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American College of Radiology
ACR Appropriateness Criteria®

Clinical Condition: **Abdominal Aortic Aneurysm: Interventional Planning and Follow-up**

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

Radiologic Procedure	Rating	Comments	RRL*
CTA abdomen and pelvis with IV contrast	9	For evaluation of known AAA without thoracic aortic involvement. Noncontrast sequence is not necessary for interventional planning.	☢☢☢☢☢
CTA chest abdomen pelvis with IV contrast	8	Useful for patients with suspected AAA but no prior workup of the thoracic aorta. Study of choice for workup of suprarenal AAA or thoracoabdominal aneurysm.	☢☢☢☢☢
CT abdomen and pelvis without IV contrast	6	At physician's discretion, chest may not be included. Appropriate for patients with contraindication to iodinated contrast. Occasionally depicts density differences between the blood pool and aortic wall/mural thrombus. Otherwise, further luminal assessment with MRI, US, or DSA would be preferred.	☢☢☢☢
MRA abdomen and pelvis without and with IV contrast	6	Alternative to CTA in patients with known AAA not involving the thoracic aorta and in whom iodinated contrast is contraindicated.	O
CT chest abdomen pelvis without IV contrast	5	Appropriate for patients with contraindication to iodinated contrast. Occasionally depicts density differences between the blood pool and aortic wall/mural thrombus. Otherwise, further luminal assessment with MRI, US, or DSA would be preferred.	☢☢☢☢
Digital subtraction angiography (DSA) aorta	5	May be appropriate in select cases, including patients who require pre-operative embolization of branch vessels or those requiring further characterization of the aortic lumen with an alternative contrast agent (such as CO_2) or intravascular US.	☢☢☢
MRA chest abdomen pelvis without and with IV contrast	5	Alternative to CTA in patients with contraindication to iodinated contrast who have had no prior evaluation of thoracic aorta.	O
MRA chest abdomen pelvis without IV contrast	4	Appropriate for patients with severe renal dysfunction.	O
MRA abdomen and pelvis without IV contrast	4	Appropriate for patients with severe renal dysfunction. At physician's discretion, chest may not be included.	O
US aorta abdomen with Doppler	3	Useful screening tool, but insufficient for AAA treatment planning. May be used in tandem with DSA in the absence of cross-sectional imaging, or as an adjunct to noncontrast CT for luminal evaluation.	O
X-ray chest abdomen pelvis	1		☢☢☢
Rating Scale: **1,2,3 Usually not appropriate; 4,5,6 May be appropriate; 7,8,9 Usually appropriate**			***Relative Radiation Level**

Clinical Condition: **Abdominal Aortic Aneurysm: Interventional Planning and Follow-up**

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

Radiologic Procedure	Rating	Comments	RRL*
CTA abdomen and pelvis with IV contrast	9	Method of choice.	☢☢☢☢☢
MRA abdomen and pelvis without and with IV contrast	7	Appropriate alternative to CTA, but less accurate for assessing endograft metallic components. Effectiveness depends on composition of endoprosthesis. 3D contrast-enhanced MRA and time-resolved MRA are highly sensitive to endoleaks.	O
CT abdomen and pelvis without IV contrast	6	Appropriate for patients with MR-incompatible devices or contraindication to iodinated contrast. Provides temporal information regarding sac morphology with reduced contrast exposure and radiation burden. US is a useful adjunctive tool for endoleak detection.	☢☢☢☢
Digital subtraction angiography (DSA) aorta	6	Selectively useful for characterization and treatment of endoleaks type I and III.	☢☢☢
MRA abdomen and pelvis without IV contrast	5	Selectively useful for assessment of renal or mesenteric vasculature in patients with contraindication to iodinated contrast.	O
US aorta abdomen with Doppler	5	Important adjunct to noncontrast CT for endoleak detection. May be useful in endoleak characterization.	O
X-ray abdomen and pelvis	4	Provides detailed survey for structural integrity of the metallic components of the endograft but not the nonmetallic components. Particularly useful with tortuous anatomy. However, inadequate as a stand-alone follow-up modality.	☢☢☢
Rating Scale: **1,2,3 Usually not appropriate; 4,5,6 May be appropriate; 7,8,9 Usually appropriate**			***Relative Radiation Level**

ABDOMINAL AORTIC ANEURYSM: INTERVENTIONAL PLANNING AND FOLLOW-UP

Expert Panel on Vascular Imaging and Interventional Radiology: Christopher J. Francois, MD[1]; J. Harald Kramer, MD[2]; Frank J. Rybicki, MD, PhD[3]; Charles E. Ray, Jr, MD, PhD[4]; Dennis F. Bandyk, MD[5]; Charles T. Burke, MD[6]; Karin E. Dill, MD[7]; Marie D. Gerhard-Herman, MD[8]; Michael Hanley, MD[9]; Eric J. Hohenwalter, MD[10]; Emile R. Mohler III, MD[11]; Paul J. Rochon, MD[12]; Matthew P. Schenker, MD.[13]

Summary of Literature Review

Introduction/Background

In 1991, Parodi et al [1] reported successful deployment of an endoluminal stent graft within the aorta via a transfemoral approach. It permanently transformed the landscape of abdominal aortic aneurysm (AAA) management and therapy. Previous treatment options were limited to expectant management combining medical control of blood pressure with close imaging surveillance, versus open surgical repair. Due to the significant perioperative morbidity of open repair, the exact point of transition to surgical intervention varied on an individual basis, but relatively well-defined guidelines were in place to help direct decision-making and led to the implementation of guidelines for screening for AAA [2,3]. These guidelines were developed based on the patient's health status, comorbidities, the anuerysm's absolute size (>5.5 cm) and rate of change (>1 cm/year), and other signs indicating impending rupture [2,4]. The arrival of the EVAR (endovascular aneurysm repair) technique introduced new variables to managing AAAs.

Multiple studies have shown significantly decreased length of hospital stay and decreased perioperative morbidity with this procedure [5-8] compared to open repair [9-11]. Though increasingly replaced by EVAR, open repair is still performed in patients with unsuitable aneurysm morphology for EVAR and in those with failed EVAR [12]. 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 to exclude a concomitant thoracic aortic aneurysm. Preoperative imaging for open repair of AAA has one main focus: to determine the need for surgery based on aneurysm size, extent, and, if borderline in size, rate of growth. Additional information on anatomical variants can also be helpful in guiding appropriate treatment and preventing unexpected complications at time of repair.

EVAR, in particular, requires accurate preoperative imaging evaluation for appropriate patient selection based on aneurysm morphology and access vessel size and patency [13,14]. Paramount considerations in evaluating an AAA for EVAR lie in the morphology of the proximal neck, which for infrarenal AAA is defined as that segment of aorta between the most caudal renal artery and the proximal boundary of the aneurysm. An unfavorable neck anatomy, based on its diameter, length, angulation, morphology, and presence of calcification, was the most frequent cause of exclusion from EVAR in the past [15-17]. For traditional EVAR, a neck size of >10-15 mm in length and <30 mm in diameter was required to provide an adequate seal proximally. However, in recent years, new devices have become available which either feature an uncovered proximal part which allows for placing the stent directly at the origin of aortic branches or possess ready-made vessel origins, eg, for the renal and mesenteric arteries [16]. These latter devices are known as branched or fenestrated devices. The uncovered, branched and festrated stents may be especially favorable in women because they are less likely to have neck and iliac diameters sufficient for traditional EVAR [14]. However, while not an absolute contraindication to EVAR, mural thrombus and atherosclerotic calcification covering more than 90 degrees 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 [17,18]. The distal landing zone is usually in the common iliac artery. With the new generation of devices, common iliac

[1]Principal Author, University of Wisconsin, Madison, Wisconsin. [2]Research Author, University of Wisconsin, Madison, Wisconsin. [3]Panel Chair (Vascular Imaging), Brigham and Women's Hospital, Boston, Massachusetts. [4]Panel Chair (Interventional Radiology), University of Colorado, Anschutz Medical Campus, Aurora, Colorado. [5]University of San Diego, La Jolla, California, Society of Vascular Surgeons. [6]University of North Carolina Hospital, Chapel Hill, North Carolina. [7]University of Chicago, Chicago, Illinois. [8]Brigham and Women's Hospital, Boston, Massachusetts, American College of Cardiology. [9]University of Virginia, Charlottesville, Virginia. [10]Froedtert & The Medical College of Wisconsin, Milwaukee, Wisconsin. [11]University of Pennsylvania, Philadelphia, Pennsylvania, American College of Cardiology. [12]University of Colorado Denver, Anschutz Medical Campus, Aurora, Colorado. [13]Brigham and Women's Hospital, Boston, Massachusetts.

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artery diameters of ≤20 mm can be considered for EVAR [19]. The minimal external iliac artery intraluminal diameter should be ≥7 mm to safely accept delivery sheaths [20].

The advantages conferred by EVAR come at a cost of lifelong imaging surveillance, due to higher rate of complications (which can occur anytime after the procedure) requiring reintervention compared to open repair [7,21]. Some 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 [22]. The most common complication of EVAR is endoleak formation, which may contribute to aneurysm sac enlargement and rupture [23]. There are different classifications for endoleaks occuring after EVAR, with three different types occuring most commonly [12]. Appropriate classification is crucial for subsequent management, and should be clarified when possible. Although EVAR is safe with a low mortality rate from AAA [24], the possibility of complications and need for reintervention remains high [9-11], requiring life-long monitoring.

The ultimate goal of endovascular therapy is to prevent aneurysm rupture, and follow-up imaging is the most useful tool to evaluate outcome, in addition to monitoring complications. Success is presumed to be reflected by aneurysm size stability or regression over time, with decreasing size of the AAA believed to indicate low risk of rupture [25]. 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 [26]. Imaging modalities should be assessed by their effectiveness in satisfying these three requirements, as well as their respective safety profiles, including use of ionizing radiation and potentially nephrotoxic contrast agents.

Computed Tomography Angiography

Computed tomography angiography (CTA), with its superior spatial resolution, faster patient throughput, and wide availability, has gained wide acceptance as the gold standard for pre-EVAR evaluation as well as post-EVAR and post-open-repair imaging surveillance. Its disadvantages include its use of ionizing radiation and contrast medium and its higher cost compared to ultrasound (US).

While not necessary in the early postoperative period, it is recommended that CT imaging be performed within 5 years of open repair of AAA to detect aneurysmal degeneration involving the pararenal aorta, iliac arteries, graft, or anastomotic sites [27]. Following EVAR, the most widely used surveillance regimen includes multiphasic contrast-enhanced CT scans at 1, 6, and 12 months and yearly thereafter. In the absence of adverse outcomes at early post-EVAR imaging, the intensity and frequency of the surveillance program may be modulated accordingly [28,29]. Compared to conventional catheter angiography, CTA may have higher sensitivity in detecting endoleaks [18] after EVAR. Compared to US, CTA is more accurate in measuring aneurysms and more sensitive for endoleak detection [30].

CT 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 radiation dose, there are proponents of eliminating the arterial phase [31], while others suggest eliminating the delayed phase [32,33]. One author has suggested including the nonenhanced sequence only at the initial 1-month follow-up [34]. There are also recent reports of acquiring images only in the delayed phase with dual-energy CT, with reconstruction of virtual nonenhanced images [35]. Determining the optimal dose-efficient CT technique is clearly a work in progress, and it will only be elucidated with more experience.

Maximum aneurysm diameter was used initially in the majority of studies monitoring EVAR results [36]. This method has been shown to be unreliable due to substantial interobserver variability [37]. Volume analysis has since been recognized as a more robust method for determining success of the procedure, and for providing management guidelines [38,39]. In an effort to reduce radiation and contrast exposure, some authors have proposed using serial volumetric analysis of aortic aneurysms with nonenhanced CT as the screening test for post-EVAR follow-up [40,41]. Volume discrepancy due to interoperator variability has been previously demonstrated to be less than 2% when the procedure is performed by experienced personnel [42]. In patients in whom contrast agents are contraindicated, serial volume measurements of the nonenhanced aortic aneurysm provides valuable information in guiding management [43].

Catheter Angiography

Catheter angiography can accurately assess aortic side branch patency, which is crucial for deployment of conventional and branched or fenestrated endografts. However, it fails to demonstrate mural thrombus that compromises diameter measurement and landing zone assessment, and is therefore not an adequate examination for preoperative evaluation for the EVAR procedure. Due to its relatively invasive nature, catheter angiography is also not commonly used as the first-line modality for post-EVAR surveillance. In addition, this technique imparts ionizing radiation and uses iodinated contrast. Though less sensitive than CTA in detecting endoleaks, digital subtraction angiography (DSA) is more accurate than conventional CTA in classifying endoleaks because the direction of blood flow in or out of the aneurysm sac can be assessed by DSA. One study showed only 86% agreement in endoleak classification between DSA and CTA, and subsequent correct classification of endoleaks by DSA significantly improved patient management [44]. It stands to reason that catheter angiography may be best used as a second-line imaging modality in post-EVAR patients, playing a vital role in endoleak classification and reintervention.

Magnetic Resonance Angiography

The advantage of magnetic resonance imaging/angiography (MRI/MRA) relative to CT/CTA is its lack of ionizing radiation exposure. Until recently, MR contrast agents were felt to have low nephrotoxicity, which was traditionally regarded as a favorable feature of MRI. However, this concept has since come under scrutiny, as some gadolinium-based contrast agents have been linked to nephrogenic systemic fibrosis. Hence, evaluation of renal function before contrast is used is recommended. The disadvantages of MRI/MRA include its cost, relative inaccessibility, long scanning time, patient claustrophobia, decreased spatial resolution, and contraindication in patients with cardiac pacemakers. Additionally, susceptibility artifact from the stent graft presents a diagnostic challenge for assessing device integrity and may mimic graft stenosis.

For the purpose of pre-EVAR planning, T1-weighted spin-echo (black blood) images and flow-based methods such as time-of-flight or phase contrast (white blood imaging) 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 therefore are suboptimal for evaluating small-vessel lesions or small side branches. Furthermore, the flowing blood techniques are susceptible to flow artifacts that may overestimate stenoses or even falsely demonstrate an occlusion [45]. 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 blooming artifacts and has a high signal-to-noise ratio for evaluating small vessels and 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 [46].

When considering using MRI for post-EVAR surveillance, structural contents and orientation of the stent graft are important considerations. Stents are usually made of nitinol, elgiloy, or stainless steel. Nitinol is an alloy of nickel and titanium which causes relatively few artifacts on MRI, and it allows for visualization of the stent lumen and adjacent structures. Elgiloy is an alloy of cobalt, chromium, and nickel which may obscure the stent lumen while allowing visualization of the adjacent structures. Patients with nitinol stents are the best candidates for MRA, and those with stainless steel or elgiloy stents may experience significant artifacts that compromise visualization of the stent lumen and limit morphological resolution of stent wall [47]. However, artifacts may arise even with nitinol stents secondary to stent geometry [48].

MRA of the post-EVAR aorta shares multiple features with CTA. MR images may be reformatted three-dimensionally for volume or diameter measurements. In patients with nitinol stents, aortic diameter measurements for MRA have been shown to be as reliable as those obtained with CTA [49]. For detection and sizing of endoleak, MRA is at least as sensitive as, and probably better than CTA [50-53]. Indeed, the higher rate of endoleak detection seen with MRA in cases of negative CTA may shed light on the phenomenon of endotension [51]. Also, time-resolved MRA has recently been used to characterize endoleaks. It was found to provide relevant information regarding contrast dynamics and direction of flow of endoleaks, and it shows promise in replacing DSA as an effective, noninvasive method for endoleak characterization [54].

Color Duplex Ultrasound

Color duplex US is a viable imaging solution for post-EVAR follow-up. It is convenient, noninvasive, and relatively inexpensive, and it has a favorable safety profile. For these reasons, some authors advocate performing color duplex US for post-EVAR screening [55,56]. Although excellent correlation between AAA diameter measurements on CT and US has been noted, there is fairly uniform agreement that US underestimates aneurysm diameter by ~2 mm [30,55,57]. For detection of endoleak formation, color-coded duplex US has high specificity but limited sensitivity, reported to be 91%-93% and 66%-69%, respectively, in two large meta-analysis studies [58,59]. Moreover, image quality of US is highly dependent on operator experience, patient preparation, and body habitus [60].

Not unexpectedly, published results regarding the accuracy of duplex US in post-EVAR follow-up have been varied [30,56-58,61,62]. Nevertheless, real-time US does offer the distinct advantage of determining endoleak flow direction, which is useful for guiding management. Spectral waveform analysis of intrasac reperfusion also has prognostic value, where type II endoleaks with bidirectional flow [63] and low flow velocities [64] have been associated with spontaneous closure. In patients with absolute contraindications to iodinated contrast, whether due to severe renal impairment or to life-threatening contrast allergy, color duplex US becomes an important adjunct to nonenhanced CT. Furthermore, infusion of microbubbles increases the diagnostic accuracy of US for endoleak detection, and it has the potential to replace CTA as the primary surveillance modality [65].

Radiography

Radiographs were previously considered to be a useful adjunct to CT for detecting structural changes in the stent graft. This examination cannot be used as a stand-alone study, as it clearly does not assess for changes in the size of the excluded aneurysm sac or for the presence of endoleak, and therefore does not meet guideline criteria outlined by the Society of Interventional Radiology [26]. Despite its limitations, anterior and lateral radiographs have been shown to be useful for detecting stent migration or modular separation of the stent graft, and oblique films can detect wire fractures [66]. However, three-dimensional postprocessed CTA images can provide this information, in addition to detecting endoleak formation and changes in aneurysm size. Indeed, advances in three-dimensional visualization tools may render radiographs redundant, and its traditional role as an adjunct examination to CTA should be carefully re-evaluated.

Summary

EVAR is a revolutionary technique that irrefutably altered the approach to AAA management. Appropriate patient selection through thorough preprocedural CT evaluation is paramount to a successful EVAR. Since its use was first reported, there has been ongoing research to investigate its efficacy and complications. In addition, EVAR may be a more costly procedure than open repair owing to a higher rate of reintervention and a need for lifelong surveillance [21,67]. How to deliver care without placing an unrealistic financial burden on society is another important consideration when evaluating each imaging modality.

It is clear that EVAR is a much safer procedure than conventional open repair for treatment of AAAs. As a consequence of its low operative mortality rate, the role of early EVAR in treating relatively small aneurysms, defined as 4-5 cm, is also being assessed. Early data from the PIVOTAL (Positive Impact of Endovascular Options for Treating Aneurysms Early) trial suggest beneficial effects from early treatment of small aneurysms by EVAR, providing up to 3 years of protection from rupture [68]. However, recent data also suggest that early EVAR for AAAs <5.5 cm is not likely to be cost-effective compared to elective repair at 5.5 cm [69]. Furthermore, two large multicenter studies comparing EVAR to open repair [9,10] have shown that EVAR has a lower rate of operative mortality but a higher rate of graft-related complications, resulting in similar rates of survival for the two procedures.

- Despite its high success rate, complications of EVAR remain frequent and require monitoring. The most common among these complications are endoleaks, with the majority present on the initial post-EVAR examination [29]. Proper classification of endoleaks is important for subsequent management.
- Although multiple imaging modalities are available for follow-up, there is currently no available ideal stand-alone imaging modality, after consideration is given to their safety profiles, availability, reproducibility, accuracy, and cost [70].
- CTA is a highly accurate method for detecting endoleak, but no consensus has been reached on an optimal protocol, and it also involves using ionizing radiation and potentially nephrotoxic contrast agents.
- Color Doppler US is safe, but special expertise is needed to perform and interpret imaging after EVAR for endoleak and sac morphology. It is also less accurate than CT/CTA and less reproducible, especially in large patients.

- MRI/MRA may be a viable alternative to CT in select patients with favorable stent composition and geometry, but its cost and relative lack of availability may prohibit wide acceptance at this time.
- Ultimately, the imaging solution for EVAR follow-up is likely not going to rest on one single modality. Further investigation is needed for patient risk stratification. Appropriate imaging protocols involving combinations of various imaging modalities can then be optimized for each patient subset.

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, both because of 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 to 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
O	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”.

Supporting Documents

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

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