

**American College of Radiology  
ACR Appropriateness Criteria®**

## Abdominal Aortic Aneurysm or Dissection-Interventional Planning and Follow-up

### **Variant: 1 Planning for pre-endovascular repair (EVAR) or open repair of AAA.**

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

### **Variant: 2 Follow-up for post-endovascular repair (EVAR) or open repair of AAA.**

Procedure	Appropriateness Category	Relative Radiation Level
CTA abdomen and pelvis with IV contrast	Usually Appropriate	⦿⦿⦿⦿
MRA abdomen and pelvis without and with IV contrast	Usually Appropriate	○
Aortography abdomen	May Be Appropriate	⦿⦿⦿
CT abdomen and pelvis without and with IV contrast	May Be Appropriate	⦿⦿⦿⦿
CT abdomen and pelvis without IV contrast and US aorta abdomen with duplex Doppler	May Be Appropriate	⦿⦿⦿⦿
MRA abdomen and pelvis without IV contrast	May Be Appropriate	○
US duplex Doppler aorta abdomen	May Be Appropriate	○
CT abdomen and pelvis with IV contrast	May Be Appropriate (Disagreement)	⦿⦿⦿
CT abdomen and pelvis without IV contrast	May Be Appropriate	⦿⦿⦿
Radiography abdomen and pelvis	May Be Appropriate	⦿⦿⦿

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### **Summary of Literature Review**

### **Introduction/Background**

In 1991, Parodi et al [1] reported successful deployment of an endoluminal stent graft within the abdominal aorta via a transfemoral approach. This permanently transformed the landscape of abdominal aortic aneurysm (AAA) management and therapy. Previous treatment options were limited to expectant management that combined medical blood pressure control with close imaging surveillance versus traditional open surgical repair. Given the significant perioperative morbidity of open repair, the point of transition to surgical intervention varied by on a case-by-case basis. Guidelines for AAA screening were subsequently established to assist medical decision making [2,3]. These guidelines were developed based on a patient's health status, comorbidities, the aneurysm's maximum diameter ( $>5.5$  cm) and rate of change ( $>1$  cm/year) and other signs that indicated impending rupture [2,4]. The arrival of the endovascular aneurysm repair (EVAR) technique introduced new variables to managing AAAs. Relatively recent development of the fenestrated endovascular aneurysm repair (FEVAR) and percutaneous endovascular aneurysm repair (PEVAR) has advanced therapeutic potential while maintaining low morbidity [5-7].

Multiple studies have shown significantly decreased length of hospital stay and decreased perioperative morbidity with EVAR [8-11] compared to open repair [12-14]. Despite this, open repair is still performed in patients with unsuitable aneurysm morphology for EVAR and in those with failed EVAR [15]. For patients who present de novo for treatment of AAA without any prior imaging available, the entire aorta (including the thoracic portion) should be assessed to fully characterize the aneurysm and exclude a concomitant thoracic aortic aneurysm. Preoperative imaging for open repair of AAA has one primary focus: to determine the need for surgery based on aneurysm size, extent, and rate of growth. Additional information regarding potential variant anatomy can also be helpful in guiding appropriate treatment and preventing unexpected complications at the time of repair.

EVAR, requires accurate preoperative imaging evaluation for appropriate patient selection based on aneurysm morphology, access vessel size, and patency [16,17]. Paramount considerations in evaluating an AAA for EVAR lie in the morphology of the proximal neck, which for an infrarenal AAA is defined as the segment of aorta between the most caudal renal artery and the proximal boundary of the aneurysm. Unfavorable neck anatomy, based on its diameter, length, angulation, morphology, and presence of calcification, is the most frequent cause of exclusion from EVAR [18-20]. Over 50% of patients having aneurysm morphology unsuitable for conventional EVAR [7]. In conventional EVAR, a neck size of  $>10$  to  $15$  mm in length and  $<30$  mm in diameter is required to provide an adequate proximal graft seal. Although not an absolute contraindication to EVAR, mural thrombus and atherosclerotic calcification covering more than  $90^\circ$  of the circumference of the aortic diameter in the proximal neck is associated with a higher risk for Type I endoleak and stent-graft migration [20]. The distal landing zone is usually located within one or both of the common iliac arteries. With newer-generation devices, common iliac artery diameters of  $\leq 20$  mm can be considered for EVAR [21]. The minimal external iliac artery intraluminal diameter should be  $\geq 7$  mm to safely accept delivery sheaths [22].

In recent years, new devices have become available to mitigate unfavorable aortic neck anatomy. Several designs feature an uncovered proximal portion that allows for placement of the stent directly at the origin of aortic branches, whereas others possess ready-made vessel origins for placement within the renal and mesenteric arteries [18]. FEVAR is an alternative approach for those with aortic necks of inadequate length. In FEVAR, fenestrations within the graft material allow for perfusion of major visceral arteries while securing an adequate proximal seal [7]. A variant of the

FEVAR technique describes the placement of bridging stents through these fenestrations [23]. Such devices may be especially favorable in women, as these patients are less likely to have aneurysm neck and iliac diameters sufficient for traditional EVAR [16]. FEVAR obviates the need for open femoral exposure and offers the benefit of shorter procedure times, lower complication rates, and shorter hospital stays [5]. FEVAR requires common femoral artery anatomy that is suitable for percutaneous access and free of significant calcification. Candidates for FEVAR should be carefully selected, as the presence and degree of vessel calcification is a major determinant of technical failure [24].

The advantages of EVAR come at a cost of lifelong imaging surveillance. This is due to a higher rate of complications that require reintervention when compared to open repair [11,25]. Complications of EVAR include stent graft migration, kinking, infection, thrombosis, and renal dysfunction. The most important complication to detect is continued aneurysm expansion leading to eventual rupture, which can occur even after successful EVAR [26]. The most common complication of EVAR is endoleak formation, which may contribute to aneurysm sac enlargement and rupture [27]. Endoleaks are classified by their etiology, with Types I and III most commonly leading to rupture [15,28]. Appropriate classification is therefore crucial for subsequent management and should be clarified whenever possible. Although EVAR is safe and has a low mortality rate [29], the possibility of complications and need for reintervention remains high [12-14], thereby requiring life-long monitoring.

The ultimate goal of endovascular therapy is to prevent aneurysm rupture. Follow-up imaging is the most useful tool for evaluating post-therapeutic outcomes and monitoring potential complications. Successful therapy results in an aneurysm that remains stable or decreases in size over serial follow-up imaging examinations, with decreasing size of the aneurysm sac believed to indicate a low risk of future rupture [30,31]. All available imaging modalities have been investigated over time for their efficacy in post-EVAR follow-up. According to Society of Interventional Radiology guidelines, the imaging modality of choice should allow at least (1) measurement of aortic aneurysm diameter, (2) detection and classification of endoleaks, and (3) detection of morphologic details of the stent grafts [32]. Imaging modalities should be assessed by their effectiveness in satisfying these three requirements, as well as their respective safety profiles and use of potentially nephrotoxic contrast material.

## **Overview of Imaging Modalities**

### **CT and CTA**

Computed tomography (CT) is a cross-sectional imaging modality that offers excellent spatial resolution, fast image acquisition times, and widespread availability. However, without contrast material administration, its ability to assess vascular structures is limited. Evaluation of the vessel lumen is accomplished through CT angiography (CTA), a technique that utilizes the administration of iodinated contrast material. The addition of 3-D volumetric postprocessing techniques allow the abdominal aorta and associated vasculature to be viewed in any obliquity and affords quantification of luminal diameter, cross-sectional area, and sac volume. A disadvantage of CTA includes potential nephrotoxicity from administered contrast material [33-35].

For the purposes of distinguishing between CT and CT angiography (CTA), ACR Appropriateness Criteria topics use the definition in the [ACR–NASCI–SIR–SPR Practice Parameter for the Performance and Interpretation of Body Computed Tomography Angiography \(CTA\)](#) [36]:

“CTA uses a thin-section CT acquisition that is timed to coincide with peak arterial or venous enhancement. The resultant volumetric dataset is interpreted using primary transverse reconstructions as well as multiplanar reformations and 3D renderings.”

All procedure elements are essential: (1) timing, (2) recons/reformats, and (3) 3-D renderings. Standard CTs with contrast also include timing issues and recons/reformats. Only in CTA, however, is 3-D rendering a required element. This corresponds to the definitions that CMS has applied to the CPT codes.

CTA imaging may be performed as a single arterial phase, biphasic study (noncontrast and arterial or arterial and delayed phases), or as a triphasic study (noncontrast, arterial, and delayed phases). To reduce the cumulative lifetime radiation dose of patients undergoing CTA surveillance, several authors have proposed eliminating either the arterial phase [37] or delayed phase [38,39], although one author has suggested eliminating noncontrast scans from all surveillance examinations with the exception of an initial 1-month follow-up [40].

Several studies have reported significant dose reduction using dual-energy CT with acquisition of delayed-phase images only [41,42]. Accompanying software allows for the isolation of iodine from a selected region and enables reconstruction of virtual noncontrast images. A colored overlay can be applied to voxels containing iodine, rendering detection of contrast material within the aneurysm sac external to the stent-graft more visible [41]. Dual-phase dual-energy CT can potentially reduce the radiation dose by 19.5% when compared to a standard triphasic CT examination [34]. Additional dose reduction techniques include the use of automatic exposure control and iterative reconstruction algorithms [34].

Determining the optimal dose-efficient CT technique is a work in progress that will continue to evolve with increased experience and technological advancement.

## **Aortography**

Aortography is an invasive imaging modality that can accurately assess aortic side branch patency, knowledge of which is crucial for deployment of conventional and fenestrated endografts with or without bridging stents. However, it fails to demonstrate mural thrombus, thereby limiting diameter measurements and landing zone assessment. Though less sensitive than CTA in detecting endoleaks, aortography is able to demonstrate the direction of blood flow in or out of the aneurysm sac, rendering it more accurate than CTA in classifying endoleaks [43]. Although traditional aortography relies on iodinated contrast material, recent studies suggest that carbon dioxide may be an acceptable alternative for evaluating endoleaks in patients at risk for contrast-related nephropathy [44,45].

## **MRA**

The major advantage of MR angiography (MRA) relative to CTA is improved soft tissue characterization. Despite relatively low nephrotoxicity, gadolinium-based contrast media (GBCM) have been linked to nephrogenic systemic fibrosis (NSF) [46]. As such, evaluation of renal function in high-risk patients before administering a GBCM is recommended. Disadvantages of MRA include relatively long scanning duration, patient claustrophobia, decreased spatial resolution, and contraindication in patients with certain implantable devices. MRA is also limited in its ability to

detect intimal calcification [33]. Additionally, susceptibility artifact from the metal interstices of the stent graft presents a diagnostic challenge for assessing device integrity and may mimic graft stenosis. Although the presence of an implanted cardiac pacemaker was previously an absolute contraindication to MRI, several new models are FDA-approved for conditional use.

Superior soft-tissue characterization inherent to MRA may assist clinicians in differentiating slow-growing aneurysms from fast-growing aneurysms. A recent study demonstrated that AAAs containing intraluminal thrombus that have high T1-weighted signal intensity are associated with higher growth rates [47].

## **US**

Color duplex ultrasound (CDUS) is a noninvasive imaging modality that is portable and safe, sparing patients from nephrotoxic contrast material administration. CDUS is able to assess blood flow dynamics in real-time and allows for quantification of luminal diameter and cross-sectional area. Image quality in CDUS is highly dependent on operator experience, patient cooperation, and patient body habitus [48,49]. Although excellent correlation between AAA diameter measurements made by CT and CDUS is well documented, there is general agreement that conventional ultrasound (US) techniques systematically underestimate aneurysm diameter by ~2 mm [35,50-52].

Contrast-enhanced ultrasound (CEUS) utilizes the infusion of stabilized sodium hexafluoride gas to visualize the vessel lumen. Unlike iodinated contrast materials used in CTA, this gas is not nephrotoxic and is safely eliminated via the respiratory system. The advent of 3-D CEUS utilizes positional information for magnetic field emitters to assemble collected US reflections into a high-resolution 3-D image, which results in improved image quality relative to CDUS [53]. 3-D CEUS is reported to be more accurate than 2-D methods in quantifying maximum vessel diameter, as the former allows measurements to be made orthogonal to vessel centerline [50].

For patients with absolute contraindications to iodinated contrast material, whether due to severe renal impairment or life-threatening contrast allergy, US is an important adjunct to nonenhanced CT.

## **Discussion of Procedures by Variant**

### **Variant 1: Planning for pre-endovascular repair (EVAR) or open repair of AAA.**

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##### **A. Radiography**

Radiographs are unable to adequately visualize the abdominal aorta, thereby prohibiting proximal landing zone assessment and luminal diameter quantification. As such, there is no role for radiography in the preoperative evaluation of AAA. However, given the high spatial resolution of radiography, this modality affords optimal visualization of stent graft geometry. When utilizing consistent centering protocols, this allows for reliable detection of kinks and stent graft migration to within 2 mm [54].

#### **Variant 1: Planning for pre-endovascular repair (EVAR) or open repair of AAA.**

##### **B. CT and CTA**

Due to its superior spatial resolution and rapid image acquisition, CTA with 3-D volumetric

reconstruction and vessel analysis has gained wide acceptance as the gold standard for pre-EVAR evaluation. The utilization of 3-D reconstruction software has become paramount in EVAR planning, as it diminishes the impact of vessel tortuosity on diameter and length measurements, in addition to reducing intraobserver variability [55]. One author found that routine 3-D analysis of pre-EVAR images led to a significant reduction in Type I endoleaks [56]. Reformatted CTA images in the coronal and sagittal planes should be utilized for increased diagnostic accuracy. In most cases, a CTA of the abdomen and pelvis is appropriate to ensure coverage of the entire aneurysm and vascular access. The CTA should include the chest in patients with thoracoabdominal aortic aneurysms (TAAA).

#### **Variant 1: Planning for pre-endovascular repair (EVAR) or open repair of AAA.**

##### **C. Aortography**

As aortography and radiography are unable to accurately provide aneurysm sac diameter measurements and landing zone assessment, these modalities are inadequate for pre-EVAR or open repair evaluation. However, aortography may be of value in assessing branch vessel patency and is usually part of branch vessel occlusion procedures before aneurysm repair.

#### **Variant 1: Planning for pre-endovascular repair (EVAR) or open repair of AAA.**

##### **D. MRA**

For the purpose of pre-EVAR planning, T1-weighted spin-echo images and flow-based methods such as time of flight or phase contrast provide adequate details regarding aneurysm morphology and relevant vascular anatomy. However, these techniques are limited by low spatial resolution and signal-to-noise ratio and are therefore suboptimal for evaluating small-vessel lesions or diminutive side branches [33]. Furthermore, flow-based sequences are susceptible to flow artifacts that may overestimate the degree of stenosis or falsely demonstrate an occlusion [57]. To overcome these limitations, contrast-enhanced MRA (CE-MRA) should be added to conventional T1- and T2-weighted spin-echo sequences. CE-MRA is much less susceptible to flow and susceptibility artifacts and has a high signal-to-noise ratio for evaluating small vessels and fine structural details. The effectiveness of CE-MRA has been found to be comparable to that of CTA in assessing the suitability of aneurysms for EVAR [58]. In most cases, an MRA of the abdomen and pelvis is appropriate to ensure coverage of the entire aneurysm and vascular access. The MRA should include the chest in patients with TAAA.

Acquisition of noncontrast balanced steady state free precession (bSSFP) images may be useful in the preoperative evaluation of patients who poorly tolerate GBCM or are at risk for NSF. One study found that AAA measurements obtained by noncontrast MRA were not significantly different from those measured by CTA [59].

#### **Variant 1: Planning for pre-endovascular repair (EVAR) or open repair of AAA.**

##### **E. US**

Although the United States Preventative Services Task Force currently recommends one-time US screening for AAA in men ages 65 to 75 years who have ever smoked [60], no evidence is present within the medical literature to support the use of either CDUS or CEUS in the formal preoperative evaluation of AAA.

#### **Variant 2: Follow-up for post-endovascular repair (EVAR) or open repair of AAA.**

#### **Variant 2: Follow-up for post-endovascular repair (EVAR) or open repair of AAA.**

##### **A. CT and CTA**

The exceptional spatial resolution and fast imaging speeds of CTA has made it the de facto gold standard for post-EVAR and post-open repair imaging surveillance. After EVAR, the most widely used surveillance regimen utilizes multiphasic contrast-enhanced CT at 1 month, 12 months, and yearly thereafter. If an abnormality is detected 1 month post-EVAR, a follow-up scan at 6 months is performed. In the absence of adverse outcomes at the 1-month follow-up imaging, the intensity and frequency of the surveillance program may be modulated accordingly [61-64]. Compared to aortography, CTA has higher sensitivity in detecting endoleaks after EVAR. Compared to US, CTA is better able to visualize kinking and migration of the stent-graft and is equivalent in quantifying aneurysm sac size [34].

Initial post-EVAR surveillance studies monitored the maximum diameter of the aneurysm sac as a marker for response to therapy [65]. This method has been shown to be unreliable due to substantial interobserver variability [66]. Volume analysis of the aneurysm sac has since proven to be the most reliable indicator for aneurysm rupture and/or need for reintervention [67-69]. In an effort to reduce radiation dose and contrast material exposure, several authors have proposed using serial volumetric analysis of AAAs with noncontrast CT as the sole screening test for post-EVAR follow-up [70-73]. Volume discrepancy due to interoperator variability has been demonstrated to be less than 2% when the procedure is performed by experienced personnel [72,74]. In patients in whom contrast materials are contraindicated, serial volume measurements of the nonenhanced aneurysm sac provides valuable information in guiding management [75].

In most cases, a CTA of the abdomen and pelvis is appropriate to ensure coverage of the treated aneurysm and stent graft. The CTA should include the chest in patients with TAAA.

## **Variant 2: Follow-up for post-endovascular repair (EVAR) or open repair of AAA.**

### **B. Aortography**

Due to the relatively invasive nature of aortography, it is not practical for routine post-EVAR surveillance. However, in the setting of a known endoleak, aortography may be more accurate than CTA in classifying endoleaks. One study revealed only 86% agreement in endoleak classification between aortography and CTA, in which subsequent correct classification by aortography significantly improved patient management [43]. It therefore stands to reason that aortography may be best utilized as a second-line imaging modality in post-EVAR patients, playing a vital role in endoleak classification and reintervention [35].

## **Variant 2: Follow-up for post-endovascular repair (EVAR) or open repair of AAA.**

### **C. MRA**

When considering using MRA for post-EVAR surveillance, stent material and orientation are important considerations. Typical stent construction employs nitinol, elgiloy, or stainless steel. Nitinol is a nickel-titanium alloy that causes relatively few artifacts on MRA, while allowing adequate visualization of the stent lumen and adjacent structures. Elgiloy is an alloy of cobalt, chromium, and nickel that may obscure the stent lumen but still allows for visualization of adjacent structures. Patients with nitinol stents are the optimal candidates for MRA, while those with elgiloy or stainless steel stents may experience significant artifacts that compromise visualization of the stent lumen and limit morphological resolution of the stent wall [76]. However, artifacts may arise even with nitinol stents secondary to stent geometry [77]. Due to severe susceptibility artifact associated with stainless steel embolization coils, MRA is poor in the follow-up of patients who have undergone coil embolization of the internal iliac artery before EVAR [35].

MRA of the post-EVAR aorta shares multiple features with CTA. Like CTA, isotropic 3-D MRA images may be reformatted in any plane for volume analysis or orthogonal diameter measurements. In patients with nitinol stents, aortic diameter measurements for MRA have been shown to be as reliable as those obtained with CTA [78]. MRA has been shown to be more sensitive than CTA for the detection of endoleaks [35,79]. Consequently, the higher rate of endoleak detection seen by MRA in cases with a negative CTA may shed light on the phenomenon of endotension [80]. More recently, time-resolved MRA has been used in the characterization of endoleaks and may provide relevant information regarding contrast and flow dynamics within endoleaks [35]. As such, replacing aortography as an effective and noninvasive method for endoleak characterization shows promise [81].

In most cases, MRA of the abdomen and pelvis is appropriate to ensure coverage of the treated aneurysm and stent graft. The MRA should include the chest in patients with TAAA.

Blood pool contrast materials such as ferumoxytol [82,83] remain intravascular for a prolonged duration, thereby allowing for generation of high-resolution 3-D multiplanar images [82,83]. Use of these contrast materials may improve detection of slow-flow endoleaks [82,83].

Patients intolerant of GBCM or those at risk for NSF may benefit from the acquisition of noncontrast bSSFP images in post-EVAR surveillance. One small retrospective study found that noncontrast bSSFP images can be used to exclude endoleak after EVAR, with postcontrast imaging reserved for verification and further characterization of a suspected endoleak [84].

## **Variant 2: Follow-up for post-endovascular repair (EVAR) or open repair of AAA.**

### **D. US**

CDUS and CEUS are being increasingly recommended for post-EVAR follow-up. These are convenient, noninvasive, and have a favorable safety profile. In the evaluation of endoleak, CDUS has high specificity but limited sensitivity, reported in two large meta-analyses to be 91% to 93% and 66% to 69%, respectively [85,86]. The major limitations of US are the inability to detect stent-graft kinking, fracture, migration, or component separation [87-89]. For this reason, adjunct four-view radiographs are recommended to be obtained with all post-EVAR US examinations [49,53,84,87,89,90]. For FEVARs that involve the celiac trunk, US is unable to adequately visualize the proximal sealing zone [89].

Not unexpectedly, published results regarding the accuracy of CDUS in post-EVAR follow-up are varied [51,85,91-93]. Nevertheless, US offers the ability to determine endoleak flow direction and therefore assist in guiding management. Spectral waveform analysis of reperfusion to the aneurysm sac has been shown to have prognostic value, in which Type II endoleaks with bidirectional flow [94] and low flow velocities [95] have been associated with spontaneous closure.

Several studies have compared 2-D CEUS to CDUS in the setting of post-EVAR follow-up, with a recent meta-analysis finding no clinically significant differences between the two [96]. In the setting of post-FEVAR follow-up, 2-D CEUS was found to be equivalent to CTA in aneurysm sac measurement and in assessing patency of visceral vessels [84,89]. Additional studies have demonstrated the superiority of 3-D CEUS over standard 2-D methods in both endoleak detection [53] and sac measurement [50]. Three-dimensional CEUS has been found to be equivalent or superior to CTA in endoleak detection [53,88] and sac measurement, in addition to being highly reproducible [50,97].

Many have advocated replacing CTA with US for post-EVAR surveillance due to its lack of exposure to nephrotoxic contrast [52,90,92]. Specifically, it has been suggested that CDUS be used in conjunction with noncontrast CT to follow patient's post-EVAR who have renal insufficiency [98]. US surveillance protocols currently being developed seek to drastically reduce the cost of follow-up without compromising accuracy [34,35,90], with CTA reserved for further evaluation of suspicious findings.

## **Variant 2: Follow-up for post-endovascular repair (EVAR) or open repair of AAA.**

### **E. Radiography**

Radiographs were previously considered a useful adjunct to CT for detecting stent graft migration and underlying structural change. This modality cannot be used as a stand-alone study, as it is unable to assess aneurysm sac size or detect endoleak. Radiography alone therefore does not meet guideline criteria outlined by the Society of Interventional Radiology [32] in AAA postoperative surveillance. Despite its limitations, anterior and lateral radiographs have been shown to be useful for detecting stent migration, kinking, or modular separation of the stent graft components, whereas oblique projections may detect wire fractures [99]. Three-dimensional-reconstructed CTA images also provide this information, in addition to detecting endoleaks and changes in aneurysm size. As such, advances in 3-D visualization tools will likely render radiographs redundant and unnecessary when used in conjunction with CT. However, if US is used as the primary imaging modality in post-EVAR surveillance, radiographs become a vital adjunct examination [49,53,84,87,89,90].

### **Summary of Recommendations**

- For preoperative AAA repair planning, CTA abdomen and pelvis and MRA abdomen and pelvis are appropriate procedures.
- After repair of AAA, CTA abdomen and pelvis and MRA abdomen and pelvis are appropriate procedures.

### **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, please go to the ACR website at <https://www.acr.org/Clinical-Resources/Clinical-Tools-and-Reference/Appropriateness-Criteria>.

### **Appropriateness Category Names and Definitions**

<b>Appropriateness Category Name</b>	<b>Appropriateness Rating</b>	<b>Appropriateness Category Definition</b>
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.

## 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 (e.g., region of the body exposed to ionizing radiation, the imaging guidance that is used). The RRLs for these examinations are designated as "Varies."

## References

- Schmidt T, Muhlberger N, Chemelli-Steingruber IE, et al. Benefit, risks and cost-effectiveness of screening for abdominal aortic aneurysm. [Review] [50 refs]. ROFO Fortschr Geb Rontgenstr Nuklearmed. 182(7):573-80, 2010 Jul.
- Truijers M, Resch T, Van Den Berg JC, Blankensteijn JD, Lonn L. Endovascular aneurysm repair: state-of-art imaging techniques for preoperative planning and surveillance. [Review] [69 refs]. J Cardiovasc Surg (Torino). 50(4):423-38, 2009 Aug.

3. Nelson PR, Kracjer Z, Kansal N, et al. A multicenter, randomized, controlled trial of totally percutaneous access versus open femoral exposure for endovascular aortic aneurysm repair (the PEVAR trial). *J Vasc Surg.* 2014;59(5):1181-1193.
4. Oderich GS, Greenberg RK, Farber M, et al. Results of the United States multicenter prospective study evaluating the Zenith fenestrated endovascular graft for treatment of juxtarenal abdominal aortic aneurysms. *J Vasc Surg.* 2014;60(6):1420-1428 e1421-1425.
5. Tambyraja AL, Fishwick NG, Bown MJ, Nasim A, McCarthy MJ, Sayers RD. Fenestrated aortic endografts for juxtarenal aortic aneurysm: medium term outcomes. *Eur J Vasc Endovasc Surg.* 2011;42(1):54-58.
6. Lee JT, Lee GK, Chandra V, Dalman RL. Comparison of fenestrated endografts and the snorkel/chimney technique. *J Vasc Surg.* 2014;60(4):849-856; discussion 856-847.
7. Manunga JM, Gloviczki P, Oderich GS, et al. Femoral artery calcification as a determinant of success for percutaneous access for endovascular abdominal aortic aneurysm repair. *J Vasc Surg.* 2013;58(5):1208-1212.
8. Brewster DC, Cronenwett JL, Hallett JW, Jr., Johnston KW, Krupski WC, Matsumura JS. Guidelines for the treatment of abdominal aortic aneurysms. Report of a subcommittee of the Joint Council of the American Association for Vascular Surgery and Society for Vascular Surgery. *J Vasc Surg.* 2003; 37(5):1106-1117.
9. Parodi JC, Palmaz JC, Barone HD. Transfemoral intraluminal graft implantation for abdominal aortic aneurysms. *Ann Vasc Surg.* 1991; 5(6):491-499.
10. Greco G, Egorova NN, Gelijns AC, et al. Development of a novel scoring tool for the identification of large  $\geq 5$  cm abdominal aortic aneurysms. *Ann Surg.* 2010; 252(4):675-682.
11. Dillavou ED, Muluk SC, Makaroun MS. Improving aneurysm-related outcomes: nationwide benefits of endovascular repair. *J Vasc Surg.* 2006; 43(3):446-451; discussion 451-442.
12. Schermerhorn ML, O'Malley AJ, Jhaveri A, Cotterill P, Pomposelli F, Landon BE. Endovascular vs. open repair of abdominal aortic aneurysms in the Medicare population. *N Engl J Med.* 2008; 358(5):464-474.
13. Arko FR, Filis KA, Seidel SA, et al. How many patients with infrarenal aneurysms are candidates for endovascular repair? The Northern California experience. *J Endovasc Ther.* 2004; 11(1):33-40.
14. Ahanchi SS, Carroll M, Almaroof B, Panneton JM. Anatomic severity grading score predicts technical difficulty, early outcomes, and hospital resource utilization of endovascular aortic aneurysm repair. *J Vasc Surg.* 2011; 54(5):1266-1272.
15. De Bruin JL, Baas AF, Buth J, et al. Long-term outcome of open or endovascular repair of abdominal aortic aneurysm. *N Engl J Med.* 2010; 362(20):1881-1889.
16. Greenhalgh RM, Brown LC, Powell JT, Thompson SG, Epstein D, Sculpher MJ. Endovascular versus open repair of abdominal aortic aneurysm. *N Engl J Med.* 2010; 362(20):1863-1871.
17. Mestres G, Zarka ZA, Garcia-Madrid C, Riambau V. Early abdominal aortic endografts: a decade follow-up results. *Eur J Vasc Endovasc Surg.* 40(6):722-8, 2010 Dec.
18. Pitoulas GA, Schulte S, Donas KP, Horsch S. Secondary endovascular and conversion procedures for failed endovascular abdominal aortic aneurysm repair: can we still be

optimistic? *Vascular*. 2009; 17(1):15-22.

19. AbuRahma AF, Campbell J, Stone PA, et al. The correlation of aortic neck length to early and late outcomes in endovascular aneurysm repair patients. *J Vasc Surg*. 2009; 50(4):738-748.
20. Sweet MP, Fillinger MF, Morrison TM, Abel D. The influence of gender and aortic aneurysm size on eligibility for endovascular abdominal aortic aneurysm repair. *J Vasc Surg*. 2011; 54(4):931-937.
21. Yeung JJ, Hernandez-Boussard TM, Song TK, Dalman RL, Lee JT. Preoperative thrombus volume predicts sac regression after endovascular aneurysm repair. *J Endovasc Ther*. 2009; 16(3):380-388.
22. Iezzi R, Cotroneo AR. Endovascular repair of abdominal aortic aneurysms: CTA evaluation of contraindications. *Abdom Imaging*. 2006; 31(6):722-731.
23. Timaran CH, Lipsitz EC, Veith FJ, et al. Endovascular aortic aneurysm repair with the Zenith endograft in patients with ectatic iliac arteries. *Ann Vasc Surg*. 2005; 19(2):161-166.
24. Endovascular aneurysm repair versus open repair in patients with abdominal aortic aneurysm (EVAR trial 1): randomised controlled trial. *Lancet*. 2005; 365(9478):2179-2186.
25. Lovegrove RE, Javid M, Magee TR, Galland RB. A meta-analysis of 21,178 patients undergoing open or endovascular repair of abdominal aortic aneurysm. *Br J Surg*. 2008; 95(6):677-684.
26. Schanzer A, Greenberg RK, Hevelone N, et al. Predictors of abdominal aortic aneurysm sac enlargement after endovascular repair. *Circulation*. 123(24):2848-55, 2011 Jun 21. *Circulation*. 123(24):2848-55, 2011 Jun 21.
27. Ronsivalle S, Faresin F, Franz F, Rettore C, Zanchetta M, Olivieri A. Aneurysm sac "thrombization" and stabilization in EVAR: a technique to reduce the risk of type II endoleak. *J Endovasc Ther*. 2010; 17(4):517-524.
28. Ilyas S, Shaida N, Thakor AS, Winterbottom A, Cousins C. Endovascular aneurysm repair (EVAR) follow-up imaging: the assessment and treatment of common postoperative complications. [Review]. *Clin Radiol*. 70(2):183-96, 2015 Feb.
29. Brewster DC, Jones JE, Chung TK, et al. Long-term outcomes after endovascular abdominal aortic aneurysm repair: the first decade. *Ann Surg*. 2006; 244(3):426-438.
30. Bastos Goncalves F, Baderkhan H, Verhagen HJ, et al. Early sac shrinkage predicts a low risk of late complications after endovascular aortic aneurysm repair. *Br J Surg*. 2014;101(7):802-810.
31. Veith FJ, Baum RA, Ohki T, et al. Nature and significance of endoleaks and endotension: summary of opinions expressed at an international conference. *J Vasc Surg*. 2002; 35(5):1029-1035.
32. Geller SC. Imaging guidelines for abdominal aortic aneurysm repair with endovascular stent grafts. *J Vasc Interv Radiol*. 2003; 14(9 Pt 2):S263-264.
33. Picel AC, Kansal N. Essentials of endovascular abdominal aortic aneurysm repair imaging: preprocedural assessment. [Review]. *AJR Am J Roentgenol*. 203(4):W347-57, 2014 Oct.
34. Picel AC, Kansal N. Essentials of endovascular abdominal aortic aneurysm repair imaging:

postprocedure surveillance and complications. [Review]. *AJR Am J Roentgenol*. 203(4):W358-72, 2014 Oct.

35. Tse DM, Tapping CR, Patel R, et al. Surveillance after endovascular abdominal aortic aneurysm repair. [Review]. *Cardiovasc Intervent Radiol*. 37(4):875-88, 2014 Aug.
36. American College of Radiology. ACR–NASCI–SIR–SPR Practice Parameter for the Performance and Interpretation of Body Computed Tomography Angiography (CTA). Available at: <https://gravitas.acr.org/PPTS/GetDocumentView?docId=164+&releaseld=2>.
37. Macari M, Chandarana H, Schmidt B, Lee J, Lamparello P, Babb J. Abdominal aortic aneurysm: can the arterial phase at CT evaluation after endovascular repair be eliminated to reduce radiation dose? *Radiology*. 2006; 241(3):908-914.
38. Hong C, Heiken JP, Sicard GA, Pilgram TK, Bae KT. Clinical significance of endoleak detected on follow-up CT after endovascular repair of abdominal aortic aneurysm. *AJR*. 2008; 191(3):808-813.
39. Iezzi R, Cotroneo AR, Filippone A, et al. Multidetector CT in abdominal aortic aneurysm treated with endovascular repair: are unenhanced and delayed phase enhanced images effective for endoleak detection? *Radiology*. 2006; 241(3):915-921.
40. Stavropoulos SW, Charagundla SR. Imaging techniques for detection and management of endoleaks after endovascular aortic aneurysm repair. *Radiology*. 2007; 243(3):641-655.
41. Buffa V, Solazzo A, D'Amico A, et al. Dual-source dual-energy CT: dose reduction after endovascular abdominal aortic aneurysm repair. *Radiol Med (Torino)*. 119(12):934-41, 2014 Dec.
42. Stolzmann P, Frauenfelder T, Pfammatter T, et al. Endoleaks after endovascular abdominal aortic aneurysm repair: detection with dual-energy dual-source CT. *Radiology*. 2008; 249(2):682-691.
43. Stavropoulos SW, Clark TW, Carpenter JP, et al. Use of CT angiography to classify endoleaks after endovascular repair of abdominal aortic aneurysms. *J Vasc Interv Radiol*. 2005; 16(5):663-667.
44. Huang SG, Woo K, Moos JM, et al. A prospective study of carbon dioxide digital subtraction versus standard contrast arteriography in the detection of endoleaks in endovascular abdominal aortic aneurysm repairs. *Ann Vasc Surg*. 27(1):38-44, 2013 Jan.
45. Sueyoshi E, Nagayama H, Sakamoto I, Uetani M. Carbon dioxide digital subtraction angiography as an option for detection of endoleaks in endovascular abdominal aortic aneurysm repair procedure. *J Vasc Surg*. 61(2):298-303, 2015 Feb.
46. American College of Radiology. Manual on Contrast Media. Available at: <https://www.acr.org/Clinical-Resources/Contrast-Manual>.
47. Nguyen VL, Leiner T, Hellenthal FA, et al. Abdominal aortic aneurysms with high thrombus signal intensity on magnetic resonance imaging are associated with high growth rate. *Eur J Vasc Endovasc Surg*. 48(6):676-84, 2014 Dec.
48. Hoffmann B, Bessman ES, Um P, Ding R, McCarthy ML. Successful sonographic visualisation of the abdominal aorta differs significantly among a diverse group of credentialed emergency department providers. *Emerg Med J*. 2011; 28(6):472-476.
49. Millen A, Canavati R, Harrison G, et al. Defining a role for contrast-enhanced ultrasound in

endovascular aneurysm repair surveillance. *J Vasc Surg.* 58(1):18-23, 2013 Jul.

50. Bredahl K, Taudorf M, Long A, et al. Three-dimensional ultrasound improves the accuracy of diameter measurement of the residual sac in EVAR patients. *Eur J Vasc Endovasc Surg.* 46(5):525-32, 2013 Nov.
51. AbuRahma AF, Welch CA, Mullins BB, Dyer B. Computed tomography versus color duplex ultrasound for surveillance of abdominal aortic stent-grafts. *J Endovasc Ther.* 2005; 12(5):568-573.
52. Bargellini I, Cioni R, Napoli V, et al. Ultrasonographic surveillance with selective CTA after endovascular repair of abdominal aortic aneurysm. *J Endovasc Ther.* 2009; 16(1):93-104.
53. Abbas A, Hansrani V, Sedgwick N, Ghosh J, McCollum CN. 3D contrast enhanced ultrasound for detecting endoleak following endovascular aneurysm repair (EVAR). *Eur J Vasc Endovasc Surg.* 47(5):487-92, 2014 May.
54. Thurnher S, Cejna M. Imaging of aortic stent-grafts and endoleaks. *Radiol Clin North Am.* 2002;40(4):799-833.
55. Corriere MA, Islam A, Craven TE, Conlee TD, Hurie JB, Edwards MS. Influence of computed tomography angiography reconstruction software on anatomic measurements and endograft component selection for endovascular abdominal aortic aneurysm repair. *Journal of Vascular Surgery.* 59(5):1224-31.e1-3, 2014 May.
56. Sobocinski J, Chenorhokian H, Maurel B, et al. The benefits of EVAR planning using a 3D workstation. *Eur J Vasc Endovasc Surg.* 2013;46(4):418-423.
57. Tatli S, Lipton MJ, Davison BD, Skorstad RB, Yucel EK. From the RSNA refresher courses: MR imaging of aortic and peripheral vascular disease. *Radiographics.* 2003; 23 Spec No:S59-78.
58. Ludman CN, Yusuf SW, Whitaker SC, Gregson RH, Walker S, Hopkinson BR. Feasibility of using dynamic contrast-enhanced magnetic resonance angiography as the sole imaging modality prior to endovascular repair of abdominal aortic aneurysms. *Eur J Vasc Endovasc Surg.* 19(5):524-30, 2000 May.
59. Goshima S, Kanematsu M, Kondo H, et al. Preoperative planning for endovascular aortic repair of abdominal aortic aneurysms: feasibility of nonenhanced MR angiography versus contrast-enhanced CT angiography. *Radiology.* 267(3):948-55, 2013 Jun.
60. Shreibati JB, Baker LC, Hlatky MA, Mell MW. Impact of the Screening Abdominal Aortic Aneurysms Very Efficiently (SAAAVE) Act on abdominal ultrasonography use among Medicare beneficiaries. *Arch Intern Med.* 2012;172(19):1456-1462.
61. Garg T, Baker LC, Mell MW. Adherence to postoperative surveillance guidelines after endovascular aortic aneurysm repair among Medicare beneficiaries. *Journal of Vascular Surgery.* 61(1):23-7, 2015 Jan. *J Vasc Surg.* 61(1):23-7, 2015 Jan.
62. Gill HL, Ladowski S, Sudarshan M, et al. Predictive value of negative initial postoperative imaging after endovascular aortic aneurysm repair. *J Vasc Surg.* 60(2):325-9, 2014 Aug.
63. Patel MS, Carpenter JP. The value of the initial post-EVAR computed tomography angiography scan in predicting future secondary procedures using the Powerlink stent graft. *J Vasc Surg.* 2010; 52(5):1135-1139.
64. Sternbergh WC, 3rd, Greenberg RK, Chuter TA, Tonnessen BH. Redefining postoperative

surveillance after endovascular aneurysm repair: recommendations based on 5-year follow-up in the US Zenith multicenter trial. *J Vasc Surg.* 2008; 48(2):278-284; discussion 284-275.

65. Farner MC, Carpenter JP, Baum RA, Fairman RM. Early changes in abdominal aortic aneurysm diameter after endovascular repair. *J Vasc Interv Radiol.* 14(2 Pt 1):205-10, 2003 Feb.
66. Cayne NS, Veith FJ, Lipsitz EC, et al. Variability of maximal aortic aneurysm diameter measurements on CT scan: significance and methods to minimize. *J Vasc Surg.* 2004; 39(4):811-815.
67. Bargellini I, Cioni R, Petruzzi P, et al. Endovascular repair of abdominal aortic aneurysms: analysis of aneurysm volumetric changes at mid-term follow-up. *Cardiovasc Intervent Radiol.* 2005; 28(4):426-433.
68. Demehri S, Signorelli J, Kumamaru KK, et al. Volumetric quantification of type II endoleaks: an indicator for aneurysm sac growth following endovascular abdominal aortic aneurysm repair.[Erratum appears in *Radiology.* 2015 Oct;277(1):308 Note: Steinger, Michael L [corrected to Steigner, Michael L]; PMID: 26402504]. *Radiology.* 271(1):282-90, 2014 Apr.
69. Prinssen M, Verhoeven EL, Verhagen HJ, Blankensteijn JD. Decision-making in follow-up after endovascular aneurysm repair based on diameter and volume measurements: a blinded comparison. *Eur J Vasc Endovasc Surg.* 2003; 26(2):184-187.
70. Bley TA, Chase PJ, Reeder SB, et al. Endovascular abdominal aortic aneurysm repair: nonenhanced volumetric CT for follow-up. *Radiology.* 2009;253(1):253-262.
71. Bobadilla JL, Suwanabol PA, Reeder SB, Pozniak MA, Bley TA, Tefera G. Clinical implications of non-contrast-enhanced computed tomography for follow-up after endovascular abdominal aortic aneurysm repair. *Ann Vasc Surg.* 27(8):1042-8, 2013 Nov.
72. Cani A, Cotta E, Recaldini C, et al. Volumetric analysis of the aneurysmal sac with computed tomography in the follow-up of abdominal aortic aneurysms after endovascular treatment. *Radiol Med (Torino).* 117(1):72-84, 2012 Feb.
73. Nambi P, Sengupta R, Krajcer Z, Muthupillai R, Strickman N, Cheong BY. Non-contrast computed tomography is comparable to contrast-enhanced computed tomography for aortic volume analysis after endovascular abdominal aortic aneurysm repair. *Eur J Vasc Endovasc Surg.* 2011; 41(4):460-466.
74. Caldwell DP, Pulfer KA, Jaggi GR, Knuteson HL, Fine JP, Pozniak MA. Aortic aneurysm volume calculation: effect of operator experience. *Abdom Imaging.* 2005; 30(3):259-262.
75. Czermak BV, Fraedrich G, Schocke MF, et al. Serial CT volume measurements after endovascular aortic aneurysm repair. *J Endovasc Ther.* 2001; 8(4):380-389.
76. Merkle EM, Klein S, Kramer SC, Wisianowsky C. MR angiographic findings in patients with aortic endoprostheses. *AJR.* 2002; 178(3):641-648.
77. Klemm T, Duda S, Machann J, et al. MR imaging in the presence of vascular stents: A systematic assessment of artifacts for various stent orientations, sequence types, and field strengths. *J Magn Reson Imaging.* 2000; 12(4):606-615.
78. Ayuso JR, de Caralt TM, Pages M, et al. MRA is useful as a follow-up technique after endovascular repair of aortic aneurysms with nitinol endoprostheses. *J Magn Reson*

Imaging. 2004; 20(5):803-810.

- 79.** Habets J, Zandvoort HJ, Reitsma JB, et al. Magnetic resonance imaging is more sensitive than computed tomography angiography for the detection of endoleaks after endovascular abdominal aortic aneurysm repair: a systematic review. [Review]. *Eur J Vasc Endovasc Surg.* 45(4):340-50, 2013 Apr.
- 80.** Pitton MB, Schweitzer H, Herber S, et al. MRI versus helical CT for endoleak detection after endovascular aneurysm repair. *AJR.* 2005; 185(5):1275-1281.
- 81.** Lookstein RA, Goldman J, Pukin L, Marin ML. Time-resolved magnetic resonance angiography as a noninvasive method to characterize endoleaks: initial results compared with conventional angiography. *J Vasc Surg.* 2004; 39(1):27-33.
- 82.** Ersoy H, Jacobs P, Kent CK, Prince MR. Blood pool MR angiography of aortic stent-graft endoleak. *AJR Am J Roentgenol.* 182(5):1181-6, 2004 May.
- 83.** Ichihashi S, Marugami N, Tanaka T, et al. Preliminary experience with superparamagnetic iron oxide-enhanced dynamic magnetic resonance imaging and comparison with contrast-enhanced computed tomography in endoleak detection after endovascular aneurysm repair. *J Vasc Surg.* 58(1):66-72, 2013 Jul.
- 84.** Resta EC, Secchi F, Giardino A, et al. Non-contrast MR imaging for detecting endoleak after abdominal endovascular aortic repair. *Int J Cardiovasc Imaging.* 29(1):229-35, 2013 Jan.
- 85.** Ashoke R, Brown LC, Rodway A, et al. Color duplex ultrasonography is insensitive for the detection of endoleak after aortic endografting: a systematic review. *J Endovasc Ther.* 2005; 12(3):297-305.
- 86.** Sun Z. Diagnostic value of color duplex ultrasonography in the follow-up of endovascular repair of abdominal aortic aneurysm. *J Vasc Interv Radiol.* 2006; 17(5):759-764.
- 87.** Gargiulo M, Gallitto E, Serra C, et al. Could four-dimensional contrast-enhanced ultrasound replace computed tomography angiography during follow up of fenestrated endografts? Results of a preliminary experience. *Eur J Vasc Endovasc Surg.* 48(5):536-42, 2014 Nov.
- 88.** Gurtler VM, Sommer WH, Meimarakis G, et al. A comparison between contrast-enhanced ultrasound imaging and multislice computed tomography in detecting and classifying endoleaks in the follow-up after endovascular aneurysm repair. *J Vasc Surg.* 58(2):340-5, 2013 Aug.
- 89.** Perini P, Sediri I, Midulla M, Delsart P, Gautier C, Haulon S. Contrast-enhanced ultrasound vs. CT angiography in fenestrated EVAR surveillance: a single-center comparison. *J Endovasc Ther.* 19(5):648-55, 2012 Oct.
- 90.** Gray C, Goodman P, Herron CC, et al. Use of colour duplex ultrasound as a first line surveillance tool following EVAR is associated with a reduction in cost without compromising accuracy. *Eur J Vasc Endovasc Surg.* 44(2):145-50, 2012 Aug.
- 91.** AbuRahma AF. Fate of endoleaks detected by CT angiography and missed by color duplex ultrasound in endovascular grafts for abdominal aortic aneurysms. *J Endovasc Ther.* 2006; 13(4):490-495.
- 92.** Collins JT, Boros MJ, Combs K. Ultrasound surveillance of endovascular aneurysm repair: a safe modality versus computed tomography. *Ann Vasc Surg.* 2007; 21(6):671-675.
- 93.** Manning BJ, O'Neill SM, Haider SN, Colgan MP, Madhavan P, Moore DJ. Duplex ultrasound

in aneurysm surveillance following endovascular aneurysm repair: a comparison with computed tomography aortography. *J Vasc Surg.* 2009; 49(1):60-65.

- 94.** Parent FN, Meier GH, Godziachvili V, et al. The incidence and natural history of type I and II endoleak: a 5-year follow-up assessment with color duplex ultrasound scan. *J Vasc Surg.* 2002; 35(3):474-481.
- 95.** Arko FR, Filis KA, Siedel SA, et al. Intrasc flow velocities predict sealing of type II endoleaks after endovascular abdominal aortic aneurysm repair. *J Vasc Surg.* 2003; 37(1):8-15.
- 96.** Karthikesalingam A, Al-Jundi W, Jackson D, et al. Systematic review and meta-analysis of duplex ultrasonography, contrast-enhanced ultrasonography or computed tomography for surveillance after endovascular aneurysm repair. *Br J Surg.* 2012;99(11):1514-1523.
- 97.** Causey MW, Jayaraj A, Leotta DF, et al. Three-dimensional ultrasonography measurements after endovascular aneurysm repair. *Ann Vasc Surg.* 27(2):146-53, 2013 Feb.
- 98.** Chaikof EL, Brewster DC, Dalman RL, et al. SVS practice guidelines for the care of patients with an abdominal aortic aneurysm: executive summary. *J Vasc Surg.* 2009;50(4):880-896.
- 99.** Murphy M, Hodgson R, Harris PL, McWilliams RG, Hartley DE, Lawrence-Brown MM. Plain radiographic surveillance of abdominal aortic stent-grafts: the Liverpool/Perth protocol. *J Endovasc Ther.* 2003; 10(5):911-912.
- 100.** Smith T, Quencer KB. Best Practice Guidelines: Imaging Surveillance After Endovascular Aneurysm Repair. [Review]. *AJR. American Journal of Roentgenology.* 214(5):1165-1174, 2020 05.
- 101.** Gallitto E, Faggioli G, Gargiulo M, et al. Planning, Execution, and Follow-up for Endovascular Aortic Aneurysm Repair Using a Highly Restrictive Iodinated Contrast Protocol in Patients with Severe Renal Disease. *Annals of Vascular Surgery.* 47:205-211, 2018 Feb.
- 102.** Reginelli A, Capasso R, Ciccone V, et al. Usefulness of triphasic CT aortic angiography in acute and surveillance: Our experience in the assessment of acute aortic dissection and endoleak. *International Journal Of Surgery.* 33 Suppl 1:S76-84, 2016 Sep.
- 103.** Saratzis A, Dattani N, Brown A, et al. Multi-Centre Study on Cardiovascular Risk Management on Patients Undergoing AAA Surveillance. *European Journal of Vascular & Endovascular Surgery.* 54(1):116-122, 2017 Jul.
- 104.** Dong H, Raterman B, White RD, et al. MR Elastography of Abdominal Aortic Aneurysms: Relationship to Aneurysm Events. *Radiology.* 304(3):721-729, 2022 09.
- 105.** Lee R, Bellamkonda K, Jones A, et al. Flow Mediated Dilatation and Progression of Abdominal Aortic Aneurysms. *European Journal of Vascular & Endovascular Surgery.* 53(6):820-829, 2017 Jun.
- 106.** Schinkel AF, Kaspar M, Staub D. Contrast-enhanced ultrasound: clinical applications in patients with atherosclerosis. [Review]. *The International Journal of Cardiovascular Imaging.* 32(1):35-48, 2016 Jan.
- 107.** Schaeffer JS, Shakhnovich I, Sieck KN, Kallies KJ, Davis CA, Cogbill TH. Duplex Ultrasound Surveillance After Uncomplicated Endovascular Abdominal Aortic Aneurysm Repair. *Vascular & Endovascular Surgery.* 51(5):295-300, 2017 Jul.

- 108.** Chisci E, Harris L, Guidotti A, et al. Endovascular Aortic Repair Follow up Protocol Based on Contrast Enhanced Ultrasound Is Safe and Effective. *European Journal of Vascular & Endovascular Surgery*. 56(1):40-47, 2018 07.
- 109.** Johnsen L, Hisdal J, Jonung T, Braaten A, Pedersen G. Three-dimensional ultrasound volume and conventional ultrasound diameter changes are equally good markers of endoleak in follow-up after endovascular aneurysm repair. *Journal of Vascular Surgery*. 75(3):1030-1037.e1, 2022 03.
- 110.** Nayeemuddin M, Pherwani AD, Asquith JR. Imaging and management of complications of open surgical repair of abdominal aortic aneurysms. [Review]. *Clin Radiol*. 67(8):802-14, 2012 Aug.
- 111.** Pratesi C, Esposito D, Apostolou D, et al. Guidelines on the management of abdominal aortic aneurysms: updates from the Italian Society of Vascular and Endovascular Surgery (SICVE). *Journal of Cardiovascular Surgery*. 63(3):328-352, 2022 Jun.
- 112.** Postoperative imaging of the aorta.
- 113.** Serizawa F, Ohara M, Kotegawa T, Watanabe S, Shimizu T, Akamatsu D. The Incidence of Para-Anastomotic Aneurysm After Open Repair Surgery for Abdominal Aortic Aneurysm Through Routine Annual Computed Tomography Imaging. *European Journal of Vascular & Endovascular Surgery*. 62(2):187-192, 2021 08.
- 114.** Charbonneau P, Hongku K, Herman CR, et al. Long-term survival after endovascular and open repair in patients with anatomy outside instructions for use criteria for endovascular aneurysm repair. *Journal of Vascular Surgery*. 70(6):1823-1830, 2019 12.
- 115.** Baba T, Ohki T, Kanaoka Y, et al. Clinical Outcomes of Total Endovascular Aneurysm Repair for Aortic Aneurysms Involving the Proximal Anastomotic Aneurysm following Initial Open Repair for Infrarenal Abdominal Aortic Aneurysm. *Annals of Vascular Surgery*. 49:123-133, 2018 May.
- 116.** Gifford JN, Cheong HW, Teoh WC. Late-onset type I endoleak characterized by contrast enhanced ultrasound after endovascular repair of aortic aneurysm. *Journal of Clinical Ultrasound*. 46(6):424-429, 2018 Jul.
- 117.** Rubenthaler J, Reiser M, Cantisani V, Rjosk-Dendorfer D, Clevert DA. The value of contrast-enhanced ultrasound (CEUS) using a high-end ultrasound system in the characterization of endoleaks after endovascular aortic repair (EVAR). *Clinical Hemorheology & Microcirculation*. 66(4):283-292, 2017.
- 118.** Shukla K, Messner M, Albuquerque F, Larson R, Newton D, Levy M. Safety of Utilizing Ultrasound as the Sole Modality of Follow-Up after Endovascular Aneurysm Repair. *Annals of Vascular Surgery*. 92:172-177, 2023 May.
- 119.** Jean-Baptiste E, Feugier P, Cruzel C, et al. Computed Tomography-Aortography Versus Color-Duplex Ultrasound for Surveillance of Endovascular Abdominal Aortic Aneurysm Repair: A Prospective Multicenter Diagnostic-Accuracy Study (the ESSEA Trial). *Circulation. Cardiovascular imaging*. 13(6):e009886, 2020 06.
- 120.** Faccioli N, Foti G, Casagrande G, Santi E, D'Onofrio M. CEUS versus CT Angiography in the follow-up of abdominal aortic endoprostheses: diagnostic accuracy and activity-based cost analysis. *Radiologia Medica*. 123(12):904-909, 2018 Dec.

121. Gabriel M, Tomczak J, Snoch-Ziolkiewicz M, et al. Superb Micro-vascular Imaging (SMI): a Doppler ultrasound technique with potential to identify, classify, and follow up endoleaks in patients after Endovascular Aneurysm Repair (EVAR). *Abdominal Radiology*. 43(12):3479-3486, 2018 12.
122. Kawada H, Goshima S, Sakurai K, et al. Utility of Noncontrast Magnetic Resonance Angiography for Aneurysm Follow-Up and Detection of Endoleaks after Endovascular Aortic Repair. *Korean Journal of Radiology*. 22(4):513-524, 2021 04.
123. Zierler RE. Duplex ultrasound follow-up after fenestrated and branched endovascular aneurysm repair (FEVAR and BEVAR). [Review]. *Seminars in Vascular Surgery*. 33(3-4):60-64, 2020 Dec.
124. Rouet L, Dufour C, Collet Billon A, Bredahl K. CT and 3D-ultrasound registration for spatial comparison of post-EVAR abdominal aortic aneurysm measurements: A cross-sectional study. *Computerized Medical Imaging & Graphics*. 73:49-59, 2019 04.
125. Berczeli M, Chinnadurai P, Chang SM, Lumsden AB. Time-Resolved, Dynamic Computed Tomography Angiography for Characterization of Aortic Endoleaks and Treatment Guidance via 2D-3D Fusion-Imaging. *Journal of Visualized Experiments*. (178), 2021 12 09.

## Disclaimer

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.

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