# The Role of Intravascular Ultrasound in Venous Thromboembolism

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## Abstract

Venous thromboembolism (VTE) remains a serious problem, and treatments surrounding this potentially life-threatening disease continue to evolve. Evidence-based guidelines purport the need for minimally invasive catheter-based procedures as part of the armamentarium to prevent and treat VTE. When the appropriate clinical scenarios arise, intravascular ultrasound (IVUS) becomes a necessary part of those procedures to provide alternative imaging that complements traditional venography. IVUS of the major axial veins provides a 360-degree two-dimensional gray scale ultrasound image of lumen and vessel wall structures. IVUS remains the criterion standard for venous imaging when contemplating catheter-based procedures from the common femoral vein to the inferior vena cava. Not only can precise location and size of these veins be determined by the IVUS probe from key landmarks and venous branches, but other important abnormalities can be visualized. These include external compression, acute and chronic thrombus, fibrosis, mural wall thickening, spurs, and trabeculations. Specific procedures that use IVUS include the treatment of venous obstruction and the placement of vena cava filters at the bedside. IVUS remains a vital part of accurately imaging the major axial veins when contemplating catheter-based procedures to prevent or treat VTE-related disorders.

**Keywords**

- Intravascular
- ultrasound
- vascular
- venous
- thromboembolism
- embolism
- vein
- thrombus
- obstruction
- filter
- imaging

**Objectives:** Upon completion of this article, the reader should be able to identify intravascular ultrasound and its use in venous obstruction and inferior vena cava filter placement.

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Although venous thromboembolism (VTE) continues to remain a devastating problem, affecting 350,000 to 600,000 individuals per year in the United States, treatment options are expanding because of new knowledge, techniques, and devices. Minimally invasive catheter-based techniques to prevent or treat VTE are increasingly being performed. Publications such as the *Surgeon General's Call to Action to Prevent Deep Venous Thrombosis and Pulmonary Embolism,* the supplement guide for evaluation of acute and chronic venous disease from the American Venous Forum, and recommendations in *Antithrombotic and Thrombolytic Therapy: American College of Chest Physicians Evidence-Based Clinical Practice Guidelines* are directing physicians to take a more aggressive approach toward prevention and treatment of VTE.[1–3]

Along with increasing data to support catheter-based interventions for VTE, a plethora of catheters, wires, and devices traditionally used for arterial procedures are now being applied to VTE management. Simultaneous improvements in imaging techniques have also fueled the ability to effectively diagnose venous problems and assess outcomes.

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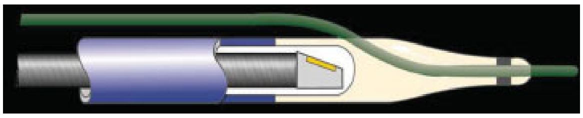

**Figure 1** Mechanical intravascular ultrasound system housing a rotating ultrasound crystal at the tip of a flexible high-torque catheter.

Moreover, having the ability to make precise measurements and observe end results of catheter-based treatments with different imaging modalities in real time becomes pivotal to achieving long-term success.

Intravascular ultrasound (IVUS) provides a precise imaging modality to assess lumen and vessel wall structures of major axial veins. This additional modality complements imaging provided by traditional venography. Magnetic resonance imaging and computed tomography venography can provide pre- and postprocedural imaging assessments. Traditional duplex ultrasound can provide adequate imaging of some axial veins of the extremities, but generally long penetration depths in the abdomen and pelvis and single-plane limitations cannot provide the same real-time luminal imaging that is often necessary for endovascular procedures performed in the treatment of VTE.

## Intravascular Ultrasound Basics

There are two types of IVUS catheters that can produce simultaneous 360-degree ultrasound imaging of a vein.[4] Each provides a luminal image that is perpendicular to the long axis of the catheter. The first type of system, mechanical IVUS, houses a rotating ultrasound crystal at the tip of a flexible high-torque catheter (►**Fig. 1**). The transducer is slightly angled, which provides an image just forward to it. To compensate for wire artifact, mechanical IVUS systems have a dual-purpose channel within the catheter that allows removal of the wire and placement of the IVUS transducer. Once inside the catheter, the transducer can be moved back and forth (proximally and distally) to view a designated length of the vein. Wire artifact from older systems was from either monorail or coaxial access. The other type of IVUS system, electronic IVUS, consists of an array of up to 64 transducer elements positioned in a circular fashion on the catheter (►**Fig. 2**). This phased array of transducers produces a whole IVUS image by having each element produce its own image in a rapid sequential sequence.

## Probes and Imaging

Similar to conventional ultrasound imaging, excitation frequency primarily determines image resolution with IVUS. As frequency increases, two-point discrimination improves. This improvement in resolution with increasing probe frequency sacrifices the ability of the probe to penetrate at a greater depth. As probe frequency increases, so too does the amount of tissue absorption of the sound waves. Therefore, when choosing the optimal IVUS probe, a balance between resolution and penetration must be made.

Commercially available IVUS probes have frequencies between 8 and 50 MHz. Generally, veins of the femoral-popliteal and aorto-iliac regions require probes in the 8 to 12 MHz range. In contrast, higher frequency probes may be more useful in arteries of the femoral-popliteal or coronary circulation. The diameter of the catheters, ranging from 3 to 9F, increases as the frequency decreases. Similarly, smaller IVUS probes use 0.014-inch guidewires; larger ones use a 0.038-inch platform. Fortunately, low-pressure axial veins are accommodating to larger catheter sizes.

IVUS imaging can be projected on a portable console or as part of a fixed endovascular suite, whereby the processing and control console is remote. A portable IVUS can be moved from place to place, whereas a fixed screen with remote console allows for decreased clutter in an endovascular suite and direct side-by-side comparison to other imaging such as venography.

Traditional IVUS provides a two-dimensional gray scale image that allows varying discernment of the intimal, medial, and adventitial layers of a blood vessel. These layers are more readily apparent in muscular arteries such as the femoral artery. In large and medium size veins, these layers are less demarcated due to the much thinner nature of the medial and adventitial layers. The intimal layer appears brightly echogenic, whereas the medial and adventitial layers produce fewer echoes and are less well demarcated (►**Fig. 3**).

IVUS imaging of veins can provide valuable information about defects within the lumen, degree of stenosis, and structures immediately adjacent to the veins. Thrombus

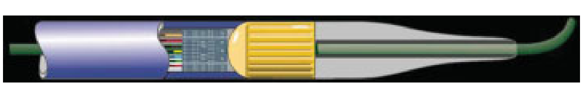

**Figure 2** Electronic intravascular ultrasound system consisting of an array of up to 64 transducer elements positioned in a circular fashion on the catheter.

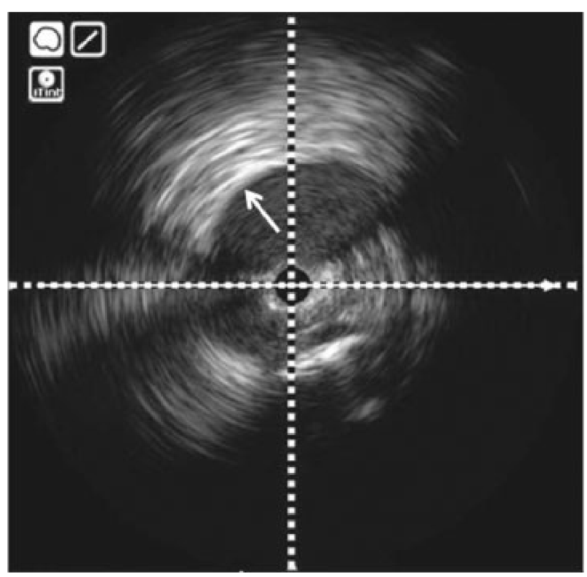

**Figure 3** Intravascular ultrasound image of the common femoral vein. Note the more echogenic internal layer (arrow) compared to the medial/adventitial later.

from deep vein thrombosis (DVT) can have a varying spectrum of echogenicity depending on its age. Acute nonoccluding thrombus may not be visible on IVUS due to its high concentration of red blood cells, whereas chronic thrombus can be highly echogenic due to its more organized composition of fibrin. Luminal defects and/or external compression of a vein visualized by IVUS can be useful in determining the degree of stenosis. Unlike atherosclerotic lesions visualized by IVUS, whereby discrete changes in intimal and subintimal thickness allow for a traditional calculation of stenosis, calculation of stenoses in veins can be more challenging, thus accentuating the advantages of using IVUS in conjunction with venography. Patients with recanalized DVT can have an array of fibrous bands, webs, spurs, and trabeculations. Venography may not show a discrete stenosis due to contrast flowing around and through these defects within the vein; IVUS, in contrast, can readily show a dramatically different view of the same vein (►**Figs. 4A** and **4B**). External compression of a vein can be another area where IVUS provides valuable information as to whether obstruction may be present. Due to the low pressures of a vein, external compression may flatten the vein and make it appear ovoid. This type of "stenosis" or degree of obstruction may be more or less discernable or calculable on venography, depending on projection, due to the contrast being effaced (►**Figs. 5A** and **5B**). Adjacent structures can also be visualized next to veins using IVUS and provide important information. The right renal artery, which lies directly dorsal to the inferior vena cava (IVC), can provide orientation as to the location of the IVUS probe. Structures that compress the veins, such as tumors, arterial aneurysms, and ligaments, can also readily be visualized. May-Thurner syndrome, whereby the right common iliac artery compresses the left common iliac vein against the sacral promontory, leading to DVT, can be diagnosed using IVUS.

IVUS technology has developed other imaging modalities that have had limited application in the veins thus far. These added capabilities that have had some preliminary use in the arterial tree include color imaging, three-dimensional imaging, and virtual histology.[5–7] Briefly, color IVUS compares sequential axial images and records any difference in position of echogenic blood particles between images. Although velocities cannot be determined, a color map of low to high flow can be created with the assistance of special software. This technology may have some application when trying to determine whether there is complete or partial thrombosis. Soft echolucent thrombus, plaque, or intimal hyperplasia can become difficult to discern from flowing blood in traditional gray scale mode. Three-dimensional reconstructions can be created from the same software. Several images are obtained over a specified length of the vessel using an automated pullback system, and volume rendering can then provide a longitudinal image of the vessel. Virtual histology helps provide an image of the different components of atherosclerotic plaque. Analysis of ultrasound frequency and amplitude backscatter can be translated into four different colors, each assigned to the different components of plaque (calcification, fibrosis, fibrofatty component, and necrotic lipid core).

## Intravascular Ultrasound Applications Related to Venous Thromboembolism

### Venous Obstruction

The role of IVUS cannot be underestimated in determining abnormalities causing obstruction in the major axial veins, particularly those extending from the common femoral vein to the IVC. Indeed, IVUS better identifies obstructive lesions than venography, which can fail to detect even severe obstruction.[8,9] Neglén et al compared IVUS and transfemoral venography on suspicion of chronic iliac vein obstruction and

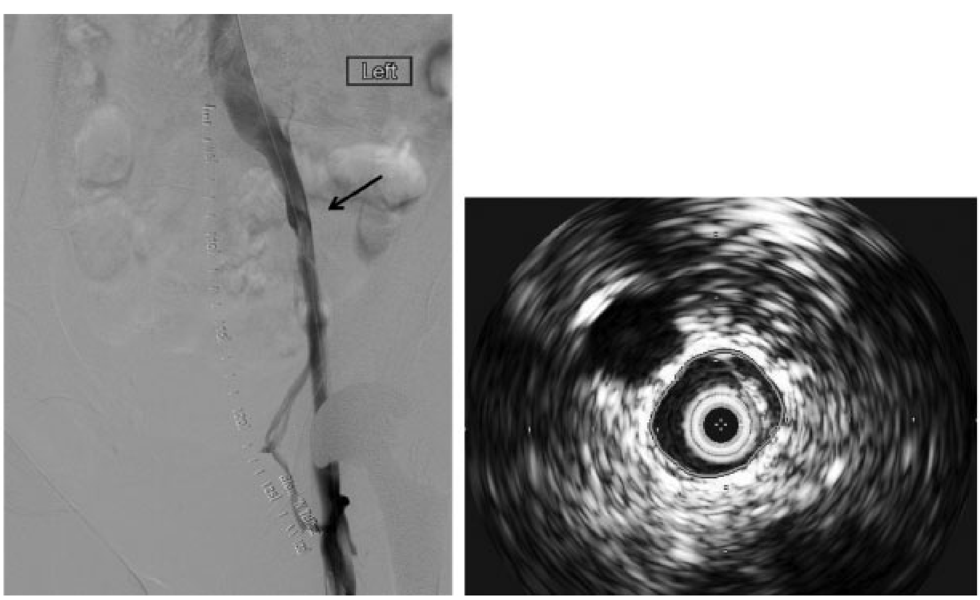


**Figure 4** (A) Venography of the left common iliac vein (arrow). Note the lack of a discrete stenosis. (B) Intravascular ultrasound image demonstrating a markedly narrowed iliac vein (outlined).


**Figure 5** (A) Venography of the left common iliac vein (arrow) demonstrating a normal venographic appearance. (B) Three-dimensional rendering of a contrast-enhanced CT demonstrating stenosis of the left common iliac vein (arrow) not appreciated on the venogram.

found the median stenosis on venography was 50%, compared with 80% by IVUS. Similarly, the stenotic area was significantly more severe when measured with IVUS compared with venography.[10]

Hemodynamically significant stenosis from obstruction has been difficult to define in the venous system. Some authors have suggested that any stenosis >25% is significant, and relief of symptoms can be obtained with venous stenting. ►**Figs. 6A** and **6B** demonstrate IVUS imaging of left common iliac vein compression by the right common iliac artery with resultant stenting.

Abnormalities identified on IVUS can include extrinsic venous compression, acute thrombus, chronic thrombus, fibrosis, webs, spurs, trabeculations, frozen valves, and mural wall thickening. Chronic compression of the left common iliac vein between the right common iliac artery (anterior to the vein) and the sacrum (posterior to the vein), which can lead to acute venous thrombosis or May-Thurner syndrome, can be a common cause of many of these abnormalities found on IVUS. Other areas of compression of the iliac veins by the iliac arteries include the right common or external iliac vein being compressed by the right common or external iliac artery, where it crosses anteriorly from medial to lateral. The left internal iliac artery can also compress the left external iliac vein as it crosses anteriorly to the vein, from lateral to medial.[11] Iliac vein compression can cause unilateral leg swelling, with or without valvular dysfunction and signs of chronic venous insufficiency.[12–15] Particularly in this patient population, IVUS becomes critical to identifying stenosis by compression via antegrade access to the femoral vein and the pull-back method. Critical landmarks during 360-degree insonation of the IVC and iliac veins include visualization of the right atrium, right renal artery, renal veins, common iliac vein bifurcation, right common iliac artery, and external/internal iliac vein bifurcation.

## Inferior Vena Cava Filter Placement

Filter placement for the prevention of pulmonary embolism is increasingly being performed with the sole use of IVUS. This procedure has been primarily directed to patients who are critically ill and/or have multitrauma and cannot be safely transported to an angiography suite for placement under fluoroscopy.[16–18] By performing these procedures at the bedside, in a closely monitored environment, critically ill patients can avoid the hazards of transport to an interventional, catheterization, or endovascular suite. Additionally, intravenous contrast can be avoided, which may be hazardous to certain critically ill patients suffering from acute or chronic renal failure. Exposure to radiation can also be avoided with the use of IVUS.

IVC filter placement with the use of IVUS at the bedside can be performed by either a single- or double-puncture technique. Briefly, with puncture technique, the right common femoral vein is used preferentially. If DVT involves the right leg, the left common femoral vein can be assessed. Duplex ultrasound should be performed on these veins prior to access to assure patency. Using a micropuncture kit under ultrasound guidance allows transition to a 0.36-inch J-wire using

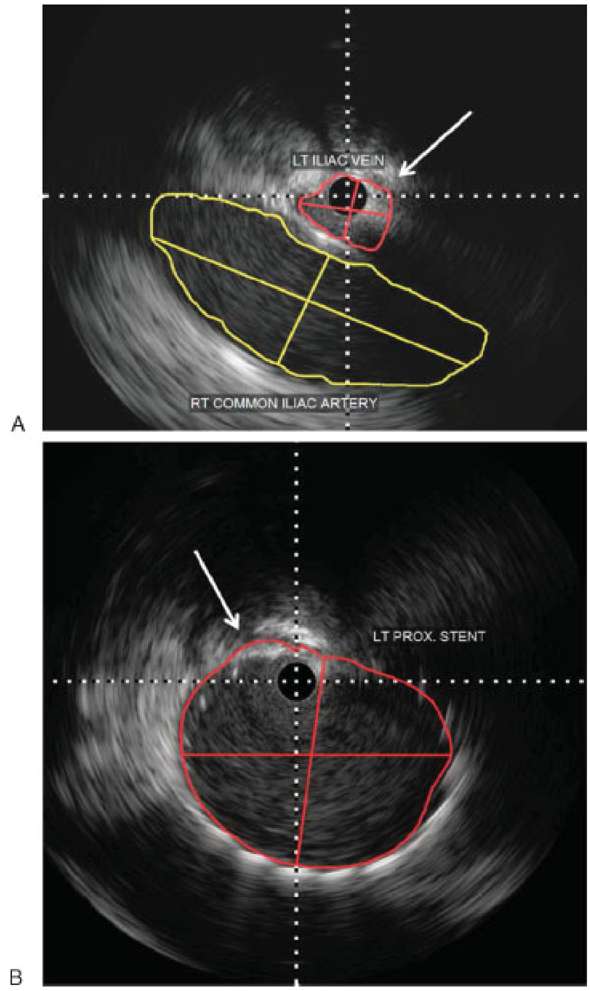


**Figure 6** (A) IVUS of left common iliac vein being compressed between the right common iliac artery and sacrum (arrow). (B) Stenting of the left common iliac vein (arrow) with marked improvement in the diameter of the vein.

the Seldinger technique. A general estimation of the wire length is carefully forwarded into the IVC, followed by placement of an 8 or 9F sheath. The IVUS catheter is advanced over the wire, and venous anatomy is interrogated in a "pullback" fashion. Key venous anatomical landmarks include right atrium, left and right renal veins, accessory renal veins, right renal artery, common iliac vein, and external/internal iliac vein bifurcations. Additionally, the presence of caval thrombus as well as measuring venous diameters should be done with IVUS prior to filter deployment. The right renal artery serves as the landmark for filter deployment. Chiou describes using an external marker from the point of catheter insertion while the catheter tip is at the right renal artery; this serves as a reference point on the filter deployment catheter to the same length for deployment.[19] Depending on the manufacturer's recommended filter deployment method, consideration must be made as to whether the filter is pushed forward or the sheath is retracted. Alternatively, Jacobs et al describe a technique whereby the IVUS catheter is placed through the long working sheath of the filter.[20] After the tip of the IVUS probe is positioned at the right renal artery, the sheath is advanced to the tip of the IVUS. The IVUS catheter is removed and the filter is deployed accordingly with retraction of sheath after the filter is placed at the sheath tip.

The double-puncture technique allows real-time imaging of placement of the filter in a position just inferior to the renal veins. Two common femoral vein punctures are made in the same groin 1 cm apart. One access uses IVUS to view live positioning of filter through the other access. Similar anatomical landmarks are used, and after deployment IVUS ensures appropriate strut spacing and apposition. Generally, in the single-puncture technique, passing the wire through a newly deployed filter in a blind fashion, so as to assure good placement, is generally not recommended. All patients should have fluoroscopic or plain film X-ray confirmation of placement after IVUS-guided filter deployment.

Using the previously outlined techniques of placement, bedside placement of IVC filters using portable IVUS has been reported with high success rates. As previously stated, this procedure can be a good alternative for critically ill and multitrauma patients. Not only are many critically ill patients too sick to transport to the operating room or angiography suite, but more cost is incurred by use of those extra facilities as well. Ashely et al compared the accuracy of IVUS and contrast venography for IVC filter deployment in multitrauma patients. Using selective renal venography last as the criterion standard for filter placement 1 cm below the renal veins, filter placement guided by IVUS was significantly closer to the renal veins ($3.7 \pm 5.6$ mm) than filter placement guided by nonselective IVC contrast venography ($16.3 \pm 13.8$ mm) ($p = 0.001$).[21] Another study in critically ill patients assessed IVUS filter placement followed by contrast venography (part 1) and later evaluated bedside placement using just IVUS (part 2). Results from part 1 demonstrated 10 successful filter deployments; in part 2 33 of 35 patients had successful deployment. One patient had a filter deployed in the ipsilateral common iliac vein and in the other, IVC thrombus was noted.[17] A recent large series from a large tertiary care center over a 1-year period of time reported 109 patients undergoing an IVUS-directed bedside filter placement.[18] In this study, two patients (1.9%) had inadequate visualization with IVUS to allow safe deployment of a filter. Of the remaining 107 who underwent filter placement, 3 had malpositioning requiring repositioning, filter tilt was $\geq$15 degrees in 2, and arteriovenous fistula occurred in 1 patient.

The use of IVUS to guide filter deployment can also be helpful in bariatric patients, particularly in the super morbidly obese with a body mass index (BMI) $>$50 kg/m$^2$. These patients often cannot undergo contrast venography because of limited visualization of the IVC due to inadequate fluoroscopic penetration. Table weight limits also play a role. Kardys et al reported the outcome of 27 super morbidly obese patients (mean BMI: 70 kg/m$^2$) undergoing filter placement with the use of IVUS prior to bariatric operation.[22] Technical success was 96.3%, and one patient had deployment of a filter in the common iliac vein that could not be repositioned. One patient developed a non-fatal PE detected by computed tomography 2 months after operation.

## Intravascular Ultrasound Limitations

Several image artifacts are important to recognize during the use of IVUS. First, if using a system that requires a guidewire, image dropout of $\sim$15 degrees will occur in the location of the wire. Dual-channel catheters have resolved this problem because the wire can be removed. Second, acoustic shadowing can occur from calcification, stent struts, and IVC filters, limiting the visibility of structures deep to these artifacts. Third, mechanical IVUS systems require careful flushing of saline into a small portion of the catheter housing the transducer. If air bubbles are present, a distorted image will appear. Fourth, if a mechanical IVUS catheter bends too much from being in a tortuous vessel, nonuniform rotational distortion artifact occurs because the transducer is not able to rotate properly. Reverberation or re-reflections can occur when the transducer itself reflects the returning reflected ultrasound beam, as evidenced by multiple circular echoes created equidistant from the catheter probe. Understanding and recognizing these limitations will allow more effective use of this user-dependent device for venous imaging.

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