Imaging the Intraluminal Thrombus of Abdominal Aortic Aneurysms: Techniques, Findings, and Clinical Implications

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ABSTRACT

Intraluminal thrombus (ILT) is known to influence the natural history of abdominal aortic aneurysms, and its effect on the arterial wall may predict the risks of rupture. The main features of ILT believed to be associated with aneurysm growth and increased rupture risk are size; presence of fissures, dissections, or calcifications in the ILT; and inhomogeneity in its internal structure. Modern imaging allows for detailed depiction of the ILT. This review describes the techniques, findings, clinical implications, advantages, and disadvantages of imaging the ILT by ultrasound, contrast-enhanced computed tomography, and magnetic resonance imaging.

ABBREVIATIONS

AAA = abdominal aortic aneurysm, ILT = intraluminal thrombus

Ruptures of abdominal aortic aneurysms (AAAs) account for 15,000 deaths annually in the United States. They represent a common cause of death and account for a substantial financial burden on the health care system (1). Both their incidence (2) and rupture (3) have increased during recent years. Most AAAs are asymptomatic until rupture, which proves lethal in approximately 75% of patients (4). About half the deaths occur before the patient reaches a hospital. Even then, surgical mortality rates exceed 40% in these patients (5).

For asymptomatic AAAs, imaging findings of a diameter exceeding 5.5 cm (6,7) and/or diameter growth exceeding 7 mm per 6 months or 1 cm per year are indications for surgery (8), whereas in cases of smaller sizes and slower growth, surveillance with repeated ultrasound (US) or computed tomography (CT) examinations is recommended.

However, the predictive value of the imaging findings of diameter and rate of growth are far from perfect. Many patients with aneurysms exceeding 5.5 cm in diameter die from causes other than rupture, and rupture can also occur in cases in which the AAA diameter is less than 5.5 cm. Moreover, the risk of rupture as predicted by a high growth rate has not been confirmed by population-based studies (9). For these reasons, it would be extremely valuable to develop imaging features that would enable rupture prediction.

IMPORANCE OF INTRALUMINAL THROMBUS

Ninety-seven percent of AAAs that are larger than 5 cm in diameter contain an intraluminal thrombus (ILT) that adheres to the aneurysm wall (10). The ILT is often circumferential (11) and is most commonly thickest on the ventral side of the aneurysm (12). Autopsy studies conducted on patients who died from ruptured aneurysms have demonstrated that a majority of the ruptures are located beneath the ILT (13), suggesting that the thrombus may have a weakening effect on the underlying arterial wall. The aneurysm wall underlying the thrombus has in fact been shown to be thinner and weaker (14), and also shows signs of a higher degree of proteolysis and infiltration of inflammatory cells compared with wall segments exposed to flowing blood (15). All these findings could be associated with increased rupture risk. Therefore, the ILT is suspected to exert detrimental effects on the AAA wall and facilitate its rupture.

From the point of view of imaging, there are three ILT characteristics that may help in identifying the AAA rupture risk: ILT size and growth rate, presence of fissures and...
structural inhomogeneities in the ILT, and presence of calcifications in the ILT.

Measurement of ILT size, especially volume, can be important because ILT volume growth is a predictor of AAA diameter growth (16). The AAA growth rate is related to thrombus growth, and the growth of the ILT is associated with an increased risk of rupture (17,18). However, the effect of thrombus size as a whole on rupture risk is controversial. Previous imaging studies have shown increased thrombus volume in expanding and ruptured AAAs (19,18), but this could be because large aneurysms have an increased risk of rupture and also contain more thrombus (10,20,21).

ILTs may break or fissure, and their internal structure may be inhomogeneous (22), which accounts for the changes in stiffness throughout the thrombus demonstrated by ex vivo studies (23). In line with such findings, in vitro studies have shown that the ILT breaks at loads much smaller than those required to break the underlying wall (24).

AAA imaging in vivo can show longitudinal fissures that develop as dissections between layers of the ILT (25), as well as more localized fissures. These findings are associated with impending aneurysm rupture (26).

Finally, the presence of calcifications, reported in at least 25% of cases, is associated with increased wall stress in the AAA (27), and because increased wall stress has been proposed as a better parameter than diameter for predicting rupture risk (28), thrombus calcifications may be associated with increased rupture. However, this has yet to be demonstrated in clinical studies.

The Table summarizes the advantages and disadvantages of US, CT, and magnetic resonance (MR) in the imaging of ILT, measurement of ILT size, and depiction of its internal structure, including the presence of fissures, dissections, and calcifications.

### IMAGING OF ILT

**US**

Transabdominal US allows for detailed depiction of ILT morphology. With the use of low-frequency (e.g., 4-MHz) probes, the echogenic ILT will be delineated against the echo-free aortic lumen. The main advantages of US include speed, low cost, widespread availability, and lack of patient exposure to ionizing radiation. However, US is imprecise in measuring aneurysm size (29) and is limited by a high degree of inter- and intraobserver variability (30,31), which reduces accuracy in tracking the evolution of ILT over time. Moreover, the reproducibility of US is strongly influenced by the body mass index of the patient and other factors such as intestinal gas, which may decrease the quality of the image (32). Volume measurements based on US are therefore never as reliable as those based on contrast-enhanced CT.

US studies first described fissures and dissections in the ILT and correlated them to the pathologic finding of serosanguinous areas of thrombus liquefaction (33). They appear as areas of decreased echogenicity in the ILT. If the fissures and dissections in the ILT communicate with the lumen, the administration of US-specific intravenous contrast agents may enhance this finding. In this case, the hyperechogenic contrast agent filling the fissure or dissection will be easily identified against the hypoechogenicity of the ILT. In some cases, US may identify fissures and dissections in the ILT (Fig 1) with better accuracy than contrast-enhanced CT (Fig 2).

Signs of AAA rupture include inhomogeneities in the echogenicity of ILT, cracks in the ILT at its lumen interface, and layers of ILT attached on one side but free within the lumen on the other side (34). However, these signs lack specificity (Fig 2).

US can show calcifications in the ILT as areas of hyperechogenicity accompanied by an echo-free shadow artifact. However, US is not as specific as contrast-enhanced CT for showing calcifications in the ILT because artifacts can create the illusion of calcifications at the blood–thrombus interface (35).

### CT

Contrast-enhanced CT allows for a detailed depiction of ILT morphology by delineating the low-attenuating ILT against the contrast agent–filled, high-attenuating aortic lumen. The discrimination between the ILT and the aortic lumen is best obtained by scanning the aneurysm during the arterial phase of contrast agent injection. With multidetector contrast-enhanced CT, this is best performed with high-
speed intravenous contrast agent injection (ie, 4–6 mL/s), bolus-tracking techniques, and saline solution chase injections. The main advantages of contrast-enhanced CT include its speed and widespread availability, as well as easy standardization of the images from examination to examination, which allows for a very accurate study of the evolution of the ILT over time. However, this happens at the cost of a relatively high radiation burden and the potentially unwanted effects of intravenously administered iodinated contrast agents.

Contrast-enhanced CT allows for a well standardized and accurate measurement of ILT size. In the past, measurements of ILTs by contrast-enhanced CT were based on area measurements on the axial projection (19). Today, however, multislice examination techniques permit multiplanar reconstruction orthogonal to a line that follows the center of the aortic lumen (ie, centerline reconstruction). This makes measurement of the ILT diameter more accurate and reproducible. For an even more accurate measurement, the use of postprocessing software allows volume-rendering reconstructions after segmentation of the ILT to measure the volume of the ILT.

With contrast-enhanced CT, a halo-shaped area of high attenuation in the thrombus—the “crescent sign”—can be visualized (36). The crescent represents the axial section of a dissection in the ILT, with the hyperattenuating blood distributed through the long axis of the thrombus. It has been suggested as a predictor of imminent rupture (25) (Fig 3). The presence of areas of high attenuation, representing diffuse bleeding into the ILT, could be a sign of imminent rupture and therefore an indication for early surgery (26).

The soft tissue differentiation of contrast-enhanced CT is not as good as that of MR imaging in depicting differences in the internal structure of the ILT. Contrast-enhanced CT shows calcifications in the ILT better than any other imaging method, but calcification may have attenuation similar to that of the contrast agent. To reliably distinguish high attenuation caused by calcifications from high attenuation caused by the penetration of contrast agent through fissures and dissections in the ILT, it is useful to obtain a nonenhanced (ie, native) scan before the injection of contrast agent. Dual-source CT could circumvent the need to perform a native scan.

**MR Imaging**

MR imaging was used to study AAAs as early as 1985 (37). Since then, several approaches have been suggested for the study of AAAs, including contrast-enhanced MR angiography (38) and non–contrast-enhanced techniques (39). MR imaging allows for a detailed ILT depiction by delineating the morphology within the ILT against the dark aortic lumen when using pulse sequences with the “black blood” technique. This technique uses the outflow effect, which occurs in a pulse sequence when spins in an
image section move between excitation and readout. This technique does not need intravenous contrast agents. Therefore, MR imaging is better than contrast-enhanced CT for the study of the internal structure of ILT.

The main advantages of MR include its high contrast resolution, the broad number of scanning techniques that can be used depending on the clinical setting, and the opportunity to standardize image acquisition, allowing a very accurate study of ILT evolution over time without the use of ionizing radiation. Relative to US and contrast-enhanced CT, the examination cost is higher and its availability may be more limited, particularly in the acute setting.

When assessing ILT in AAAs by means of MR imaging on a 1.5-T system, a four-channel, parallel-imaging–compatible synergy body coil should be used for signal reception. After the aneurysm is localized with a coronal localizer with a three-planar fast gradient-echo sequence, the entire aneurysm should be covered by high-resolution transaxial respiratory-triggered T2-weighted turbo spin-echo sequences (repetition time, 1,800 ms; echo time, 120 ms). In the same localization, T1-weighted spoiled gradient-echo sequences with fat and water in-phase and opposed-phase (repetition time, 161–174 ms; echo times, 2.3 s/4.6 s) can also be obtained, as well as a fast steady-state free precession sequence (repetition time, 3.4 ms; echo time, 1.7 ms; Fig 4). The T2-weighted sequence should be performed with as high spatial resolution as possible to assess ILT morphology, and the addition of the T1-weighted sequence also helps to characterize the presence of fat and blood degradation products. With MR imaging, ILT size can be measured in any desired imaging plane, with an accuracy comparable to that of contrast-enhanced CT (40).

As early as 1995, Castrucci et al (41) demonstrated good correlation between the MR imaging signal intensity characteristics of mural thrombi and surgical findings in the characterization of the mural thrombus as organized (ie, mostly solid), unorganized (ie, mostly fluid), or partially organized. Examples of organized and unorganized ILT are shown in Figure 5. Experimental studies of human atherosclerotic plaques have demonstrated that MR imaging can also differentiate calcifications and thrombus (42).

**Future Investigations**

Dynamic CT (43) and dynamic MR angiography (44) have been used to quantify changes in ILT volume occurring during the cardiac cycle, a parameter of ILT compressibility. Thrombus compressibility may have a clinical relevance because a more compressible thrombus may act as a biomechanical buffer and reduce the wall stress, preventing rupture. Therefore, in the future, CT- or MR-based studies of the mechanical properties of ILT in vivo could help define aneurysm rupture risk.

Nuclear medicine imaging techniques may give fresh insight into the biology of ILT. The literature reveals that, to date, no studies have examined the features of ILTs on positron emission tomography/CT. However, an experimental positron emission tomography study in an animal model of aneurysm (45) demonstrated that the uptake of technetium-99m–marked Annexin V can be successfully traced to the ILT (45). To the contrary, MR imaging has been used in experiments to image microscopic features of ILT: MR imaging can visualize components within aortic atherosclerotic plaque, and the addition of contrast-enhanced T1-weighted images with gadolinium chelates improves visualization of the fibrous cap (46). Other studies have attempted to detect complicated plaques in the thoracic aorta by identifying methemoglobin on fat-saturated T1-weighted images (47), as well as to identify experimental
fibrin-specific contrast agents for the detection of mural thrombi. These have been tested but not yet used in clinical practice (48,49). Therefore, in the future, tailor-made positron emission tomography/CT–detectable markers of, for example, inflammatory activity in the ILT, or tailor-made MR contrast agents, could shed light on the internal processes of the ILT in vivo in an effort to correlate them to rupture risk.

**CONCLUSIONS**

The increasing incidence of AAA in the aging population constitutes an important burden on health care systems. The high mortality rate associated with rupture emphasizes the need for improved evaluation of rupture risk. The majority of AAAs with diameters large enough to be considered to

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**Figure 4.** Images from a 49-year-old man with an infrarenal aortic aneurysm. On contrast-enhanced CT (a), the semiannular thrombus surrounding the left aspect of the aneurysm is homogeneous. On MR images obtained with T2 weighting (b), steady-state free precession (c), and T1 weighting with fat and water in-phase and opposed-phase sequences (d, e), different layers within the ILT are clearly visible, indicating that the thrombus is only partly organized.

**Figure 5.** T2-weighted MR images of AAAs of comparable size exhibit organized (a) and minimally organized (b) ILT.
represent an indication for surgery contain an ILT. In the past, ILT has been considered an inert component of the AAA, and its role has been neglected by imaging studies. However, there is increasing evidence that ILT size and growth can influence AAA growth and the risk of rupture. Some studies suggest that wall stress is diminished by the ILT, but this requires that the ILT be intact. Bleeding into the ILT caused by dissections and fissures is associated with impending AAA rupture through the weakened wall covered by the ILT (26).

In summary, the main imaging characteristics of the ILT are its size, which is associated with aneurysm growth; fissures and dissections, which are associated with increased rupture risk; internal structure, with areas of greater or lesser organization of thrombus having yet-unknown significance; and calcifications, which are associated with increased wall stress. Imaging of these features by US, contrast-enhanced CT, and MR imaging are each associated with advantages and disadvantages, which are described here and in the Table. US and contrast-enhanced CT, which are widely used in the diagnosis, surveillance, and pre- and postoperative imaging of AAAs, allow for good measurement and good delineation of the ILT. However, only MR imaging offers insight into the structural variations of ILT, which, it has been postulated, may influence its mechanical characteristics and thereby wall stress of the AAA.

More research will be needed in the future to define a gold standard for ILT imaging. This will possibly include the characteristics of the ILT among the parameters to be considered in the surgical or conservative management of aneurysms.

REFERENCES

CME TEST QUESTIONS

Examinations are available at http://Learn.SIRweb.org

The CME questions in this issue are derived from the article “Imaging the Intraluminal Thrombus of Abdominal Aortic Aneurysms: Techniques, Findings, and Clinical Implications” by Labruto, Blomqvist, and Swedenborg.

1. Intraluminal thrombus (ILT) evaluation is important with regard to abdominal aortic aneurysm (AAA) because:
   a) The majority of ruptures are located opposite the intraluminal thrombus.
   b) The wall underlying the thrombus is thicker and stronger, and thus it is protected from rupture.
   c) There is a lower degree of proteolysis and infiltration of inflammatory cells adjacent to the thrombus.
   d) Fissures that develop between layers are associated with impending rupture.

2. When evaluating thrombus size:
   a) Ultrasound (US) measurements are just as reliable, compared with contrast-enhanced computed tomography (CT) and magnetic resonance (MR) imaging.
   b) Contrast-enhanced CT measurements are particularly useful using multiplanar reconstruction orthogonal to the aortic lumen center line.
   c) MR imaging is only accurate when measured in the axial plane.
   d) The absolute thrombus volume is probably more important than changes in thrombus volume.

3. Fissures and dissections in the ILT:
   a) Appear as areas of increased echogenicity in the ILT on US.
   b) Are not demonstrated any better with the administration of US-specific contrast agents, as they fail to improve evidence of communication with the aortic lumen.
   c) Appear as the “crescent sign” on contrast-enhanced CT, which is a sign of imminent rupture.
   d) Are best depicted with contrast-enhanced CT, as that is the best modality for demonstrating the internal structure of the ILT.

4. With regard to evaluation of calcifications in patients with AAA:
   a) US is not as specific as contrast-enhanced CT, because artifacts may mimic the appearance of calcifications.
   b) Contrast-enhanced CT is the best modality for identifying calcifications, as they clearly have different attenuation compared to administered contrast.
   c) MR imaging cannot reliably differentiate calcifications from the thrombus.
   d) They are associated with decreased wall thickness, which may be a better predictor of rupture than diameter.