Abdominal aortic aneurysm (AAA) is a significant disease affecting the circulatory system. Risk factors include smoking, hypertension, sex, and a possible hereditary predisposition. AAAs remain asymptomatic for years, and various imaging methods are used in their detection, diagnosis, and treatment. This article reviews the anatomy and physiology of the aorta as well as the signs and symptoms, pathophysiology, epidemiology, and risk factors for the development of AAA. The use of ultrasonography and other imaging modalities for pre- and post-treatment is discussed, as is endovascular aortic repair.

After completing this article, the reader should be able to:
- Describe aortic anatomy.
- State the preventive screening recommendations for abdominal aortic aneurysm (AAA).
- Identify the most common locations of AAA occurrence.
- Recall the preferred imaging modalities for AAA and their specific applications.
- Discuss treatments for AAA.

The aorta is the largest artery in the human body. Originating from the left ventricle, it extends into the chest and down into the abdomen. The vessel is the main conduit for distributing oxygenated blood from the heart to the body. Abdominal aortic aneurysm (AAA) is a localized enlargement within the abdominal cavity.

Anatomy and Physiology

The aorta is the major artery of the body carrying oxygenated blood from the heart through the thoracic and abdominal cavities of the body (see Figure 1). The aorta attaches superiorly to the left ventricle. Blood is pumped through the aorta with every left ventricular contraction. A 3-leaflet valve at the junction of the left ventricle and aorta (aortic valve) prevents retrograde flow of blood into the ventricle.

The aorta is divided into 4 sections: ascending aorta, aortic arch, thoracic aorta, and abdominal aorta. The ascending aorta, which rises superiorly from the left ventricle, is approximately 3 cm in diameter but can vary depending on patient sex, age, and size. At the root of the ascending aorta are 3 anatomical dilatations called the aortic sinuses. From the left and right aortic sinuses arise the left and right coronary arteries, respectively. The coronary arteries vascularize the heart (see Figure 2). The posterior sinus has no coronary artery.
As the aorta rises superiorly from the heart, it makes a downward curve, which is known as the aortic arch. The aortic arch often is visible on chest radiographs; from it arises arteries supplying blood to the head, neck, and upper limbs—the brachiocephalic artery (which bifurcates to form the right subclavian artery and right common carotid artery), left common carotid artery, and left subclavian artery. The aortic arch also has function in homeostasis, containing baroreceptors and chemoreceptors that send information about carbon dioxide levels and blood pH to the medulla oblongata.2,3

Beyond the aortic arch, the aorta descends caudally, which is called the descending aorta. The descending aorta is divided into 2 parts based on location. The initial section of the aorta that passes through the mediastinum and chest is called the thoracic aorta. Many branches originate from the thoracic descending aorta, including intercostal and subcostal arteries, bronchial arteries, and branches that supply blood to the esophagus, mediastinum, pericardium, and diaphragm.2

The aorta enters the abdominal cavity through the diaphragm and then divides into 2 major vessels: common iliac arteries and the median sacral artery. Important branches of the abdominal aorta are the lumbar and musculophrenic arteries, renal and suprarenal arteries, and arteries that vascularize the abdominal viscera, such as the celiac trunk and the superior and inferior mesenteric arteries.2

Generally, all arteries have 3 layers. The layers of the aorta are composed of smooth muscle, nerves, intimal cells, and extracellular matrix. The aortic wall is divided into 3 layers (from external to lumen): tunica externa (or tunica adventitia), tunica media, and tunica intima (see Figure 3). The vascular supply to the tunica externa and tunica media is provided by an extensive network of small blood vessels known as the vasa vasora.2

Blood flows through the aorta in pulses due to contraction of the left ventricle. The elasticity of the aorta allows it to expand and contract as the heart pumps blood through it. The tunica media contains collagen and elastin filaments that allow it to stretch and contract in response to the pulsatile flow of blood, assisting in the propulsion of blood through the circulatory system. For
example, as the left ventricle contracts (systole), blood is forced into the aorta, which expands. This distention provides the potential energy that helps to maintain blood pressure during diastole. The aorta’s elastic recoil also helps the heart conserve energy. The pressure of the blood through the aorta, termed the pulse pressure, equals systolic pressure minus diastolic pressure.

The measure of the pressure of blood flow through the aorta is called mean arterial pressure (MAP), often abbreviated as $P_{\text{mean}}$. MAP is a measure of the cardiac output, systemic vascular resistance, and central venous pressure. MAP is highest at the aorta and decreases across the circulatory system as the aorta branches into arteries and then into arterioles, capillaries, and veins.

Measuring the velocity of the blood pulse wave also aids in assessing aortic function. Pulse wave velocity (PWV) is a measure of aortic stiffness and can be measured invasively via flow meters or catheter-based pressure probes in patients undergoing cardiac catheterization, or noninvasively with ultrasonography. The aorta stiffens with age, which results in increased:

- Blood pressure.
- Risk of developing blood pressure-related diseases and pathologies.
- Correlation with cardiovascular events and mortality.

Pathophysiology

In general, an AAA is a focal, localized enlargement (dilatation) of a section of the abdominal aorta of 3.0 cm or greater, or when the diameter of the dilatation is 50% larger than normal (see Figure 4). Dilatation of the aortic wall occurs when the tunica media weakens. The pulsating force of the blood through the aorta causes the tunica intima and externa to stretch and expand. As the vessel wall layers progressively weaken, the aneurysm continues to enlarge, often resulting in a fatal rupture.

Prevalence

AAAAs are the most common arterial aneurysm, with approximately 80% occurring below the renal arteries at the area of aortic bifurcation. Studies of adults 50 years and older indicate an AAA prevalence of 3.9% to 7.2% in men and 1.0% to 1.3% in women. Worldwide, the prevalence is higher in western countries than in Asiatic countries, and higher in Australia than in the United States and Europe. If diagnosed before becoming symptomatic, an AAA can be treated and cured. However, a ruptured AAA is considered a medical emergency, with a 59% to 90% mortality rate if it occurs outside a hospital environment. The operative mortality for AAA, defined as death regardless of cause occurring within 30 days after surgery, is approximately 40%. Mortality rates for elective (ie, nonemergency) AAA repair are significantly lower, ranging from 0.6% to 5.3%. Therefore, careful screening to detect AAAs and follow-up when diagnosed are necessary, specifically with at-risk patients.

The diameter of the aneurysm influences the potential for rupture. For AAAs 3.0 cm to 3.9 cm in diameter, the annual risk for rupture is negligible. The risk is 1% for aneurysms that are between 4.0 cm and 4.9 cm, and...
increases to 11% for those that are between 5.0 cm and 5.9 cm. The majority of deaths from ruptured AAAs are found among men 65 years or older; for women, most deaths occur after age 80 years.

**Risk Factors**

The etiology of AAA is unknown; however, several risk factors are associated with an increased incidence. One significant risk factor is smoking. The risk of AAA development increases with the number of cigarettes smoked daily and the number of years smoking. Singh et al posited that an individual’s number of years smoking is the critical risk factor. Occasional, past, short-term tobacco use also was found to increase the risk of AAA, although this risk decreased over time after cessation of smoking.

Many studies include high blood pressure and chronic hypertension (systolic > 160 mm Hg; diastolic > 95 mm Hg) as risk factors. However, conflicting evidence exists over whether the risk of AAA from hypertension is gender specific. Analysis by Forsdahl et al, for example, indicated that the risk exists only in women. In addition, the prevalence of AAA among men older than 50 years of age is 4 to 6 times greater than that of women of the same age. Interestingly, AAAs appear to develop 10 to 15 years later in women than in men. The peak prevalence of AAA in men is 5.9% at ages 80 to 85 years. However, among women the peak prevalence is 4.5% at 90 years or older.

A hereditary link for the development of AAAs has been hypothesized, prompting studies into the effects of genetics on AAA development among twins and other close relatives. Results from the Swedish Twin Registry, which contains data on twins in Sweden since 1886, indicated that monozygotic twins (ie, 2 offspring developed from a single fertilized ovum) had a 24% probability of having an AAA if the other twin had one. Another study indicated that a positive family history of AAA in a first-degree relative increases the risk of aortic aneurysm by up to a factor of 10. Research continues in an attempt to determine the specific genes associated with AAA development.

**Signs and Symptoms**

Because AAAs are asymptomatic until they expand enough to press on local organs or rupture, they can go undetected for years. Similarly, the rate of AAA expansion is difficult to predict. The most common presentation of a nonruptured AAA is vague, yet persistent and deep, back and abdominal pain that might extend to the flanks and groin. A pulsatile pain might be felt around the umbilicus; however, this pain often is noticeable only on examination.

The symptoms of a ruptured AAA are more significant, yet still ambiguous. These include pain in the abdomen or back and can be confused with renal calculus, diverticulitis, or herniation. This severe pain might appear suddenly, be constant, or spread to the groin, buttocks, legs, or scrotum. Tachycardia and dizziness on standing also is common. Other symptoms include syncope, loss of consciousness, sweaty/clammy skin, nausea, and vomiting. Internal bleeding from a ruptured AAA can result in hypovolemic shock with symptoms such as hypotension, cyanosis, skin mottling, and altered mental status. These symptoms are serious considering that nearly 65% of patients with a ruptured AAA die of sudden cardiovascular collapse.

Medical imaging plays an important role in the diagnosis, surveillance, treatment, and follow up for AAA. Because the majority of AAAs are asymptomatic, their initial diagnosis might be an incidental finding during imaging.

**Screening and Surveillance**

The U.S. Preventive Services Task Force (USPSTF) is an independent panel of experts in primary care and prevention that systematically reviews the evidence of effectiveness and develops recommendations for clinical preventive services. The USPSTF offers separate AAA screening recommendations for men and women. For a man aged 65 to 75 years who has smoked 100 or more cigarettes in his lifetime, the Task Force recommends one-time screening. For this group, it also recommends clinicians be selective when counseling those in the same age cohort who have never smoked because the benefit for screening is small. For male nonsmokers, the individual and his physician(s) should base their decision on the individual’s medical and family history, other risk factors, and personal values. The USPSTF does not recommend routine AAA screening for female nonsmokers, regardless of age, because the evidence about its benefit is insufficient.
However, recommendations differ. The American College of Cardiology and the American Heart Association, for example, suggest screening for men 60 years and older who have a first-degree relative with AAA. The American Society for Vascular Surgery and the European Society for Vascular Surgery advocate for screening for all men 65 years and older, regardless of smoking history. Both vascular surgery societies also recommend screening for women who are considered high risk based on smoking or family history.

Color duplex ultrasonography is the recommended tool for AAA screening. Advantages include high sensitivity and specificity for AAA, low cost, availability, short examination time, patient acceptance, and no radiation exposure. Recommendations for screening ultrasonography for the abdominal aorta are promoted in a joint resolution by the American College of Radiology (ACR), the American Institute of Ultrasound in Medicine, and the Society of Radiologists in Ultrasound. These organizations formed a consensus group that advocates use of real-time scanners using transducers that allow for appropriate penetration and resolution. Suggested parameters include longitudinal (along the long axis of the aorta) and transverse images (perpendicular to the long axis of the aorta) that include the proximal (inferior to diaphragm, near the celiac artery), mid (near the level of the renal arteries), and distal (above the iliac bifurcation) sections of the aorta (see Figure 5).

The Society for Vascular Ultrasound recommends use of duplex instrumentation that displays 2-D structures and motion in real-time and Doppler. Recommendations for spectral analysis and color Doppler imaging include:

- Proper sample volume size and positioning.
- An angle of 60° or less with respect to the vessel wall and direction of blood flow.
- Measurement of spectral velocities.
- Imaging carrier frequency between 2.25 MHz and 4.0 MHz as needed for penetration.
- Doppler carrier frequency of 2.5 MHz to 4.0 MHz as needed for penetration.

AAAs should be measured in the anteroposterior dimension, and the greatest dimension should be reported.

Aortic diameters smaller than 3.0 cm are considered normal, and they require no further screening or surveillance. According to Lederle et al, small to medium-sized AAAs (3.0-5.4 cm) should undergo surveillance and follow up. Aneurysms in the 3.0-cm to 3.9-cm range require a conservative management approach that seeks to slow the growth of the AAA. Aneurysms in this range are at risk for enlarging and should be monitored every 2 to 3 years. Medium-sized aneurysms (4.0-5.4 cm) should be monitored every 6 months. AAAs 5.5 cm or larger require treatment.

Regardless of surveillance frequency, life-long control of risk factors, such as smoking, hypertension, hyperlipidemia, and diabetes, is necessary. Pharmacotherapy might be required. The role of beta blockers, used to control hypertension, in reducing AAA growth and improving health outcomes is questionable.

Figure 5. Ultrasound images of AAA in transverse (A) and longitudinal (B) views. Calipers size the AAA at 60.3 mm and 51.9 mm in the transverse and longitudinal views, respectively. Reprinted with permission from Brekken R, Dahl T, Hernes TA. Ultrasound in abdominal aortic aneurysm. In: Grundmann R, ed. Diagnosis, Screening and Treatment of Abdominal, Thoracoabdominal and Thoracic Aortic Aneurysms. Rijeka, Croatia: InTech; 2011:103-124.
Pretreatment Planning

Computed tomography angiography (CTA) is considered the preferred imaging surveillance method for pre- and post-endovascular aneurysm repair (EVAR) as well as for postopen surgical repair.\(^4^\)\(^-\)\(^6^\) Figure 6 depicts a sagittal CT scan demonstrating a sizeable infrarenal AAA. Chaer recommends obtaining 2.5 mm or smaller slices of the abdomen and pelvis using 3-D reconstruction.\(^4^\) This method allows for accurate measurements perpendicular to the true axis of the aorta. Three-dimensional aortic measurements are more accurate than 2-D measurements and aid sizing of the graft (see Figure 7).\(^4^\)\(^6^\)\(^7^\)

Anatomic considerations from preoperative imaging include aneurysm morphology and measurements. Examples of important aortic measurements for sizing an endograft include aortic neck\(^4^\)\(^6^\)\(^8^\):

- Diameter at the most caudal renal artery branch.
- Length, or distance from most caudal renal artery to the origin of the aneurysms.
- Angulation, or angle formed between points connecting the lowest renal artery, the origin of the aneurysm, and the aortic bifurcation.

Figure 8 illustrates several AAA measurements as described by Goshima et al.\(^8^\) The various measurements allow for accurate sizing of the stent-graft and aids in placement.

**Figure 6.** Sagittal maximum intensity projection computed tomography (CT) demonstrating infrarenal AAA. Reprinted with permission from Higashigaito K, Schmid T, Puippe G, et al. CT angiography of the aorta: prospective evaluation of individualized low-volume contrast media protocols. Radiology. 2016:151982.

**Figure 7.** CT reconstruction of an AAA (arrows). Reprinted with permission from Bakerstmd under a Creative Commons license. https://commons.wikimedia.org/wiki/File:AneurysmAortaWithArrows.jpg. Accessed October 4, 2016.
from the base of the lungs to the symphysis pubis, timed to a bolus tracking at the celiac trunk of 150 HU over the baseline.

**Magnetic Resonance Angiography**

Magnetic resonance angiography (MRA) with gadolinium is an alternative for pre-EVAR planning in patients for whom iodinated contrast is contraindicated. However, because nephrogenic systemic fibrosis (a rare syndrome involving fibrosis to internal organs, skin, and joints) is linked to gadolinium-based contrast agents and anaphylactic reactions, evaluation of renal function prior to MRA contrast is recommended.

MRA has a lower sensitivity (ie, ability to identify true positive cases) than does CTA to detect small blood vessels and renal arteries with diameters smaller than 2 mm. For pre-EVAR planning, the ACR recommends T1- and T2-weighted spin-echo image sequences for assessing aneurysm morphology and relevant vascular anatomy. The use of noncontrast MRA sequences are gaining acceptance but should be performed only in centers with expertise in the technique.

**Other Modalities**

Unlike CTA and MRA, neither digital subtraction angiography nor ultrasonography are recommended for pre-EVAR measurements. Specifically, digital subtraction angiography is limited by measurement errors arising from parallax and magnification, and it cannot evaluate the true aortic lumen diameter.

**Treatment**

Various options are available for treating AAAs, including endovascular and open surgery, and
Open Repair

Open repair is the traditional approach for treating AAAs. Once open repair is decided upon, imaging is used to identify anatomical variants to guide treatment and prevent unexpected complications. Open repair is conducted under general anesthesia, and a large incision is made either transperitoneally or retroperitoneally to access the abdominal aorta. Research indicates no significant differences in outcome between the 2 approaches; thus, the choice of approach might be based on patient body habitus, patient preference, the surgeon’s experience and preference, or a combination of these factors.

The affected portion of the aorta is resected and replaced with a synthetic graft (see Figure 10). If the AAA involves the iliac arteries, the synthetic graft is extended to include those vessels. An aneurysm proximal to the renal arteries results in the arteries being reimplanted into the graft, or the creation of a bypass graft.

Aortic replacement graft materials include polyester (eg, Dacron), polytetrafluoroethylene, and autogenous vein; woven polyester most commonly is used. Important qualities in graft material include ease in handling, durability, and appropriate porosity. The diameter of the selected graft should match the aortic diameter; the diameter of a graft usually is smaller than the diameter of an endograft used in the same location, if endovascular management is elected.

Table 1

<table>
<thead>
<tr>
<th>Diameter (cm)</th>
<th>Rupture Risk (%/year)</th>
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<tbody>
<tr>
<td>&lt; 4</td>
<td>0</td>
</tr>
<tr>
<td>4-4.9</td>
<td>1</td>
</tr>
<tr>
<td>5-5.9</td>
<td>5-10</td>
</tr>
<tr>
<td>6-6.9</td>
<td>10-20</td>
</tr>
<tr>
<td>7-7.9</td>
<td>20-40</td>
</tr>
<tr>
<td>&gt; 8</td>
<td>30-50</td>
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</tbody>
</table>

*Elective surgical repair should be considered for aneurysms > 5 cm.*
from various manufacturers. Stents typically are made of nitinol, Elgiloy, or stainless steel (see Figure 11). Complications of EVAR include infection, thrombosis, incorrect placement of the graft (ie, kinking, angulation), graft migration, and endoleaks (ie, the flow of blood into the aneurysm sac after graft placement). EVAR requires more frequent imaging followup than does open repair.

**Ruptured AAA Repair**

A ruptured AAA is defined as a bleeding outside of the wall of the aneurysm that requires immediate treatment, as the condition nearly always is fatal; death usually occurs within hours. The mortality rate from ruptured AAAs during open repair is approximately 50%; EVAR has a lower mortality rate—between 20% and 30%. Although outcomes can improve with EVAR over open repair, the emergent nature of a ruptured AAA creates major challenges. For example, most medical institutions are not equipped to treat ruptured AAAs with EVAR. In addition, patients experience better outcomes undergoing a procedure at the institution to which they are first admitted; a 17% to 19% increase in mortality has been reported when patients are transferred to another facility for open repair. Specific to AAA, additional imaging reconstruction techniques are used to obtain accurate measurements. Multiple vendors supply software that allow for semiautomated measurements of vessel diameter and length in relation to the proximal and distal margins of the aneurysm. Three-dimensional analysis includes volume rendering, maximum-intensity projection, and curved planar reformations. Benefits of reformatted and reconstructed images include more accurate pretreatment measurements. Three-dimensional volume rendering provides excellent depiction and precise measurement of any angulation in tortuous AAAs.

**Post-treatment Imaging**

Imaging after AAA treatment is routine to detect issues or complications with the graft, which can include endoleak and fistula formation, as well as to monitor aneurysm size. The timing of follow-up imaging varies with
Abdominal Aortic Aneurysms

Iezzi et al recommend that a 90-ml to 130-ml bolus of contrast be administered at a rate of 3 ml/s to 4 ml/s during the arterial phase. Bolus-tracking software is used to delay the scan until a 100-HU change develops in the opacification of the aorta. Delayed phase images are acquired after the arterial phase, typically 60 to 120 seconds after the initial contrast material injection. Postprocessing includes maximum-intensity project and volume rendering. Because of the frequency of CT scans for post-EVAR follow-up, radiation dose reduction methods should be employed.

Although MRA is an appropriate alternate to CTA, it is less accurate for assessing the metallic components of the endograft, which might induce artifacts.

Abdominal CTA techniques for post-EVAR patients vary between institutions, but imaging parameters can include:

- Single arterial phase.
- Biphasic (ie, noncontrast CT and either the arterial phase, or arterial and delayed phases).
- Triphasic (noncontrast CT, arterial phase, and delayed phases).

the type of treatment employed. For example, in patients who underwent open repair, a CT scan is recommended within 5 years to detect aneurysm degeneration involving the pararenal aorta, iliac arteries, endograft, or anastomotic sites. However, compared to open repair, EVAR requires more frequent imaging follow up. Post-EVAR contrast-enhanced CT is recommended at the 1-, 6-, and 12-month marks—as well as for lifelong annual surveillance—and is the ACR’s suggested imaging modality of choice.

The primary goal of post-EVAR is to evaluate the integrity of the stent-graft, including evaluation for migration, kinking, structural failure, and endoleak (see Figure 12). Decreasing aneurysm sac size is evidence of a well-functioning stent-graft. Volume analysis of the aneurysm sac is recommended by the ACR because it entails all dimensions of the AAA.

Abdominal CTA techniques for post-EVAR patients vary between institutions, but imaging parameters can include:

- Single arterial phase.
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- Triphasic (noncontrast CT, arterial phase, and delayed phases).

According to the ACR, the following imaging results have been found for the various endograft elements:

- Nitinol (nickel and titanium alloy) – causes relatively few MR artifacts and allows for visualization of the stent lumen and adjacent structures; considered the best candidates for MRA.
- Elgiloy (alloy of cobalt, chromium, and nickel) – might cause significant artifacts and compromise visualization of the stent-graft lumen while allowing visualization of the adjacent structures.
- Stainless steel – might cause significant artifacts similar to Elgiloy.

Despite potential artifact issues, MRA has been found highly sensitive to endoleaks. In addition, MR images can be reformatted for volume and diameter measurements.

Duplex ultrasonography also is used in post-EVAR follow up and is recommended as an adjunct to non-contrast CT. Sandford et al recommend the use of contrast enhancement to improve post-EVAR scanning. Angiography is, at best, “a second-line imaging modality in post-EVAR patients” because of its invasiveness and use of contrast. Digital subtraction angiography is less sensitive than CTA in detecting endoleaks, but its ability to assess the direction of blood flow makes it more accurate in classifying endoleaks.

**Dose Reduction**

Dose reduction during CT and CTA is important considering patients will undergo a lifetime of surveillance following EVAR. A variety of techniques and methods has been employed to reduce radiation dose, including automatic exposure control, change in technical parameters, iterative reconstruction, and dual-energy CT. Use of automatic tube current modulation (or automatic exposure control) can reduce radiation dose by up to 50%. Automatic exposure control systems available for some of the major CT scanner manufacturers are listed in **Table 2**. Similarly, decreasing tube voltage also reduces dose. A dose reduction of approximately 33% results from a decrease from 120 kV to 100 kV. However, Raman states that changing the kV is a rarely used option because of a potential increase in image noise and that technologists and radiologists must appraise a variety of factors individually to determine whether a lower kV is appropriate.

Increasing the pitch has been demonstrated to reduce radiation dose in a retrospective study of thoracolumbar

**Table 2**

<table>
<thead>
<tr>
<th>Vendor</th>
<th>System Name(s)</th>
<th>Parameter Explanation</th>
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<tbody>
<tr>
<td>GE</td>
<td>AutmA; SmartmA</td>
<td>Measure of image quality/noise level defined related to uniform water phantom</td>
</tr>
<tr>
<td>Philips</td>
<td>Dose Right</td>
<td>Image quality expressed in terms of noise level of an existing optimal clinical image</td>
</tr>
<tr>
<td>Siemens</td>
<td>CARE Dose 4D</td>
<td>mAs that would be used for an average-sized patient</td>
</tr>
<tr>
<td>Toshiba</td>
<td>SUREExposure 3D</td>
<td>Standard deviation of pixel values in an image (higher standard deviation = higher noise)</td>
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</table>
CTAs. \(^73\) In comparing high-pitch (3.4) to standard-pitch (0.8) CTA examinations with all other imaging parameters identical, very little difference in arterial attenuation, signal-to-noise ratio, or contrast-to-noise ratio was found. Although noise consistently was higher in high-pitch scans, radiation dose reductions between 45% and 50% were achieved with similar diagnostic quality. In addition, considerably less contrast media was required to obtain the same arterial attenuation. \(^73\)

Relatedly, a radiation dose reduction is possible in CTA using a lower iodine concentration contrast media with a resultant kV decrease. The benefit of reduced iodine concentration is avoidance of contrast-induced acute kidney injury, an abrupt deterioration in renal function associated with iodinated contrast use also known as contrast-induced nephropathy. \(^74\) However, low-iodine contrast media resulted in poor vascular attenuation, image quality, and diagnostic accuracy. \(^75,76\) Although not a direct evaluation of AAA imaging, a 2015 study by Shen et al assessed the image quality of the aorta using dual-source CT with a lower-than-typical concentration of iodinated contrast (270 mg I/mL vs 370 mg I/mL). \(^77\)

Patient's scans using a pitch of 3.2, and a tube voltage of 100 kV and 20 mA were acquired as compared to the typical 120 kV scans. Objective image quality was evaluated by comparing mean aortic, signal-to-noise, and contrast-to-noise ratios. Results indicated no significant differences in these quality parameters except for more image noise among low-iodine scans. A subjective image evaluation by 2 radiologists also found no significant differences in the scanning techniques. However, radiation exposure—as measured by CT dose index volume and dose length product—was 34.3% less when using low-iodinated contrast and lower tube voltage. \(^77\)

Thus, reduced tube voltage should be considered a feasible dose-reduction strategy.

Dose reduction also arises from using dual-energy CT. This technique entails the simultaneous acquisition of CT data using 2 different energy levels that result in different degrees of photon attenuation. As a result, contrast can be subtracted from CTA to create nonenhanced images, thus negating the nonenhanced CT scan mentioned previously. This technique reportedly decreased dose by nearly 20%. \(^78\)

Larger dose reductions were reported by Buffa et al in their comparison of single-phase dual-energy CT to conventional CTA. \(^79\) Each patient underwent a single-energy nonenhanced scan, an arterial phase, and a delayed phase. The delayed phase began 30 seconds after the arterial phase using the dual-source mode. The researchers found that the effective dose from the dual-energy mode acquisition (delayed phase) was 40.3% less than the 2 scans in the single-energy mode (ie, nonenhanced and arterial phases). An estimated dose reduction of 61.7% was achieved when the dual-energy acquisition was compared to a single-source, triple-phase CTA (ie, noncontrast and 2 arterial phase scans). \(^79\)

Iterative reconstruction—or more accurately, statistical iterative reconstruction—is a data reconstruction method that improves on the commonly used filtered back-projection in CT. Iterative reconstruction allows for lower radiation dose via lower tube potentials and current levels without the increase in image noise common in filtered back-projection. In iterative reconstruction algorithms:

\[
\text{[P]rojection data are predicted based on an assumption about the initial attenuation coefficients of all voxels. These predicted data are compared to measured projection data, and the voxel attenuation values are modified until an acceptable level of error between the predicted and measured data is achieved.} \quad \text{\cite{62}}
\]

\section*{Prognosis}

The data are mixed regarding mortality differences in open repair compared to EVAR. Improved outcomes have been reported for EVAR over open repair, including decreased length of hospitalization and lower perioperative morbidity. \(^80,84\) However, the benefits of EVAR are accompanied by lifelong radiologic surveillance and possible radiation exposure because of the higher rate of complications compared to open repair. Complications include endoleak, stent-graft migration, kinking, and thrombosis. \(^43,44,48\) Nonetheless, EVAR is recommended for patients with multiple risk factors for a poor prognosis following open repair and who have anatomy suitable for stent-graft placement. \(^85\)

The incidence rate for endograft complications ranges from 11% to 30%. \(^86\) The most common complication of EVAR is endoleaks, which places the post-EVAR
A patient at continued risk for aneurysm sac enlargement or rupture.\(^7\) This persistent flow of blood into the sac post-EVAR represents a failure to exclude the aneurysm completely.\(^7\) Estimates for the prevalence of endoleaks ranges from 4% to 23%.\(^{66-90}\) Endoleaks are classified into 5 types, with each varying in severity, prevalence, reason for leakage, and risk of secondary rupture (see Figure 13).\(^{91-92}\)

Type I endoleaks result from an incompetent seal at the proximal or distal stent-graft attachment sites. These leaks consist of the flow of blood into the aneurysm sac proximal or distal to the stent graft. Type I endoleaks typically occur either immediately after insertion or soon thereafter.\(^{91,93}\) Treatment of type I endoleaks is recommended at the time of diagnosis because the aneurysm sac can grow and rupture from systemic pressure. Follow-up imaging, usually CT, demonstrates blood outside the stent-graft.\(^{94}\) This type of endoleak can be repaired through endovascular means; open surgical repair is a viable but secondary option for repair.\(^{91-93}\) Up to 10% of endoleaks are type I.

A type II endoleaks comprise between 10% and 45% of all endoleaks.\(^{46,95}\) These endoleaks entail retrograde blood flow from aortic branch vessels (eg, lumbar, internal iliac, accessory renal, middle sacral, and inferior mesenteric arteries). Risk factors for type II endoleak development include the number of patent lumbar arteries and the diameter of lumbar arteries, as larger arteries tend to be associated with persistent endoleak.\(^{88,96-98}\) These endoleaks generally are considered the most benign because they do not provide arterial pressure to the aneurysm sac.\(^99\) Type II might not be visible on the arterial phase of a CT scan, resulting in the need for delayed imaging. Color duplex ultrasonography or arteriography also might be needed for diagnosis.\(^{46,94}\) According to Chaer, controversy exists regarding the significance and management of type II endoleaks.\(^{46}\) The majority of researchers believe that follow-up imaging for changes in aneurysm sac diameter and shape are most important because spontaneous resolution has occurred in approximately one-third of cases.\(^{46,95}\) However, evidence of increased diameter of the aneurysm sac necessitates repair, usually endovascularly.\(^{46,99}\) Repair consists of the embolization of the patent arteries involved.\(^{89,100,101}\)

![Figure 13. Illustration of endoleak classification. Reasons for aneurysm sac filling, expansion, or both include: A. Type I, incomplete or ineffective seal. B. Type II, retrograde branch flow of blood. C. Type III, tear in graft fabric. D. Type IV, porous graft fabric. E. Type V, no clear evidence for filling. © ASRT 2015.](image-url)
A type III endoleak is serious because it originates at the junctions of the endograft components, or from holes or tears in the endograft fabric. The resulting leak increases the pressure in the aneurysm sac, leading to the potential for aneurysm expansion and rupture.46,99 Typical repair of type III leaks consist of the deployment of additional stent-grafts to seal the hole or tear, or to bridge the disconnected endograft components.46

Type IV endoleaks occur when blood is leaking from either the graft wall fabric or suture holes; however, this type of endoleak has become less common because of improvements in graft technology and materials. Type IV endoleaks have not been associated with long-term adverse events and typically are self-resolving.46

With a type V endoleak, also referred to as endotension, the aneurysm sac continues to expand without an identified or demonstrable source of leakage or flow via any imaging modality.102 Although poorly understood, type V endoleaks are believed to have been improved with a change in graft design.92,94

Migration of a stent-graft entails the movement from its original location after EVAR, with a migration of 0.5 cm to 1 cm considered significant.44 The use of prior images is critical for comparing the original location of the stent-graft with the location from later images to detect and evaluate migration. The use of consistent anatomic landmarks from radiologic images, such as the renal and superior mesenteric arteries, can be used to detect migration. Factors related to stent-graft migration include device type, landing zone length, and neck diameter and configuration. Although preoperative planning is important, morphologic changes in the aneurysm (eg, neck enlargement) can lead to stent-graft migration.44

Endograft kinking or occlusion is a complication more commonly seen in EVAR patients than those undergoing open repair (2.3% vs 0.2%, respectively).105 Results from a European study reveal post-EVAR endograft kinking in 1.7% to 3.7% of cases with a significant association with type I and III endoleaks.104,105 A final complication is arterial thrombosis, estimated to occur in approximately 3% of EVAR patients. A key to reducing the risk of thrombosis is identifying healthy catheter entrance vessels using a thorough preoperative evaluation. Evaluation of the entry vessels is recommended to include the degree of calcification, artery diameter, and tortuosity.106 Although the complication rate of AAA treatment is small, the aforementioned complications might require intervention depending on their severity.

Conclusion
Aortic abdominal aneurysm is a focal, localized enlargement or dilatation of a section of the abdominal aorta and is the most common type of arterial aneurysm affecting older adults. Medical imaging, including CT, MR, ultrasonography, and angiography, plays an important role in the detection, diagnosis, treatment, and follow-up of AAAs. Various imaging modalities, including ultrasonography, are used as a screening tool to detect AAAs while they are small. Surgical and endovascular treatment options for AAA are available and improve patients’ survival. Post-treatment, radiologic imaging plays an important role in assessing the treatment and monitoring the patient.

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References


Abdominal Aortic Aneurysms

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1. An abdominal aortic aneurysm (AAA) is a focal, localized enlargement of a section of the abdominal aorta at least ______ cm, or when the diameter is ______ % larger than normal.
   a. 7; 30
   b. 3; 50
   c. 4; 75
   d. 6; 15

2. For a man aged 65 to 75 years who has smoked 100 or more cigarettes in his lifetime, the U.S. Preventive Services Task Force recommends screening:
   a. once.
   b. every 5 years.
   c. every 10 years.
   d. at various times based on other risk factors.

3. ______ is the recommended tool for AAA screening.
   a. Color duplex ultrasonography
   b. Magnetic resonance angiography (MRA)
   c. Computed tomography angiography (CTA)
   d. Endovascular aneurysm repair (EVAR)

4. Suggested parameters of ultrasound imaging for AAA include:
   1. coronal (back to front)
   2. longitudinal (along the long axis of the aorta).
   3. transverse (perpendicular to the long axis of the aorta).
   a. 1 and 2
   b. 1 and 3
   c. 2 and 3
   d. 1, 2, and 3

continued on next page
5. ______ is considered the preferred method for pre- and post-EVAR as well as postopen surgical repair imaging surveillance.
   a. Color Doppler ultrasonography
   b. CTA
   c. MRA
   d. Radiography

6. Anatomic considerations from preoperative imaging include aneurysm morphology and measurements. Examples of important aortic measurements for sizing an endograft include all of the following except aortic neck:
   a. diameter.
   b. length.
   c. angulation.
   d. density.

7. ______ is an alternative for pre-EVAR planning in patients for whom iodinated contrast is contraindicated.
   a. Color Doppler ultrasonography
   b. MRA with gadolinium
   c. CT without contrast
   d. Plain film radiography

8. MRA has a lower sensitivity than ______ in detecting blood vessels and renal arteries with a diameter smaller than 2 mm.
   a. CTA
   b. digital subtraction angiography
   c. color Doppler ultrasonography
   d. CT without contrast

9. The mortality rate from ruptured AAAs during open repair is approximately ______ %; EVAR has a mortality rate between 20% and 30%.
   a. 30
   b. 50
   c. 65
   d. 75

10. Dose reduction techniques during CT and CTA, such as using ______, are important because patients will undergo a lifetime of surveillance after EVAR.
    1. automatic exposure control
    2. dual-energy CT
    3. iterative reconstruction
    a. 1 and 2
    b. 1 and 3
    c. 2 and 3
    d. 1, 2, and 3