavian artery to the injury, (c) the length of the vascular injury, and (d) any anatomic variants (83). These can be easily determined by using sagittal oblique multiplanar reformations or curved reformatted images generated on a three-dimensional workstation or volume viewer. Technical success, defined as complete exclusion of the vascular injury, approaches 100% (84,88–90). Short-term complications include stroke, puncture-site complications, device collapse, and recurrent laryngeal nerve damage, with morbidity ranging 3%–36% (84,91–93). One limitation of this technique is the lack of small-caliber devices for use in young

patients or those with a small aorta. Mortality ranges 0%–20%, compared with 15%–50% with emergent thoracotomy (82,89,93).

Very little data are available in the literature concerning long-term outcomes and complications of endovascular repair of thoracic aortic injuries, but data to date appear promising (83,84,88,89,92–94). At the time of this review, the Food and Drug Administration has not yet approved the use of stent-graft devices for the treatment of traumatic or nontraumatic thoracic aortic aneurysms.

Future of Aortic Trauma Imaging

Cardiac gating in the setting of thoracic trauma has been entertained since the inception of 64-detector CT technology. The presumed advantage would be the “freezing” of motion of the ascending aorta and a decrease in pulsation artifact within the descending aorta. However, to our knowledge, clinical data in the setting of acute trauma have yet to be presented. Performing cardiac-gated chest multidetector CT in all patients with thoracic trauma may not be practical in the acute trauma setting for a number of reasons, including the additional time of preparing the patient for cardiac gating, potential patient hemodynamic instability, tachycardia, and limited availability of adequately trained technologists. Finally, the longer breath hold may result in unintended artifacts from breathing that may mitigate the advantage of cardiac gating. As such, it is likely to remain predominantly a problem-solving tool.

Summary

The imaging evaluation, diagnosis, and management of ATAI have undergone rapid change over the past 20 years. Previously considered a screening modality for the detection of mediastinal hematoma, multidetector CT is now the accepted initial imaging modality for suspected ATAI, and in those patients with unequivocal evidence of aortic injury, no further diagnostic imaging evaluation is necessary. Angiography, TEA,

and intravascular US remain useful in equivocal multidetector CT cases and for problem solving in unusual presentations of ATAI. While urgent or emergent repair remains the standard of care, the treatment of ATAI is in the process of undergoing a similar shift, with endovascular stent-grafting techniques playing a larger role in initial management.

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