

**American College of Radiology  
ACR Appropriateness Criteria®  
Thoracic Aortic Aneurysm or Dissection-Treatment Planning and Follow-Up**

**Variant 1: Adult. Known thoracic aortic aneurysm or dissection without repair. With or without symptoms. Follow-up imaging.**

Procedure	Appropriateness Category	Relative Radiation Level
CTA chest abdomen pelvis with IV contrast	Usually Appropriate	⊕⊕⊕⊕⊕
CTA chest with IV contrast	Usually Appropriate	⊕⊕⊕
MRA chest abdomen pelvis with IV contrast	Usually Appropriate	○
MRA chest abdomen pelvis without IV contrast	Usually Appropriate	○
MRA chest with IV contrast	May Be Appropriate	○
MRA chest without IV contrast	May Be Appropriate	○
CT chest abdomen pelvis with IV contrast	May Be Appropriate	⊕⊕⊕⊕
CT chest abdomen pelvis without and with IV contrast	May Be Appropriate	⊕⊕⊕⊕
CT chest with IV contrast	May Be Appropriate	⊕⊕⊕
US echocardiography transesophageal	May Be Appropriate	○
US echocardiography transthoracic resting	May Be Appropriate	○
CT chest without and with IV contrast	May Be Appropriate	⊕⊕⊕
CT chest abdomen pelvis without IV contrast	Usually Not Appropriate	⊕⊕⊕⊕
Aortography chest abdomen pelvis	Usually Not Appropriate	⊕⊕⊕⊕
CT chest without IV contrast	Usually Not Appropriate	⊕⊕⊕
Radiography chest	Usually Not Appropriate	⊕

**Variant 2:****Adult. Prethoracic endovascular repair or open repair of thoracic aorta aneurysm or dissection. Preprocedure planning.**

Procedure	Appropriateness Category	Relative Radiation Level
CTA chest abdomen pelvis with IV contrast	Usually Appropriate	⊕⊕⊕⊕⊕
MRA chest abdomen pelvis with IV contrast	Usually Appropriate	○
CT chest abdomen pelvis with IV contrast	May Be Appropriate	⊕⊕⊕⊕
CT chest abdomen pelvis without and with IV contrast	May Be Appropriate	⊕⊕⊕⊕
CTA chest with IV contrast	May Be Appropriate	⊕⊕⊕
CT chest with IV contrast	May Be Appropriate	⊕⊕⊕
CT chest without and with IV contrast	May Be Appropriate	⊕⊕⊕
MRA chest abdomen pelvis without IV contrast	May Be Appropriate (Disagreement)	○
MRA chest with IV contrast	May Be Appropriate	○
MRA chest without IV contrast	May Be Appropriate	○
US echocardiography transesophageal	Usually Not Appropriate	○
US echocardiography transthoracic resting	Usually Not Appropriate	○
Aortography chest abdomen pelvis	Usually Not Appropriate	⊕⊕⊕⊕
CT chest abdomen pelvis without IV contrast	Usually Not Appropriate	⊕⊕⊕⊕
CT chest without IV contrast	Usually Not Appropriate	⊕⊕⊕
US duplex Doppler iliofemoral arteries	Usually Not Appropriate	○
US duplex Doppler aorta abdomen	Usually Not Appropriate	○

**Variant 3:****Adult. Post thoracic endovascular repair of thoracic aortic aneurysm or dissection. Surveillance.**

Procedure	Appropriateness Category	Relative Radiation Level
CTA chest abdomen pelvis with IV contrast	Usually Appropriate	⊕⊕⊕⊕⊕
CTA chest with IV contrast	Usually Appropriate	⊕⊕⊕
MRA chest abdomen pelvis with IV contrast	Usually Appropriate	○
CT chest abdomen pelvis with IV contrast	May Be Appropriate	⊕⊕⊕⊕
CT chest abdomen pelvis without and with IV contrast	May Be Appropriate	⊕⊕⊕⊕
CT chest abdomen pelvis without IV contrast	May Be Appropriate	⊕⊕⊕⊕
CT chest with IV contrast	May Be Appropriate	⊕⊕⊕
CT chest without and with IV contrast	May Be Appropriate	⊕⊕⊕
MRA chest abdomen pelvis without IV contrast	May Be Appropriate	○
MRA chest with IV contrast	May Be Appropriate	○
MRA chest without IV contrast	May Be Appropriate	○
CT chest without IV contrast	May Be Appropriate	⊕⊕⊕
Aortography chest abdomen pelvis	Usually Not Appropriate	⊕⊕⊕⊕⊕
Radiography chest	Usually Not Appropriate	⊕
US echocardiography transthoracic resting	Usually Not Appropriate	○
US duplex Doppler aorta abdomen	Usually Not Appropriate	○
US echocardiography transesophageal	Usually Not Appropriate	○

**Variant 4:****Adult. Post open repair of thoracic aortic aneurysm or dissection. Surveillance.**

Procedure	Appropriateness Category	Relative Radiation Level
CTA chest abdomen pelvis with IV contrast	Usually Appropriate	⚠⚠⚠⚠⚠
CTA chest with IV contrast	Usually Appropriate	⚠⚠⚠
MRA chest abdomen pelvis with IV contrast	Usually Appropriate	○
CT chest abdomen pelvis with IV contrast	May Be Appropriate	⚠⚠⚠⚠
MRA chest abdomen pelvis without IV contrast	May Be Appropriate	○
MRA chest with IV contrast	May Be Appropriate	○
CT chest abdomen pelvis without and with IV contrast	May Be Appropriate	⚠⚠⚠⚠
CT chest with IV contrast	May Be Appropriate	⚠⚠⚠
CT chest without and with IV contrast	May Be Appropriate	⚠⚠⚠
MRA chest without IV contrast	May Be Appropriate	○
CT chest abdomen pelvis without IV contrast	May Be Appropriate	⚠⚠⚠⚠
CT chest without IV contrast	Usually Not Appropriate	⚠⚠⚠
Aortography chest abdomen pelvis	Usually Not Appropriate	⚠⚠⚠⚠
Radiography chest	Usually Not Appropriate	⚠
US duplex Doppler aorta abdomen	Usually Not Appropriate	○
US echocardiography transesophageal	Usually Not Appropriate	○
US echocardiography transthoracic resting	Usually Not Appropriate	○

## THORACIC AORTIC ANEURYSM OR DISSECTION-TREATMENT PLANNING AND FOLLOW-UP

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### Summary of Literature Review

#### **Introduction/Background**

Diseases of the thoracic aorta include 2 broad categories: aneurysmal dilation, involving all 3 layers of the intact aortic wall, and acute aortic syndromes, wherein at least one layer of the aortic wall is disrupted, such as in aortic dissection. These diseases carry a variable risk of subsequent aortic rupture, which is associated with high morbidity and mortality. Imaging is critical in the diagnosis, surveillance, and treatment of this constellation of diseases.

Thoracic aortic aneurysm (TAA) is defined as permanent dilation of the aorta by more than 2 SDs over the mean. The prevalence is 4.2% for patients without predisposing factors [1]. The prevalence is higher in those with risk factors, which include hypertension, atherosclerosis, bicuspid aortic valve, familial TAA diseases, vasculitis, and heritable connective tissue disorders [1]. Sixty percent of TAAs involve the ascending aorta and/or aortic arch [1]. The risk of rupture increases with the size of the aneurysm, roughly doubling with every 1 cm of growth over 5 cm [2]. Aneurysms 6.0 to 6.5 cm carry a 7% annual risk of rupture [1,2]. Symptomatic aneurysms and those that grow at an annual rate >1 cm are also more prone to rupture [3].

Acute aortic syndrome comprises 3 potentially life-threatening pathologies: penetrating atherosclerotic ulcer (PAU), intramural hematoma (IMH), and acute dissection [4,5]. Dissections are defined by a tear in the intimal wall that opens a false lumen for blood to flow into, which is then trapped between the intima and media [6]. In contrast, a PAU is a focal erosion of the intima from long-standing atherosclerotic disease that allows for intraluminal blood to reach the media [6]. An IMH is thought to arise from a spontaneous hemorrhage of vessels within the aortic wall, disrupting the relationship between the intima and media; however, in contrast to dissections and PAU, there is no intimal tear to allow for luminal blood to enter the aortic wall [6]. Both PAU and IMH may progress to dissection and are managed similarly to dissection [6]. Risk factors for these pathologies include male sex, hypertension, hyperlipidemia, arteriosclerosis, and smoking. There are also genetic syndromes that underly this constellation of diseases, including Marfan syndrome, Loeys-Dietz syndrome, and other familial TAAs. The Stanford classification defines dissections by anatomic location and is helpful for treatment categorization. Classically, type A dissections involve the ascending aorta or arch to the point of the left subclavian artery origin with or without descending aorta involvement, whereas type B dissections involved only the descending aorta distal to the left subclavian artery origin. The Society for Vascular Surgery/Society of Thoracic Surgeons classification published in 2020 includes aortic zones to provide more precise information on the location of the entry tear, with type A dissection describing an entry tear in zone 0, and type B dissection describing an entry tear in zone 1 to 9 [7]. Under this new classification, the aortic arch is included within the definition of a type B dissection.

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Complicated acute type B aortic dissections (TBADs) are defined by the presence of any of the following: hemodynamic instability, clinical or radiological findings of aortic rupture or impending rupture, or malperfusion syndrome (defined by end organ ischemia) [8-10].

### **Medical Management Versus Aortic Repair**

Treatment for thoracic aortic pathologies includes medical management versus repair (surgical, endovascular, or hybrid approach). The decision between medical management versus repair for acute aortic syndrome is multifactorial and rests on whether the patient has responded to medical therapy, whether the patient is symptomatic, and the location of the acute aortic syndrome [11]. Medical management focuses on decreasing the forces felt by the aortic wall by decreasing blood pressure [12], whereas repair focuses on preventing aneurysmal degeneration/rupture, maintaining true lumen patency, and preventing end organ malperfusion [4]. A certain percentage of patients will ultimately fail optimal medical management and require intervention [13].

Clinical guidelines suggest elective surgical repair of ascending TAA at 5.5 cm in patients without underlying connective tissue disorders and earlier intervention (eg, at 4.5-5.0 cm) in patients with underlying connective tissue disorders or a bicuspid aortic valve [1]. Intervention is also considered when aneurysms are persistently symptomatic or if impending rupture is suspected [2,3]. Type A dissection is almost always repaired, given the concern for extension to involve carotid arteries, aortic root, and/or aortic valve leaflets and the potential for rupture into the pericardial sac and published incidence of improved outcomes compared with conservative management [10]. Cases of complicated type B dissection are considered for repair [14,15]. Uncomplicated acute TBAD is usually managed with antihypertensives and surveillance, with an in-hospital mortality rate between 1% and 10% [16,17]. However, patients with uncomplicated acute TBAD and high-risk features (aortic diameter >4.4 cm, a false lumen diameter >2.2 cm, or >60 years of age on admission) are thought to carry increased risk of mortality and are increasingly considered for thoracic endovascular aortic repair (TEVAR) [12]. The goal of TEVAR in all cases of dissection is to induce favorable remodeling of the aorta by re-establishing true lumen blood flow and covering intimal tear entry sites to induce false lumen thrombosis [14,18-23]. Complicated pathologies involving the ascending aorta, arch vessels, or visceral arteries often require an open surgical or hybrid surgical and endovascular approach [24]. However, there is evidence to suggest TEVAR, particularly with ongoing advances in devices, can be used successfully in patients with ascending aortic dissection or equivalent that are poor surgical candidates [25,26].

### **Discussion of Procedures by Variant**

#### **Variant 1: Adult. Known thoracic aortic aneurysm or dissection without repair. With or without symptoms. Follow-up imaging.**

Imaging is fundamental in surveillance of both aortic aneurysms and dissection. In cases of TAA, aneurysm diameter and growth rate are the main data points that inform management decisions [27]. Independent of imaging modality, consistency of measurement methodology is paramount to avoid technical variability that could trigger a clinical decision to intervene based on diameter-based cutoffs [28].

Aortic dissection surveillance aims to identify late complications that may require interventions [29]. Dissection surveillance is based largely on aortic diameter and growth rate, which is a predictor of aortic complications and death [16,17]. A retrospective study looking at aortic aneurysm growth rate in 108 patients with acute type B dissection found that 37% eventually required operative intervention, underscoring the need for ongoing surveillance in this population [16]. Imaging surveillance is also important for detecting increased inflow and decreased blood outflow into the false lumen, which can increase false lumen diastolic pressure; this can increase the risk of aneurysmal dilation, true lumen collapse, and aortic rupture [10,17,30]. Other important findings on surveillance imaging include findings of malperfusion syndrome, involvement of branch vessels (eg, dissection flap enters vessel or obstructs the vessel), and end organ ischemia [10].

#### **Aortography Chest Abdomen Pelvis**

The literature does not support the use of aortography of the chest, abdomen, and pelvis for follow-up of known TAA or dissection without repair.

#### **CT Chest Abdomen Pelvis With IV Contrast**

Although not ideal, the use of contrast-enhanced CT can provide some information on progression and anatomic extent of vascular pathology [31-33]. The principal limitations of this study are the lack of electrocardiographic (ECG) gating,

lack of standard thin-section image acquisition, lack of arterial-phase bolus timing, and lack of 3-D renderings with routine contrast-enhanced CT [34].

#### **CT Chest Abdomen Pelvis Without and With IV Contrast**

Although not ideal, the use of multiphase CT (without and with intravenous [IV] contrast) can provide some information on progression and the anatomic extent of vascular pathology [31-33]. The principal limitations of this study are the lack of ECG gating, lack of standard thin-section image acquisition, lack of arterial-phase bolus timing, and lack of 3-D renderings with routine contrast-enhanced CT [34].

For patients in need of follow-up imaging of known IMH, noncontrast images can be helpful for visualization of the hyperattenuating crescent within the aortic wall, which is often masked on contrast-enhanced images by attenuation of the aortic wall [5]. Dual-layer dual-energy CT (DECT) allows for virtual noncontrast images by discriminating materials with different effective atomic numbers [35]. A retrospective study performed of 21 patients at 2 institutions demonstrated no significant difference in the diagnostic confidence between true noncontrast and virtual noncontrast images from dual-layer DECT for the diagnosis of IMH [35].

#### **CT Chest Abdomen Pelvis Without IV Contrast**

Noncontrast CT as a standalone study can detect changes in aortic diameter, identify IMH, and aid in identifying mediastinal or pericardial hemorrhage that could be sequelae of aortic rupture in cases of acute aortic syndrome but otherwise has little use in the follow-up of TAA or dissection.

#### **CT Chest With IV Contrast**

Because thoracic aortic pathology can extend to involve the abdominal aorta and iliac arteries, imaging of the chest, abdomen, and pelvis is standard in the evaluation of vascular pathology. However, if serial studies have shown that the pathology remains limited to the thorax, inclusion of the abdomen and pelvis may be unnecessary.

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#### **CTA Chest Abdomen Pelvis With IV Contrast**

CTA provides superior spatial and temporal resolution and provides homogeneous intraluminal contrast enhancement [36]. The small (near) isotropic voxels achievable by thin-section acquisition allow for multiplanar reformatting, facilitating centerline/double oblique true short axis measurements of aortic diameter [27,37,38]. Using 3-D data sets also facilitates maximum intensity projection, volume rendering, and multiplanar curved reformats, which may be

helpful in providing an overview of pathology and adjacent anatomy [34]. Software programs can be used to semiautomatically draw a center line through the aortic lumen to facilitate repeatable measurements such as the length of affected aortic segments and diameters at proximal and distal landing zones for graft sizing [39].

ECG gating is particularly useful for temporal resolution of the ascending aorta, where cardiac motion can lead to artifacts [1,40]. ECG gating also ensures that measurements are being made reliably in the same phase of the cardiac cycle. One study of 27 patients found a 5% to 10% difference in diameter of proximal descending thoracic aortic measurements during systole and diastole [41].

CTA protocols for aortic pathology usually include an arterial and a delayed contrast phase. For patients in need of follow-up imaging of known IMH, noncontrast images can be helpful for visualization of the hyperattenuating crescent within the aortic wall, which is often masked on contrast-enhanced images by attenuation of the aortic wall [5]. A retrospective study of 306 patients with acute chest pain assessed the need for noncontrast images for diagnosis of IMH by comparing the diagnostic sensitivity, specificity, and accuracy of a dual-phase CTA (unenhanced and enhanced) versus a single-phase CTA (enhanced) for IMH [42]. The researchers found a 12% incidence of IMH in their study sample (36/306 patients) and significantly improved sensitivity, specificity, and accuracy of dual-phase CTA (inclusion of a noncontrast series) versus single-phase CTA for diagnosis of IMH [42].

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The accuracy of CTA for aortic dissection is high, with sensitivity and specificity in the 98% to 100% range [5]. In cases of dissection, the intimal flap is visible by CTA approximately 70% of the time [37]. A study of 22 consecutive patients with type A IMH demonstrated that the maximum aortic diameter as assessed by CTA was the strongest predictor for progression of type A IMH; a cutoff of 50 mm has a positive predictive value of 83% and a negative predictive value of 100% [43]. If descending aortic dissection is identified, a careful assessment of visceral organs should be made to ensure that malperfusion is not being missed. Extension of CTA to include the chest, abdomen, and pelvis is useful in assessment and surveillance of patients with TBAD to document intimal flap extension below the diaphragm and into the visceral arteries [44]. In one study, 68 of 69 patients with complicated TBAD had dissections that extended below the diaphragm (98.6%), highlighting the need to include imaging of the abdomen and pelvis for optimal characterization [20]. In cases of aortic root or ascending aortic pathology, an assessment of the aortic valve, coronary arteries, pericardial sac, and mediastinum should be made.

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### **MRA Chest Abdomen Pelvis With IV Contrast**

Contrast-enhanced MR angiography (CE-MRA) typically uses gadolinium contrast for 3-D aortic depiction. ECG gating is particularly important for imaging of the ascending aorta because artifacts from cardiac motion and aortic pulsatility can lead to artifacts in critical aortic root structures [45,46]. Alternative contrast agents such as ferumoxytol have a long half-life in the blood pool, which further facilitates ECG and respiratory gating. A retrospective study of 45 patients who underwent ECG- and respiratory-gated MRA of the chest either with an iron-based contrast agent (ferumoxytol) (n = 23) or without contrast (n = 22), found that contrast improved qualitative image quality and quantitative assessment of the aortic annulus and ascending aorta, with substantially improved reproducibility of aortic valve annulus measurements [47].

A retrospective study of 127 patients compared thoracic aortic measurements made on CTA, MRA (ECG-gated balanced steady-state free precession [bSSFP] and nongated CE-MRA images), and transthoracic echocardiography (TTE) studies; the researchers found no differences in measurements between CTA and MRA but found that TTE underestimates maximum aortic root diameter when compared with CTA and MRA [48].

The literature suggests that MRA is an alternative to CTA. A study of 50 patients presenting to the emergency department for evaluation of thoracic aortic dissection found that MRA was well-tolerated, which resulted in diagnosis allowing for appropriate ED disposition [49].

CE-MRA can also be useful in differentiating aortic wall inflammation from IMH and atheromatous disease [36].

### **MRA Chest Abdomen Pelvis Without IV Contrast**

Noncontrast MRA includes several sequences that allow excellent visualization of aortic lumen, such as steady-state free precession (SSFP) and bSSFP sequences that do not require contrast administration, given their inherent contrast between blood pool and vessel wall/myocardium [1,50,51]. A prospective study of 31 patients who underwent both ECG-gated CTA and ECG-gated and pulse-gated breath-hold noncontrast bSSFP-MRA (ECG-MRA, precession-MRA) found excellent agreement in thoracic aortic measurements, although image quality for both MRA sequences was rated as poorer than that of CTA [52]. A retrospective study of 30 patients comparing SSFP-MRA with CE-MRA found that double oblique short axis thoracic aortic measurements were comparable between the 2 methods, with improved inter- and intraobserver reproducibility with SSFP-MRA for ascending and root aortic measurements [50].

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Three-dimensional black-blood MRI sequences such as 3-D simultaneous noncontrast angiography and intraplaque hemorrhage (SNAP) and 3-D volume isotropic turbo spin echo acquisition (VISTA) have been used to assess atherosclerotic plaque in the thoracic aortic wall and can be useful in the assessment of PAU and IMH [53].

### **MRA Chest With IV Contrast**

Because thoracic aortic pathology often extends to involve the abdominal aorta, imaging of the chest, abdomen, and pelvis is standard in the evaluation of vascular pathology. However, if serial studies have shown that the pathology remains limited to the thorax, inclusion of the abdomen and pelvis may be unnecessary.

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### **Radiography Chest**

The literature does not support the use of chest radiography for follow-up of known TAA or dissection without repair. An abnormal chest radiograph may be the first suggestion of acute aortic syndrome but is more typically used to rule out other causes of acute chest pain.

### **US Echocardiography Transesophageal**

Transesophageal echocardiography (TEE) excels at diagnosis of aortic dissection, with a sensitivity and specificity of 96.8% and 100%, respectively [5]. TEE may additionally provide information about aortic valve dysfunction, pericardial tamponade, or cardiac wall motion abnormalities, which may aid in both diagnosis and preprocedural planning [5]. Intrinsic limitations of TEE acquisitions in the distal aspect of the ascending aorta are caused by obstructed views from air in the trachea and major bronchi [54]. Another limitation is the small field of view afforded by TEE, although this is beginning to be addressed with experimental image fusion strategies [55]. The need for sedation is also a drawback.

## **US Echocardiography Transthoracic Resting**

Two-dimensional TTE measurements of the aortic root and ascending aorta are widely used for detection and follow-up of disease at these locations, often obtained from the parasternal long-axis view [1]. Measurements by TTE have long been the basis of surgical decision-making, with published outcomes data and multiple ultrasound (US)-based nomograms for aortic measurements [28]. The sex- and age-specific nomograms for aortic root measurements established from the Framingham Heart Study were obtained using 2-D US [1]. However, there is some heterogeneity over measurement technique (eg, inner edge versus leading edge) and which phase within the cardiac cycle measurements should be made at (diastole versus systole), leading to divergence in measurements of the annulus, sinuses of Valsalva, and sinotubular junction when different methods are used [28]. TTE faces limitations presented by the anatomy surrounding the thoracic aorta, particularly for the descending aorta (lack of clear acoustic window posterior to the left atrium from the isthmus to the mid-descending aorta, adjacent bone, intrapulmonary gas, distance from chest wall) [5,56]. In a study of 40 patients who underwent TTE of the thoracic aorta, the mid-portion of the descending aorta was not visualized in 30% [56].

A retrospective study of 127 patients compared thoracic aortic measurements made on CTA, cardiac MRI (ECG-gated bSSFP and nongated CE-MRA images), and TTE studies; the researchers found no differences in measurements between CTA and cardiac MRI but found that TTE underestimates maximum aortic root diameter when compared with CTA and cardiac MRI [48].

A prospective study of 50 patients with ascending aortic dilation compared thoracic ascending and arch aortic diameter measurements made by 2-D TTE, 3-D TTE, and multidetector CT (MDCT) [57]. Three-dimensional TTE measurements had the best correlation and agreement with MDCT measurements. Three-dimensional probes allow X-plane views, which means that more accurate true short axis measurements may be achieved [57]. A prospective case control cohort study of 40 patients compared descending aortic diameter values between TTE and CTA and found that TTE slightly underestimated the descending aortic diameter relative to CTA at the level of the diaphragm [56].

## **Variant 2: Adult. Prethoracic endovascular repair or open repair of thoracic aorta aneurysm or dissection. Preprocedure planning.**

The decision for open surgical, endovascular, or hybrid repair depends on patient anatomy and pathology, comorbidities, and expected durability of repair [58]. Areas of focus include size of vascular access (iliofemoral arteries), sufficient length and angulation of proximal and distal aortic landing zones, and acceptable levels of vessel tortuosity involving the vessels that must be traversed by the delivery system [58]. Imaging plays a significant role in identifying candidates for these procedures [37,38,59].

For TAAs, size and location are key determinants in whether repair is indicated [37,38]. Measurements of the pathologic aorta are used to determine appropriate stent graft size and length. In addition, stent graft placement requires a suitable landing zone (2.0-2.5 cm of normal aorta proximally and distally). Consideration is given to intraluminal thrombus and calcifications as well as the location of entry and intimal tears in the case of thoracic aortic dissection [38]. Unlike with treatment for aneurysms, the distal landing zone may be in an area of dissection [9].

Iliofemoral arteries must be able to accept the delivery systems required for TEVAR, which typically range between 7 and 9.5 mm (18-26F) in outer diameter [59]. Access through a transapical approach is also an option in cases with poor vascular access, as well as in select cases with severe atherosclerotic disease of the descending thoracic aorta [59-63].

For ascending aorta repairs, distance from coronary artery ostia and aortic valve need to be assessed. Confirming the absence of coronary artery bypass grafts inserting into the aorta is needed. When the arch is involved, branch vessel anatomy should be assessed for variants (eg, direct origin of the left vertebral artery from the aorta) to assess the need for bypass or transposition of the great vessels [61,62]. In either case, a hybrid or staged surgical and endovascular approach may be required. Coverage of the artery of Adamkiewicz and extension of pathology into the abdominal aorta and involvement of the abdominal visceral arteries should be noted.

## **Aortography Chest Abdomen Pelvis**

Invasive imaging with risk of access site complication has limited utility in planning aside from answering very specific questions such as the location of origin of the artery of Adamkiewicz [64].

### **CT Chest Abdomen Pelvis With IV Contrast**

Although not ideal, the use of contrast-enhanced CT can provide some information about the anatomic extent of vascular pathology. The principal limitations of this study are the lack of ECG gating, lack of standard thin-section image acquisition, lack of arterial-phase bolus timing, and lack of 3-D renderings with routine contrast-enhanced CT, which can be particularly important when a dedicated CTA has not been previously performed to evaluate the aortic pathology [34].

### **CT Chest Abdomen Pelvis Without and With IV Contrast**

Although not ideal, the use of multiphase CT (without and with IV contrast) can provide some information with regard to the anatomic extent of vascular pathology. The principal limitations of this study are the lack of ECG gating, lack of standard thin-section image acquisition, lack of arterial-phase bolus timing, and lack of 3-D renderings with routine contrast-enhanced CT, which can be particularly important when a dedicated CTA has not been previously performed to evaluate the aortic pathology [34].

### **CT Chest Abdomen Pelvis Without IV Contrast**

The literature does not support the use of CT without IV contrast for preoperative aortic evaluation.

### **CT Chest With IV Contrast**

Because thoracic aortic pathology often extends to involve the abdominal aorta, imaging of the chest, abdomen, and pelvis is standard in the evaluation of vascular pathology. Extension to include the abdomen and pelvis allows for the assessment of iliofemoral artery diameters, extent of calcification, and tortuosity, which is important for TEVAR planning [63]. Lack of imaging of the abdomen and pelvis in this study is a limitation, particularly if TEVAR is being considered. Other limitations of this study are the lack of ECG gating, lack of standard thin-section image acquisition, lack of arterial-phase bolus timing, and lack of 3-D renderings with routine contrast-enhanced CT, which can be particularly important when a dedicated CTA has not been previously performed to evaluate the aortic pathology [34].

### **CT Chest Without and With IV Contrast**

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### **CT Chest Without IV Contrast**

The literature does not support the use of CT without IV contrast for preoperative aortic evaluation.

### **CTA Chest Abdomen Pelvis With IV Contrast**

CTA extension to include the abdomen and pelvis allows for the assessment of iliofemoral artery diameters, extent of calcification, and tortuosity, which is important for TEVAR planning [63]. CTA protocols for aortic pathology usually include both an arterial phase and a delayed contrast phase. A noncontrast phase may also be included, depending on the indication (eg, characterizing IMH). Multidetector CTA is used for preoperative assessment for thoracic aortic pathologies, given spatial resolution, isotropy, and compatibility with software programs used in measurements. ECG gating is particularly useful for temporal resolution of the ascending aorta, where cardiac motion can lead to artifacts [1,40]. ECG gating also ensures that measurements are being made reliably in the same phase of the cardiac cycle. One study of 27 patients found a 5% to 10% difference in diameter of proximal descending thoracic aortic measurements during systole and diastole [41].

A critical component of planning for TEVAR is measuring patient anatomy to ensure correct sizing and placement of a stent graft. CTA is used in planning the coverage zone (including proximal and distal landing zones), identifying potential complications, and sizing devices [37]. CTA is particularly useful in mapping complex anatomies such as the aortic arch in planning for aneurysm or dissection repair. This includes obtaining dimensions for landing zones, distances between and alignment of arch vessels, and overall length of pathologic aorta to be covered [65]. If the landing zone is adjacent to or overlapping with the left subclavian artery take-off, embolization of the artery or bypass may need to be considered. CTA is useful in identifying high-risk features that might predict postintervention complications. For example, increased aortic tortuosity in the proximal landing zone is associated with increased risk of endoleak after TEVAR. In a study of 40 patients, quantitative analysis of the curvature of the median centerline was performed on CTA data sets, and tortuosity indexes were calculated at proximal and distal fixation zones, as well as

within the diseased portion [66]. The tortuosity index of the proximal fixation zone and the diseased segment were significantly higher in patients who developed type III endoleaks. In another study of 77 consecutive patients who underwent TEVAR for aneurysm, the preoperative aortic tortuosity index was calculated by CTA; patients in the high-tortuosity index group were at greater risk of endoleak, stroke, and all-cause mortality [67]. The authors conclude that identification of this population at greater risk of adverse events before intervention may argue for more attention to procedural planning, perioperative procedures, and postoperative surveillance. This is particularly an issue in the aortic arch, where a highly angulated or curved arch may prevent the stent graft from being able to conform appropriately. Over time, the lack of apposition of the stent to the lesser curvature of the aorta results in a gap between the stent graft and the aortic wall, referred to as a bird-beak configuration, and is associated with a higher risk of endoleak, in particular type Ia endoleak [68,69]. A retrospective study of 38 patients demonstrated how postprocessing of CTA data to measure aortic arch angulation along the center line could be used to predict which patients may be at increased risk of developing a bird-beak configuration post-TEVAR [68]. These patients may require closer imaging follow-up postprocedure to screen for late-developing endoleak [69].

### **CTA Chest With IV Contrast**

Because thoracic aortic pathology can extend to involve the abdominal aorta and iliac arteries, imaging of the chest, abdomen, and pelvis is standard in the evaluation of vascular pathology. Assessment of iliofemoral artery diameters, extent of calcification, and tortuosity is important for TEVAR planning [63]. Lack of imaging of the abdomen and pelvis in this study is a limitation, particularly if TEVAR is being considered.

CTA protocols for aortic pathology usually include both an arterial phase and a delayed contrast phase. A noncontrast phase may also be included, depending on the indication (eg, characterizing IMH). Multidetector CTA is used for preoperative assessment for thoracic aortic pathologies, given spatial resolution, isotropy, and compatibility with software programs used in measurements. ECG gating is particularly useful for temporal resolution of the ascending aorta, where cardiac motion can lead to artifacts [1,40]. ECG gating also ensures that measurements are being made reliably in the same phase of the cardiac cycle. One study of 27 patients found a 5% to 10% difference in diameter of proximal descending thoracic aortic measurements during systole and diastole [41].

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### **MRA Chest Abdomen Pelvis With IV Contrast**

Because thoracic aortic pathology can extend to involve the abdominal aorta and iliac arteries, imaging of the chest, abdomen, and pelvis is standard in evaluation of vascular pathology. Inclusion of the abdomen and pelvis allows for the assessment of iliofemoral artery diameters and tortuosity, which is important for TEVAR planning [63].

CE-MRA typically uses gadolinium contrast for 3-D aortic depiction. ECG gating is particularly important for imaging of the ascending aorta because artifacts from cardiac motion and aortic pulsatility can lead to artifacts in critical aortic root structures [45,46]. Alternative contrast agents such as ferumoxytol have a long half-life in the blood pool, which further facilitates ECG and respiratory gating. A retrospective study of 45 patients who underwent ECG- and respiratory-gated MRA of the chest either with an iron-based contrast agent (ferumoxytol) (n = 23) or without contrast (n = 22) found that contrast improved the qualitative image quality and quantitative assessment of the aortic annulus and ascending aorta, with substantially improved reproducibility of aortic valve annulus measurements [47].

A retrospective study of 127 patients compared thoracic aortic measurements made on CTA, MRA (ECG-gated bSSFP and nongated CE-MRA images), and TTE studies; the authors found no differences in measurements between CTA and MRA but found that TTE underestimates maximum aortic root diameter when compared to CTA and MRA [48].

#### **MRA Chest Abdomen Pelvis Without IV Contrast**

Noncontrast MRA includes several sequences that allow excellent visualization of aortic lumen, such as SSFP and bSSFP sequences that do not require contrast administration, given their inherent contrast between blood pool and vessel wall/myocardium [1,50,51]. A prospective study of 31 patients who underwent both ECG-gated CTA and ECG-gated and pulse-gated breath-hold noncontrast bSSFP-MRA (ECG-MRA, precession-MRA) found excellent agreement in thoracic aortic measurements, although image quality for both MRA sequences was rated as poorer than that of CTA [52]. A retrospective study of 30 patients comparing SSFP-MRA to CE-MRA found that double oblique short axis thoracic aortic measurements were comparable between the 2 methods, with improved inter- and intraobserver reproducibility with SSFP-MRA for ascending and root aortic measurements [50].

A retrospective study of 127 patients compared thoracic aortic measurements made on CTA, MRA (ECG-gated bSSFP and nongated CE-MRA images), and TTE studies; the authors found no differences in measurements between CTA and MRA but found that TTE underestimates maximum aortic root diameter when compared to CTA and MRA [48].

A prospective study of 24 patients with thoracic aortic dilation compared CTA with a prototype noncontrast free-breathing 3-D radial bSSFP whole-heart MRA sequence combined with compressed sensing-based reconstruction [70]. Intraclass correlation coefficients (ICCs) were used to assess agreement between CTA and MRA for area, circumference, and diameter of the thoracic aorta at multiple levels, with good to excellent agreement.

#### **MRA Chest With IV Contrast**

Because thoracic aortic pathology can extend to involve the abdominal aorta and iliac arteries, imaging of the chest, abdomen, and pelvis is standard in the evaluation of vascular pathology. Assessment of iliofemoral artery diameters, extent of calcification, and tortuosity is important for TEVAR planning [63]. Lack of imaging of the abdomen and pelvis in this study is a limitation if TEVAR is being considered.

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#### **MRA Chest Without IV Contrast**

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### **US Duplex Doppler Aorta Abdomen**

The literature does not support the use of duplex Doppler US of the abdominal aorta for preprocedural planning.

### **US Duplex Doppler Iliofemoral Arteries**

The literature does not support the use of duplex Doppler US of the iliofemoral arteries for standalone preprocedural planning.

### **US Echocardiography Transesophageal**

TEE is not helpful as a standalone method for preprocedural planning. Intrinsic limitations of TEE acquisitions in the distal aspect of the ascending aorta are caused by obstructed views from air in the trachea and major bronchi [54]. Another limitation is the small field of view afforded by TEE, although this is beginning to be addressed with experimental image fusion strategies [55].

TEE can be a useful adjunct in planning for cases of ascending aorta repair by alerting the operator to plaque that may put the patient at risk for atheroembolic complications such as stroke [54]. TEE can also provide information about aortic valve dysfunction, pericardial tamponade, or cardiac wall motion abnormalities, which may aid in preprocedural planning [5]. TEE is also often used intraoperatively, because the location of the probe in the esophagus allows for real-time visualization of atheromatous disease that may increase the risk for periprocedural stroke and peripheral embolic events [55]. A study comparing TEE with direct aortic palpation and epiaortic US (US probe applied directly to the exposed aorta during surgery) found that TEE underestimated the presence and severity of ascending aortic atherosclerosis compared with epiaortic US, particularly in the distal half of the ascending aorta, but outperformed palpation [54].

### **US Echocardiography Transthoracic Resting**

TTE is not helpful as a standalone imaging method for preprocedural planning. TTE faces limitations presented by the anatomy surrounding the thoracic aorta, particularly for the descending aorta (lack of clear acoustic window posterior to the left atrium from the isthmus to the mid-descending aorta, adjacent bone, intrapulmonary gas, distance from chest wall) [5,56]. In a study of 40 patients who underwent TTE of the thoracic aorta, the mid-portion of the descending aorta was not visualized in 30% [56].

### **Variant 3: Adult. Post thoracic endovascular repair of thoracic aortic aneurysm or dissection. Surveillance.**

Careful assessment for graft stability, aortic true and false lumen diameter, and presence of endoleak are paramount in the follow-up period after TEVAR. Imaging follow-up is usually performed at 1, 6, and 12 months postprocedure and annually thereafter, although there is still some debate about appropriate frequency and timing of follow-up [38,71-73]. The goal of post-TEVAR surveillance imaging is to identify patients with early or late complications or disease progression who require reintervention or other treatment changes [8,73]. A retrospective study of 329 patients undergoing TEVAR found that 35% of patients had at least 1 postoperative aorta-specific complication, with roughly half of these patients requiring a reintervention [72]. A prospective study that included 56 patients who underwent TEVAR for complicated TBAD found 14% required reintervention [74]. For patients post-TAA repair, persistent aneurysmal sac enlargement is suggestive of disease progression or device failure and occurs in 7% to 15% of cases [2]. Other complications assessed on follow-up imaging include stent-graft migration, fracture, and endoleak. Device migration is less common (0.7%-4%) [2]. Graft collapse is rare but devastating when it occurs.

Identification of endoleaks is an important aspect of post-TEVAR imaging for patients treated for aneurysm. Endoleaks are broadly defined as continued blood flow into the aneurysm sac, occur in up to 20% of patients, and are the most important risk factor for aortic rupture [38]. Endoleaks are broken into 5 categories or types [75]. Late endoleaks occur in a small percentage of cases but necessitate evaluation for need for reintervention [75].

For patients treated for dissection, post-TEVAR imaging focuses on assessing for unfavorable aortic remodeling, (eg, incomplete thrombosis or failure of the false lumen diameter to shrink in size), which are negative prognostic factors [21,74,76]. The number, location, and size of intimal tears are also assessed, because these are associated with unfavorable aortic remodeling [76,77]. A prospective, single-center cohort of patients treated for acute TBAD found that initially only 26% presented with complications [78]. However, of those who presented initially as uncomplicated, 37.5% developed complications within a mean of 7.1 days following presentation, suggesting the need for close follow-up in this time frame [78].

### **Aortography Chest Abdomen Pelvis**

The literature does not support the use of this study in routine post-TEVAR surveillance.

### **CT Chest Abdomen Pelvis With IV Contrast**

Although not ideal, the use of contrast-enhanced CT can provide some information with regard to the anatomic extent of vascular pathology, aneurysm sac size, and detection of stent fracture or migration [31-33]. The principal limitations of this study are the lack of ECG gating, lack of standard thin-section image acquisition, lack of 3-D renderings, and lack of multiphase imaging, which can be particularly helpful for identifying sites and types of endoleak [34].

### **CT Chest Abdomen Pelvis Without and With IV Contrast**

Although not ideal, the use of multiphase CT (without and with IV contrast) can provide information with regard to the anatomic extent of vascular pathology, aneurysm sac size, detection of stent fracture or migration, and development of endoleaks [31-33]. The principal limitations of this study are the lack of ECG gating, lack of standard thin-section image acquisition, and lack of 3-D renderings [34].

### **CT Chest Abdomen Pelvis Without IV Contrast**

Although not ideal, noncontrast CT alone can be of use in post-TEVAR surveillance as an alternative option for patients; by using aneurysm sac size as a proxy for graft integrity, noncontrast CT can aid in the diagnosis of stent failure if sac size increases by >2% [79]. Noncontrast CT can detect stent fracture and stent migration [36]. Limitations of this study are the lack of ECG gating, lack of standard thin-section image acquisition, lack of 3-D renderings, and lack of multiphase imaging, which can be particularly helpful for identifying sites and types of endoleak [34].

### **CT Chest With IV Contrast**

Because thoracic aortic pathology often extends to involve the abdominal aorta, imaging of the chest, abdomen, and pelvis is standard in evaluation of post-TEVAR repair that extended to include the abdominal aorta.

Although not ideal, the use of contrast-enhanced CT can provide some information with regard to the anatomic extent of vascular pathology, aneurysm sac size, and detection of stent fracture or migration [31-33]. The principal limitations of this study are the lack of ECG gating, lack of standard thin-section image acquisition, lack of 3-D renderings, and lack of multiphase imaging, which can be particularly helpful for identifying sites and types of endoleak [34].

### **CT Chest Without and With IV Contrast**

Because thoracic aortic pathology often extends to involve the abdominal aorta, imaging of the chest, abdomen, and pelvis is standard in the evaluation of post-TEVAR repair that extended to include the abdominal aorta.

Although not ideal, the use of multiphase CT (without and with IV contrast) can provide some information with regard to the anatomic extent of vascular pathology, aneurysm sac size, detection of stent fracture or migration, and development of endoleaks [31-33]. The principal limitations of this study are the lack of ECG gating, lack of standard thin-section image acquisition, and lack of 3-D renderings.

### **CT Chest Without IV Contrast**

Because thoracic aortic pathology often extends to involve the abdominal aorta, imaging of the chest, abdomen, and pelvis is standard in the evaluation of post-TEVAR repair that extended to include the abdominal aorta.

Although not ideal, noncontrast CT alone can be of use in post-TEVAR surveillance in patients with pathology and endograft confined to the thorax; by using aneurysm sac size as a proxy for graft integrity, noncontrast CT can aid in the diagnosis of stent failure if sac size increases by >2% [79]. Noncontrast CT can detect stent fracture and stent



migration [36]. Limitations of this study are the lack of ECG gating, lack of standard thin-section image acquisition, lack of 3-D renderings, and lack of multiphase imaging, which can be particularly helpful for identifying sites and types of endoleak [34].

### **CTA Chest Abdomen Pelvis With IV Contrast**

Post-TEVAR CTA allows for the assessment of stent placement, efficacy, and evaluation of any complications (immediate or delayed) [37]. Multiplanar reformatted sagittal oblique images are optimal for visualizing stent-graft position and morphology and for accurate measurements of excluded aneurysm sac size [80]. Complications such as stent migration, formation of a pseudoaneurysm at either end of the stent, and dissection resulting from stent placement can all be diagnosed by CTA [37]. CTA aids in the diagnosis of endograft infection, with findings such as perigraft gas, fat stranding, and erosion into adjacent structures (eg, aortoenteric and aortobronchial fistulas) [81].

Triple-phase CTA (noncontrast, arterial, and delayed phase) is most commonly used post-TEVAR and is integral to detection and diagnosis of endoleak [82]. There is some debate over the optimal length of delay, with some arguing for up to 300-second delays to ensure that low-flow endoleaks are diagnosed. A retrospective study of 48 patients looked at dual-source DECT to determine if the standard triphasic protocol could be condensed into a single- or dual-phase using DECT [83]. All patients underwent the standard noncontrast and bolus-triggered arterial phase as well as a late-delayed phase (300 sec) using DECT. Virtual noncontrast images were generated from this DECT acquisition. Comparisons were made between 1) standard noncontrast, arterial, and delayed phases; 2) virtual noncontrast, arterial, and delayed phases; and 3) virtual noncontrast and delayed phase only (no arterial phase). One potential pitfall of virtual noncontrast is the inadvertent subtraction of calcium, although that was not seen in this study. The study also suggested that the arterial phase may not be needed. The removal of the arterial phase from diagnostic consideration decreased the diagnostic confidence level from 94.6% to 86.5%, but this difference was not statistically significant. Removal of the arterial phase led to an 85.7% sensitivity and a 100% specificity for endoleak diagnosis, compared with a 100% sensitivity and specificity when arterial and late phase were both considered [83].

In cases of patients treated for dissection, the trend over time of increased true lumen and decreased false lumen diameter on CTA is consistent with favorable aortic remodeling and better outcomes (less incidence of complications and need for reintervention) [12,19,21-23,74,82]. CTA can also confirm resolution of IMH post-TEVAR [84,85]. For cases of dissection post-treatment, the presence of new, postprocedural communications (fenestrations) between the true and false lumen are best detected on CTA imaging; these carry important prognostic information because the number of communications correlated to accelerated growth in aortic aneurysms [86,87]. Long-term CTA follow-up is also important for monitoring for retrograde type A dissection and aortic rupture postrepair of complicated TBAD [20]. Stent graft–induced new entry and retrograde type A dissection are common complications post-TEVAR for Stanford TBAD [88].

### **CTA Chest With IV Contrast**

Because thoracic aortic pathology often extends to involve the abdominal aorta, imaging of the chest, abdomen, and pelvis is standard in the evaluation of post-TEVAR repair that extended to include the abdominal aorta.

Post-TEVAR CTA allows for the assessment of stent placement, efficacy, and evaluation of any complications (immediate or delayed) [37]. Multiplanar reformatted sagittal oblique images are optimal for visualizing stent-graft position and morphology and for accurate measurements of excluded aneurysm sac size [80]. Complications such as stent migration, formation of a pseudoaneurysm at either end of the stent, or dissection resulting from stent placement can all be diagnosed by CTA [37]. CTA aids in the diagnosis of endograft infection, with findings such as perigraft gas, fat stranding, and erosion into adjacent structures (eg, aortoenteric and aortobronchial fistulas) [81].

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In cases of patients treated for dissection, the trend over time of increased true lumen and decreased false lumen diameter on CTA is consistent with favorable aortic remodeling and better outcomes (less incidence of complications and need for reintervention) [12,19,21-23,74,82]. CTA can also confirm resolution of IMH post-TEVAR [84,85]. For cases of dissection post-treatment, the presence of new, postprocedural communications (fenestrations) between the true and false lumen are best detected on CTA imaging; these carry important prognostic information because the number of communications correlated to accelerated growth in aortic aneurysms [86,87]. Long-term CTA follow-up is also important for monitoring for retrograde type A dissection and aortic rupture postrepair of complicated TBAD [20]. Stent graft–induced new entry and retrograde type A dissection are common complications post-TEVAR for Stanford TBAD [88].

### **MRA Chest Abdomen Pelvis With IV Contrast**

Potential challenges of MRA for post-TEVAR imaging include susceptibility artifacts due to stent-graft material or in-graft signal loss due to radiofrequency shielding [89]. Safety issues such as radiofrequency heating and shielding are also considerations [90]. These issues are more recently mitigated by the use of MR-compatible metals in newer generation stents.

A small study compared CE-MRA (breath-hold 3-D gradient-echo sequence) and multiphase CTA (arterial phase and 120 sec delay) for post-TEVAR follow-up evaluation; 10 patients underwent both examinations serially at 1 week, 3 months, and every 6 months thereafter post-TEVAR (follow-up ranging from 5 to 664 days in the study population) [91]. Some aspects of image quality were rated slightly lower for CE-MRA (eg, contrast inhomogeneity and stent-graft signal loss), but aneurysm geometry and exclusion were comparable between the 2 techniques. Out of 5 patients with endograft leaks, 1 was prospectively missed by CE-MRA but retrospectively identified.

Another study of 20 consecutive patients who presented with aortic rupture and were treated with TEVAR underwent both a contrast-enhanced CTA and an MRI that included 1) a 3-D SSFP series, 2) a contrast-enhanced T1 gradient-echo series, and 3) a retrospectively gated SSFP multislice acquisition technique with breath-held stacks acquired centered at the proximal, middle, and distal portions of the stent graft [92]. Stent-graft artifacts were more pronounced on native SSFP images in comparison with CE-MRA. Delineation of stent-graft struts was superior on CTA when compared with all MRI sequences. However, MRI was rated as at least mediocre for all patients, multislice acquisition technique MRI was sufficient to observe stent dynamics across the cardiac cycle, and measurements of stent-graft diameter had excellent agreement between MRI and CTA.

### **MRA Chest Abdomen Pelvis Without IV Contrast**

MRA of the chest, abdomen, and pelvis without IV contrast can be useful for assessing sac size measurements. For patients post-TAA repair, persistent aneurysmal sac enlargement is suggestive of disease progression or device failure and occurs in 7% to 15% of cases [2]. Although the lack of IV contrast limits identification of the location and type of endoleak, a proof-of-concept study looking at abdominal aortic aneurysms post-EVAR used a morphologic bSSFP (true-FISP) sequence to detect blood flow in the excluded sac with a high sensitivity but low specificity, highlighting the potential of noncontrast MRI for endoleak rule-out [93]. Potential challenges of MRI for post-TEVAR imaging include susceptibility artifacts due to stent-graft material or in-graft signal loss due to radiofrequency shielding [89]. Safety issues such as radiofrequency heating and shielding are also considerations [90]. These issues are more recently mitigated by the use of MR-compatible metals in newer generation stents.

### **MRA Chest With IV Contrast**

Because thoracic aortic pathology often extends to involve the abdominal aorta, imaging of the chest, abdomen, and pelvis is standard in the evaluation of post-TEVAR repair that extended to include the abdominal aorta.

Potential challenges of MRI for post-TEVAR imaging include susceptibility artifacts due to stent-graft material or in-graft signal loss due to radiofrequency shielding [89]. Safety issues such as radiofrequency heating and shielding are also considerations [90]. These issues are more recently mitigated by the use of MR-compatible metals in newer generation stents.

A small study compared CE-MRA (breath-hold 3-D gradient-echo sequence) and multiphase CTA (arterial phase and 120 sec delay) for post-TEVAR follow-up evaluation; 10 patients underwent both examinations serially at 1 week, 3 months, and every 6 months thereafter post-TEVAR (follow-up ranging from 5 to 664 days in the study population) [91]. Some aspects of image quality were rated slightly lower for CE-MRA (eg, contrast inhomogeneity and stent-

graft signal loss), but aneurysm geometry and exclusion were comparable between the 2 techniques. Out of 5 patients with endograft leaks, 1 was prospectively missed by CE-MRA but retrospectively identified.

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### **MRA Chest Without IV Contrast**

Because thoracic aortic pathology often extends to involve the abdominal aorta, imaging of the chest, abdomen, and pelvis is standard in the evaluation of vascular pathology and in post-TEVAR repair that extended to include the abdominal aorta. However, for post-TEVAR surveillance of disease confined to the chest, MRA of the chest without IV contrast can be useful for assessing excluded sac size measurements. For patients post-TAA repair, persistent aneurysmal sac enlargement is suggestive of disease progression or device failure and occurs in 7% to 15% of cases [2]. Although the lack of IV contrast limits identification of the location and type of endoleak, a proof-of-concept study looking at abdominal aortic aneurysms post-EVAR used a morphologic bSSFP (true-FISP) sequence to detect blood flow in the excluded sac with a high sensitivity but low specificity, highlighting the potential of noncontrast MRI for endoleak rule-out [93].

Potential challenges of MRI for post-TEVAR imaging include susceptibility artifacts due to stent-graft material or in-graft signal loss due to radiofrequency shielding [89]. Safety issues such as radiofrequency heating and shielding are also considerations [90]. These issues are more recently mitigated by the use of MR-compatible metals in newer generation stents.

### **Radiography Chest**

A radiograph can provide some information about overall graft positioning, including endograft migration and separation of components. Wire fractures may also be detected. However, radiographs are seldom used alone in post-TEVAR surveillance.

### **US Duplex Doppler Aorta Abdomen**

The literature does not support the use of abdominal aortic US for routine follow-up post-TEVAR. US is not helpful for assessing the apposition of the endograft and position with respect to proximal and distal landing zones [73]. This study could be used in adjunct to evaluate for progression of aneurysm or dissection into the abdominal aorta post-TEVAR.

### **US Echocardiography Transesophageal**

The literature does not support the use of this study in routine post-TEVAR surveillance.

### **US Echocardiography Transthoracic Resting**

The literature does not support the use of this study in routine post-TEVAR surveillance.

### **Variant 4: Adult. Post-open repair of thoracic aortic aneurysm or dissection. Surveillance.**

Imaging follow-up post-open thoracic aortic repair is usually performed at 1, 6, and 12 months postprocedure and annually thereafter, although there is still some debate about appropriate frequency and timing of follow-up. As with imaging post-TEVAR, the goals of postsurgical surveillance imaging are to rule out near and late-term complications, ensure favorable aortic remodeling, and identify instances where reintervention may be warranted. There are a variety of surgical techniques and hybrid surgical and endovascular techniques that are employed in thoracic aortic repair, and a fundamental understanding of the surgical technique will aid in postprocedural imaging evaluation, regardless of the imaging modality being used [24].

### **Aortography Chest Abdomen Pelvis**

The literature does not support the use of this study in routine post-TEVAR surveillance.

### **CT Chest Abdomen Pelvis With IV Contrast**

Although not ideal, the use of contrast-enhanced CT can provide some information with regard to the anatomic extent of vascular pathology and aneurysm sac size [31-33]. The principal limitations of this study are the lack of ECG gating,

lack of standard thin-section image acquisition, lack of arterial-phase bolus timing, and lack of 3-D renderings, which can be important for post–open repair imaging [34].

#### **CT Chest Abdomen Pelvis Without and With IV Contrast**

Although not ideal, the use of contrast-enhanced CT can provide some information with regard to the anatomic extent of vascular pathology and aneurysm sac size [31-33]. The principal limitations of this study are the lack of ECG gating, lack of standard thin-section image acquisition, lack of arterial-phase bolus timing, and lack of 3-D renderings, which can be important for post–open repair imaging [34].

#### **CT Chest Abdomen Pelvis Without IV Contrast**

Although not ideal, the use of noncontrast CT can provide some information with regard to aneurysm sac size [31-33]. The principal limitations of this study are the lack of contrast, lack of ECG gating, lack of standard thin-section image acquisition, lack of arterial-phase bolus timing, and lack of 3-D renderings, which can be important for post–open repair imaging [34].

#### **CT Chest With IV Contrast**

Because thoracic aortic pathology often extends to involve the abdominal aorta, imaging of the chest, abdomen, and pelvis is standard in evaluation of vascular pathology. Extension of imaging to involve the abdomen and pelvis is often warranted post–surgical repair of dissections, because many extend to the level of the iliac arteries [6]. Other limitations of this study are the lack of ECG gating, lack of standard thin-section image acquisition, lack of arterial-phase bolus timing, and lack of 3-D renderings, which can be important for post–open repair imaging [34].

#### **CT Chest Without and With IV Contrast**

Because thoracic aortic pathology often extends to involve the abdominal aorta, imaging of the chest, abdomen, and pelvis is standard in evaluation of vascular pathology. Extension of imaging to involve the abdomen and pelvis is often warranted postsurgical repair of dissections, as many extend to the level of the iliac arteries [4]. Other limitations of this study are the lack of ECG gating, lack of standard thin-section image acquisition, lack of arterial-phase bolus timing, and lack of 3-D renderings, which can be important for post–open repair imaging [34].

#### **CT Chest Without IV Contrast**

The literature does not support the use of this study in routine post–open repair of TAA or dissection.

#### **CTA Chest Abdomen Pelvis With IV Contrast**

CTA provides superior spatial and temporal resolution and small slice thickness and provides homogeneous intraluminal contrast enhancement [34,36]. The small (near) isotropic voxels achievable by CT allow for multiplanar reformatting, facilitating true centerline/double oblique true short axis measurements of aortic diameter [27,37,38]. Three-dimensional data sets also facilitate maximum intensity projection, volume rendering, and multiplanar curved reformats, which may be helpful in providing an overview of pathology and adjacent anatomy [34].

ECG gating is particularly useful for temporal resolution of the ascending aorta, where cardiac motion can lead to artifacts [1,40]. In cases of surveillance post–open repair that involved the ascending aorta, it is important to include ECG-gated imaging to cover the aortic valve and root, to rule out complications [80]. ECG gating also ensures that measurements are being made reliably in the same phase of the cardiac cycle. One study of 27 patients found a 5% to 10% difference in diameter of proximal descending thoracic aortic measurements during systole and diastole [41].

One challenge of postsurgical imaging is to distinguish postoperative change from pathology [80]. Interposition grafts are sewed into the remaining native anatomy after excision of the diseased aorta. With inclusion grafts, the native aorta is wrapped around the synthetic graft [80]. Knowing what surgical technique was used can help troubleshoot whether CT imaging findings are pathological or expected postsurgical change. A noncontrast sequence allows appropriate identification of hyperattenuating felt rings or pledgets placed surgically, ensuring that they are distinguished from potential pseudoaneurysms [24], and can also be useful in identifying hyperdense Dacron graft material if the surgical history is unclear [24,80].

CT is also important in the diagnosis of aortic graft infection. The Management of Aortic Graft Infection Collaboration (MAGIC) created diagnostic criteria for aortic graft infection that defined the following CT imaging features as satisfying a major criterion: increasing perigraft gas volume on serial CT images, perigraft gas present >7 weeks postprocedure, or perigraft fluid present 3 months postimplantation [94]. CTA can be used to diagnose graft dehiscence by demonstrating the presence of contrast material external to the interposition graft [80]. CTA can also be important in identifying postsurgical infections or fistula formation between the aorta and adjacent structures such as the esophagus or bowel [80].

As with post-TEVAR imaging for aortic dissection repair, it is important to assess for favorable remodeling of the residual true and false lumen. In a study of 67 patients after open repair for type A acute aortic dissection, multiphase CTA (arterial and delay) was used to determine true and false lumen status [95]. Partial thrombosis of a segment of false lumen in the proximal descending thoracic aorta was predictive of a greater regional aortic growth rate and greater late reoperation rate but did not affect 10 year survival rate. A retrospective study of 477 patients who underwent surgical repair for acute type A aortic dissection identified 105 patients with postoperative CT scans available [96]. Of these 105 patients, a residual dissection flap was present in 80 patients (76%), a patent false lumen was present in 52 patients (50%), and a thrombosed false lumen was present in 28 patients (26%). There was progression of aortic aneurysms in 15 patients (14%). Postoperative descending aortic diameter >40 mm and Marfan syndrome were independent predictors of aorta-related reoperations.

### **CTA Chest With IV Contrast**

Because thoracic aortic pathology often extends to involve the abdominal aorta, imaging of the chest, abdomen, and pelvis is standard in the evaluation of vascular pathology. Extension of imaging to involve the abdomen and pelvis is often warranted after surgical repair of dissections, because many extend to the level of the iliac arteries [4].

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### **MRA Chest Abdomen Pelvis With IV Contrast**

CE-MRA can be useful in postoperative evaluation of the aorta and adjacent structures. It can additionally provide functional data, including quantification of flow, assessment of wall stiffness and shear stress, and aortic leaflet morphology and motion [97,98].

### **MRA Chest Abdomen Pelvis Without IV Contrast**

MRA has the benefit of imaging techniques such as SSFP and bSSFP sequences that do not require contrast administration, given their inherent contrast between blood pool and vessel wall/myocardium [1,50,51]. These sequences are also amenable to cardiac and respiratory gating, which improves image accuracy by compensating for motion, but at the cost of longer acquisition times (on the order of tens of minutes) [70,99].

A prospective study of 64 patients with Marfan syndrome who underwent surgical aortic root placement  $6.9 \pm 5.9$  years previously aimed to determine the diagnostic use of noncontrast bSSFP imaging versus CE-MRA [51]. ECG-gated, breath-hold, noncontrast 2-D bSSFP imaging acquired in transversal, coronal, and parasagittal planes (along the curvature of the aortic arch) was compared against 3-D CE-MRA for the following: subjective image quality of the aorta, presence of image artifacts, and presence of aortic dissection or other relevant aortic pathology (eg, aneurysm). No significant difference between bSSFP and CE-MRA was found for image quality, artifacts, or the presence of aortic dissection. CE-MRA resulted in statistically larger diameters at all aortic levels. The authors concluded that noncontrast bSSFP imaging is helpful for serial follow-up after aortic root replacement, although they noted that banding artifacts and artifacts caused by surgical material remain potential drawbacks of this technique [51].

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### **Radiography Chest**

Radiographs have little use in postsurgical surveillance beyond the early postoperative period, wherein mediastinal hematomas, pleural effusions, or other associated postoperative change may be noted.

### **US Duplex Doppler Aorta Abdomen**

The literature does not support the use of this study in routine follow-up for after open repair of TAA or dissection.

### **US Echocardiography Transesophageal**

The literature does not support the use of this study in routine follow-up for after open repair of TAA or dissection.

### **US Echocardiography Transthoracic Resting**

The literature does not support the use of this study in routine follow-up for after open repair of TAA or dissection.

### **Summary of Highlights**

This is a summary of the key recommendations from the variant tables. Refer to the complete narrative document for more information.

- **Variant 1:** CTA chest abdomen pelvis with IV contrast, or CTA chest with IV contrast, or MRA chest abdomen pelvis with IV contrast, or MRA chest abdomen pelvis without IV contrast is usually appropriate for follow-up imaging in an adult patient with known TAA or dissection without repair, with or without symptoms. These

procedures are equivalent alternatives (ie, only one procedure will be ordered to provide the clinical information to effectively manage the patient’s care).

- **Variation 2:** CTA chest abdomen pelvis with IV contrast or MRA chest abdomen pelvis with IV contrast is usually appropriate for preprocedure planning in an adult patient with prethoracic endovascular repair or open repair of thoracic aorta aneurysm or dissection. These procedures are equivalent alternatives (ie, only one procedure will be ordered to provide the clinical information to effectively manage the patient’s care). The panel did not agree on recommending MRA chest abdomen pelvis without IV contrast in this clinical scenario. There is disagreement in expert opinion about whether this study should be rated as usually appropriate versus may be appropriate. There is insufficient medical literature to conclude whether or not these patients would benefit from MRA chest abdomen pelvis without IV contrast in this clinical scenario. Imaging with this option in this patient population is controversial but may be appropriate.
- **Variation 3:** CTA chest abdomen pelvis with IV contrast, or CTA chest with IV contrast, or MRA chest abdomen pelvis with IV contrast is usually appropriate for surveillance in an adult patient with post-thoracic endovascular repair of TAA or dissection. These procedures are equivalent alternatives (ie, only one procedure will be ordered to provide the clinical information to effectively manage the patient’s care).
- **Variation 4:** CTA chest abdomen pelvis with IV contrast, or CTA chest with IV contrast, or MRA chest abdomen pelvis with IV contrast is usually appropriate for surveillance in an adult patient with post-open repair of TAA or dissection. These procedures are equivalent alternatives (ie, only one procedure will be ordered to provide the clinical information to effectively manage the patient’s care).

### Supporting Documents

The evidence table, literature search, and appendix for this topic are available at <https://acsearch.acr.org/list>. The appendix includes the strength of evidence assessment and the final rating round tabulations for each recommendation.

For additional information on the Appropriateness Criteria methodology and other supporting documents go to <http://www.acr.org/ac>.

### Gender Equality and Inclusivity Clause

The ACR acknowledges the limitations in applying inclusive language when citing research studies that pre-dates the use of the current understanding of language inclusive of diversity in sex, intersex, gender and gender-diverse people. The data variables regarding sex and gender used in the cited literature will not be changed. However, this guideline will use the terminology and definitions as proposed by the National Institutes of Health [100].

## Appropriateness Category Names and Definitions

Appropriateness Category Name	Appropriateness Rating	Appropriateness Category Definition
Usually Appropriate	7, 8, or 9	The imaging procedure or treatment is indicated in the specified clinical scenarios at a favorable risk-benefit ratio for patients.
May Be Appropriate	4, 5, or 6	The imaging procedure or treatment may be indicated in the specified clinical scenarios as an alternative to imaging procedures or treatments with a more favorable risk-benefit ratio, or the risk-benefit ratio for patients is equivocal.
May Be Appropriate (Disagreement)	5	The individual ratings are too dispersed from the panel median. The different label provides transparency regarding the panel's recommendation. "May be appropriate" is the rating category and a rating of 5 is assigned.
Usually Not Appropriate	1, 2, or 3	The imaging procedure or treatment is unlikely to be indicated in the specified clinical scenarios, or the risk-benefit ratio for patients is likely to be unfavorable.

## Relative Radiation Level Information

Potential adverse health effects associated with radiation exposure are an important factor to consider when selecting the appropriate imaging procedure. Because there is a wide range of radiation exposures associated with different diagnostic procedures, a relative radiation level (RRL) indication has been included for each imaging examination. The RRLs are based on effective dose, which is a radiation dose quantity that is used to estimate population total radiation risk associated with an imaging procedure. Patients in the pediatric age group are at inherently higher risk from exposure, because of both organ sensitivity and longer life expectancy (relevant to the long latency that appears to accompany radiation exposure). For these reasons, the RRL dose estimate ranges for pediatric examinations are lower as compared with those specified for adults (see Table below). Additional information regarding radiation dose assessment for imaging examinations can be found in the ACR Appropriateness Criteria® [Radiation Dose Assessment Introduction](#) document [101].

Relative Radiation Level Designations		
Relative Radiation Level*	Adult Effective Dose Estimate Range	Pediatric Effective Dose Estimate Range
○	0 mSv	0 mSv
⊕	<0.1 mSv	<0.03 mSv
⊕⊕	0.1-1 mSv	0.03-0.3 mSv
⊕⊕⊕	1-10 mSv	0.3-3 mSv
⊕⊕⊕⊕	10-30 mSv	3-10 mSv
⊕⊕⊕⊕⊕	30-100 mSv	10-30 mSv

\*RRL assignments for some of the examinations cannot be made, because the actual patient doses in these procedures vary as a function of a number of factors (eg, region of the body exposed to ionizing radiation, the imaging guidance that is used). The RRLs for these examinations are designated as "Varies."

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The ACR Committee on Appropriateness Criteria and its expert panels have developed criteria for determining appropriate imaging examinations for diagnosis and treatment of specified medical condition(s). These criteria are intended to guide radiologists, radiation oncologists and referring physicians in making decisions regarding radiologic imaging and treatment. Generally, the complexity and severity of a patient's clinical condition should dictate the selection of appropriate imaging procedures or treatments. Only those examinations generally used for evaluation of the patient's condition are ranked. Other imaging studies necessary to evaluate other co-existent diseases or other medical consequences of this condition are not considered in this document. The availability of equipment or personnel may influence the selection of appropriate imaging procedures or treatments. Imaging techniques classified as investigational by the FDA have not been considered in developing these criteria; however, study of new equipment and applications should be encouraged. The ultimate decision regarding the appropriateness of any specific radiologic examination or treatment must be made by the referring physician and radiologist in light of all the circumstances presented in an individual examination.