Sonographic Evaluation of the Abdominal Aorta

Shweta Bhatt, MD\textsuperscript{a}, Hamad Ghazale, MS, RDMS\textsuperscript{b}, Vikram S. Dogra, MD\textsuperscript{a,*}

Abdominal aortic aneurysm (AAA) is a disease of aging, and the prevalence is expected to increase as the population of elderly patients grows. AAAs are associated with high mortality, as rupture of an AAA is the tenth leading cause of death in the United States. AAA can be diagnosed with CT, magnetic resonance imaging (MR imaging), and ultrasonography (US). US has nearly 100% sensitivity in detecting AAA and is readily available for routine and emergency evaluation\textsuperscript{[1]}. In addition, there are no risk factors associated with US examination of the aorta as there are with CT and MR imaging, including exposure to ionizing radiation, risks associated with intravenous contrast, expense, and perhaps most important, time delay in performing the study. This review describes the sonographic technique for evaluation of the abdominal aorta (AA) and associated pathologies of the AA, including AAA.

**Sonographic anatomy and technique**

The AA is a continuation of the thoracic aorta, beginning at the aortic hiatus in the diaphragm (thoracic vertebra level 12) and ending at the fourth lumbar vertebra, where it divides into the common iliac arteries. It descends in the midline, anterior to the vertebral column and to the left of the inferior vena cava. The normal luminal diameter of the infrarenal AA varies with age and gender. In young patients who do not have vascular disease, the infrarenal AA measures 2.3 cm in males and 1.9 cm.
in females [2]. It increases in diameter with age. In
one study, men who had a mean age of 70.4 years
who did not have AAA had an average luminal
diameter of 2.8 cm [3].

Abdominal aortic ultrasound is preferably per-
formed after 8 to 12 hours of fasting. Fasting reduces
bowel gas, which helps provide a better view of the
AA. The standard protocol for scanning the AA con-
sists of obtaining longitudinal and transverse im-
ages from the level of the diaphragm to the level
of bifurcation of the AA, where the common iliac
arteries are visualized like binoculars in the trans-
vverse view (Fig. 1). Abdominal aortic diameter is re-
corded at the proximal, mid, and distal aorta, along
with measurement of the common iliac arteries just
distal to the bifurcation. The inferior vena cava is
also evaluated to document normal flow.

Sonographic evaluation of the AA is performed in
a supine position or right and left lateral decubitus
or right and left posterior oblique positions. Images
are obtained in coronal and transverse planes. Plac-
ing the patient in the left lateral position and imag-
ing in a coronal scan plane allows for better
visualization of both iliac arteries in one image
(Fig. 2). Application of gentle pressure or compres-
sion and changing the transducer angle may also
help displace bowel gas and improve visualization
of the aorta. The patient’s body habitus plays an im-
portant role in determining the optimal type of
transducer and frequency to be used. Usually 2.5
to 5 MHz sector, curvilinear array transducers pro-
vide optimal visualization of the aorta.

Sonographically the normal aorta has an an-
echoic echo-free lumen with echogenic walls. Arti-
factual intraluminal echoes may result from
increased gain and slice-thickness or reverberation
artifacts (Fig. 3). These types of echoes can be con-
fused with thrombus or intraluminal tumor. The
sonographer must change the patient’s position or
angulation of the transducer and correct the gain
to see if these echoes can be eliminated. If these ech-
oes disappear, they most likely represent an artifact.

The anteroposterior (AP) diameter of the aorta
should be measured from a longitudinal image, be-
cause this allows correct placement of the calipers
perpendicular to the long axis of the vessel. The

---

Fig. 1. Normal aorta. (A) Longitudinal and (B) transverse gray scale sonogram demonstrates the normal appear-
ance of the proximal abdominal aorta (A, abdominal aorta; IVC, inferior vena cava; P, portal vein; L, liver). (C, D)
Transverse gray scale and corresponding power Doppler sonograms of aortic bifurcation into common iliac
arteries (arrows) are seen as “binocular” in appearance.
measurement should be taken from outer wall to outer wall and should not exceed 3 cm in diameter [4]. The diameter of the aorta decreases as it courses inferiorly. Consequently the AP measurement varies from one segment of the aorta to another and is also depends on age and the presence or absence of disease. When an aneurysm is observed, the operator must obtain the maximum true length, width, and transverse dimensions of the aneurysm and must measure the true lumen. The shape and location of the aneurysm should be determined. The exact relationship of the AAA to the origin of the renal arteries and the bifurcation should be noted. Involvement (ie, dilatation) of the common iliac arteries should also be documented.

Color flow Doppler is helpful in determining the patency and direction of blood flow in the aorta. The color box should be kept small, which improves the frame rate and enhances the color resolution. The color Doppler gain should be set at less than noise level and a low pulse repetition frequency (PRF) should be avoided to prevent aliasing. Methods of optimization of color flow Doppler are given in Table 1 [5].

Normal blood flow in the aorta is laminar. The flow pattern in the aorta is considered a

---

**Fig. 2.** Aortic bifurcation. (A) Longitudinal gray scale and (B) color flow Doppler images demonstrate the normal aortic bifurcation.

---

**Fig. 3.** (A) Longitudinal gray scale sonogram of the proximal aorta demonstrates a hypoechoic area of low level echoes along the anterior wall (arrow), mimicking a thrombus. This is an artifact secondary to partial volume averaging. (B) Longitudinal gray scale sonogram of the proximal aorta demonstrates a luminal echogenic focus (arrow), mimicking an intraluminal thrombus, arising secondary to a reverberation artifact.
The proximal aorta normally demonstrates a biphasic waveform with reversal of flow in early diastole. The distal aorta demonstrates a triphasic waveform with a small component of forward flow in late diastole (Fig. 4) [6].

### Table 1: Optimization of color flow Doppler

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Color box</td>
<td>Keeping the color box small results in improved frame rate and better color resolution</td>
</tr>
<tr>
<td>Doppler gain</td>
<td>Just below the noise level</td>
</tr>
<tr>
<td>Color scale (PRF)</td>
<td>Low PRF is more sensitive to low volume and low velocity flow but may lead to aliasing</td>
</tr>
<tr>
<td>Beam steering</td>
<td>Adjust to obtain satisfactory vessel angle</td>
</tr>
<tr>
<td>Gate size (sample volume)</td>
<td>Set the sample volume to a correct size, usually two thirds of the vessel lumen</td>
</tr>
<tr>
<td>Wall filter</td>
<td>A higher filter cuts out the noise and but also the slower velocity flow; keep the filter at 50–100 Hz</td>
</tr>
<tr>
<td>Focal zone</td>
<td>Color flow image is optimized at the level of the focal zone</td>
</tr>
</tbody>
</table>

(From Bhatt S, Dogra V. Doppler imaging of the uterus and adnexae. Ultrasound Clinics 2006;1:201–21; with permission.)

### Abdominal aortic aneurysm

An aortic aneurysm is defined as a focal dilation of the aorta with a diameter of at least 1.5 times that of the expected normal diameter of that given aortic segment; in the AA, enlargement of the aortic diameter of more than 3 cm is usually considered aneurysmal. Alternatively an AAA can be defined as a ratio of infrarenal to suprarenal aortic diameter of 1.2, or a history of AAA repair [7]. Prevalence of AAA has been estimated at 1.2% to 12.6% for men in the sixth to ninth decades, with almost two thirds of AAAs involving only the AA [8]. Overall, up to 13% of all patients in whom an aortic aneurysm is diagnosed have multiple aneurysms, with 25% to 28% of patients who have thoracic aortic aneurysms having concomitant AAAs [9]. Published data from the National Vital Statistics Report on deaths from the year 2000 showed that AAAs and aortic dissection were the tenth leading cause of death in white men of 65 to 74 years of age and accounted for nearly 16,000 deaths overall [10]. The high mortality associated with AAAs has led to an increase in the need to identify risk factors so that appropriate screening procedures can be undertaken for early diagnosis. AAA is most commonly a sequelae of atherosclerosis; therefore, predisposing risk factors for atherosclerosis, such as older age, smoking, and hypertension, are strongly associated with the development of AAA [11,12]. Although moderate alcohol consumption has been found to have a beneficial effect on coronary artery disease because of its positive effect on high-density lipoproteins, Wong and colleagues [13] found that higher alcohol consumption (>2 drinks per day) increased the risk for aortic aneurysmal disease in...
men who did not have pre-existing cardiovascular disease.

Predisposing factors for AAA are listed in Box 1.

Screening

Most AAAs are asymptomatic until there is a rapid expansion of the aneurysm or rupture. The classic clinical triad of hypotension, back pain, and pulsatile abdominal mass is observed in only approximately 50% of patients presenting with a ruptured AAA [14]. Most patients who have AAA, however, present for the first time with abdominal pain. Pain may or may not be accompanied by hypovolemia and shock and is often mistaken for other more common causes of abdominal pain, such as a renal colic or diverticulitis [15]. Failure or delay to diagnose ruptured AAA on clinical presentation contributes to the high mortality rate. This emphasizes the need for an appropriate AAA screening method to identify and repair AAAs before they rupture. Schilling and colleagues were the first to begin screening for AAA in 1964 [16], but it has been justified for regular use only recently [17].

Lee and colleagues [18] analyzed the cost effectiveness of ultrasound screening for AAA and proposed that all men older than age 60 years should be screened for AAA and that this screening should be adopted and reimbursed by Medicare and other insurers. Effective January 1, 2007 the Centers for Medicare and Medicaid Services (CMS) approved Medicare reimbursement for a one-time AAA screening by abdominal US for men between the ages of 65 and 75 years who have ever smoked or who have a first-degree family history of AAA. Women who manifest other risk factors in a beneficiary category recommended for screening by the United States Preventive Services Task Force regarding AAA may also be eligible for receiving this reimbursement. Individualization of care, however, is recommended in the case of a woman seeking reimbursement for screening. For example, a healthy female smoker in her early seventies who has a first-degree family history for AAA that required surgery may be an eligible beneficiary [19].

Screening tests

Although abdominal palpation was the original method of AAA screening, ultrasound is currently considered the preferred method of screening. Ultrasound has several advantages, such as accuracy (nearly 100% sensitivity and specificity for AAA), low cost, patient acceptance, no radiation exposure, short length of examination time (a quick screening takes less than 5 minutes [18]), and easy availability. CT of the abdomen is often obtained preoperatively for exact measurement and assessment of the geometry of the AAA, especially if the patient is being considered for stent graft placement, but it is not currently recommended for screening purposes.

Selective screening

There are three important risk factors that are definitely associated with AAA, and patients who have these risk factors are therefore considered for selective screening. They include gender (males are 3–6 times more likely than women to have AAA) [20], age (most AAAs occur in patients older than 65 years) [21], and a history of smoking (smokers are 3–5 times more likely than nonsmokers to have AAA) [22]. Because of the high prevalence of AAA in these categories, limiting screening to a sub-selected population based on these criteria is useful. Besides these criteria, positive association with AAA is also seen with a positive family history, white race, a history of occlusive vascular disease, and the absence of diabetes [22].

Effectiveness of screening

Various studies have demonstrated a significant reduction in mortality rates from AAA as a result of screening for aortic aneurysm. Four randomized trials [23–26] of AAA screening, including more than 125,000 men, have now reported results for up to 5 to 10 years of follow-up, and all four trials documented a reduction in AAA-related mortality, ranging from 21% to 68% [17].

Making the diagnosis

US is the most commonly used screening modality for AAA, with an accuracy of almost 100% [18]. Sonographically the most common appearance of AAA is of a dilated vessel with associated atherosclerotic changes, such as an irregular wall with calcifications or echogenic mural thrombus, located circumferentially or eccentrically (Fig. 5). Measurement of the aorta is critical to make a diagnosis of

---

**Box 1: Predisposing risk factors for abdominal aortic aneurysm**

1. Smoking
2. Age; more common after the sixth decade
3. Hypertension
4. Hyperlipidemia
5. Atherosclerosis
6. Moderate alcohol consumption; >2 drinks per day
7. Gender; men are 10 times more likely to have AAA than women
8. Positive family history
9. Congenital disorders such as Marfan and Ehlers Danlos syndrome
AAA. Criteria for making the diagnosis of AAA on the basis of measurement have been mentioned, and include: (1) focal dilatation of the AA more than 3.0 cm, (2) increase in the aortic diameter to 1.5 times the normal expected diameter, and (3) ratio of infrarenal to suprarenal aortic diameter more than or equal to 1.2. There may be variations in measurement of the aneurysm size depending on technique. The aneurysmal sac should be measured from outer wall to outer wall from a longitudinal image. The transverse diameter should be measured perpendicular to the long axis of the aorta (Fig. 6). This is particularly important in ectatic aortas, in which a transverse measurement may give an erroneously high number, because it is actually an oblique rather than true transverse measurement. Sometimes the presence of concentric thrombus may make the aortic diameter look smaller. Three-dimensional (3D) US is a useful technique for assessment of AAA, allowing measurements to be made with multiplanar reconstructions from the 3D volume data. An attempt should also be made to visualize the abdominal aortic branches and to demonstrate whether or not they are also aneurysmally dilated.

Color flow Doppler evaluation should follow the gray scale examination of the aorta. Sudden change in the aortic lumen diameter causes turbulent flow within the aneurysmal sac. This turbulent flow may give rise to the “pseudo yin-yang” sign (Fig. 7) and must not be mistaken for a pseudoaneurysm. Flow within the AAA may also be turbulent because of the presence of mural thrombus [27].

**Classification of abdominal aortic aneurysm**

AAAs can be classified according to location, morphologic shape, and etiology. See Fig. 8 and Table 2 [28] for details.
Aneurysm rupture

The high mortality rate associated with AAAs is secondary to rupture of the aneurysm leading to exsanguination. Spontaneous rupture of an AAA (>6 cm) has a mortality rate ranging from 66% to 95%. Of patients who have AAA rupture, 40% to 50% die before they reach the hospital, and the overall mortality rate of a ruptured AAA is greater than 90% [29].

The most important role of ultrasound, therefore, is to assess the size of the aneurysm and its rate of enlargement, which are the two most important factors in predicting the likelihood of rupture. AAAs do not conform to the law of Laplace, however, and there is growing evidence that aneurysm rupture involves a complex series of biologic changes in the aortic wall [30] and is not just related to diameter.

The most frequent site of aortic rupture is in the left retroperitoneum [31,32]. Rupture also most commonly involves the middle one third of the aneurysm, where the aneurysmal diameter is the largest [32]. In an autopsy series of AAA, aneurysm ruptures were found to occur more frequently in the posterior wall (67%) and in the inferior portion (61%) [33].

Predictors of aneurysm rupture

Maximum diameter

Size of the aneurysm refers to the maximum cross-sectional diameter of the aorta. The best predictor of rupture risk for an AAA is the size at the most recent ultrasound. Because of a higher variability in the measurement of the transverse diameter of the aorta, measurement of the anteroposterior diameter is the preferred method for measuring an AAA by ultrasound [3]. The risk for rupture increases sharply for aneurysms 6 cm or greater in size [34]. In a 15-year study by Brown and colleagues [35], AAAs measuring 5.0 to 5.9 cm had a risk for rupture of 1% per year. If the AAA measured 6 cm or more in maximal diameter, however, risk for rupture increased to 14% per year. Women who had similarly sized AAAs had a fourfold higher risk for rupture [35]. Newer studies, however, have reported that the “maximum diameter criterion” is not reliable in predicting aneurysm rupture because of the lack of a physically sound theoretic basis. Biomechanical factors such as wall stress and strain also play a major role in predicting the risk for aneurysm rupture [36].
Expansion rate
Mean growth rate of AAAs in men is 3.2 mm per annum and in women it is 2.6 mm per annum. The risk for rupture was first attributed to expansion rate by Limet and colleagues [37]. This association of increased rate of expansion with aortic rupture was further confirmed by Lederle and colleagues [38] and Brown and colleagues [35]. Cronenwett [39], however, found that expansion rate depended on current AAA diameter rather than a fixed rate, and this was further supported by Vega de Ceniga and colleagues [40]. Expansion rate is approximately 2.2 mm per annum for an AAA of less than 3 cm and 6.4 cm for an AAA of greater than 5 cm in diameter. Other factors reported to be associated with expansion rate are pulse pressure, systolic and diastolic blood pressure, and smoking. Diabetes, for unknown reasons, has a negative correlation with growth of AAAs.

Mural thrombus
Other factors associated with rupture are the presence of mural thrombus and calcifications. Siegel and colleagues [41] in a retrospective study demonstrated that aneurysms that ruptured had less mural thrombus and calcification than AAAs that did not rupture, stating that mural thrombus has a protective effect on the AAA by cushioning the pulsations of flowing blood and thus preventing its rupture. Results obtained by Simao da Silva and colleagues [33], however, who found mural thrombus at the site of aortic rupture in 80% of autopsy specimens they studied, contradicted the concept of mural thrombus as being protective. There is a possibility, however, that these thrombi may have formed post-rupture. This theory was further supported by Fontaine and colleagues [42], who concluded that mural thrombus acts as a source of proteases in

Table 2: Classification of abdominal aortic aneurysms

<table>
<thead>
<tr>
<th>According to location</th>
<th>Suprarenal</th>
<th>Above the origin of the renal arteries</th>
</tr>
</thead>
<tbody>
<tr>
<td>Juxtarenal</td>
<td>AAA involving the part of the abdominal aorta in which the renal arteries originate</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Often involves the renal arteries</td>
<td></td>
</tr>
<tr>
<td>Infrarenal</td>
<td>Most common location</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>According to morphology</th>
<th>Fusiform</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Appears as a symmetric enlargement of the AA secondary to a circumferential weakness in the aortic wall</td>
</tr>
<tr>
<td>Fusiform</td>
<td>Saccular</td>
</tr>
<tr>
<td></td>
<td>Localized dilatation with eccentric outpouching of the aortic wall</td>
</tr>
<tr>
<td></td>
<td>Usually a pseudoaneurysm secondary to trauma or enlargement of a penetrating ulcer and infection</td>
</tr>
<tr>
<td></td>
<td>Hourglass (Fig. 8)</td>
</tr>
<tr>
<td></td>
<td>Two noncontiguous areas of focal dilatation of aorta separated by normal caliber aorta</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>According to etiology</th>
<th>Atherosclerotic</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Most common type of AAA</td>
</tr>
<tr>
<td>Inflammatory [50]</td>
<td>5% to 10% of all AAA</td>
</tr>
<tr>
<td>Younger age group</td>
<td>Three distinct features:</td>
</tr>
<tr>
<td></td>
<td>– Marked thickening of aneurysm wall</td>
</tr>
<tr>
<td></td>
<td>– Fibrosis of adjacent retroperitoneum</td>
</tr>
<tr>
<td></td>
<td>– Rigid adherence of adjacent structures to anterior aneurysm wall</td>
</tr>
<tr>
<td>Mycotic [28]</td>
<td>Less than 1% of all aortic aneurysms</td>
</tr>
<tr>
<td></td>
<td>Atypical location and age group should raise suspicion of mycotic AAA.</td>
</tr>
<tr>
<td></td>
<td>Commonly saccular</td>
</tr>
<tr>
<td></td>
<td>Common causative organisms: <em>Salmonella</em> spp and <em>Staphylococcus aureus</em></td>
</tr>
<tr>
<td></td>
<td>High mortality rate</td>
</tr>
</tbody>
</table>
|                             | Patients are often septic, with positive blood cultures.
aneurysms and thus increases the likelihood of enlargement and rupture.

**Gender**
Female sex is another independent factor for rupture of AAAs, with evidence of a more rapid growth rate of aneurysms in females [43]. AAAs are less common among women than men, but when present they rupture three times more frequently and at a smaller aortic diameter (mean, 5 cm versus 6 cm) [44].

**Abdominal aortic wall strain**
Recently biomechanical factors such as abdominal aortic wall stress and wall strength have been suggested as more reliable parameters in predicting the risk for rupture, rather than the maximum diameter of AAA [36]. AAA rupture occurs when the stresses acting on an AAA exceed its wall strength. Current ultrasound modalities do not allow for assessment of these biomechanical factors, and measurements of biomechanical stress factors are still in the experimental stage. Long and colleagues [45] have described the usefulness of tissue Doppler imaging (TDI) in the measurement of compliance parameters in AAAs, including dilation, wall strain, and wall stiffness. TDI has been proposed as a simple and reliable method for aortic compliance measurement during routine ultrasound examination.

**Sonographic findings**
With current state-of-the-art technology, ultrasound can be used successfully to triage patients when an AAA rupture is clinically suspected. Although at the authors’ institution ultrasound is not used as a diagnostic modality for AAA rupture, rupture may incidentally noted while a patient is being screened for AAA. It helps, therefore, to be aware of the possible ultrasound findings in AAA rupture.

The most common ultrasound findings of AAA rupture include retroperitoneal hematoma, which appears as an echogenic retroperitoneal fluid collection, particularly in periaortic location, and hemo-peritoneum [46]. Other less common sonographic findings that can be seen in AAA rupture include morphologic deformation of the AA, hypoechoic or anechoic areas within the thrombus or abrupt interruption of the thrombus, floating thrombus within the aortic lumen, and a break in the continuity of the abdominal wall with or without the para-aortic hypoechoic area [46]. Hemorrhage into the psoas muscle has also been described. Contrast-enhanced CT is considered superior for the detection of ruptured AAAs, and these US findings often need to be confirmed by a follow-up CT scan, except in hypotensive patients. In rare instances, the presence of an active leak can also be demonstrated on ultrasound as a focal discontinuity in the aortic wall, with blood leaking through the break in the aortic wall on color Doppler (Fig. 9). Contrast-enhanced sonography (CES) is potentially useful for assessment of aortic aneurysmal rupture, with comparable efficacy as CT and with the added advantages of easy bedside availability and relative cost-effectiveness [47]. Demonstration of active extravasation of contrast medium on CES has significant potential as an indicator for rupture of AAA.

![Fig. 9](image-url) Rupture of an AAA. A 62-year-old man presented with abdominal pain and hypotension. (A) Longitudinal gray scale sonogram of the AA demonstrates an AAA with peripheral thrombus. Posteriorly, at the upper end of the aneurysm, is a tubular hypoechoic structure (arrows), which is continuous with the lumen of the aneurysm sac. Also seen is a small hypoechoic area in the thrombus (arrowhead), which is a sequela of aortic wall rupture. (B) Corresponding color flow Doppler image demonstrates the presence of active bleeding. Such cases need no further imaging confirmation and the patient should be taken directly to the operating room without further delay. Surgery confirmed the sonographic findings.
with higher sensitivity and specificity [48]. The authors believe, however, that because of the urgency involved in diagnosing AAA rupture, contrast-enhanced US may not evolve as a preferred imaging modality because of the time factor.

Simplicity of ultrasound technique also enables emergency physicians to perform quick ultrasounds for immediate evaluation of aortic rupture [49]. At the authors’ institution, however, a CT is preferred whenever an AAA rupture is clinically suspected.

**Inflammatory abdominal aortic aneurysm**

Inflammatory AAAs account for 5% to 10% of all cases of AAAs and typically occur in a younger age group. Inflammatory AAAs usually present with back or abdominal pain and have three distinct features: (1) marked thickening of the aneurysm wall, (2) fibrosis of the adjacent retroperitoneum, and (3) rigid adherence of the adjacent structures to the anterior aneurysm wall [50].

A high index of suspicion is required for diagnosis in the early stages. Clinical presentation of such aneurysms often includes fever, abdominal or back pain, leukocytosis, and expansile abdominal mass. In the pre-antibiotic era, bacterial endocarditis with *Streptococcus pyogenes* was the most common cause of mycotic aneurysms. Today *Staphylococcus aureus* and *Salmonella* species are the most commonly identified etiologic agents, most often secondary to arterial trauma or underlying immuno deficiency [52].

Mycotic aneurysms often develop at atypical locations in the AA, such as suprarenal, and in an atypical age group, ie, children [53]. They are typically smaller, eccentrically located, and saccular in shape.

Ultrasound findings in mycotic aneurysms have been rarely described. CT is the imaging modality of choice for diagnosis. Certain sonographic findings, however, can suggest the diagnosis. Mycotic aneurysms often present as a rapidly expanding aneurysm with lack of atherosclerotic changes within the aorta, such as absence of intimal calcification and thrombus. Occasionally air caused by infection may be identified in the wall of the AAA as echogenic foci with reverberation artifact. The presence of air is suggestive of an infective etiology [54]. Periaortic inflammatory changes such as retroperitoneal abscess and vertebral changes may be present. Ultrasound may be able to detect a large retroperitoneal abscess; however, detection of abnormalities in the bony cortex of the vertebral bodies is beyond the routine scope of ultrasound, and CT is required for evaluation of the adjacent vertebral bodies and disc spaces.

**Pseudoaneurysm**

A pseudoaneurysm is a focal outpouching from the aorta resulting from disruption of one or more layers of the aortic wall. Pseudoaneurysms of the AA are rare and account for only 1% of all abdominal aneurysms [55]. Most commonly they develop secondary to trauma, which may be caused by blunt or penetrating injuries or may be iatrogenic secondary to vascular procedures [56]. They may also develop from penetrating atherosclerotic ulcers [57]. Rarely they can be mycotic in origin, such as tubercular [58]. Most reported cases of pseudoaneurysms have been seen in males, are associated with penetrating injuries, and involve the suprarenal aorta [59,60]. They are usually saccular in shape with a narrow neck. These can be diagnosed with Doppler ultrasound by demonstrating a to-and-fro flow pattern of blood flow in the neck of the pseudoaneurysm [61,62] and a yin-yang pattern within the sac.

**Endograft evaluation**

Currently endovascular aneurysm repair (EVAR) of an infrarenal AAA can be performed with Food and Drug Administration (FDA)-approved endografts that use either suprarenal or infrarenal fixation [63]. The Dutch Randomized Endovascular Aneurysm Management (DREAM) trial and the British Endovascular Aneurysm Repair (EVAR-1) trial showed favorable short-term results (reduced 30-day postoperative mortality) for endovascular repair of AAA. Recent study [64], however, which compared conventional (open repair) to endovascular treatment of AAAs over 2 years, demonstrated more deaths in the endovascular repair group of patients than in the open repair group, thus questioning its long-term effectiveness.

After graft placement, long-term follow-up is needed to determine whether the aneurysm sac has shrunk and also to monitor for the presence or absence of an endoleak. Endoleaks are defined as the persistence of blood flow outside the lumen of the endoluminal graft but within the aneurysm sac [65]. It is important to identify these endoleaks to prevent possible rupture of the aorta secondary...
to continued increase in size of the aneurysm. Endoleaks can be identified in 15% to 52% of patients after endovascular repair [66]. Endoleaks are classified into four types (Box 2) (Fig. 10). Type I and III endoleaks have been found to be associated with aneurysm rupture, whereas the risk for rupture of aneurysms with type II endoleaks and endotension appears small. Type I and III endoleaks should be corrected, preferably by endovascular means, because of the risk for rupture [67].

Contrast-enhanced CT (CECT) is the preferred imaging modality to assess the anatomy and migration of the graft and to assess for endoleaks. CEUS is an alternative in patients who have poor renal function [71]. Color Doppler imaging demonstrates blood flow between the endograft and the wall of the aortic aneurysm if an endoleak is present. The diameter of the aorta should be carefully measured to assess for interval growth. Type I leaks demonstrate high velocity flow at the site of the proximal attachment. Leaks at the distal limb attachment site demonstrate flow in the sac opposite the direction of flow in the lumen. IMA flow is antegrade in type I leaks. Type II leaks are characterized by slower flow within the aneurysm sac and retrograde flow in the IMA [72].

Endoleak detection

CT is considered the gold standard for detection of endoleaks. MacLafferty and colleagues [73] demonstrated that color flow Doppler when compared with CT had a sensitivity of 100%, specificity of 99%, positive predictive value of 88%, negative predictive value of 100%, and accuracy of 99% in the detection of endoleaks. Although color Doppler ultrasound is highly accurate in identifying the presence of an endoleak, it is not very accurate (66.7%) in distinguishing the type of endoleak [74]. Identification of an endoleak is based on the presence of color flow outside the endograft but within the aneurysm sac. Color Doppler ultrasound can serve as a useful adjunct to CT and is considered better for type II endoleak detection because of its real-time capability. It is also helpful in distinguishing “pseudo-endoleak” seen on CT caused by trapped perigraft contrast following AAA repair [75].

Color flow Doppler can also give false positive results secondary to the movement of clotted blood within the aneurysm sac. It is demonstrated as a color artifact secondary to transmitted pulsatile motion of the adjacent endograft. It is usually seen in the early postoperative period [69]. True endoleaks are identified as a uniform color Doppler appearance with demonstration of a peripheral flow waveform [69]. Demonstration of an arterial waveform confirms the continuity of the true endoleak with the vessel lumen and differentiates it from pulsating clotted blood. An increase in the diameter of the aneurysm sac by more than 0.5 cm is also an indication of endoleak or endotension.

CEUS has been reported to have 80% sensitivity, 100% specificity, and 100% positive predictive value in detecting endoleaks (Fig. 11) [76]. This may be superior in patients who have negative studies with CECT or in patients who have spinal hardware that may interfere with evaluation by CT [77,71]. Further studies are needed, however, to determine the role of CEUS in evaluating patients who have endografts.

**Box 2: Classification of endoleaks**

*White classification of endoleaks [68]*

Type I: Direct communication between the graft and aneurysm sac by way of an ineffective seal at the graft ends or attachment sites

Type II: Retrograde flow through lumbar arterialis, the inferior mesenteric artery (IMA), or accessory renal arteries feeds into the aneurysm sac.

Type III: Seen in modular, multisegmental grafts. Leak occurs through deficiency in graft fabric and may be a result of altered hemodynamics secondary to aneurysm sac shrinkage.

Type IV: On contrast CT, appears as a blush of contrast outside the graft from contrast diffusion through the naturally porous graft fabric or through small defects in the fabric at the site of sutures or struts; may require angiography to distinguish from type III graft.

Endotension [69]. It is seen as a continued expansion in size of the aneurysm sac without evidence of endoleak. It is believed to be associated with high pressure inside the aneurysm sac and may potentially rupture if left untreated [70].
Aortic dissection

Abdominal aortic dissection is usually an extension of thoracic aortic dissection. The peak incidence of aortic dissection is in the sixth and seventh decades of life, with men affected twice as often as women [78]. Approximately three fourths of patients who have aortic dissection have a history of hypertension. The dissection is termed acute when it is diagnosed within 14 days after the first symptoms appear; it is termed chronic when it is diagnosed later [79].

Hypertension is believed to be a major risk factor for aortic dissection [78]. Atherosclerosis is not believed to be an independent risk factor for aortic dissection; however, an association between dissection and atherosclerosis may be found, which suggests increased incidence of aortic dissection in the presence of atherosclerosis [80,81]. Causes of aortic dissection are listed in Box 3.

Sonographically, aortic dissection can be diagnosed by the identification of an intimal flap. The intimal flap is visualized as a linear hyperechoic area within the aortic lumen, dividing the lumen into a true and false lumen (Fig. 12A–C). In acute dissection, the true and false lumens can be identified on color flow Doppler ultrasound as two parallel lumens with or without an entry point from the true into the false lumen (Fig. 12D). In chronic aortic dissections, there may be thrombosis of the false lumen with nonvisualization of the intimal flap. Such an appearance may mimic an AAA if the aorta is dilated and can be distinguished on ultrasound by the presence of intimal calcification in the inner wall of the thrombus.

Aortic dissection can be mimicked by the presence of layers of mural thrombi of varying echogenicities that may give a pseudo-appearance of two lumens within the aorta.

B-flow imaging

B-flow is a new mode of imaging blood flow, introduced by General Electric Medical Systems in the...
late 1990s. It is a noninvasive, non-Doppler flow imaging tool that gives a gray scale morphologic display of intraluminal blood flow and tissue simultaneously (Fig. 13) [82]. It is based on a principle of coded excitation, wherein the digitally encoded ultrasound pulses are used in such a manner that it amplifies the particulate components of blood, giving the appearance of mobile, bright echoes in regions of flowing blood [83]. This mode has the advantage of an improved signal-to-noise ratio arising from binary coded transmissions, along with motion detection, to produce direct B-mode images of moving blood [84]. The purpose of introducing this modality was to overcome some of the disadvantages of color Doppler in vascular imaging, which include overwriting of the vessel wall (blooming or bleeding artifact), low frame rates, persistence, and angle dependency.

B-flow has high sensitivity in demonstrating intraluminal blood flow and the morphology of the blood vessel, such as the aortic wall thickness and atherosclerotic plaques. It can be particularly useful in imaging of ectatic aortas in which the angle dependency of Doppler imaging may result in erroneous measurement of peak systolic velocities.

**Box 3: Predisposing conditions for aortic dissection**

- Hypertension
- Marfan syndrome
- Bicuspid aortic valves
- Coarctation
- Turner syndrome
- Noon syndrome
- Ehlers-Danlos syndrome
- Cocaine use
- Pregnancy
- Trauma

---

**Fig. 12.** Abdominal aortic dissection. (A) Longitudinal and (B) transverse gray scale sonograms of the AA demonstrate a linear echogenic band (arrowhead) traversing anteriorly within the lumen of the aorta. (C) Transverse color flow Doppler image demonstrates the false lumen anteriorly (in blue) and the true lumen posteriorly (in red). (D) Longitudinal color flow Doppler image demonstrates the entry point (arrowhead) of an intimal tear causing dissection. Gray scale finding of an aortic dissection may be mimicked by reverberation artifact and can be confirmed by changing the position of the transducer and obtaining transverse and longitudinal views. True dissection flap persists, whereas the artifact disappears with change in position of transducer.
Keeping in mind some of the limitations of B-flow listed in Table 3, this modality can serve as an important adjunct to color Doppler imaging for assessing the aorta and other abdominal vessels. Clevert and colleagues [85] compared B-flow, color Doppler, and power Doppler in arterial (carotid, vertebral, and abdominal aortic) dissection and found that B-flow had better accuracy for the diagnosis of arterial dissection compared with color Doppler and power Doppler [85]. Flow within the true and false lumen, hypoechoic thrombi, intramural hematoma, and even movements of the dissection membrane are better distinguished with B-flow compared with color and power Doppler [85].

**Table 3: B-flow imaging advantages and disadvantages**

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>No aliasing</td>
<td>No flow quantification</td>
</tr>
<tr>
<td>No blooming</td>
<td>No aliasing</td>
</tr>
<tr>
<td>All velocities imaged</td>
<td>Limited penetration</td>
</tr>
<tr>
<td>simultaneously</td>
<td></td>
</tr>
<tr>
<td>Angle-independent</td>
<td></td>
</tr>
<tr>
<td>Flow direction indicated</td>
<td></td>
</tr>
<tr>
<td>Tissue and B-flow</td>
<td></td>
</tr>
<tr>
<td>information are displayed</td>
<td></td>
</tr>
<tr>
<td>simultaneously</td>
<td></td>
</tr>
<tr>
<td>High spatial and time</td>
<td></td>
</tr>
<tr>
<td>resolution</td>
<td></td>
</tr>
</tbody>
</table>

Although ultrasound is highly accurate in detecting AAA and aortic dissection, it is limited in several ways, as shown in **Box 4**.

**Box 4: Limitations of sonography**

1. Bowel gas, acute abdominal pain, or obesity may limit the exam.
2. The absence of free intraperitoneal fluid does not exclude rupture.
3. The presence of retroperitoneal hemorrhage cannot be reliably identified.
4. Small saccular aneurysms may be overlooked.
5. Oblique or angled imaging planes exaggerate the true aortic diameter.
6. Large para-aortic nodes may be confused with the aorta or may mimic AAA.

**Limitations of sonography for evaluation of abdominal aortic aneurysm and rupture**

US is accurate in detecting AAAs and is readily available, inexpensive, and less time consuming than other imaging methods for screening patients for AAAs and for emergency evaluation for rupture of AAAs. Sonographic diagnosis of AAA is based on the maximum diameter of the aorta, and a diameter greater than 3 cm is considered an AAA. Sonography also helps in monitoring patients after endovascular repair and can detect endoleaks, although CT remains the gold standard. Sonography is also useful in detecting abdominal aortic dissection, because it can identify the intimal flap and sometimes even the entry point. Newer modes of US imaging such as B-flow imaging serves as an important adjunct to color Doppler imaging in assessment of the aorta and other abdominal vessels.

**References**


