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INTRAVASCULAR IMAGING (A. G. TRUESDELL, SECTION EDITOR)

Intravascular Imaging for Venous Interventions

Vijaywant Brar[1] · Rahul Dhawan[2] · Eric A. Secemsky[3,4] · S. Elissa Altin[5] · Andrew J. P. Klein[6] · Omar Hyder[7,8] · Andrew M. Goldsweig[2]

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Abstract

Purpose of Review This review surveys the clinical landscape of intravascular imaging for endovenous interventions.

Recent Findings Endovascular imaging has become increasingly important for diagnosing venous pathology and guiding venous interventions. In particular, intravascular ultrasound (IVUS) provides 3D high-resolution cross-sectional imaging of vessel and surrounding tissues, often in anatomic locations inaccessible to surface ultrasound, namely the superior vena cava, inferior vena cava, and caval-iliac veins.

Summary Current well-established indications for venous IVUS include diagnostic studies, venoplasty, transjugular intrahepatic portosystemic shunt (TIPS) creation, inferior vena cava filter placement, and transjugular liver biopsy. In the future, optical coherence tomography may play an increasing role in venous assessment and intervention.

Keywords Venous · Endovascular · Intravascular ultrasound · Venoplasty · Transjugular intrahepatic portosystemic shunt · Inferior vena cava filter · Transjugular liver biopsy

Introduction

Venous anatomy has traditionally been imaged using duplex ultrasound. However, the central veins (superior vena cava (SVC), inferior vena cava (IVC), and iliac veins) have been more challenging to accurately and consistently image due to their deep location. Although computed tomography (CT) and magnetic resonance venography (MRV) can provide excellent pre- and post-procedural imaging, they are not useful for procedural guidance. Intra-procedurally, endovascular imaging is critical in venous intervention for both vessel sizing as well as delineation of pathology. Though the traditional method for imaging has been intravascular ultrasound (IVUS), optical coherence tomography (OCT) has recently also been used in these vascular beds. In this review, we discuss the current role of IVUS and emerging role of OCT in venous interventions.

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✉ Andrew M. Goldsweig
andrew.goldsweig@unmc.edu

[1] Division of Cardiovascular Medicine, MedStar Heart and Vascular Institute, Washington, DC, USA

[2] Division of Cardiovascular Medicine, University of Nebraska Medical Center, 982265 Nebraska Medical Center, Omaha, NE 68198, USA

[3] Smith Center for Outcomes Research, Division of Cardiology, Department of Medicine, Beth Israel Deaconess Medical Center, Boston, MA, USA

[4] Harvard Medical School, Boston, MA, USA

[5] Division of Cardiovascular Medicine, Yale University, New Haven, CT, USA

[6] Piedmont Heart Institute, Atlanta, GA, USA

[7] Lifespan Cardiovascular Institute, Providence, RI, USA

[8] Division of Cardiovascular Medicine, Warren Alpert Medical School of Brown University, Providence, RI, USA

Intravascular Ultrasound (IVUS)

Catheter-based intravascular ultrasound (IVUS) was first developed in the 1980s [1] to improve visualization of vascular disease and optimize treatment. Since its inception, IVUS has been used extensively to image atherosclerotic coronary artery disease and to guide coronary interventions [2, 3], and IVUS-guided percutaneous coronary intervention (PCI) has been shown to improve outcomes by decreasing the risk of target vessel failure [4]. IVUS has also been used to guide various peripheral arterial interventions [5] and is particularly useful at defining arterial pathology and optimizing interventions. For instance, IVUS can be used in renal artery intervention to visualize webs as seen in fibromuscular dysplasia (FMD) and guiding balloon angioplasty. On the venous side, given the plasticity of the venous bed and need for accurate vessel sizing for the implantation of devices, such as IVC filters and stents, IVUS is increasingly being used to assist with interventions.

IVUS Equipment and Technique

IVUS is performed using a small catheter-based ultrasound transducer attached to an imaging console [6]. To acquire venous images, venous access is obtained with the appropriate caliber sheath for the intended imaging device. Anticoagulation is then administered, a guidewire is advanced across the region of interest, and the IVUS catheter is introduced into the vessel over the guidewire. Cross-sectional IVUS images are then acquired during either manual or automated pullback of the catheter.

IVUS devices are available for use with 0.014-, 0.018-, and 0.035-in. guidewires and vary in maximum visualized diameter (Table 1). Modern IVUS images are high resolution (to approximately 150 μm). This permits evaluation and measurement of the vessel lumen and walls, visualization of thrombi, valves, and stents, and assessment of nearby structures that may lead to external compression of a vein, such as seen in May-Thurner syndrome. Precise quantitative measurements, including areas and thicknesses of various structures, can also be obtained from the axial images. Automated pullback systems offer the ability to determine linear distances between image frames as well. Some imaging systems are also capable of co-registering IVUS and angiographic images. A virtual histology (VH) feature may help characterize the makeup of different tissues seen by IVUS, although the clinical utility of this feature remains unproven.

Venous Applications

Chronic Lower Extremity Deep Venous Disease

Chronic lower extremity deep venous disease is a highly prevalent condition and is associated with significant morbidity and healthcare costs. It can result from prior acute or chronic venous thrombosis, superficial venous disease, and non-thrombotic causes including extrinsic compression, trauma, surgery, and congenital abnormalities. For patients in whom the cause of chronic venous obstruction is not apparent on conventional imaging, IVUS can provide circumferential visualization of the affected vein and the surrounding perivascular structures to establish a diagnosis and characterize any anatomic abnormality or cause of obstruction. Furthermore, IVUS is invaluable in patients undergoing venoplasty and stenting, enabling accurate assessment of the diameter of the vein, and degree and length of stenosis, thereby facilitating appropriate stent selection, deployment location, and optimal post-dilation sizing.

Chronic Iliocaval Venous Obstruction

Venoplasty and stenting of the iliac vein is a safe alternative to open bypass grafting surgery [7]. Given their location, the iliac veins are difficult to image with surface ultrasound. Traditionally, iliocaval venoplasty has been guided by venography; however, many studies have recognized the inaccuracy of transfemoral venography in the delineation of iliac venous outflow obstruction. In such cases, IVUS-guided identification of morphologically significant stenoses may be the best available method for the diagnosis of clinically important chronic iliac vein obstruction. In one study, Neglen et al. [8] compared IVUS with standard, single-plane, transfemoral venography in 304 consecutive limbs during interventions in obstructed iliac venous segments

Table 1 Commercially available IVUS catheters used for peripheral vascular interventions

IVUS catheter name	Maximum guidewire compatibility (inch)	Sheath size (Fr)	Frequency (MHz)	Maximum imaging diameter (mm)	Manufacturer	Images
VISION PV 0.014	0.014	5	20	20	Philips	Gray-scale, VH, ChomaFlo
VISION PV 0.14P RX	0.014	5	20	20	Philips	Gray-scale, VH, ChomaFlo
EAGLE EYE PLATINUM ST	0.014	5	20	20	Philips-Volcano	Gray-scale, VH, ChomaFlo
VISION PV 0.018	0.018	6	-	24	Philips	Gray-scale, VH, ChomaFlo
OPTICROSS 18	0.018	6	30	12	Boston Scientific	Gray-scale
VISION PV 0.035	0.035	8.5	10	60	Philips	Gray-scale

VH virtual histology

and concluded that IVUS was superior to single-plane venography for the morphologic diagnosis of iliac venous outflow obstruction, documenting an average diameter reduction of 50% by quantitative venography vs. 80% by IVUS.

May-Thurner Syndrome

May-Thurner syndrome refers to compression of the left common iliac vein between the right common iliac artery and the vertebral body (Fig. 1). This extrinsic venous compression can lead to venous endothelial damage and fibrosis, resulting in "spur" formation further narrowing of the venous lumen and superimposed thrombosis. Many patients with May-Thurner syndrome develop significant edema of the left lower extremity and require stenting of the left common iliac vein for symptom relief [9]. In such cases, IVUS can be particularly helpful, offering improved visualization of intra- and extramural details including external compression, trabeculation, frozen valves, and mural thickening. In addition, IVUS allows accurate measurement of the cross-sectional area proximal and distal to the site of stenosis, permitting the selection of appropriately sized stents. Given absence of adequate hemodynamic testing for important venous obstruction, IVUS assessment is the best available tool for assessment of clinically significant stenosis and vessel sizing.

Inferior Vena Cava Filter Placement

Inferior vena cava (IVC) filter placement can be guided safely and effectively by IVUS alone (Fig. 2) without fluoroscopy. This is particularly important for patients in whom conventional fluoroscopy-guided IVC filter placement techniques are absolutely or relatively contraindicated, including those with preexisting acute or chronic kidney disease, pregnancy, and critically ill patients who cannot be transported safely to an angiography suite.

In a series of 109 critically ill patients undergoing IVUS guided IVC filter placement, there was procedural success in 97.2% of patients [10], similar to the rates with fluoroscopic guidance. In addition, there were no procedure-related deaths, with very low rates of periprocedural complications, including malpositioning of the IVC filter requiring retrieval and repositioning in three patients, filter tilt $\geq 15°$ in two patients and arteriovenous fistula in one patient. In another study, Kardys et al. demonstrated that IVUS-guided IVC filter placement could be safely performed with an excellent success rate in bariatric patients, including those with body mass index > 50 [11]. Furthermore, Kassavin et al. compared fluoroscopy alone vs. fluoroscopy plus IVUS-guided IVC filter deployment in non-trauma patients and showed that IVUS use was safe and associated with less radiation and contrast exposure to patients [12]. In addition, they showed that IVUS use did not prolong the overall procedure duration.

Technique:

IVUS-guided IVC filter placement can be performed by either a single or double venous access technique. Studies have reported high success rates of IVUS-guided IVC filter placement using both techniques [14, 15].

In the single-access technique, after large bore femoral venous access is obtained, the IVUS catheter is advanced over a guidewire to the right atrium. With pullback, key venous anatomical landmarks are defined, the size of the IVC is determined, and the presence of IVC thrombosis is excluded. Next, the tip of the IVUS catheter is placed at the level of the right renal vein, which acts as a reference for filter placement. Following this, the filter delivery catheter is advanced through

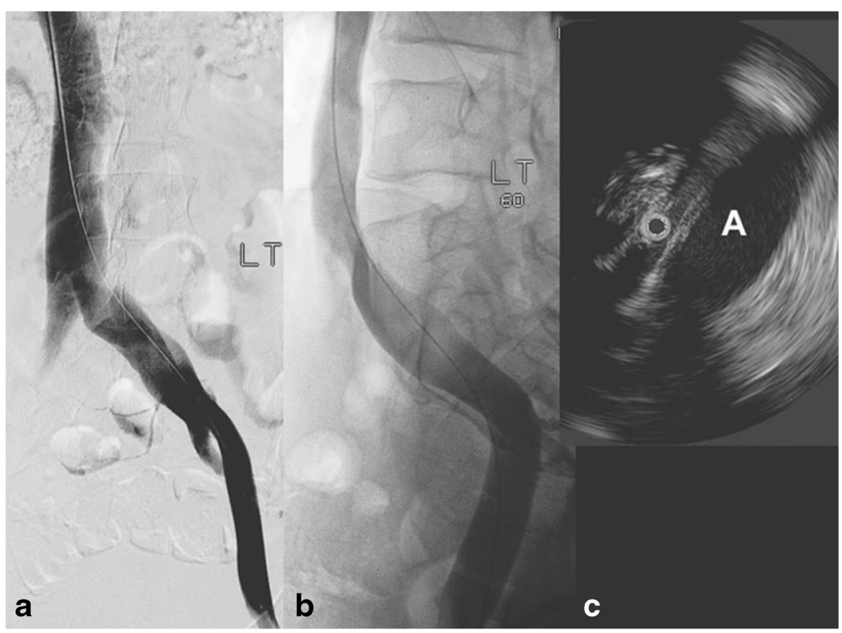

Fig. 1 Transfemoral venogram in anteroposterior (AP) view (**a**) and with 60° rotation (**b**). The right common iliac artery (labeled with white A in **c**) makes a distinct corkscrew-like impression on the vein in the oblique projection, while only a slight lucency is seen on the AP view. The severity of the stenosis at the vessel crossing is much better appreciated on IVUS. The black circle within the vein in **c** is the IVUS catheter. Image from Neglén et al. [19], reproduced with permission

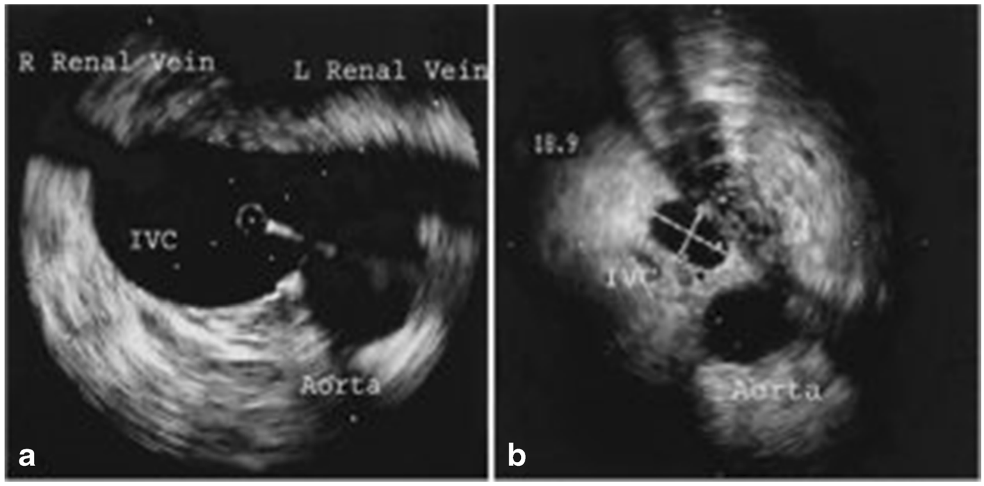

Fig. 2 Intravascular ultrasound images of IVC at the level of the renal veins (**a**) and at the intended site of filter deployment just below the level of the renal veins (**b**). IVUS allows accurate measurement of the diameter of the IVC. Image from Garrett et al. [20], reproduced with permission

the same access site to the tip of the IVUS catheter. Then, the IVUS catheter is removed and the IVC filter is deployed. All patients should undergo post-procedural X-ray confirmation of appropriate IVC filter placement.

In the double-access technique, after two femoral venous access sites are obtained, the IVUS catheter is advanced through one access site and used to provide real-time guidance for IVC filter placement using the other access site and the same anatomical landmarks as detailed above for single-access deployment. Because the IVUS and filter catheters pass through different sheaths, the double-access technique requires smaller bore access than the single-access technique.

Transjugular Intrahepatic Portosystemic Shunt (TIPS)

Hepatic cirrhosis is frequently complicated by portal hypertension (PHT) with its sequelae, including ascites and variceal bleeding. The latter can be reduced by lowering portal venous pressures through creation of a transhepatic portosystemic venous shunt (TIPS) between the right portal and hepatic veins. Typically, TIPS is performed from the right internal jugular vein under fluoroscopic guidance. The major disadvantage of using only fluoroscopy to guide TIPS is the inability to visualize the anatomic path of the needle at the time of portal venous puncture, increasing the rate of unintentional arterial, biliary, or extracapsular punctures. IVUS can provide real-time imaging of the needle to reduce the risk of such complications. Furthermore, IVUS has been shown to be especially useful for TIPS guidance in patients with distorted anatomy, such as portal vein thrombosis, Budd-Chiari syndrome, and hepatic tumors [13].

Several studies have compared traditional TIPS with IVUS-guided TIPS and concluded that IVUS use is associated with lower total radiation exposure to the patient, shorter time to portal vein access, shorter total procedure time, fewer needle-related capsular perforations, and less contrast agent volume utilized [14, 15].

Transcaval Liver Biopsy

IVUS plays a cardinal role in guiding liver biopsy from the transcaval approach. Traditional fluoroscopy-guided transjugular liver biopsy requires at least one patent hepatic vein (generally the right or middle hepatic vein) through which a hepatic puncture is performed. Many patients are not suitable for this approach due to the lack of patent or readily accessible hepatic veins. Such patients include those with Budd-Chiari syndrome, hepatic malignancy impeding access to hepatic veins, or liver transplant patients with challenging anatomy. By providing real-time visualization of the needle and its course, IVUS allows direct puncture of the liver from the IVC, permitting transvenous liver biopsy in even the most challenging patients and anatomy [16].

Technique:

After obtaining femoral venous access, the IVUS probe is positioned in the intrahepatic IVC. The liver biopsy system is then advanced into the IVC using the transjugular approach. Next, IVUS is used to guide direct needle puncture of the caudate lobe of the liver from the IVC using the biopsy system's 19-gauge, 60-cm needle. IVUS allows real-time imaging of the needle tip and its spatial relationship to the liver parenchyma. Using IVUS, the entire needle track from the IVC into the hepatic parenchyma can be planned and visualized.

Overall Advantages of IVUS

For endovenous studies and interventions, IVUS offers many unique advantages over invasive angiography, and non-invasive multi-slice CT or MR imaging.

- IVUS provides imaging in 3 dimensions, quantifying the area and length of stenoses. In contrast, two-dimensional fluoroscopy is highly dependent upon the imaging angle and therefore much less accurate in determining the severity and extent of pathology.

- Diagnostic vascular imaging can be performed with IVUS without the use of any iodinated contrast. If no adjunctive fluoroscopy is performed, there is also no radiation exposure to the patient.
- Even when used as an adjunct to fluoroscopy, IVUS use may result in lower iodinated contrast use and radiation exposure in patients undergoing angiographic procedures.
- Endovenous IVUS provides visualization of the entire circumference of the vessel wall, enabling more accurate assessment of the vessel size, luminal defects, degree and length of stenosis, and perivascular structures.
- IVUS allows direct visualization of the intimal, medial, and adventitial layers of the venous wall. In large- and medium-sized veins, the intimal layer appears brightly echogenic, clearly demarcated from thrombus, fibrosis, or stents.

Disadvantages of IVUS

Despite the various advantages offered by IVUS, there are several disadvantages associated with its use.

- Endovenous IVUS is an invasive modality, which can expose patients to the risk of vascular access complications, including vascular injury, bleeding, and infections. These risks, however, are similar to those of conventional angiography.
- IVUS use may be limited in the presence of high-grade venous obstruction.
- The acquisition and the interpretation of IVUS images is dependent on operator familiarity with imaging artifacts, including reverberation artifact, distortion artifact, and ring down artifact resulting from ultrasound reverberations within air bubbles adjacent to the catheter.
- IVUS use may be associated with increased procedural cost, including the cost of the imaging system and the disposable catheters.
- In some circumstances, IVUS use may be associated with longer procedure times. This may be a particularly important barrier to using IVUS during emergent cases.

Optical Coherence Tomography (OCT)

Optical coherence tomography (OCT) is a relatively novel endovascular imaging technology, which uses back-scattered infrared light to generate ultra-high resolution cross-sectional and 3D images from within the vasculature. The OCT catheter contains a single optical fiber that emits infrared light. The images are generated based on the echo time delay and the intensity of the detected optical echo from tissue.

OCT was initially developed for coronary artery imaging and to guide percutaneous coronary interventions. However, potential uses of OCT have expanded to peripheral artery imaging [17, 18]. To our knowledge, there have been no studies that have systematically examined OCT use to image the venous system; however, anecdotal reports of such usage have emerged. While OCT offers extremely high-resolution imaging, it has a penetration depth of less than 1 mm, and it requires displacement of blood from the vessel being imaged using contrast or dextran, which may be relative disadvantages compared to IVUS. Further research is necessary before this technique becomes mainstream.

Conclusion

Endovenous imaging has become increasingly important for diagnosing venous pathology and guiding venous interventions. In particular, IVUS provides detailed, high-resolution cross-sectional imaging of vessels and their surrounding tissues, often in anatomic locations inaccessible to surface ultrasound. Current indications for venous IVUS include diagnostic studies, venoplasty, stent sizing, TIPS creation, IVC filter placement, and transjugular liver biopsy. Many features of IVUS guidance render it superior to standard fluoroscopy and venography guidance alone. In the future, OCT may play an increasing role in venous assessment and intervention, but this role has yet to be adequately explored.

Compliance with Ethical Standards

Conflict of Interest The authors declare that they have no conflict of interest.

Human and Animal Rights and Informed Consent This article does not contain any studies with human or animal subjects performed by any of the authors.

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