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INTRAVASCULAR IMAGING (A TRUESDELL, SECTION EDITOR)

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Intravascular Imaging for Peripheral Vascular Disease and Endovascular Intervention

Eric Rothstein[1] · Herbert Aronow[2] · Beau M. Hawkins[3] · Michael N. Young[1]

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Abstract

Purpose of Review Intravascular imaging has been increasingly incorporated into endovascular practice. The goal of this review is to explore the contemporary technologies used to perform intravascular imaging as well as the evidence supporting their use in the diagnostic assessment and treatment of peripheral vascular disease.

Recent Findings Although intravascular imaging has been more extensively studied in the coronary vasculature, there is a growing body of literature studying its use in other vascular territories. There are unique advantages and disadvantages for the two most commonly employed imaging modalities—intravascular ultrasound (IVUS) and optical coherence tomography (OCT). Either may enhance the diagnostic capabilities of conventional angiography depending upon the clinical situation. IVUS and OCT guidance for angioplasty and stent sizing in peripheral interventions has been shown to be safe, feasible and in many instances, effective. Studies suggest that clinically relevant outcomes such as vessel primary patency and long-term patency may be improved by utilizing these imaging technologies.

Summary While still employed as adjunctive modalities to angiography and peripheral intervention, IVUS or OCT may provide a potential pathway towards improving short- and long-term outcomes for a variety of vascular disease entities. At this time, further research is still warranted to better define the optimal role for these devices in non-coronary vascular beds.

Keywords Intravascular imaging · Intravascular ultrasound · Optical coherence tomography · Peripheral arterial disease · Vascular disease

Introduction

Historically, angiography has been considered the "gold standard" for the assessment of coronary or vascular disease. Recent evidence indicates that the addition of intravascular imaging to traditional coronary angiography results in improved clinical outcomes [1–8, 86]. For instance, the IVUS-XPL clinical trial recently demonstrated an absolute difference of 3–5% fewer adverse cardiac events at 1 year in patients who had undergone intravascular ultrasound (IVUS)-guided versus angiography-guided stent implantation (hazard ratio 0.48, $p = 0.007$) [9]. Borrowing on data and experience in the coronary arteries, operators have employed similar ancillary imaging approaches for peripheral vascular disease [10••]. Operators may utilize intravascular imaging technologies to characterize disease in the peripheral vasculature, improve obstructive lesion assessment prior to and after intervention, augment the capability to treat complex lesions such as chronic total occlusions (CTOs), and refine the safety and efficacy of atherectomy [11]. The majority of intravascular imaging studies performed in the periphery utilize IVUS, although there is increasing experience with

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✉ Michael N. Young
michael.n.young@dartmouth.edu

Eric Rothstein
Eric.S.Rothstein@hitchcock.org

Herbert Aronow
Herbert.Aronow@Lifespan.org

Beau M. Hawkins
Hawkins@ouhsc.edu

[1] Cardiology Division, Dartmouth-Hitchcock Medical Center, Geisel School of Medicine at Dartmouth, 1 Medical Center Drive, Lebanon, NH 03756, USA

[2] Cardiology Division, Alpert Medical School of Brown University, Lifespan Cardiovascular Institute, Providence, RI, USA

[3] Cardiology Section, University of Oklahoma Health Sciences Center, Oklahoma City, OK, USA

optical coherence tomography (OCT) for many of the same reasons that IVUS is employed.

Foundational Imaging Concepts

Image resolution differs across modalities and can be characterized according to space, time and contrast [12]. Spatial resolution refers to an imaging modality's ability to discriminate between two small objects within an image and is measured in units of length (millimeters). In the setting of tomographic (cross-sectional) imaging, spatial resolution is further subdivided into two principle directions, axial resolution (parallel to the beam) and longitudinal resolution (perpendicular to the beam) [13]. Contrast resolution refers to the ability of a modality to distinguish between subtle differences (signal-to-noise ratio) in the intensity of an image [12]. For IVUS imaging, contrast resolution is also referred to as "dynamic range." An IVUS image with low dynamic range appears predominantly black and white with few shades of gray in between, whereas an IVUS image with high dynamic range preserves many of the subtleties of the image [13]. Temporal resolution, measured in units of time (ms), refers to an imaging modality's ability to resolve moving objects [12]. Although the peripheral vasculature is a relatively static structure, the IVUS catheter is almost always in motion during pullback imaging. Due to this phenomenon, temporal resolution determines the rate at which an IVUS or OCT catheter can be pulled back without missing significant sections of the target vessel of interest. Table 1 shows a comparison of these attributes among different cardiovascular imaging modalities.

Available Intravascular Imaging Technologies

Intravascular Ultrasound

The majority of experience with intravascular imaging in the periphery is with IVUS, a modality that provides excellent spatial and temporal resolution. An IVUS catheter utilizes a transducer containing piezoelectric crystalline material that produces ultrasound waves when electrically excited. These waves are partially attenuated, backscattered, and reflected back to the transducer to varying degrees based upon the composition of the tissues they encounter. This reflected ultrasound signal is converted and processed into a cross-sectional image that is viewable in real-time.

The two IVUS catheter designs currently implemented are solid and mechanical state catheters. A mechanical state catheter has a single rotating element that transmits and receives signals with each revolution while a solid state catheter has multiple phased array elements that sequentially transmit and receive signals that are arranged circumferentially around the distal tip of the catheter. The IVUS catheter is typically advanced beyond the region of interest and withdrawn across the lesion, typically at a rate of 0.5 mm/s, while recording images at a rate of ~ 30 frames/s. The ultrasound data can be further analyzed by dedicated software to characterize tissue and plaque components, a post-processing algorithm that is referred to as virtual histology (VH-IVUS) [13].

Optical Coherence Tomography

OCT was originally developed for imaging of the retina and relies on the analogous concept of wave emission, backscatter, and reflection. As opposed to IVUS catheters that utilize sound waves, OCT catheters emit light waves in the 1.3 μm (near-infrared range), which are attenuated, backscattered, and reflected back to the catheter. These signals are serially converted into an image in real-time to allow viewing by the operator [15]. Since light is significantly attenuated by blood, OCT requires the vessel to be "bloodless" or "cleared" during imaging. This is typically accomplished through automated or hand-facilitated contrast injections.

Technical Considerations of IVUS vs OCT

Representative intracoronary IVUS and OCT images are depicted in Fig. 1. Both modalities have their own unique advantages and disadvantages with respect to vascular imaging. IVUS has an axial resolution of ~ 100 μm, allowing for identification of

Table 1 Comparison of image resolution among cardiovascular imaging modalities

Modality	Spatial resolution	Contrast resolution	Temporal resolution
Coronary CTA	0.5–1 mm	Low to moderate	100–220 ms
Cardiac MRI	1–2 mm	High	20–50 ms
Catheter angiography	0.3 mm	Moderate	1–10 ms
Cardiac SPECT	4–15 mm	Very high	9×10^5 ms
Echocardiography	0.5–2 mm	Low to moderate	5 ms
IVUS	0.1–0.2 mm[a]	Low to moderate	33 ms
OCT	0.01–0.02 mm[a]	High	10 ms

Reference: [14]

[a] Axial resolution

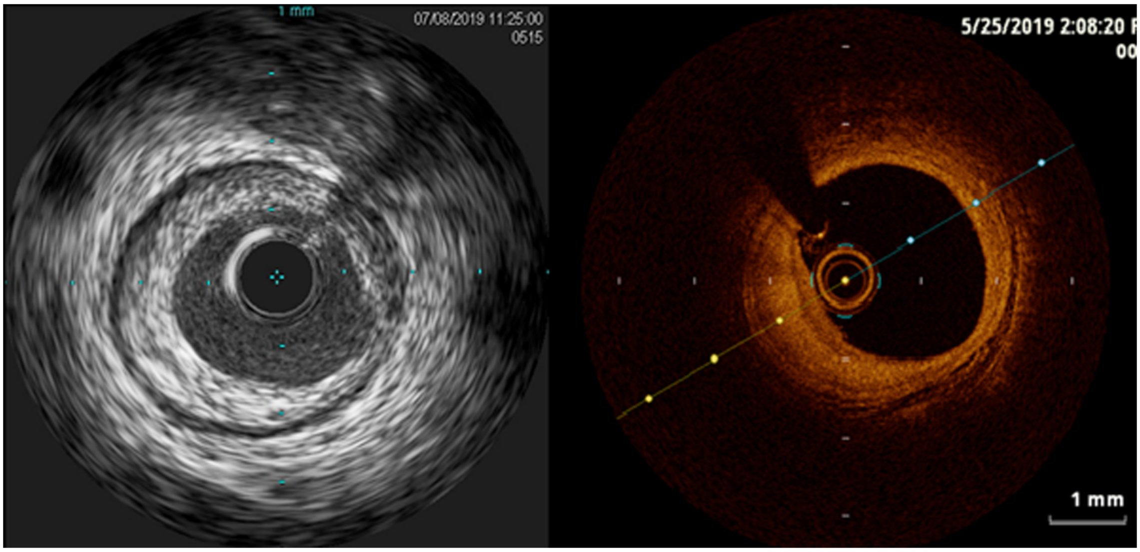

Fig. 1 IVUS (left) of a left anterior descending coronary artery with circumferential atherosclerotic plaque versus OCT (right) of a left circumflex coronary artery with concentric atherosclerotic plaque

thicker structures such as the lumen-intima and media-adventitial interfaces in normal arteries. For structures thinner than 100 µm, such as the single-cell layer intima, IVUS may be unable to provide the level of detail necessary for accurate evaluation of these structures. OCT, however, provides an axial resolution of 10 µm and can visualize this thin intima-media interface. Clinically, this enhanced spatial resolution allows for OCT to better visualize the thickness of atherosclerotic fibrous plaques, provide assessment for vulnerability to rupture, and identify intimal tears in the setting of vessel dissection.

IVUS has several properties that make it uniquely advantageous in the peripheral vascular bed (Table 2). Foremost, the longer wavelengths allow for increased penetration, which may be more favorable in the assessment of the lumen and arterial wall structures of larger vessels. Due to its decreased penetration, OCT is limited in this regard. Furthermore, because high frequency light waves are backscattered by erythrocytes, OCT imaging of the vessel wall requires clearance of the vessel via contrast injections [16]. This is of particular concern in patients at increased risk of contrast-induced nephropathy. Newer frequency domain optical coherence tomography (FD-OCT) catheters are able to obtain images rapidly at rates of 100 frames per second, allowing for detailed imaging of arteries up to 10 mm in diameter with smaller contrast injections [17].

Table 2 Qualitative considerations between IVUS and OCT

Measure	IVUS (40–45 MHz)	OCT (frequency domain)
Evidence for PAD imaging	Moderately studied	Limited studies
Spatial resolution	Good (~ 100 µm)	Superior (~ 10 µm)
Tissue penetration	Superior (> 5 mm)	Limited (1–2 mm)
Severity of calcification	Good	Excellent
Lumen-intimal interface	Not as well seen	Well visualized
Blood clearance	Can image through blood	Requires contrast injections
Full-thickness vessel wall visualization	Well seen	Limited
Lipid plaque evaluation	Attenuated plaque	Lipid plaque and cap thickness
Positive remodeling	Well visualized	Difficult to see
Stent diameter sizing	Excellent	Good
Stent length sizing	Very good	Excellent
Stent malapposition	Good	Excellent
Stent edge dissection	Fair	Excellent
Vessel dissection	Can only visualize the dissection flap	Can see the intimal tear and dissection flap

Reference: [16]

In the coronary vascular bed, two trials have been performed comparing IVUS to OCT, showing similar results in minimal lumen area and clinical outcomes [18, 19]. At this time, there are no robust head-to-head studies comparing IVUS to OCT for peripheral vascular intervention. Overall, there is still limited experience with OCT in the peripheral vasculature despite its rapid development as an effective tool for intracoronary imaging. At this time, IVUS remains the most commonly utilized peripheral intravascular imaging modality in clinical practice. The majority of available peripheral vascular imaging studies are thus centered on IVUS imaging.

Intravascular Imaging for Enhanced Diagnosis of Vascular Pathology

The ability of IVUS to image the entire vessel in vivo has enhanced the understanding of vascular disease [20]. While not commonly utilized for diagnosis in acute aortic syndromes, there are multiple case series where operators have utilized IVUS to visualize and differentiate penetrating aortic ulcers and aortic intramural hematomas that were not appreciated on non-invasive imaging [21, 22]. Intravascular imaging can also aid in diagnosing lesion etiology in lower extremity arteries and differentiating atherosclerosis from less common conditions such as fibromuscular dysplasia, cystic adventitial disease, and vasculitides. VH-IVUS is also capable of providing a color-coded map of plaque components—calcified, fibrous, fibro-fatty, and necrotic lipid core—which correlate strongly with ex vivo histologic analyses of atherosclerotic plaques [23].

While the clinical utility of characterizing atherosclerotic plaque composition remains under debate, researchers are investigating whether these data can be used to determine plaque stability versus vulnerability [24]. Additionally, operators have attempted to use IVUS-derived plaque composition to guide intervention, by evaluating the risk of embolization, need for atherectomy, and resistance to balloon dilatation [16, 25, 26]. Using VH-IVUS to estimate the risk of plaque embolization during intervention has been studied in small populations for both carotid and renal artery interventions with conflicting results [27]. It is hypothesized that an increased percentage of necrotic lipid core in plaque may be associated with elevated risk of distal plaque embolization post-intervention in all vascular beds. Yamada et al. found that while necrotic lipid core identified by VH-IVUS was useful for predicting distal embolization following carotid artery stenting, it offered no significant advantage over non-invasive plaque evaluation for predicting clinically relevant and silent strokes [28]. Takumi et al. reported that the percentage of necrotic lipid core noted on VH-IVUS plaque evaluation was significantly associated with renal deterioration following renal artery intervention [29].

OCT has also been compared to IVUS in the examination of atherosclerotic carotid plaques. Yoshimura et al. showed that in 34 patients undergoing carotid artery stenting examined by both OCT and IVUS, OCT was able to safely visualize different components of atherosclerotic plaques more accurately than IVUS. Specifically, OCT was better able to accurately detect neovascularization (38 vs 0%, $p < 0.001$), thrombus (44 vs 3%, $p < 0.001$), and ulceration (9 vs 0%) than IVUS. Neovascularization and thrombus were more frequently associated with symptomatic than asymptomatic plaques. Furthermore, IVUS was more sensitive than OCT in identifying calcium (100 vs 38%, $p < 0.001$) [30]. Further studies are required to verify and understand the clinical utility of these findings as they pertain to diagnostic and interventional practice.

Intravascular Imaging to Guide PAD Interventions

Aorta

There are multiple small studies examining the use of IVUS-guided interventions in various aortoiliac diseases. However, these larger caliber vessels present their own unique set of challenges with regard to intravascular imaging [31]. As larger vessels like the aorta require increased penetration for proper imaging, lower frequency (8–10) MHz catheters are required for visualization of the entire lumen as well as the vessel wall [32]. There are reported concerns that a mechanically rotating system withdrawn over a monorail introduces both non-uniform rotational distortion as well as wire artifact when compared to a phased array system withdrawn without a wire [33]. The two designs however have not been extensively studied or compared in this setting, and at the present time, device selection remains solely within an operator's discretion and comfort. Large caliber, tortuous vessels also accentuate "wire bias," which may lead to oblique views of the vessels and mismeasurement of vessel dimensions [34].

Despite these limitations, IVUS may be useful as an adjunct imaging modality to cineangiography in the setting of both endovascular aneurysm repair (EVAR) and thoracic endovascular aortic repair (TEVAR) for a variety of aortic pathologies [32]. While the majority of the published literature is focused on the use of IVUS to assist in the endovascular repair of aneurysmal disease of the descending thoraco-abdominal aorta and complex Stanford Type B dissections, there are reports of IVUS being used to guide endovascular repair for Stanford Type A dissections, blunt and penetrating aortic trauma, penetrating aortic ulcers, and intramural hematomas [32, 35]. For instance, both Hu et al. and Wei et al. have shown that in patients where a penetrating aortic ulcer is clinically suspected and not visualized on CT angiography, IVUS proved to be a more sensitive examination technique [21, 22].

For EVAR and TEVAR, IVUS may allow for optimal identification of both the proximal and distal landing zones by offering a comprehensive examination of the vessel wall at these locations prior to endograft deployment [36]. In the setting of aortic dissection, the intimal tear and site of entry can be directly visualized, allowing operators to avoid tracking equipment through the dissection flap and to help localize endograft deployment [37]. This added precision has led to improved recognition of visceral artery involvement in the setting of Type B aortic dissection [38]. As studies have shown that incorrect sizing of aortic endografts is associated with inferior outcomes, proper endograft sizing is of the upmost importance for these repairs [39, 40].

There are many inherent difficulties with attempting to size endografts on the basis of preoperative CT imaging alone, including the profound hemodynamic changes that occur either as a consequence of an aortic catastrophe or volume shifts in the perioperative state [41]. Additionally, CT angiography struggles to approximate the true vessel size and aortic borders simply due to the limited spatial resolution of even high resolution CT imaging when compared to peripheral IVUS [31]. CT has been shown to overestimate aortic diameter and underestimate aortic length, leading to a different endograft selection in up to 39% of patients studied after operators employed intraoperative IVUS [42]. However, the precise sizing of the aorta by IVUS is sometimes not possible due to oblique imaging and other catheter-based artifacts. Finally, there are reports of IVUS being successfully utilized to guide puncture and fenestration of the distal dissection flap to relieve ischemia induced by complex Type B aortic dissections [43].

Aortolliac Disease

Prior studies have demonstrated that the adjunctive use of IVUS to complement angiography for sizing of balloons and stents for aortoiliac intervention may result in improved clinical outcomes [44, 45]. In a study of 52 patients, Buckley et al. demonstrated primary patency rates of 100% at both 3 and 6 years in iliac lesions treated with IVUS-guided intervention compared to primary patency rates of 82% at 3 years and 69% at 6 years ($p < 0.001$) in lesions treated without IVUS [46]. Prior data have shown that 20–40% of iliac artery stents placed were incompletely apposed to the arterial wall and required further dilation for optimal sizing post-deployment [45]. IVUS may be helpful in determining optimal stent strategy in iliac intervention based upon vessel calcium burden. Due to the increased risk of perforation, heavy calcification may call for under-sized stents or use of either self-expanding or covered stents.

IVUS-derived parameters that confer elevated risk of in-stent restenosis (ISR) in the coronary arteries may also confer elevated risk of ISR following iliac intervention [47, 48]. Specifically, stent edge dissection, stent length, and a MSA < 17.8 mm^2 have been observed as significant predictors of ISR [44]. Future studies that may better define these risk factors will ideally help operators predict risk of ISR using IVUS. While there is no long-term comparison of primary patency rates between IVUS-assisted versus angiographic stent sizing in the iliac vessels, the primary patency rates of 87, 83, and 75% (at 5, 10, and 15 years, respectively) in the setting of IVUS-facilitated intervention suggest that long-term primary patency rates are acceptable and better than previously believed [49]. Overall, the literature suggests that IVUS may improve the efficacy of percutaneous intervention in the aortoiliac system, although the data are too limited at this time to recommend that it should be universally employed for all interventions in this vascular territory.

Femoropopliteal Disease

Intravascular imaging may improve outcomes for interventions in the femoropopliteal space, although this arterial bed is not as well-studied as in aortoiliac disease [26]. The advantages for imaging may be primarily attributed to the following components: (a) selection of ideal stent landing zones and stent length; (b) proper vessel and stent diameter sizing; (c) enhanced recognition of vessel dissection; and (d) detection of incomplete stent expansion and apposition [10••].

While no head-to-head randomized control trials have been performed comparing angiography to IVUS-guided femoropopliteal interventions, a prospective study using IVUS after superficial femoral artery (SFA) interventions revealed that 68% of patients still had stenoses that obstructed > 70% of the vessel lumen following angiographic-guided SFA intervention [50]. A retrospective review by Miki et al. demonstrated improved primary and secondary patency rates, freedom from reintervention, and adverse limb events in patients who underwent IVUS-guided endovascular intervention when compared to angiographically guided intervention alone [51]. Preliminary research has also identified that a MSA cutpoint of < 15.5 mm^2 measured by IVUS may be associated with ISR in patients undergoing SFA interventions [52•].

Following intervention, IVUS-based studies have demonstrated that vessel dissections are commonly missed on angiography and have been attributed to decreased patency rates. Therefore, IVUS-guided intervention may better detect these dissections, allow for further risk stratification, and ensure that they are addressed prior to case conclusion [53]. Figure 2 illustrates the use of IVUS-guided angioplasty of a critical left popliteal artery stenosis in a patient presenting with an ischemic left foot.

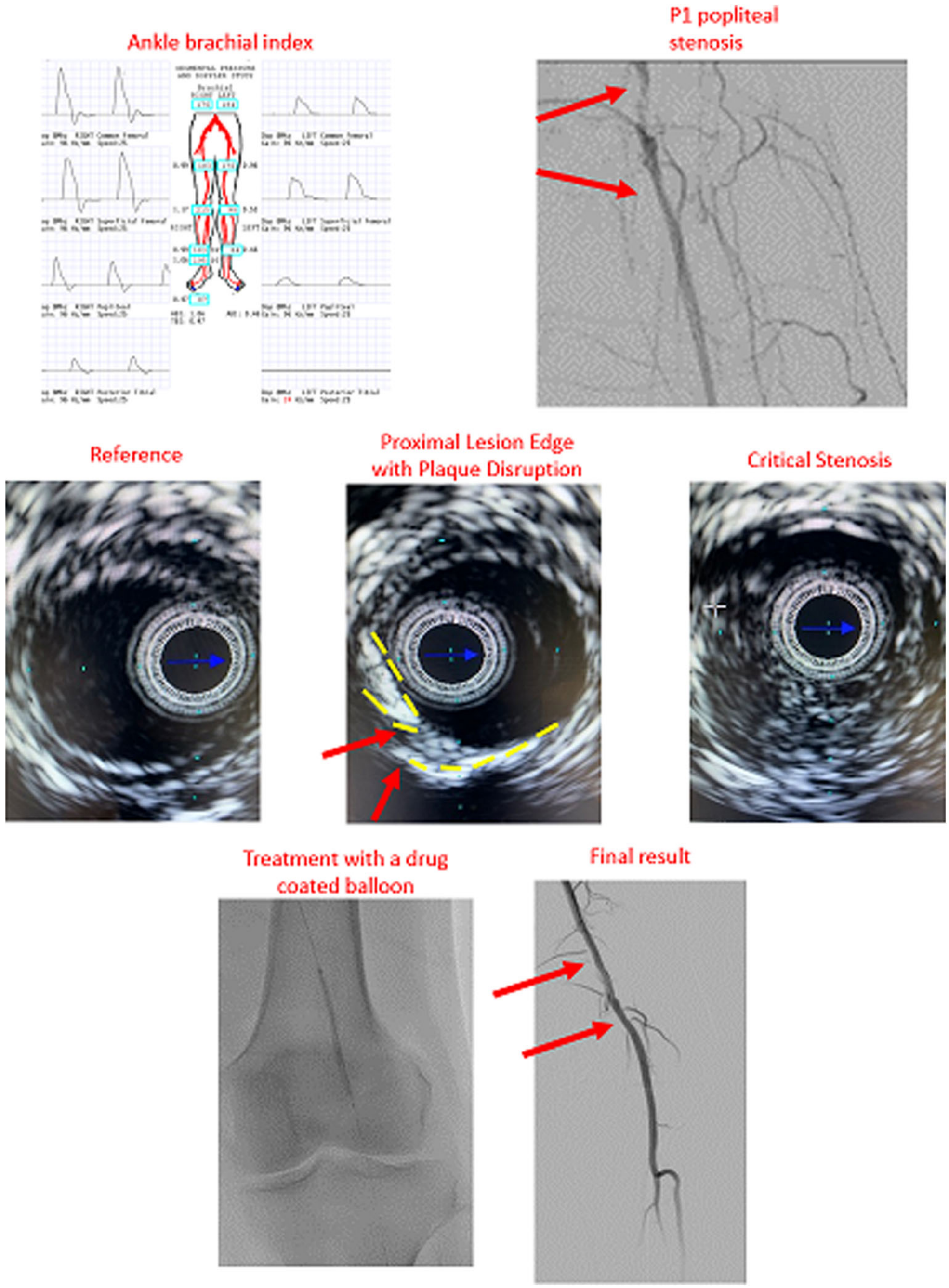

Fig. 2 ABIs (top left) suggests severe obstructive disease at the level of the popliteal artery with corresponding angiograms depicting severe left popliteal artery stenosis (top right). IVUS (middle row) demonstrated proximal plaque disruption with critical stenosis. The lesion was treated with a drug coated balloon (bottom left) with excellent angiographic result (bottom right)

Infrapopliteal Disease

There is very limited published literature examining the utility of IVUS or OCT to guide intervention in the infrapopliteal arteries. Given the relative comparability in vessel size between the coronary and the tibial arteries, it may be hypothesized that image-guided balloon or stent sizing for below-knee interventions may derive comparable benefits as observed for PCI. In technically challenging cases such as chronic total occlusion, there may be a role for IVUS-directed angioplasty requiring enhanced visualization and spatial resolution of the runoff vessels. However, these theoretical advantages for image-guided intervention for the tibioperoneal vasculature have not been well-studied.

Mesenteric and Renal Arterial Disease

The ability of IVUS to allow operators to avoid or limit iodinated contrast injections is especially advantageous in the setting of renal artery interventions due to the elevated risk of contrast-induced nephropathy in this vulnerable patient population [54]. As previously discussed, multiple studies have explored VH-IVUS assessment for predicting renal artery plaques at high risk for distal embolization [29]. Takumi et al. demonstrated a statistically significant correlation ($r = 0.47$, $p = 0.02$) between necrotic core size and deterioration of renal function following renal artery intervention. Several groups have also published their experiences using IVUS to better characterize and treat renovascular disease due to fibromuscular dysplasia with excellent technical success [55, 56]. Finally, there are multiple case reports of operators using IVUS to guide angioplasty, stenting, and atherectomy in the renal, celiac, superior mesenteric, and inferior mesenteric arteries [57, 58]. However, the overall evidence for and general practice of using intravascular imaging in these vascular territories remain quite limited.

Cerebrovascular Disease

Both IVUS and OCT have been studied in the setting of carotid artery revascularization, and both modalities have been shown to be relatively safe with no significant increase in periprocedural cerebrovascular accidents (CVA) [25, 59]. In addition to guidance of stent sizing and localization as demonstrated in other arterial systems, intravascular imaging may offer several unique benefits in the setting of carotid artery stenting (CAS). Embolic risk stratification based upon plaque lipid composition may assist operators in properly identifying high-risk lesions and more effectively deploying embolic protection devices [27, 60]. The efficacy of this concept remains under investigation.

Following stent deployment, intravascular imaging may also allow for improved diagnosis of in-stent protrusion of atherosclerotic plaque [61]. In-stent protrusion has been implicated as a major cause for intra- and post-procedural CVA, with a high risk for ischemic lesions noted on post-procedural magnetic resonance diffusion-weighted imaging (88%) as well as clinical CVA (67%); it has an estimated prevalence of 8–10% [62]. Both invasive and non-invasive imaging modalities have identified soft plaque with increased necrotic lipid cores as high-risk lesions for distal embolization and in-stent protrusion.

Although image-guided CAS for all procedures is not standard of care at this time, some have proposed that when used as an adjunct to angiography, it may reduce the stroke risk associated with CAS [63, 64]. These benefits must be weighed against the downside of increasing procedural time and possibility of inducing plaque disruption through added instrumentation of the cervical vessels.

While there are published case reports of IVUS-guided intervention in the vertebral arteries, this experience is too limited at this time to make any formal recommendations [65, 66]. With regard to treatment of disease in the subclavian arteries, a retrospective review of subclavian endovascular interventions noted higher primary patency rates in patients where IVUS guidance was used for stent sizing as opposed to angiography alone (89 vs 73%, $p = 0.03$) [67].

Venous Disease

The majority of data regarding the use of IVUS for venous intervention is focused on IVC filter placement as well as common iliac vein stenting in the setting of May-Thurner syndrome (MTS). As operators have begun placing IVC filters at the bedside without fluoroscopic guidance for patients considered too ill to leave the intensive care unit, ultrasound (transabdominal and IVUS) have allowed for accurate filter positioning and deployment [68, 69]. Unfortunately, studies examining peri-procedural outcomes of bedside IVUS-guided IVC filter deployment have been associated with increased adverse peri-procedural outcomes including malpositioning (6% in the IVUS group vs 0% in the fluoroscopy group, $p < 0.01$) and filter tilt > 20° (10% in the IVUS group vs 3% in the fluoroscopy group, $p = 0.05$) [70]. While long-term complication rates between patients receiving fluoroscopically guided and IVUS-guided IVC filters appear comparable, further studies must be performed and techniques refined prior to recommending filter placement by IVUS guidance alone [71].

With respect to iliac vein interventions, IVUS may improve an operator's ability to adequately size and deploy venous stents [72]. The most widely studied IVUS-assisted venous interventions are for MTS, where preliminary data suggest that IVUS is a useful adjunct to venographically guided stent deployment [73]. One study demonstrated that IVUS guidance resulted in 2-year patency rates of 98%, which is markedly higher than historically reported rates of 79% [74]. No head-to-head venography versus IVUS-guided iliac vein intervention studies are available at this time. Figure 3 shows representative angiographic and IVUS images of a young female patient who underwent placement of a Wallstent in the left common iliac vein for May-Thurner syndrome. Figure 4 depicts the use of IVUS for helping localize the renal veins and facilitate deployment of a retrievable IVC filter.

Intravascular Imaging to Guide Complex Endovascular Techniques

Atherectomy

As vascular medicine specialists intervene upon increasingly complex lesion sets, the role of IVUS continues to evolve. Heavily calcified lesions requiring plaque modification may benefit from further assessment with pre- and post-intravascular imaging. One prospective pilot study demonstrated that dissections induced by atherectomy were underappreciated with angiography compared to IVUS, and have

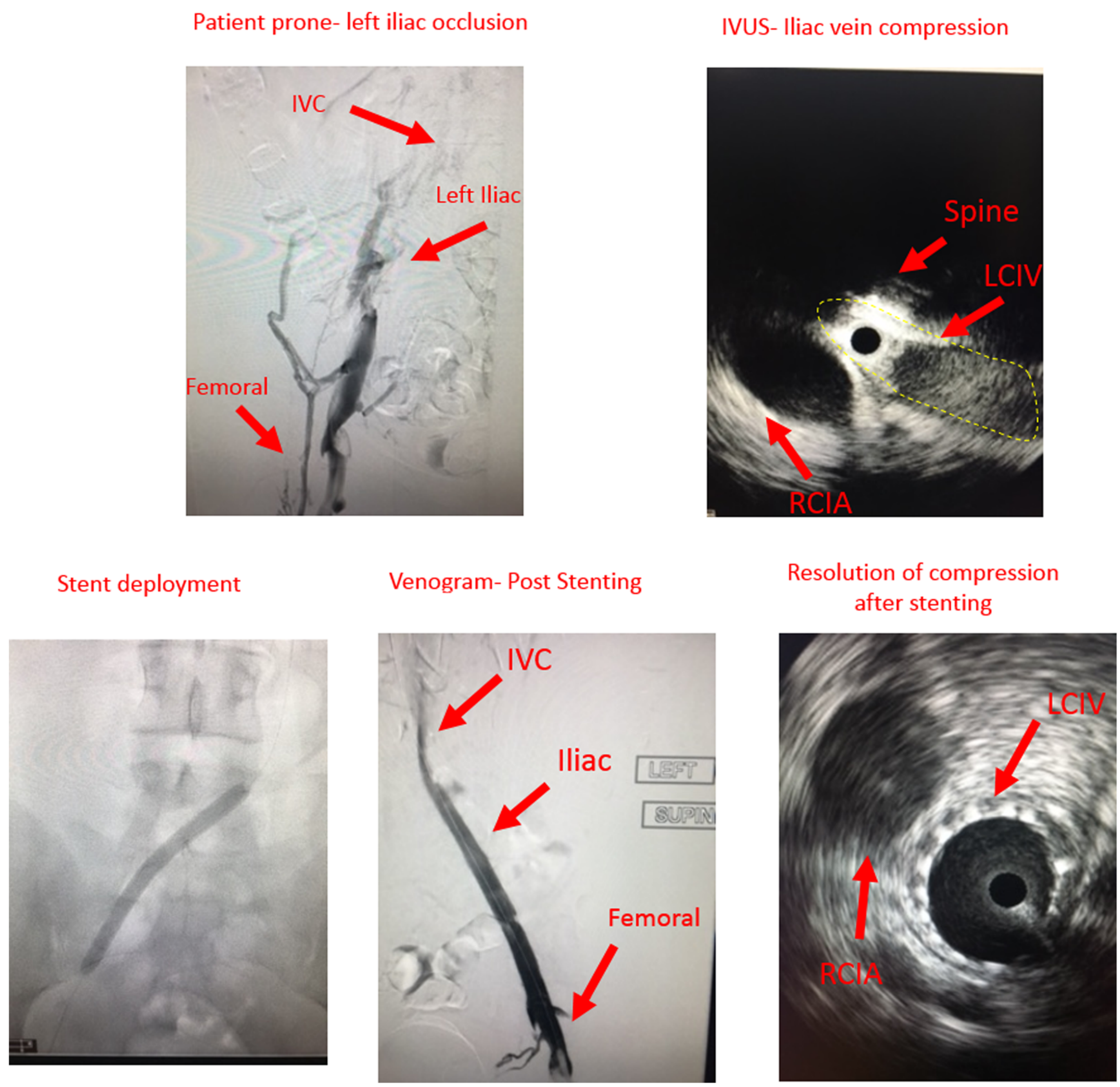

Fig. 3 A 18-year-old woman presenting with a left iliac vein thrombosis in setting of May-Thurner syndrome. Venography (top left) and IVUS (top right) of the left common iliac vein confirmed compression of the vein by the right common iliac artery. A Wallstent was deployed (bottom left) with a satisfactory venographic result (bottom center). Post-intervention IVUS revealing excellent apposition and expansion (bottom right) and no residual vessel compression

been implicated as a potential cause for increased rates of ISR following atherectomy [75]. There are several studies of IVUS used in the setting of atherectomy (rotational, orbital and laser) that demonstrate more accurate assessment of calcific disease burden with ultrasound [76, 77].

Intravascular imaging guidance also has been associated with greater plaque removal compared to fluoroscopy alone, allowing for optimal stent expansion [76]. As increased MSA has been shown to be a predictor of improved stent patency, IVUS-facilitated atherectomy may also lead to improved outcomes due to similar mechanisms [78]. There are currently new devices such as the Pantheris OCT-guided atherectomy device (Avinger, Redwood City, CA, USA) under development that incorporate both intravascular imaging and atherectomy, but real-world experience for this technology is presently very limited. Figure 5 shows an example of OCT-guided atherectomy of a severely calcified right common femoral artery in a patient with ischemic rest pain in the right leg.

Chronic Total Occlusion Intervention

Intervention on CTOs in the aortoiliac or femoropopliteal arteries represents a significant challenge for operators. Revascularization of peripheral CTOs has been plagued by lower technical success rates, longer procedural times, and poorer outcomes historically [79]. As wire navigation represents a significant challenge in these cases and understanding its relation to the vessel lumen is imperative for success, intravascular imaging can play a crucial role in guiding these interventions. For instance, when a CTO is unable to be

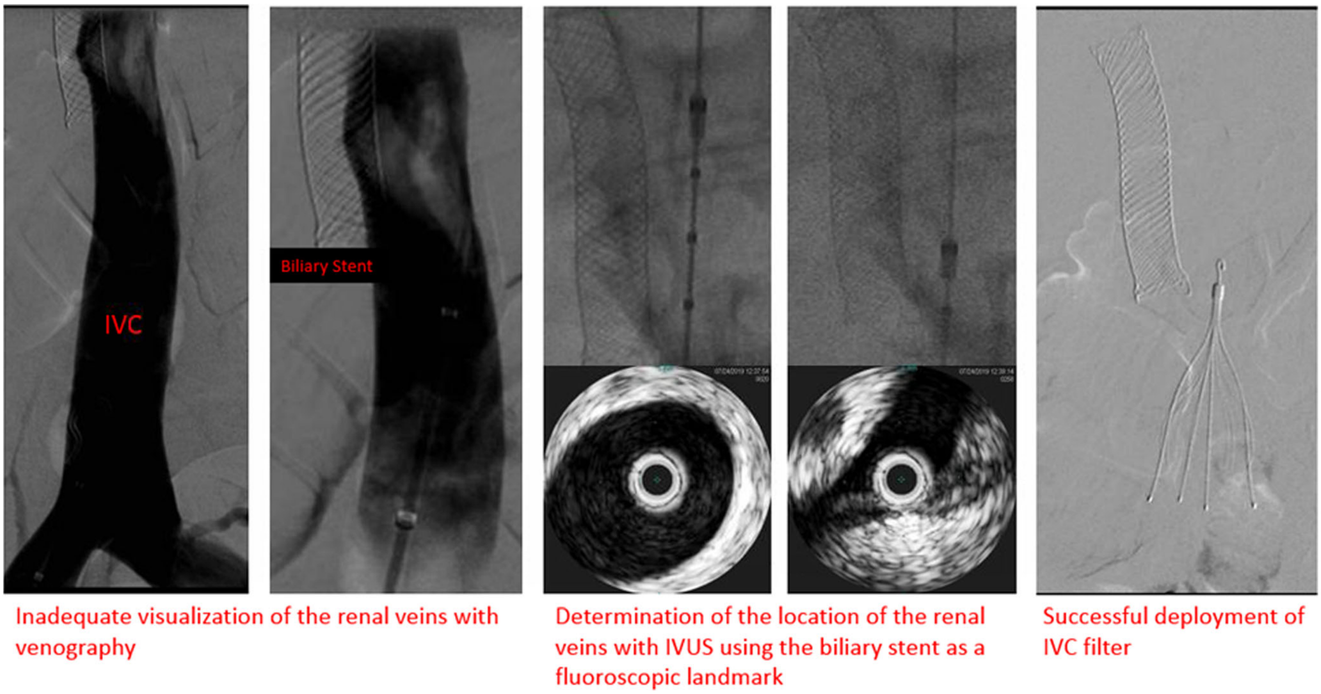

Fig. 4 Representative images of IVUS-guided deployment of a retrievable inferior vena cava filter

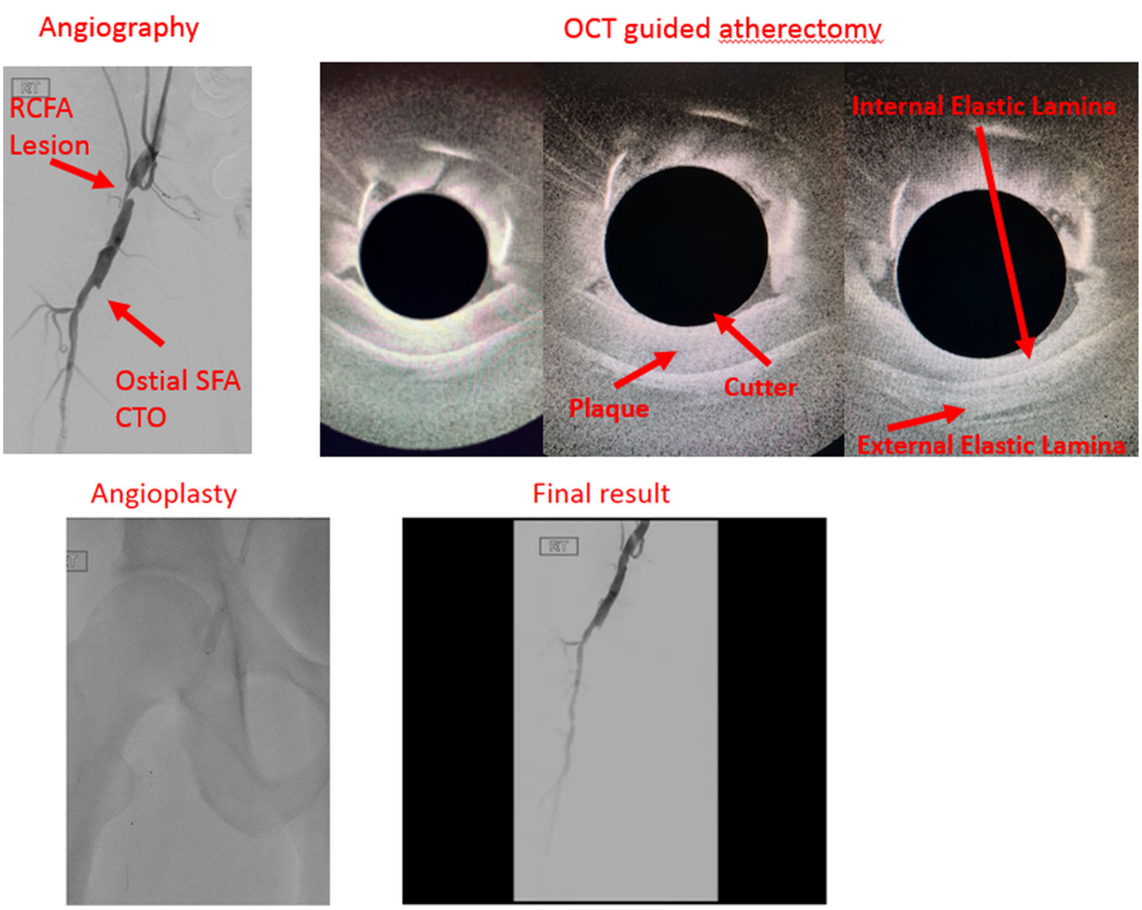

Fig. 5 A 60-year-old man with ischemic rest pain of the right lower extremity. Angiography demonstrated severe obstructive disease in his right common femoral artery and a complete occlusion of the ostial superficial femoral artery (top left). OCT-guided atherectomy was performed on the right common femoral artery lesion (top right) with sufficient plaque reduction to permit angioplasty (bottom left) yielding an excellent angiographic result (bottom right)

traversed using anterograde wire escalation alone, one alternative technique is subintimal tracking and reentry [80]. This refers to intentionally dissecting the subintimal space, advancing the wire beyond the lesion, and then reentering into the true lumen distally [81]. The vessel can subsequently be angioplastied and/or stented to restore flow to the true lumen distal to the obstruction while remaining within the architecture of the vessel [82].

The most challenging aspect of this sophisticated technique is reentry into the distal true lumen. Multiple reentry devices (REDs) have been developed specifically for this purpose, and some have incorporated intravascular imaging (either IVUS or OCT) into their design. These include the IVUS-guided Outback LTD (Cordis Corp., Bridgewater, NJ, USA) and Pioneer Plus (Volcano Corp., San Diego, CA, USA), as well as the OCT-guided Ocelot (Avinger, Redwood City, CA, USA) [83–85]. A small comparative study between fluoroscopy versus IVUS-guided REDs have failed to show a significant difference in outcomes between strategies, specifically with regard to post-procedure ABI's, technical success, and patency rates [85]. However, there is no indication at this time that OCT- or IVUS-guided REDs increase the risk of adverse outcomes during intervention, and they may possibly advance an operator's ability to tackle increasingly challenging lesion subsets with greater confidence and efficacy.

Conclusions

The field of peripheral vascular intervention continues to rapidly evolve with the maturation of endovascular techniques and equipment. Operators are increasingly attempting more complex revascularizations (e.g., chronic total occlusions) from a percutaneous approach. Intravascular imaging offers a promising approach for optimizing revascularization for a variety of vascular disease entities. The detailed imaging provided by IVUS and OCT modalities has provided operators a greater depth of understanding regarding disease anatomy and pathophysiology, thus enhancing their ability to appropriately tailor endovascular interventions. While the appropriate use and clinical efficacy of intravascular imaging within select peripheral vascular beds remains debated, the majority of the available literature supports the core concept that intravascular imaging used as an adjunct to angiography may enhance procedural success and clinical outcomes. While more data is needed to better understand when and how this technology should be applied, the current evidence base suggests a growing role for imaging guidance for peripheral interventions.

Compliance with Ethical Standards

Conflict of Interest All authors declare 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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•• Of major importance

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