Noninvasive Imaging Approaches to Evaluate the Patient With Known or Suspected Aortic Disease

Christoph A. Nienaber, MD; Stephan Kische, MD; Valeria Skriabina, MD; Hüseyin Ince, MD

Both chronic and acute aortic conditions are challenges for primary care physicians and cardiac specialists. 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 as not to delay the diagnosis of a potentially life-threatening diagnosis. Given the frequency of missed cases of dissection, atypical presentation, and time-dependent morbidity and mortality, imaging is paramount for 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 Today, invasive angiography has been replaced by noninvasive imaging strategies with multislice computed tomography (CT) and MRI for both chronic and acute pathologies; under emergency conditions, acute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 Aortic Dissection (IRAD), as early as 2002, CT was the diagnostic modality of choice for dissection in 63%, followed by TEE in 32%, and angiography and MRI in 4% and 1%, respectively.1 With excellent accuracy and similar sensitivity and specificity CT, MRI, and TEE have become diagnostic options2,3; however, hemodynamic instability of a given patient, and both availability and local expertise, determine the appropriateness of either modality.

CT Angiography of the Thoracic Aorta

Whereas invasive angiography visualizes 2D luminograms, noninvasive multidetector CT (MD-CT) is the result of rapid image acquisition and 3D reconstruction in high resolution during brief opacification by intravenous contrast material.4 The technical leap with MD-CT was the creation of a cone-shaped x-ray beam generating image data over a volume, rather than a fan-shaped beam acquiring 1 axial section per rotation,5,6 being displayed as 3D images along the centerline of flow (useful for evaluating vascular disease morphology and planning endovascular procedures).7,8 The ability to view vessels in multiple projections and orientations helps evaluating the complex 3D anatomy of the aorta accentuated by tortuosity, dilation, or spiraling dissection (Figure 1). The obvious advantages of MD-CT include rapid image acquisition, postprocessing flexibility, and less image noise resulting in high-definition CT angiography (CTA) from neck to abdomen in <20 seconds8 (Figure 2). A significant drawback of MD-CT is a radiation dose of 10 to 25 mSv, especially of concern in young patients often subject to serial cardiovascular imaging.2,9

In suspected acute aortic syndrome, a noncontrast scan through the chest is useful to screen for acute hemorrhage or intimal vascular calcifications, particularly in the aortic wall (intramural hematoma or separation of wall layers). Subsequently, to facilitate reformating images in 3 dimensions, a thin (1 mm) scan is acquired during rapid bolus administration of contrast at 4 to 5 mL/s. Because vascular imaging is dependent on iodine flux (iodine concentration multiplied by flow rate),4 excellent vascular images require injections of iodinated contrast at 4 to 5 mL/s through venous catheters or implanted ports. Arterial phase imaging is timed to coincide with arterial contrast opacification; delayed venous phase imaging is also useful to evaluate solid organs for mass lesions or for endoleaks in patients with stent grafts (by use of 3D multiplanar reconstruction). In aortic side branches such as coronaries or renal arteries, CTA tends to overestimate calcified stenoses and underestimate luminal narrowing by noncalcific plaque, potentially relevant when correlating clinical signs with imaging findings.7,8 Occasionally, CT artifacts occur in obese or uncooperative patients with noise and motion, causing image distortion. ECG-gated CT acquisition can improve image quality especially in the aortic root, where pulsation artifacts are common and likely to mimic dissection. Meanwhile, first reports emphasize the potential of virtual vascular endoscopy based on gated acquisition for both detailed anatomic evaluation and therapeutic guidance.10,11

MRI of the Thoracic Aorta

MR angiography (MRA) is a complementary rather than competing imaging modality for the thoracic aorta. With neither ionizing radiation nor iodinated contrast required,
MRA is ideal for patients with multiple follow-up scans and/or contrast allergies.

Spin-echo T1-weighted imaging provides the best patho-anatomic detail of intramural hematoma, intimal flaps, or atheromas, whereas T2-weighted images allow tissue characterization of the aortic wall or blood compounds (Figure 3). ECG triggering is essential to minimize pulsatility artifact. With additional preparatory radiofrequency pulses, superior black-blood-fast T1- and T2-weighted sequences are generated and improve image quality in any plane. Dynamic and functional information is derived from gradient-echo MRI based on flow-related signal enhancement. Whereas MRA methods without contrast enhancement have been available for some time, gadolinium-enhanced MRA has dramatically shortened examination time and emerged as preferred MR modality for aortic disease; adequate images result from only 15 mL of gadolinium. Although MRA was considered ideal in renal failure, discovery of nephrogenic systemic fibrosis in patients with renal dysfunction receiving gadolinium has tempered enthusiasm and contributed to a renaissance of nonenhanced MRA. Among established nonenhanced sequences beyond ECG-gated partial Fourier fast spin-echo, balanced steady-state free precession (SSFP) has emerged as a central technique to provide vivid imaging of flowing blood. Noncontrast SSFP imaging enables rapid exclusion of dissection in “single shot” mode and a more detailed evaluation (for entry location and flow pattern) in cine mode both visualizing dissected wall in any plane. The high signal-to-noise and contrast-to-noise ratio (due to cardiac and respiratory gating) renders SSFP particularly useful for patients incapable of breath-holding or in the setting of suspected aortic syndrome with better detection of aortic wall pathologies such as intramural hematoma than by MRA alone; scan time can be limited to 10 minutes in experienced centers. True MRA without gadolinium is also feasible using time-of-flight techniques with image quality, but it is inferior to gadolinium-enhanced MRA and 3D volume-rendering or maximum intensity (MIP) reconstruction (Figure 4).

The ability of MRI acquisition in any plane and 3 dimensions enables swift and high-resolution imaging for both chronic pathologies or even acute aortic dissection. Because of the closed bore design of the magnet and the need for monitoring and resuscitative equipment close to magnetic field, MRI is less suitable for unstable patients than CT. Both for CT and MRI, real-time video sequences and serial examinations allow assessing instantaneous hemodynamics and longitudinal evolution in transition from acute to chronic aortic dissection; 4D imaging including time domain is eventually becoming standard. Postprocessing involves multiplanar, volume-rendered, and MIP reconstructions as well as virtual endoscopy for complex evaluation of aortic dimensions, coarctation, parietal thrombus and ulcers, dissection, intramural hematoma, and perivascular fat.

Ultrasound/Transesophageal Echocardiography

Transesophageal echocardiography (TEE) has limited value for evaluation of the entire aorta, but it is highly useful in identifying aortic valve dysfunction, pericardial tamponade, or wall motion abnormalities and may screen for proximal and descending aortic dissection in patients with shock. It is

Figure 1. Stanford type B aortic dissection on volume-rendered 64-slice multidetector CTA with compressed true lumen (TL) and expanded false lumen (FL). Axial slices are displayed between 3D reconstruction from 2 views. The proximal entry to the dissection (black arrow) is adjacent to the offspring of a Lusorian artery (white arrow).

Figure 2. Three-dimensional reconstruction of a 64-slice multidetector CTA in a patient with severe coarctation, hypoplastic aortic arch, and ectasia of the ascending aorta. Note the detailed display of the collateral network resulting from high spatial resolution.
limited, however, in visualizing the distal ascending and transverse aorta. Advantages of TEE for detection of acute aortic syndromes result from close proximity of the esophagus to the thoracic aorta and its ability to visualize both ascending and descending aorta and parts of the arch with high spatial resolution in real time. Although TEE requires esophageal intubation, images can be acquired at the bedside and immediately interpreted (Figure 5). 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 optional color Doppler flow mapping; intimal tear(s) can be localized in the majority of patients.21 Furthermore, variants of acute aortic syndromes such as idiopathic myocardial hypertrophy, atherosclerotic penetrating ulcers, and side branch obstruction can also be identified.22 Overall, the European Cooperative Study Group and others showed that TEE can reach a sensitivity of 99% with a specificity of 89%, positive predictive accuracy of 89%, and negative predictive accuracy of 99%,22–25 findings later confirmed in IRAD.1 Although TEE is performed in unstable patients at the bedside within 15 minutes, an experienced operator is needed for image acquisition and interpretation. Yet, the adjunctive use of color Doppler interrogation is instrumental to confirm blood flow in both true and false lumen, to identify communication sites, to visualize dynamic side-branch obstruction,26 and in other aortic emergencies27; soon, 3D echograms may be acquired routinely and improve image interpretation.

TEE is limited in assessing abdominal side branches and may be unpleasant for patients who cannot tolerate topical anesthesia and moderate conscious sedation. Given these issues, and considering availability, excellent quality, and scanning speed of current generation multidetector CTA, TEE is advantageous in the emergency assessment of suspected type A dissection. Nevertheless, TEE serves also as an important imaging adjunct to safely perform endovascular stent-grafting in complicated type B dissection and to document immediate procedural success.28

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

**Acute Aortic Syndromes**
Diagnostic imaging studies in the setting of suspected aortic dissection has 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 (eg, 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 the Table. 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 the above symptoms. Although screening TTE provides vital information (eg, new-onset aortic insufficiency, pericardial effusion, or visualization of proximal dissection), additional TEE interrogation of the thoracic aorta is the logical next step, or MD-CT scanning of the entire aorta if considered safe. Both imaging modalities provide further

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**Figure 3.** MRI based on spin-echo axial images in a patient with intramural hematoma of the thoracic aorta: The acute phase T1-weighted spin-echo image shows circular wall thickening of the ascending and descending aorta (A); subsequent T2-weighted image shows high signal intensity indicative of fresh intramural blood (B). In subacute phase, formation of methemoglobin within the aortic wall is identified by high signal intensity in T1-weighted spin-echo sequences (C).

**Figure 4.** Contrast-enhanced MRA of chronic type B dissection originating from the aortic arch region in MIP (A) and as volume-rendered 3D reconstruction (B). Follow-up MRA at 7 days after stent-graft placement shows a completely sealed proximal entry to the thrombosed false lumen. The diameter of the true lumen is normalized and the descending aorta is reconstructed (C).
detail both in types A and B (or distal) dissection and are useful for strategic planning. MRI has no place in urgent diagnostic workup of acutely symptomatic patients. Additional information not crucial in immediate management includes arch vessel and side-branch involvement usually seen on CTA without the need for invasive angiography.

**Chronic Conditions**

In chronic aortic conditions, other issues such as critical diameter expansion, intraluminal thrombosis, or vascular inflammation are in focus; serial comparison to previous imaging studies is often required, and future imaging studies are expected during follow-up in an elective setting. Thus, speed and immediate access is not an issue when following the evolution of chronic dissection or aneurysm. Conversely, longitudinal changes over time and critical expansion are key issues and need to be addressed in the chronic setting; when repeat imaging is needed, MRI is most suitable, offering 3D reconstruction, exact dimensional quantification, and no radiation exposure. Flow-sensitive MR sequences even provide functional information (without gadolinium) on false lumen flow pattern in chronic dissection or aneurysm; MD-CT with or without contrast enhancement should be given preference only if MR techniques are not available.

**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. Although 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. For stable patients, any modality will work, depending on availability and expertise. For patients with suspected aortic syndromes and unfit for transportation, bedside echocardiographic techniques such as TTE and TEE with color Doppler interrogation are first priority but may miss abdominal segments because the abdominal aorta may not be ideally seen from standard subcostal windows. Conversely, MD-CT technology allows rapid acquisition of thinly collimated images of the entire aorta during arterial transit of bolus contrast administration; 16-, 64-, and 256-slice CT scanners have essentially replaced invasive diagnostic angiography for large- and medium-sized vessels of both chest and abdomen. The technology is robust.

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**Table. Sequence and Choice of Diagnostic Modalities in Suspected AAS**

<table>
<thead>
<tr>
<th>Clinical Suspicion of AAS</th>
<th>Diagnostic Evaluation by Imaging Modalities</th>
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<tbody>
<tr>
<td>Optional Exams</td>
<td>Unstable/Critical Conditions</td>
</tr>
<tr>
<td>ECG, chest radiography, biomarkers</td>
<td>1. TEE with color Doppler flow</td>
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<tr>
<td></td>
<td>2. MD-CT with CTA</td>
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| Stable Clinical Condition | TEE | 1. TEE with color Doppler flow |
|                          | 2. MD-CT with contrast enhancement | CTA |
|                          | 3. Angiography rarely required | 3D reconstruction |

AAS indicates acute aortic syndrome; numbers denote the suggested order of diagnostic testing under given conditions.
and rapidly performed with high spatial resolution to differentiate intramural hematoma from ulcers and dissection but requires transport to the diagnostic suite and stable hemodynamic conditions.

MRA is also capable of high-resolution aortic imaging with 3D after 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 (Figure 6).29 Indeed, intramural hematoma, aortic “haustrations” and asymptomatic aortic flaps, aortic ulcers, and aneurysms are reported at increasing frequency with access to tomosgraphic imaging.20,22

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) intraoperatively, with near-perfect sensitivity and specificity,1,27 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 (Figure 5). 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 before immediate transfer to surgery, with TEE performed before sternotomy. Although TTE and TEE are important bedside tools for acute dissection,18 both fail to provide sufficient anatomic detail to plan endovascular interventions (see online-only supplemental table).

Conventional or digital subtraction angiography as well as ultrasound-based techniques have recently been replaced by contrast-enhanced MD-CT and MRA; MRA requires no iodinated contrast or ionizing radiation, allows 3D multiplanar acquisition, and is particularly useful for patients unable to tolerate contrast because of allergy or renal failure. With acute aortic dissection linked to young patients with fibrillatory arrhythmias, diagnostic evaluation during pregnancy and lactation becomes an issue. Although fetal radiation exposure must be avoided (in the initial 20 weeks of pregnancy) for teratogenic and carcinogenic reasons,30 the iodine component of contrast media given during pregnancy has potential to initiate neonatal hypothyroidism. Even with MR contrast agents, a minimal teratogenic risk cannot be excluded; paramagnetic agents such as gadolinium cross the placenta with unknown long-term effects. Although exposure during the first trimester has not been associated with adverse impact on the fetus, controversy is ongoing. Whereas European guidelines consider the use of gadolinium “probably safe during pregnancy” because it is distributed extracellularly and eliminated into urine,31 most centers in the United States discourage gadolinium during pregnancy in fear of retention in amniotic fluid and toxicity.32 For suspected aortic disease in pregnancy, noncontrast MRI using SSFP techniques ensures both maximum safety and high diagnostic precision.15,33–35

MRA is not as severely affected by calcification as is CT. Heavily calcified arteries may still induce artifact on MR angiograms, but luminal narrowings and intramural hematoma are depicted even in presence of atherosclerotic calcification. Thus, MRA is better suited for evaluating occlusive disease of medium-sized arteries and therefore is the modality of choice for patients with lower or upper extremity vascular disease (Figure 6). Despite easier postprocessing, MRA has lower spatial resolution than CT, and images are sensitive to metal (implanted clips or stents), causing distortion and false diagnosis.17,36 Patients with pacemakers, defibrillators, or older mechanical valves are confined to CT angiography (contraindications for MRI). CT is less sensitive to small implants, but streak artifact from large metallic objects such as hip prostheses degrade image quality. With recent scanners, complex vessel morphology as seen in dissections, irregular aneurysms, and vascular tortuosity is better delineated by CT, whereas MRI may produce artifact in areas of turbulent blood flow.36–40 In cases of iodinated contrast allergy, CTA can also be performed after intravenous injection of gadolinium (60 to 80 mL); although gadolinium provides less intense enhancement, diagnostic images are feasible.34 The

![Figure 6. Takayasu arteritis: A, Coronal MIP 3D MRA shows significant stenosis of the right common carotid artery at its origin (small arrow). The left subclavian artery has 2 stenotic segments (large arrows) with a small area of poststenotic dilatation in between. There are also some luminal irregularities of the left common carotid artery. Axial unenhanced (C) and gadolinium-enhanced (B) T1-weighted MRIs show wall thickening of the ascending aorta (arrows).](http://circimaging.ahajournals.org/}

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**Figure 6.** Takayasu arteritis: A, Coronal MIP 3D MRA shows significant stenosis of the right common carotid artery at its origin (small arrow). The left subclavian artery has 2 stenotic segments (large arrows) with a small area of poststenotic dilatation in between. There are also some luminal irregularities of the left common carotid artery. Axial unenhanced (C) and gadolinium-enhanced (B) T1-weighted MRIs show wall thickening of the ascending aorta (arrows).
status of branch arteries and quantitative morphology of both aneurysm or dissection on CT or MRI are essential for strategic planning and thus either modality is recommended before endovascular repair of aneurysm and dissection.38 Similarly, both MRA and CTA are useful for thoracic masses, often vascular in nature such as mycotic aneurysms or traumatic pseudoaneurysm (Figure 7) and for inflammatory vascular disease (Figure 6). Moreover, loss of elastic properties, aortic shear stress, and increased wall tension can be quantified with flow-sensitive MR sequences.41 For serial follow-up after surgical or endovascular repair, 3D MRI sequences are preferred, particularly when stent-graft components consist of nitinol (Figure 8); in the presence of stainless steel, MD-CT is better to identify endoleaks or to confirm complete isolation of an aneurysm, because steel causes magnetic disturbances and MRI artifact.

Future Trends in Aortic Imaging
Although the interest in molecular imaging is largely confined to the study of neoplasia and degenerative diseases, vascular applications of molecular imaging are emerging, with the goal of identifying patients in early stages of atherosclerosis by endothelial expression of vascular adhesion molecules.42,43 Additionally, biochemical markers of acute dissection, such as elevated myosin heavy-chain concentration, D-dimer levels, and soluble elastin fragments, may assist in preselecting patients for imaging. The rapid evolution of CT and MR technology supports the investigational but emerging “triple rule-out” concept by simultaneously evaluating coronary arteries (acute coronary syndrome), thoracic aorta (dissection, ulcer), and pulmonary arteries (pulmonary embolism).44

Figure 7. Sixty-four-slice MDCT angiogram of a patient with para-anastomotic aneurysm (arrow) after previous open surgery (left). The result after placement of a customized stent graft is shown in 2 views (right).

Figure 8. MRA-MIP images of an aortic arch aneurysm in parasagittal-oblique orientation (A). Follow-up study after a hybrid procedure with initial head vessel debranching and staged endovascular repair by use of a nitinol stent graft demonstrates perfect reconstruction of the proximal aorta in parasagittal-oblique projection (B) and axial reformatted orientation (C).
Further technological advances are on the horizon with multiple x-ray sources around the patient to minimize CT scan time to seconds; 3-T MR units are already a clinical reality and provide improved signal-to-noise ratio with better MRA image contrast than 1.5-T magnets. ECG-gated CTA can accurately determine aortic distensibility in both phantom models and real patients, and 3-T MRA with 3D velocity mapping offers hemodynamic evaluation of normal and diseased thoracic aorta. Both techniques attempt to visualize stress and strain early on the aortic wall. Intravascular ultrasound imaging or optical coherence tomography may be particularly useful in conjunction with endovascular procedures to visualize wall architecture, associated plaques, hematoma, and microdissections. Moreover, real-time MR-guided vascular interventions have been demonstrated in animals and in patients.

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

Disclosures
None.

References


**KEY WORDS:** aortic diseases ■ aneurysm ■ dissection ■ tomographic imaging
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doi: 10.1161/CIRCIMAGING.109.850206
Circulation: Cardiovascular Imaging is published by the American Heart Association, 7272 Greenville Avenue, Dallas, TX 75231
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Print ISSN: 1941-9651. Online ISSN: 1942-0080

The online version of this article, along with updated information and services, is located on the World Wide Web at:
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### Supplemental Material

**Supplemental Table 1: Comparison of diagnostic imaging techniques**

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*Gd, gadolinium; NSF; nephrogenic systemic fibrosis.