The Role of Imaging in Aortic Dissection and Related Syndromes

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Aortic aneurysm and acute aortic syndrome are not uncommon conditions. Management of acute aortic dissection and related syndromes requires a multidisciplinary approach with input from the patient, clinician, imager, surgeon, and anesthesiologist. This requires an integrated evaluation of pathophysiology, anatomy, and severity to enable appropriate therapy. This review includes discussion of essential anatomy of the aortic valve and the aorta that determines the candidacy for surgical repair. It also includes discussion of various imaging modalities, particularly echocardiography, cardiac computed tomography, and cardiac magnetic resonance angiography. The relative benefits and demerits of each of these techniques are reviewed. This paper is intended to help guide management decisions for patients with acute aortic dissection and related syndromes. (J Am Coll Cardiol Img 2014;7:406–24) © 2014 by the American College of Cardiology Foundation

The human thoracic aorta, a complex geometric organ confounded by asymmetry and obliquity, consists of the ascending, arch, and descending aorta (1). The ascending aorta has 2 portions: 1) the lower portion or the aortic root, which extends from the level of the aortic valve to the sinotubular junction and includes the annulus and sinuses of Valsalva; and 2) the upper portion, which extends from the sinotubular junction to the aortic arch. The aortic root provides support to the aortic valve leaflets, allowing complete excursion of the valves during systole, and to the sinuses of Valsalva from wherein originate the coronary arteries. The aortic annulus is the junction of the proximal ascending aorta with the left ventricular outflow tract and is usually resistant to dilation because of its fibrous nature. The annulus measures 13 ± 1.0 mm/m². Most dissections of the ascending aorta and intramural hematomas begin within a few centimeters of the aortic valve (Fig. 1). As the ascending aorta is not truly or totally vertical, obtaining accurate images or measurements of the aortic diameter requires diligence. The normal aorta dilates by about 6 mm/m² at the level of the sinuses and then
tapers to within 2 to 3 mm of the annular size at the sinotubular junction. During imaging it is important to not only determine the size of the aorta but also the shape, particularly the loss of the normal “waist” of the aorta at the sinotubular junction. Loss of this normal indentation is a predictor of future aortic events. The dimensions of the ascending aorta, arch, and descending thoracic aorta are determined by body surface area and size and are similar but for the slight tapering of the descending thoracic aorta. The aortic arch gives rise to arch vessels, including the innominate artery, left common carotid artery, and left subclavian artery. The sharp curve of the aortic arch results in an oblong rather than circular contour on axial images, making it difficult to accurately measure the aortic diameter. The descending aorta begins just distal to the origin of the left subclavian artery at a point termed the aortic isthmus. The isthmus is particularly vulnerable to deceleration forces during trauma because this location is the point where the relatively mobile ascending aorta and arch become relatively fixed to the thoracic cage. As a result, most descending aortic dissections and intramural hematomas have their origin just distal to the left subclavian artery (Fig. 1). During its course, the descending thoracic aorta gives rise to paired intercostal arteries from the posterior wall at each level of the spine. The descending aorta continues downward to become the abdominal aorta at the level of the diaphragm and 12th thoracic vertebra. At this point, it often takes a sharp curve in older persons, making axial images more oblong in contour rather than circular and resulting in misleading measurements of the true aortic diameter at this point.

Aortic dissection is found in approximately 80% to 90% of the acute aortic syndromes, whereas others will manifest with acute intramural hematoma or penetrating atherosclerotic ulcer (Fig. 2). Aortic dissection occurs with an annual incidence of 10 to 30 per million individuals. There are 2 major classification schemes of aortic dissection based on the location of the dissection—the Stanford classification and DeBakey classification (Fig. 3). Depending on the involvement of the ascending aorta, the Stanford classification divides dissections into types A and B. Stanford type A dissection involves the ascending aorta, with or without extension to the descending aorta, and the Stanford type B dissection does not involve the ascending aorta. The DeBakey classification categorizes dissections into types I, II, and III. DeBakey type I originates in the ascending aorta and extends at least to the aortic arch and often to the descending aorta, frequently all the way down to the iliac arteries. DeBakey type II is when the dissection is limited to the ascending aorta. DeBakey type III originates in the descending aorta usually just distal to the origin of the left subclavian artery. It is categorized as IIIa when it is limited to above the diaphragm and IIIb when it extends below the diaphragm. Very occasionally, a type III dissection may extend proximally into the aortic arch and ascending aorta. An intramural hematoma is a hemorrhage into the medial layer and can propagate longitudinally or circumferentially; however, it does not rupture into the lumen. The presenting symptoms and signs are similar to an aortic dissection. Over 60% of the hematomas are located in the descending aorta and are often accompanied by other features of aortic dissection. Penetrating aortic ulcer (PAU) is a crater-like outpouching in the aortic wall with jagged edges and is usually accompanied by significant atheroma. Both hematomas and PAUs can break through the adventitia to form pseudoaneurysm or rupture into the mediastinum.

Both chronic and acute aortic syndromes are challenges for primary care physicians and cardiac specialists (1,2). Longitudinal progression of chronic aortic diseases and appropriate timing of open or endovascular surgery are usually derived from serial noninvasive imaging studies. Rapid imaging is necessary for the timely diagnosis of a potentially life-threatening condition. Given that the presentation is atypical, that the diagnosis of dissection is often either missed or made too late, and that the morbidity and mortality are time-dependent, imaging is an important step in the early diagnosis and treatment of any aortic disorder. An ideal imaging modality will precisely, safely, and rapidly confirm suspected acute or chronic aortic pathology with quantitative information on aneurysm formation and progression, as well as on tear location, extent, and type of dissection, including evaluation for imminent complications. Today, invasive angiography has been replaced by noninvasive imaging strategies with multislice computed tomography (CT) and magnetic resonance imaging (MRI) for both chronic and acute pathologies; under emergency conditions, acute aortic syndromes can be imaged and confirmed at the bedside by transesophageal echocardiography (TEE), particularly to identify ascending aortic pathology such as type A aortic dissection. According to the International Registry of Acute Aortic Dissection (IRAD), as early as in 2002, CT

### ABBREVIATIONS AND ACRONYMS

- **CT** = computed tomography
- **ECG** = electrocardiography
- **IMH** = intramural hematoma
- **MDCT** = multidetector computed tomography
- **MRI** = magnetic resonance imaging
- **PAU** = penetrating aortic ulcer
- **TEE** = transesophageal echocardiography
- **TTE** = transthoracic echocardiography
- **3D** = 3-dimensional
was the diagnostic modality of choice for dissection in 63% of patients, followed by TEE in 32%, and angiography and MRI in 4% and 1%, respectively (3). With excellent accuracy and similar sensitivity and specificity, CT, MRI, and TEE have become diagnostic options (4,5); however, the hemodynamic instability of a given patient and both availability and local expertise determine the appropriateness of the type of modality.

Echocardiography

Aortic dissection. The advantages of echocardiography in the assessment of patients with aortic dissection include: it is readily available, it can be performed quickly, and it offers the unique option to image at the bedside. The diagnostic finding is the presence of an intimal flap that separates the true and false lumens.

TRANSTHORACIC ECHOCARDIOGRAPHY. Trans-thoracic echocardiography (TTE) is very useful in identifying aortic valve dysfunction, pericardial tamponade, or wall motion abnormalities, and may screen for proximal 4 to 8 mm of the ascending aorta to just above the sinotubular junction in patients with good echocardiographic windows and a short segment of the descending aorta in patients with shock. It may show the intimal flap and a thickened aortic wall. The proximal ascending aorta can usually be seen in long- and short-axis parasternal views. TTE is limited, however, in visualizing the distal ascending aorta and the arch. In adolescents and children, but also in many adult patients, the suprasternal view may allow the visualization of the arch and great vessels, although placement of the transducer in the suprasternal notch may result in some patient discomfort. The descending thoracic aorta appears as a circular structure behind the left atrium in the parasternal long-axis view and occasionally may be mistaken for a dilated coronary sinus; however, the more rigid shape of the aorta as well as the proximity of the coronary sinus to the atrioventricular groove should prevent this from happening. Proximal aortic dilation is usually seen in ascending aortic dissection. The presence of normal aortic dimensions and geometry and absence of aortic regurgitation on TTE are evidence against the presence of an ascending aortic dissection, but this does not fully exclude the diagnosis. Very occasionally, a dilated descending aorta may be visualized behind the atrioventricular groove in a parasternal long-axis view, and this may indicate the presence of dissection or aneurysm in the descending aorta. The overall sensitivity of TTE in diagnosing all forms of aortic dissection is only 59% to 83% and specificity is 63% to 93% when compared with other modalities. For type A aortic dissection it has a sensitivity of 78% to 100%, but for type B dissection its sensitivity is only 31% to 55% (6–8). A negative TTE, therefore, does not exclude aortic dissection. To avoid a delay in diagnosis, TTE is not the modality of choice in suspected acute aortic syndrome. Its utility, therefore, in the emergency setting is in the rapid assessment of complications of dissection, such as aortic valve dysfunction, pericardial tamponade, or wall motion abnormalities.

TRANSESOPHAGEAL ECHOCARDIOGRAPHY. TEE is highly accurate for the detection of acute aortic syndromes as a result of the close proximity of the esophagus to the thoracic aorta and its ability to visualize both ascending and descending aortas and parts of the arch with high spatial resolution in real time. TEE is performed with a 2.5 to 7.5 MHz
transducer that is mounted at the end of a gastroscopic probe. Generally, TEE imaging of the aorta begins with the probe behind the left atrium, and the proximal 5 to 10 cm of the ascending aorta is visualized by scanning at a 120° imaging plane. By imaging at a 40° to 60° plane, TEE allows simultaneous short-axis visualization of the aortic cusps and the 3 sinuses. When evaluating the ascending aorta, artificial echoes are often encountered, but a well-trained echocardiographer should be able to discriminate this from true dissection. A true dissection flap often displays random mobility, especially when the dissection is acute, whereas an artifact has a more rigid and fixed location with respect to the aortic wall. Also, a true dissection flap will have constant echo intensity along its course, whereas an artifact will often arise as a side lobe from the sinotubular junction, and the intensity will progressively diminish toward the lumen of the aorta. Color flow imaging will show margination of flow by a true dissection flap, whereas an artifact does not affect the distribution of the color flow signal. Artifacts are also due to reverberation from the anterior wall of the left atrium or from the posterior wall of the right pulmonary artery in the middle one-third of the ascending aorta. M-mode echocardiography can be useful in distinguishing an intimal flap from imaging reverberations (9).

The descending thoracic aorta is seen by inserting the transducer deeper toward the gastroesophageal junction, rotating it 180° to face posteriorly, and scanning at the 0° imaging plane. A continuous series of short-axis views of the descending thoracic aorta can be obtained by withdrawing the transducer slowly along the length of the aorta. The image can be rotated to a 90° plane at any point during this withdrawal to obtain a longitudinal view of the aorta. The arch is also best visualized by withdrawal of the transducer to the level of the subclavian artery and by rotating it by obtaining an elongated view of the arch. The multiplane probe is rotated to a 90° imaging plane, at the point when the arch is seen at the apex of the imaging plane, to record a short-axis view of the apex of the arch of the aorta. Also, clockwise and counter-clockwise rotations of the probe from this view may allow visualization of the takeoff of the great vessels. When the arch is involved, dissections of the vasculature to the head and upper extremity should be suspected.

Although TEE requires esophageal intubation, images are acquired at the bedside and immediately interpreted (Fig. 4). Aortic dissection is confirmed when 2 lumens are separated by an intimal flap visualized within the aorta. Tears can be identified, and differentiation between true and false lumen is often easy and diagnostic with color Doppler flow mapping (Table 1). The identification of false lumen is of interest: 1) when the aortic arch is involved and the surgeon needs to know whether the supra-aortic vessels arise from the false lumen; and 2) prior to surgery or endovascular therapy, such as intimal fenestration or implantation of endoprosthesis, in patients in whom the dissection of the descending aorta has involved visceral arteries resulting in ischemic complications; percutaneous
Intimal fenestration may be an option when the main artery branches arise from the false lumen. Intimal tear(s) can be localized in 78% to 100% of patients (9–14) by TEE, and color Doppler is helpful in detection of multiple small communications between 2 lumina, especially in the descending aorta. Furthermore, variants of acute aortic syndromes such as intramural hematoma (IMH), atherosclerotic penetrating ulcers, and side branch obstruction can also be identified (15). Overall, the European Cooperative Study Group and others have shown that TEE can reach a sensitivity of 99% with a specificity of 89%, positive predictive accuracy of 89%, and negative predictive accuracy of 99% (4,15–17); these findings were later confirmed in IRAD (3). It is 100% sensitive in detecting aortic regurgitation that complicates aortic dissection and may shed light on its mechanism. TEE is able to identify the different mechanisms of aortic regurgitation and can be helpful prior to surgical correction. When the dissection flap extends into the sinus of Valsalva it disrupts the base of an aortic cusp causing abnormal coaptation of the valve leaflets and resulting in aortic regurgitation. It can also occur when the dissection results in the dilation of the sinotubular junction and valve cusp malcoaptation. In these patients, the valve itself is structurally normal and the aortic regurgitation is functional due to the dilated aortic root. Restoration of the sinotubular junction, with valve-sparing surgery, may correct this form of aortic regurgitation. TEE can also uniquely visualize aortic regurgitation occurring as a result of prolapse of an aortic dissection flap through the aortic orifice, resulting in a conduit for retrograde aortic flow (18). It is also useful in determining the origins of the coronary ostia, including whether they arise from the true or false lumen. Additionally, TEE can determine whether the dissection extends into the coronary artery and provides information about left ventricular function, wall motion abnormalities, and the presence or absence of pericardial effusion and tamponade. When the effusion is frankly hemorrhagic, fibrous or partially thrombosed components

**Figure 3. De Bakey and Stanford Classification of Aortic Dissection**

The DeBakey classification system categorizes dissections on the basis of the origin of the intimal tear and the extent of the dissection: Type I: dissection originates in the ascending aorta and propagates distally to include at least the aortic arch and typically the descending aorta; Type II: dissection originates in and is confined to the ascending aorta; Type III: dissection originates in the descending aorta and propagates most often distally; Type IIIa: limited to the descending thoracic aorta; and Type IIIb: extending below the diaphragm. The Stanford classification system divides dissections into 2 categories, those that involve the ascending aorta and those that do not. Type A: all dissections involving the ascending aorta regardless of the site of origin; and Type B: all dissections that do not involve the ascending aorta. Note that involvement of the aortic arch without involvement of the ascending aorta in the Stanford classification is labeled as Type B. Reprinted, with permission, from Hiratzka et al. (2).
may be visualized. The echocardiographic signs of tamponade may be absent when massive hemorrhage results in a volume unloaded heart (19).

Although TEE is performed in unstable patients at the bedside within 15 min, an experienced operator is needed for image acquisition and interpretation. Adequate sedation is important to avoid a hypertensive response during the procedure, usually as a result of discomfort to the patient. The utilization of color Doppler interrogation is important to confirm blood flow in both true and false lumen, to identify communication sites, and to visualize dynamic side-branch obstructions (20) and other aortic emergencies (21). TEE can be useful perioperatively to confirm post-operative aortic competence, when the aortic valve is preserved, and during placement of ascending aortic graft, which is usually accompanied by resection of the ostia of the left main coronary and right coronary arteries from the native aorta and sutured to the aortic graft (18).

TEE is limited in assessing abdominal side branches and may be unpleasant for patients who cannot tolerate topical anesthesia and moderate conscious sedation. Although TEE has been proven to be a safe and generally well-tolerated procedure, rare complications, including aspiration, arrhythmias, perforation of the esophagus, laryngospasm, and hematemesis, may occur (with an incidence of <1%). Contraindications to TEE, such as esophageal disease (severe dysphagia, bleeding of esophageal varices, esophageal stricture, diverticula, and cancer) and cervical spine disorders (severe atlantoaxial joint disorders, orthopedic conditions that prevent neck flexion), must also be considered. Occasionally, the presence of a left brachiocephalic vein adjacent to a dilated aorta may be confused for a dissection flap. Careful color flow imaging should demonstrate that the larger lumen contains pulsatile arterial flow, whereas smaller lumen contains continuous flow with a characteristic venous pattern. Several limitations of TEE need to be emphasized. First, it has limited ability to visualize the distal ascending aorta and proximal arch because of interposition of the air-filled trachea and the main bronchus. Second, the frequent appearance of reverberation artifacts may mimic a dissection flap, appearing as a mobile linear echodensity overlying the aortic lumen. False positives tend to occur when older-generation single or biplane probes are utilized or when there is confusion between an artifactual echo protruding into the aorta and a true dissection flap. Third, TEE is less suited than CT and MRI for long-term serial imaging to monitor patients after an acute aortic syndrome, in which a complete and detailed map of the entire aorta and its branches as well as serial measurements at easily identifiable landmarks are necessary (Table 2).

Given these issues, and considering availability, excellent quality, and scanning speed of current-generation multidetector computed tomography (MDCT) angiography, TEE is not the first choice, but it still has a role in the emergency assessment of suspected aortic dissection. However, TEE remains an important imaging adjunct to safely perform endovascular stent grafting in complicated type B dissection and to document immediate procedural success (22).

<table>
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<th>Table 1. Aortic Dissection: Differentiation Between True and False Lumen</th>
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<td><strong>True Lumen</strong></td>
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<td>Size</td>
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<td>Localization within the aortic arch</td>
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<td>Signs of slow flow</td>
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<td>Thrombus</td>
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Reprinted, with permission, from Erbel et al. (16).
Late complications of aortic dissection and role of imaging in aortic dissection. 

The critical imaging data that must be provided for a patient with aortic dissection include site(s) of tear and extent of involvement, and particularly whether or not the ascending aorta is affected; CT performs quite well in this regard. Detailed origins of branch vessels relative to true versus false lumen is particularly helpful prior to percutaneous repair. The degree to which a type A dissection extends into the transverse aorta and great vessels may influence the surgical approach (Fig. 5), and should be addressed by the CT examination. Of particular importance is to what degree the dissection extends into the aortic root with possible dysfunction of the aortic valve. The electrocardiography (ECG)-gated MDCT well delineates aortic valve and annulus morphology as well as calcification; multiphase CT data may be helpful in visualizing leaflet excursion, but this results in much higher radiation exposure. In general, the function of the aortic valve is better assessed by echocardiography (see the previous text).

Pericardial effusion should alert the interpreting physician to the possible proximal extension of type A dissection and the danger of imminent rupture due to thinning of the aortic wall. The interpreting physician should comment on the presence of any pericardial or pleural fluid, as these may further influence consideration of surgical repair. Hemopericardium must be suspected when the attenuation values of the pericardial fluid is over 40 Hounsfield units. Coronary ostial involvement is usually apparent by electrocardiography, but may also be indicated by CT. ECG gating of image acquisition is useful to assess the involvement of the coronary arteries. Associated congenital anomalies such as a right-sided arch, vascular rings, retroesophageal anomalous arch vessels, and coarctation should all be recognized when present. The altered flow through a diverticulum of Kommerell (Fig. 6) may favor development of aortic dissection. Involvement of visceral organs predicts patient outcome, and MDCT allows this determination with the inclusion of a late series. A cerebrovascular accident portends a worse prognosis, and in such cases a CT head scan will be required. Usually the supra-optic branches of the innominate artery and the left common carotid artery are involved with such a clinical presentation. In general, the right subclavian artery is more frequently involved than the left in patients with a dissection within the aortic arch. The usual propagation of a dissection tends to involve left-sided branches of the descending thoracic aorta and abdominal aorta more often than those on the right side. The left kidney is

Table 2. Late Complications of Aortic Dissection and Follow-Up Evaluation

<table>
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<th>Late complications</th>
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<tr>
<td>Progressive aortic insufficiency</td>
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<td>Aneurysm formation and rupture</td>
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<tr>
<td>Recurrent dissection or progression of dissection</td>
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<td>Leakages at anastomoses/stent sites</td>
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<td>Malperfusion</td>
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<td>Patients at particularly high risk</td>
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<td>Those with Marfan syndrome—very high risk of recurrent dissection or of aneurysm formation with rupture</td>
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<td>Those with a patent false lumen—increased incidence of late complications and death</td>
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Follow-up evaluation

| Regular outpatients visits and imaging controls at 1, 3, 6, and 12 months and thereafter every year |
| Optimal BP control <135/80 mm Hg with beta-blockers |
| First choice is MRI, second choice CT, and third TEE |

Reprinted, with permission, from Bossone et al. (70).

BP = blood pressure; CT = computed tomography; MRI = magnetic resonance imaging; TEE = transesophageal echocardiography.
the organ at greatest risk of ischemia during dissection. Bilateral intercostal artery involvement is more likely to result in spinal medullary infarct when compared to unilateral (generally left) involvement. In about 26% of the cases of aortic dissection, there is lower limb ischemia. MDCT is useful to recognize the different configurations of the flap involving a branch visceral artery (28,29) including: 1) when the branch originates in the false lumen without flap involvement and visceral perfusion is dependent on the flow dynamics in the false lumen; 2) when the branch originates in the true lumen without flap involvement and visceral perfusion is uncertain because of proximal/upstream dynamic obstruction true lumen; 3) when the branch originates in the true lumen with the flap prolapsing in the ostium of the branch resulting in dynamic obstruction of flow; 4) when the intimal dissection stops at a bifurcation wrestling the intima from the ostium or extending through the vessel to result in a fixed obstruction; and 5) mixed obstruction with simultaneous extension of the flap.

Similar but distinct aortic pathologies that may be detected by CT when dissection is suspected include PAU (Fig. 7) and IMH (Fig. 8). A low-attenuation crescent along the aortic wall on noncontrast CT images, produced by blood in the vessel wall, subsequently noted to be beyond the contrast-filled lumen on CT angiography readily identifies IMH. Delineation of vessel wall calcification, if present, helps define the vessel’s intimal surface (32). Either IMH or PAU may progress to aortic dissection (33,34), underscoring the importance of recognizing both conditions. The diagnosis of PAU outside of the context of acute aortic syndrome must be done judiciously, because MDCT cannot always determine the degree of penetration of the intima in an atheromatous plaque (35).

Because detection of type A dissection usually mandates surgical repair (Fig. 9), defining the presence/absence of ascending aortic involvement is crucial with imaging. Surgery for type B dissections is usually prompted by expanding aortic dimensions. Thus, it is also essential to obtain serial measurements of aortic diameters in a true cross section at the level of interest (36); multiplanar reconstructions that demonstrate orthogonal planes relative to the aorta are helpful in this regard (37). For serial assessment, a direct comparison to prior examinations ensures comparable locations of measurement to reduce interscan variability (38). Determining the rate of expansion requires the ability to reproduce the same imaging planes on serial examination, which is straightforward when using CT angiography acquisition with isotropic spatial resolution covering the volume of interest; however, with TEE the exact position is less reliably determined due to the small field of view and lack of landmarks.

Specific features that may favor CT for aortic imaging include prior aortic surgery, presence of bypass grafts that require assessment, or prior endovascular repair (39,40). While rapid magnetic resonance (MR) techniques for aortic imaging have narrowed the gap by being able to evaluate acutely ill patients, hemodynamic instability remains a relative contraindication to MR (particularly when
performed remotely from physicians attuned to managing acute cardiovascular conditions) and often is a deciding feature in selecting CT. Furthermore, CT may be safely performed in patients with implanted devices or ferromagnetic materials that preclude MR examination.

Factors that should shift one away from CT as the modality of choice for routine use include young patient age or female sex due to concerns of ionizing radiation risk. However, if dissection is strongly suspected, this risk is very small compared with the risk posed by the disease and a protracted management. Risk of allergic reaction to iodinated contrast may be mitigated with appropriate pretreatment; however, the risk can be entirely avoided by using an alternative modality, especially in patients with prior allergic response. Infrequently considered is the patient with severe untreated hypothyroidism; the considerable iodine load administered with typical contrast volumes for CT angiography is not insignificant and has been reported to precipitate thyroid storm in susceptible individuals (41). Avoidance of this rare, but potentially devastating, complication requires appropriate clinical acumen on the part of both the referring and performing physicians. Finally, renal insufficiency that occurs in isolation or with diabetes increases the risk of contrast-induced nephropathy. As with contrast allergy, risk can be minimized by appropriate patient selection, hydration strategies, and in some cases, adjuvant renoprotective therapies. Risks of iodinated contrast and radiation with CT must be weighed against the risk of inaccurate or missed diagnosis for each patient’s clinical profile and diagnostic options.

Contemporary CT technology offers relative affordability, rapid scan time, and high resolution for accurate diagnosis of aortic dissection, with considerable progress since the first CT scanners produced cross-sectional imaging of the aorta (42). Isotropic spatial resolution, or identical resolution in the x-, y- and z-directions, allows reconstruction of helically-acquired axial images in any oblique plane (43)—an important consideration for the tortuous aorta whose greatest diameter may be overestimated if measuring from axial images alone. Another important limitation of axial images is that it is limited in evaluation of the very proximal ascending aorta, particularly the portion between the annulus and the coronary artery, which represents a distance of 1 to 2 cm. Involvement of this location may be missed in axial images, and it is also difficult to be certain whether a given axial cut is above or below the plane of the aortic valve. Additionally, the plane of the aortic valve may not be confined to the plane of the axial images (that is, perpendicular to the longitudinal axis of the body) given the obliquity of the aorta. Furthermore, in an ascending aorta that has undergone elongation, the aortic valve plane may be oriented vertically, making it difficult to assess the involvement in axial images.

Two important technical advances that further improve helical CT of the aorta include: 1) multiple
detector rows for simultaneous acquisition of image data over greater z-axis lengths with 1 gantry rotation; and 2) use of more than 1 x-ray source and corresponding detector arrays such that temporal resolution can be considerably improved over single-source acquisition. With these advances, the entire thoracic and abdominal aorta can be imaged in a single breath hold, and resolution approaches 0.4 mm using current generation scanners (44). Although the reconstructions are done in the axial, sagittal, and coronal planes, the resolution is often insufficient to permit accurate assessment of the aortic shape and diameter. Specific acquisition parameters that should be considered before scanning a patient with aortic dissection include volume of coverage, whether or not ECG triggering is required, what volume of contrast should be injected at what rate and with what additional saline infusion, and what techniques can be deployed to minimize ionizing radiation dose. A typical CT aortic aneurysm survey spans the entire thoracic and abdominal aorta from just above the aortic arch to below the iliac bifurcation; this is usually done without ECG gating to avoid prohibitively high radiation exposure, but provides limited assessment of the aortic root due to cardiac motion artifact. Motion artifacts produce changes in diameter assessment as great as 7.5% to 27.5% (45). Newer-generation scanners, which deliver an ultra-low dose thanks to a large detector array covering several centimeters of the aorta with each gantry rotation, afford prospective triggering over a larger span of the aorta with less radiation. ECG triggering is essential to accurately evaluate a known or suspected type A dissection (Fig. 10), and is particularly helpful when imaging the ascending aorta and aortic valve. While CT is rarely used to characterize aortic physiology (unlike MR), its ability to image the entire aorta including the root, annulus, and valve relatively quickly make it an excellent modality to assess aortopathic conditions such as bicuspid aortic valve, Marfan syndrome, and inflammatory disorders (46).

Contrast volume, injection rate, and timing of acquisition should be optimized for individual patients. Typical imaging of the entire aorta requires 100 ml of intravenous iodinated contrast with a concentration of 300 to 350 mgI/ml (47); 30 to 50 ml of saline delivered at the same rate immediately following contrast (e.g., using dual-head injectors) helps maintain a distinct contrast bolus and minimizes opacification of venous structures. In some instances, opacification of both left and right heart structures may be desired (e.g., where both pulmonary embolism and aortic disease are equally suspected), although invariably 1 vascular bed is less optimally opacified when casting a wide imaging net to compensate for inability to clinically stratify among differential diagnoses. Small investigations using gadolinium-based contrast suggest adequate enhancement for CT angiography without nephrotoxicity (48). However, pending further large-scale investigations to establish scan protocols and performance characteristics using gadolinium-enhanced CT angiography, iodinated contrast remains the preferred medium for optimal vascular enhancement with CT.

Increased public awareness of radiation safety, which has outpaced improvement in available risk

Figure 9. Aortic Root Pseudoaneurysm at Site of Prior Type A Dissection Repair
Oblique coronal plane multiplanar reformattecd computed tomography (CT) image (left) and volume rendering (right) demonstrate contrast within a pseudoaneurysm (arrowhead), likely at the proximal graft anastomosis in a patient who had previously undergone repair for a type A aortic dissection. AAo = ascending aorta, PA = main pulmonary artery, RCA = right coronary artery.
Both nontriggered chest computed tomography (CT) (left) versus electrocardiography (ECG)-triggered CT angiography (right) were obtained in a patient with aortic dissection. On the left, cardiac motion (as well as streak artifact, in this case due to residual contrast bolus in the superior vena cava) produces a linear density in the aortic root that precludes reliable exclusion of dissection flap at the level of the sinuses. With ECG triggering, the normal appearing aortic valve leaflets are well-demonstrated, and aortic root dissection can be more accurately excluded. Dissection of the descending aorta is well-demonstrated on both studies.

**Figure 10. Usefulness of ECG Triggering for Assessment of the Ascending Aorta**

Prediction models, mandates careful attention to parameters than can minimize radiation dose while preserving diagnostic image quality. Using a dose “as low as reasonably achievable” (i.e., the ALARA principle) means paying attention to the selected tube voltage, tube current, and other dose-minimizing techniques that may vary from 1 scanner to another. As dose increases with the volume of coverage, defining the minimum scan extent to address the clinical questions helps ensure that the necessary anatomy is imaged while avoiding excess radiation. Nongated acquisitions often use information from the scout images to reduce tube current in thinner body regions, and ECG-based tube current modulation that lowers dose in systolic phases of the cardiac cycle is appropriate in the minority of instances where retrospective gating is needed. Individual patient protective devices hold appeal, particularly for the radiosensitive thyroid gland (49), even though long-term data is lacking regarding the magnitude of risk reduction benefit. Note that the thyroid shield will impair imaging of the aortic arch if assessment of this region is required as part of the CT examination.

**MRI of Aortic Dissection**

MRI is a highly accurate, noninvasive imaging modality, with a sensitivity of 95% to 98% and specificity of 94% to 98% for detecting aortic dissection (5). Additionally, it does not require ionizing radiation or iodinated contrast. With its ability to delineate the intrinsic contrast between blood flow and vessel wall, magnetic resonance (MR) provides a high degree of reliability in the diagnosis of aortic diseases. Contrast-enhanced MRI with intravenous gadolinium has emerged as the mainstay technique because it is highly accurate for aortic dissection and branch vessel involvement. However, comparative data evaluating the relative diagnostic merits of the different types of MR images are not available. Functional information by dynamic sequences expands our understanding of aortic function. Moreover, MR angiographic techniques are able to display the aortic pathological process and its interaction with other vascular structures. The capability of multiplanar imaging with 3-dimensional (3D) reconstruction techniques and cine-MRI allows for differentiating between slow-flow blood flow and clot and detection of aortic regurgitation. Images with good resolution make accurate measurements of the aorta feasible. Its radiation-free invasiveness and reproducibility of the parameters render this technique the modality of choice to evaluate disease progression during follow-up.

**MRI findings in aortic dissection.** In the diagnostic workup of aortic dissection, delineation of several anatomic details are critical for successful surgical or endovascular management. Clear anatomic definition of the intimal flap, its longitudinal extension, and involvement of tributary branches, and the presence and degree of aortic insufficiency are essential information before surgical repair of type A dissection. Moreover, the detection of the entry and re-entry sites, the relationship between true and false lumina, and perfusion of the visceral vessels, and the extension of dissection into the iliac/femoral arteries are crucial in patient selection for transcatheter endovascular repair of type B dissection.

In a suspected case of aortic dissection, the standard MRI examination should begin with rapid black blood acquisitions covering the aorta, providing a natural contrast between the lumen and the vessel wall layers (50). In the axial plane, the intimal flap is detected as a line inside of the aortic lumen. The true lumen can be differentiated from the false by the anatomic features and flow pattern: the true lumen is often smaller than the false lumen and shows a signal void, whereas the false lumen often has a higher signal intensity (Fig. 11) (51,52). In addition, the visualization of remnants of the dissected media adjacent to the outer wall of the lumen may help to identify the false lumen, especially when the true lumen is smaller than the false one. A detailed anatomic map
of aortic dissection must indicate the type and extension of dissection, distinguish the origin and perfusion of branch vessels (arch branches, celiac, superior mesenteric, renal arteries, and coronary arteries) from the true or false channels and promptly identify indicators of emergency. A high signal intensity of a pericardial effusion may indicate a bloody component and is considered a sign of impending rupture of the ascending aorta into the pericardial space. Leakage of blood from the descending aorta into the periaortic space with high signal intensity along with left-sided pleural effusion is usually better visualized on axial images. In stable patients, adjunctive gradient-echo sequences or phase contrast images can be instrumental in identifying aortic insufficiency and entry or re-entry sites as well as in differentiating slow flow from thrombus in the false lumen (53–56). The bright signal of the blood pool on gradient-echo images results from flow-related enhancement obtained by applying radiofrequency pulses to saturate a volume of tissue. With a short repetition time (4 to 8 ms) and low flip angle (20° to 30°), maximal signal is emitted by blood flowing in the voxel. An ECG signal is acquired with the imaging data so that the images, acquired with a high degree of temporal resolution throughout the cardiac cycle (up to 20 to 25 frames), are reconstructed in the different phases of the cardiac cycle and can be displayed in cine format. In gradient echo sequences, the laminar moving blood displays bright signal in contrast to stationary tissues. Turbulent flow produces rapid spin dephasing and results in a signal void. This phenomenon allows the detection of anomalous turbulence, such as aortic or mitral insufficiency or jet-like communication between the true and the false lumen. The 3D quantitative information on blood flow is obtained from modified gradient-echo sequences with parameter reconstruction from the phase rather than the amplitude of the MR signal, known as flow mapping, phase contrast, or velocity-encoded cine MRI. Flow velocity is calculated using a formula in which velocity is proportional to change in phase angle of protons in motion. MR maps of flow velocity are obtained 2-dimensionally, which is particularly important in profiles of nonuniform flow, such as that in the great vessels. Quantitative data on flow velocity and flow volume are obtained from the velocity maps throughout the cardiac cycle and can be displayed in cine format. The third step in the diagnosis of aortic dissection and definition of its anatomic detail relies on the use of MR angiography (57,58). Gadolinium MR angiography is rapidly acquired in a few seconds without any need of ECG triggering; this technique may be used even in severely ill patients. The technique relies on the contrast-induced T1-shortening effects of the contrast medium. During the short intravascular phase, the paramagnetic contrast agent provides signal in the arterial or venous system, enhancing the vessel-to-background contrast-to-noise ratio irrespective of flow patterns and velocity. Improved gradient systems allow a considerable reduction of the minimum repetition and echo times and the acquisition of complex 3D datasets within a breath hold interval. The paramagnetic contrast agent (0.2 mmol/kg of bodyweight) is generally administered intravenously (antecubital vein). Bolus timing is necessary to have the peak enhancement during the middle of MR acquisition, monitored by a real-time fluoroscopic triggering.

Non-contrast MR angiography techniques are increasingly applied, stimulated by concerns over the safety of gadolinium-based contrast in patients at risk for renal insufficiency or nephrogenic systemic fibrosis. With balanced steady-state free precession techniques, image contrast is determined by T2/T1.
ratios, which leads to inherently bright blood images with little dependence upon blood inflow. Both arteries and veins have bright signal with steady-state free precession MR angiography, which makes this technique well suited for thoracic MR angiography applications.

With MR angiography, the intimal flap is visualized as a dark longitudinal line within the 2 lumens, which can extend inside supra-aortic or visceral vessels, whereas entry and re-entry sites appear as segmental interruption of the linear intimal flap (Fig. 12). Analysis of MR angiography images should include a complete evaluation of reformatted images in all 3 planes to confirm or improve information from black blood acquisitions and to exclude artifacts. Moreover, maximum intensity projection images of the 3D multiplanar reformation provide a panoramic overview of the dissection morphologic details in a 3D format (Fig. 13).

MRI is considered the most accurate technique for detecting aortic dissection, with a sensitivity of 95% to 98% and specificity of 94% to 98% (3,4,16,17,59). There are few comparative studies concerning the performance of imaging modalities, and cumulative data on the diagnostic accuracy are limited because of different technological upgrading of each method. In a recent meta-analysis (3), the diagnostic odds ratio was highest for MRI, suggesting a possibly superior discriminative power for confirming thoracic aortic dissection. The results were homogeneous, irrespective of the type of MRI study, such as cine magnetic resonance angiography or standard spin-echo MRI. In patients at high risk for thoracic aortic dissection (pre-test probability of 50%), MRI yielded the highest values for confirming thoracic aortic dissection. In contrast, helical CT yielded the best values for ruling out thoracic aortic dissection in patients at low risk for thoracic aortic dissection (pre-test probability of 5%). Despite these advantages, MRI is rarely used as the initial imaging technique in suspected acute aortic dissection in IRAD (3) and is utilized even less frequently than angiography for several reasons. First, it is not readily available in most hospitals and emergency departments. Second, it is contraindicated in those with metallic implants, including cardiac pacemakers and defibrillators. Third, gadolinium contrast is contraindicated in those with advanced renal dysfunction.

MRI is very useful for follow-up of aortic dissection after surgical repair. In the modern era, early and accurate detection and an aggressive surgical approach have significantly increased survival after acute aortic dissection. However, surgical replacement of the ascending aorta has to be considered a lifesaving but not a healing operation; patients after surgical repair of type A aortic dissection still remain at considerable risk of future complications (60–62). A persistent distal false lumen has been reported in 75% to 100% of cases. Persistent entry tears in the descending aorta or in the aortic arch are responsible for patency of the distal dissection, which is associated with an unfavorable prognosis (63). Prosthetic graft degeneration, infection, and malfunction of the prosthetic aortic valve are additional causes of post-operative

Figure 12. Maximum Intensity Projection Image of MR Angiography of Type B Aortic Dissection

The intimal flap is visible as dark linear image between true and false lumen: differences in flow velocity display a higher signal intensity (white) in the true lumen with respect to lower signal intensity (gray) in the false lumen. Origin of the celiac and superior mesenteric artery from the true lumen.

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complications. Therefore, in patients who underwent surgery for aortic dissection, an appropriate follow-up should take into account a complete evaluation of the prosthetic material and of the residual native aorta with accurate measurements to identify early high-risk patients.

MRI has the potential to become the imaging modality of choice in post-operative evaluation. MRI measurements are highly reproducible, and reproducibility is an essential component of serial examinations, in which minimal change in dimension may represent a prognostic finding or indicate a need for preventive surgical strategies. Residual dissection is easily detected, and thrombosis of the false lumen, an important prognostic indicator, is readily identified. Slight thickening around the graft is a common finding caused by perigraft fibrosis. However, large or asymmetric thickening around the tube-graft may represent localized hematoma caused by an anastomotic leakage. Suture detachment with leakage has been reported, in particular after composite graft replacement of the ascending aorta. Reoperation for bleeding at the site of repair has been reported after composite graft operation in 8% of patients after 30 days and in 4% of patients after 1 year. The higher incidence of bleeding has been reported at the site of reimplemented coronary arteries. Contrast-enhanced spin-echo images improve the identification of suture detachment (64), and the site of bleeding appears as high signal intensity within the hematoma. Moreover, MR angiography is particularly effective in the depiction of the complex post-operative anatomy, elucidating morphology of the prosthetic tube, distal and proximal anastomoses, residual distal dissection, and reimplemented coronary, supra-aortic, or visceral vessels.

**Intramural hematoma.** The greater contrast between tissues during MRI allows it to detect small intramural hematomas that may go unnoticed by CT (65). Typical findings include wall thickening of the hyperintense aorta on T1-weighted black-blood sequences. During the initial hyperacute phase, intramural hematomas may be associated with isointense aorta in T1-weighted images and a hyperintense signal in T2-weighted images. The hyperintense T1- and T2-weighted images in the first 12 to 24 h are a result of a change in the oxyhemoglobin to methemoglobin. Semilunar-shaped mural thrombi may mimic an intramural hematoma occasionally on TEE or CT; in these instances, MR will allow differentiation because mural thrombus displays as hypointense or iso-intense in both T1- and T2-weighted images.

**Penetrating ulcer.** Black blood sequences of PAU often show intimal disruption with extension of the ulcer into the media, which is usually thickened; often there is associated intramural hematoma. Differentiating PAU from dissection can be difficult. MRI is particularly useful for investigation of intramural hemorrhage complicating PAU when renal failure is present.

**Diagnostic Algorithm for Acute and Chronic Aortic Conditions**

The diagnostic algorithm can be seen in Figure 14. Diagnostic imaging studies in the setting of suspected aortic dissection have important primary goals, such as confirmation of clinical suspicion, classification of dissection, localization of tears, and assessment of both extent of dissection and indicators of emergency (e.g., pericardial, mediastinal, or pleural hemorrhage). In the setting of suspected aortic dissection, biomarkers (such as myocardial markers, D-dimers, and smooth muscle myosin heavy chain) may be used strategically in combination with swift imaging, although an ideal integrated algorithm has yet to be determined. A concise...
and simple selection of imaging modalities is summarized in Table 3. The suspicion of acute aortic syndrome is high with abrupt or severe retrosternal or interscapular chest pain often migrating down the back; associated findings can produce signs of acute aortic insufficiency, pericardial effusion, or occluded aortic side branches causing ischemia or a pulse differential. With predisposing factors such as hypertension, connective tissue disorders, bicuspid aortic valve, coarctation, and previous cardiac surgery or recent percutaneous instrumentation, undelayed diagnostic imaging is required for any of these symptoms. Although screening TTE provides vital information (e.g., new-onset aortic insufficiency,
pericardial effusion, or even visualization of proximal dissection), additional TEE interrogation of the thoracic aorta is the logical next step, or MDCT scanning of the entire aorta if considered safe. Both imaging modalities provide further detail both in type A and B (or distal) dissection and are useful for strategic planning. MRI has no place in urgent diagnostic work-up of acutely symptomatic patients because of the longer duration required for image acquisition and the potential risk of limited accessibility to the patient during imaging, making hemodynamic and clinical monitoring challenging.

### Choice of Imaging Modality

Considering the excellent accuracy of all modalities, the imaging protocols for both chronic and suspected acute aortic diseases should adapt to specific questions about the target of interest and to local expertise. While ascending thoracic aortic aneurysms are usually isolated, infrarenal aneurysms are often associated with iliac pathologies. Therefore, in the case of descending thoracic and suprarenal pathologies (aneurysm and dissection) it makes sense to image the entire aorta for acute and chronic changes. Most emergency departments utilize contrast CT because of ready availability and high degree of sensitivity and specificity. In IRAD, CT was used as the initial imaging study in 63% of the cases, whereas TEE was used in 32% (66). MDCT technology allows rapid acquisition of thinly collimated images of the entire aorta during arterial transit of bolus contrast administration; 16-, 64- and even 256-slice CT scanners have essentially replaced invasive diagnostic angiography for large- and medium-sized vessels of both the chest and abdomen. The technology is robust and rapidly performed with high spatial resolution to differentiate intramural hematoma from ulcers and dissection. Additional information not crucial in immediate management includes arch vessel and side-branch involvement usually seen on CT angiography without the need for invasive angiography. But CT requires transport to the diagnostic suite and stable hemodynamic conditions. The risk of contrast nephropathy also tends to limit the use of this modality, in which case TEE may be a better option. For patients with suspected aortic syndromes and unfit for transportation, bedside echocardiographic techniques like TTE and TEE with color Doppler interrogation are first priority, but may miss abdominal segments as the abdominal aorta may not be ideally seen from standard subcostal windows.

MR angiography is also capable of high-resolution aortic imaging with 3D post-processing; delayed imaging allows evaluation of venous structures without additional contrast. The ability to image thin intimal flaps, intramural processes, and the morphology of aortic wall inflammation is likely to offer new insight into vascular disease detection and classification (67). Indeed, intramural hematoma, aortic “haustration,” and asymptomatic aortic flaps, aortic ulcers, and aneurysms are reported at increasing frequency with access to tomographic imaging (15,68). Noncontrast MRI can be useful under stable conditions when there is risk of contrast nephropathy.

In contrast to both CT and MR technology, modern ultrasound equipment is mobile and especially attractive at the bedside for unstable emergency cases. TEE interrogation added to transthoracic suprasternal screening ultrasound is superb for acute aortic dissection (type A) even intraoperatively with near perfect sensitivity and specificity (5,21), but has a blind spot confined to the proximal arch from bronchial air. Color Doppler is instrumental to assess entry sites and false lumen flow in real time to confirm proximal dissection (Fig. 4). In addition, important prognostic information, such as pericardial effusion, acute aortic regurgitation, and proximal coronary obstruction, can be visualized. For patients in shock and with very high clinical suspicion of ascending aortic dissection, TTE alone is reasonable prior to immediate transfer to surgery, with TEE performed prior to sternotomy. Although

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**Table 3. Comparisons of Diagnostic Imaging Techniques**

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<th>TTE/TEE</th>
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<th>MRI</th>
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<tr>
<td>Sensitivity</td>
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<td>Specificity</td>
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<td>Tear localization</td>
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<td>Aortic regurgitation</td>
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<td>Pericardial effusion</td>
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<td>Mediastinal hematoma</td>
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<td>X-ray exposure</td>
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<td>Patient comfort</td>
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<td>Follow-up studies</td>
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<td>Intraoperative availability</td>
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Reprinted, with permission, from Garcia (71). MDCT = multidetector computed tomography; TTE = transthoracic echocardiography; other abbreviations as in Table 2.
TTE and TEE are important bedside tools for acute dissection (18), both fail to provide sufficient anatomic detail to plan endovascular interventions. For stable patients, any modality will work depending on availability and expertise.

Conclusions

Aortic aneurysm and acute aortic syndrome are not uncommon conditions. Currently, TEE and noninvasive cardiac tomographic imaging play a leading role in both primary diagnosis and treatment planning. In the near future, new approaches based on modern CT scanners, refined MDCT, and MR imaging protocols will not only improve diagnostic precision, but will also allow risk stratification as part of diagnostic imaging.

References

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Key Words: acute aortic syndromes aortic dissection aortic intramural hematoma aortic ulcer cardiovascular imaging.