Adjunctive Imaging Modalities in Endovascular Therapy for CLI

Utilizing ultrasound-guided access, IVUS, and OCT to deliver current state-of-the-science endovascular treatments for patients with critical limb ischemia.

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Peripheral arterial disease (PAD) is on the rise in the United States and the Western world. Endovascular therapy is increasingly becoming the default primary approach in the treatment of patients with complex PAD and critical limb ischemia (CLI). This article focuses on the use of adjunctive imaging modalities that are essential to deliver current state-of-the-science endovascular treatments for patients with CLI in an attempt to improve outcomes and reduce complications. We discuss the routine use of ultrasound-guided (USG) arterial cannulation to gain access to different arterial beds, as well as the potential applications of intravascular imaging technologies such as intravascular ultrasound (IVUS) and optical coherence tomography (OCT), which have primarily been studied in coronary artery disease interventions. The rationale for the latter discussion is the shared histologic features of coronary and tibial vessels (frequently seen in patients with complex PAD and CLI) and the latest improvements that have been incorporated in these imaging modalities.

APPLICATIONS OF USG ACCESS

Retrograde CFA Access

There are several pitfalls associated with fluoroscopy-guided retrograde access into the common femoral artery (CFA), as well as the use of traditional anatomical landmarks. Fluoroscopic identification of the lower third of the femoral head has been considered optimal for arterial access. Observational studies show that 65% of CFA bifurcations occur at or below the level of the inferior border of the femoral head. This obviously overlooks the fact that approximately 35% of patients have a high takeoff of the deep femoral artery.[1] There is no advantage of fluoroscopic guidance over the use of anatomic landmarks.[2-4] USG for retrograde CFA access has been shown to reduce the risk of vascular access complications by 59%. There is also significant improvement in the rate of first-pass success and a significant reduction in the time required for access among patients with high bifurcations (above the inferior border of the femoral head).[1] At our institution, we generally use the Site-Rite Vision ultrasound system (Bard Peripheral Vascular, Inc., Tempe, AZ) due to its smaller size and ease of maneuverability. The system employs a variable 5- to 10-MHz linear array transducer that can image up to 6 cm in depth.

Antegrade CFA Access

Antegrade CFA access is of paramount importance for the treatment of complex PAD and CLI. However, this technique has been linked to an increased rate of vascular

Figure 1. Long-axis ultrasound view of the common femoral artery, superficial femoral artery, and profunda.

complications,[5] especially among obese female patients with diabetes. This, in conjunction with its significant learning curve, has detracted from its widespread adoption. To overcome these difficulties, at our institution we routinely use USG with either the Site-Rite Vision ultrasound system or the Philips Linear 11-MHz probe with the Philips iU22 xMatrix ultrasound system (Philips Healthcare, Andover, MA). A thin layer of gel is applied directly to the transducer, and the probe is covered with a disposable sterile cover. Sterile gel is applied directly to the patient's skin surface, and the optimal entry site is identified under direct ultrasound visualization.

First, the bifurcation of the CFA into the deep femoral and the superficial femoral arteries (SFA) is identified (Figure 1). The transducer is then moved cranially to identify the CFA in a region where vessel patency has been established by USG, avoiding regions of calcified plaque in the arterial wall (Figure 2). It is most important to avoid entering the external iliac artery. The modified Seldinger technique is used in conjunction with direct real-time visualization of needle entry into the anterior vessel wall. Utilization of a radiopaque needle, such as the Terumo Pinnacle Precision Access system (Terumo Interventional Systems, Inc., Somerset, NJ), improves access times and decreases the learning curve associated with this technique. Once antegrade CFA access is achieved, the transducer is rotated 90° to show a long-access view. This allows for direct visualization of the wire within the arterial lumen and its manipulation into the SFA.

Retrograde Tibiopedal Access

Tibiopedal arterial access is becoming one of the cornerstones of advanced endovascular therapies for patients with CLI. Assessing the ideal spot for the retrograde tibiopedal arterial access site is done by USG, which allows accurate visualization and identification of the tibial arteries and accompanying veins. The operator can evaluate the vessels with color and pulse-wave Doppler in multiple planes. This is of paramount importance, as it decreases the likelihood of venous puncture, venous sheath placement, arteriovenous fistulas, and tibial artery spasm. Arterial spasm decreases the likelihood of success, especially when the vessel lumen is already compromised. At our institution, we use the Philips linear 15-7 MHz hockey stick probe and the Philips iU22 xMatrix. By allowing direct visualization of the lumen in the longitudinal plane, operators will be able to maneuver the

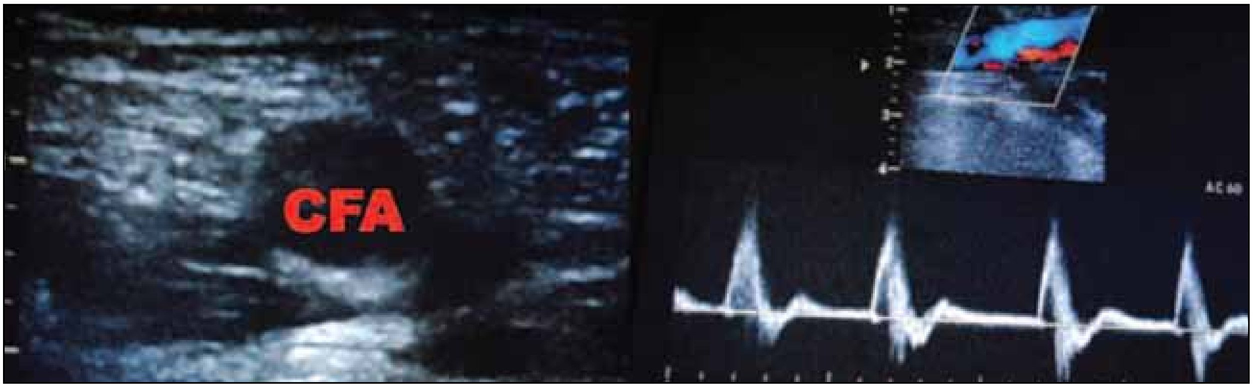

Figure 2. Short-axis view of the common femoral artery with arterial duplex waveform.

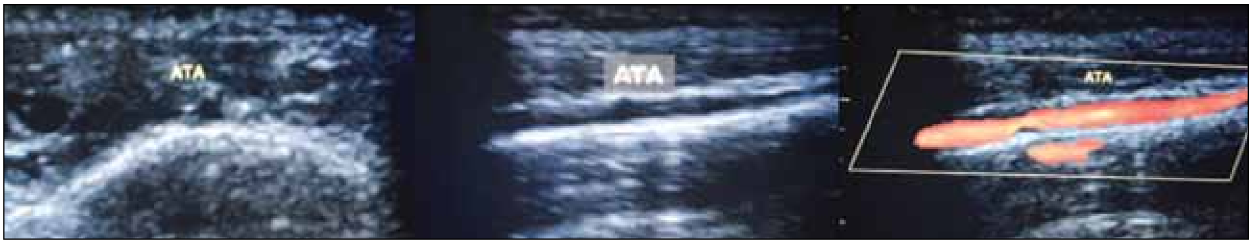

Figure 3. Ultrasound short- and long-axis view of the anterior tibial artery showing the true lumen with color-flow Doppler.

guidewire around the plaque and avoid puncturing the posterior wall (Figure 3).

As we move the probe cranially, it is easy to visualize where the tibial veins start to separate from the tibial arteries, allowing easier cannulation of the tibial vessels in a location where the veins are not located in the planned needle trajectory (Figure 4). However, when moving cranially, it is essential to keep in mind the four major anatomical compartments below the knee. These compartments lie within the gastrocnemius muscle and, most of the time, end at the insertion points of the distal gastrocnemius heads (Figure 5). It is imperative to avoid access beyond the gastrocnemius heads to decrease potential complications resulting in compartment syndrome, which in turn can lead to emergent surgical intervention (Figure 6) and, in rare occasions, even amputation. Arterial access below the gastrocnemius heads allows the operator to have complete control to address potential bleeding complications during and after tibial access procedures. For pedal access, it is also recommended to slowly tilt the transducer to obtain an image with better resolution (Figure 7), which could prove crucial in achieving access.[6]

IVUS FOR THE ASSESSMENT AND MANAGEMENT OF PAD AND CLI

Digital angiography is considered the gold standard for the invasive evaluation of PAD. However, angiography has multiple limitations. IVUS is a dynamic imaging modality that has been routinely employed for the evaluation of atherosclerotic disease within the coronary arteries. IVUS provides detailed information regarding plaque morphology, composition, and overall plaque burden.

There are two systems on the market that are currently available for use: the Volcano Virtual Histology system (Volcano Corporation, San Diego, CA) and the Galaxy system (Boston Scientific Corporation, Natick, MA). Both systems employ low-frequency catheters that can be used in arterial and venous trees. Typically, the best images are obtained when the catheter is perpendicular to the vessel wall. However, there are multiple artifacts the operator has to be aware of. One of the most common is nonuniform rotational distortion (Figure 8). This artifact is the direct result of the catheter's inability to rotate freely when it is deployed in a tortuous vessel.

IVUS is instrumental in the evaluation of the vessel wall's biology, allowing identification of plaque morphology, extent of disease, and plaque burden. Angiography only allows for evaluation of the lumen without being able to fully examine the vessel wall. Postmortem studies have shown that angiography consistently underestimates the burden of disease (Figure 9).[7,8]

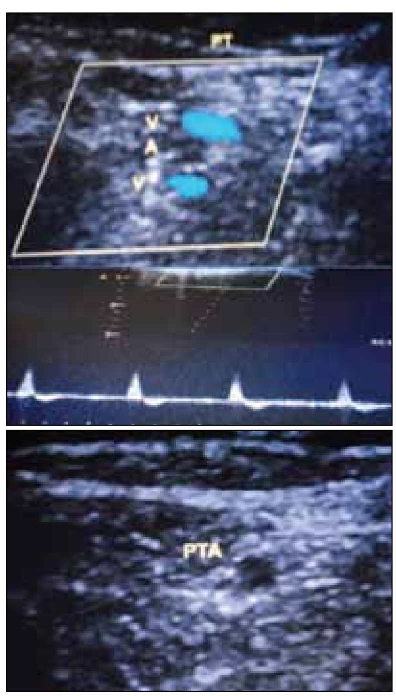

Figure 4. Ultrasound short-axis depicting the anatomical relation between the tibial arteries and associated veins.

Angiography-based endovascular therapy is becoming the predominantly used initial revascularization strategy for complex PAD and CLI patients. Given this fact, we are increasingly faced with the diagnostic and therapeutic limitations imposed by angiography. Data on coronary IVUS have consistently shown better technical success rates when stents are deployed under IVUS guidance than when they are not, leading to a higher rate of underdeployed stents and geographic miss when this adjunctive modality is not utilized. Both of these shortcomings have been recognized as significant causes of in-stent restenosis and/or stent thrombosis.[9] Using IVUS to optimize stent placement and stent strut apposition has been shown to have favorable acute results, as well as improved immediate and long-term patency rates.

In the peripheral vasculature, the versatility of this device lends itself as a

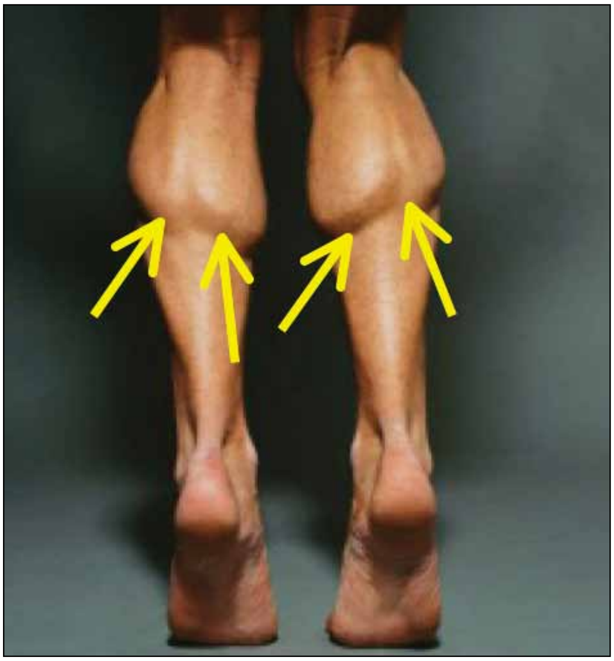

Figure 5. The distal insertion site of the gastrocnemius muscle in the lower extremities.

Figure 6. Surgical treatment of compartment syndrome.

treatment modality by aiding operators in reentering the true lumen when using subintimal techniques. The Pioneer catheter (Medtronic, Inc., Minneapolis, MN) is a reentry device that employs IVUS to help redirect the guidewire into the true lumen. In regard to CLI, we can only speculate that the use of IVUS could help us to better understand the pathological features of the SFA and the infrapopliteal vessels in this subset of patients. We could further delineate the role of different therapeutic modalities and their outcomes, as well as determine the impact of stent strut apposition on the patency rates for suprapopliteal stents (currently) and perhaps infrapopliteal stents (in the not-so-distant future). This remains to be seen.

OCT FOR THE ASSESSMENT AND MANAGEMENT OF PAD AND CLI

OCT is a novel technology for cross-sectional and three-dimensional imaging in biological systems with ultra-high resolution approaching that of histology. OCT is an optical technique that combines the principles of ultrasound with the imaging performance of a microscope. OCT images are generated by measuring of the amplitude of back-scattered light (optical echoes) returning from an infrared light source directed at the arterial wall as a function of delay. Ex vivo studies have shown resolution capabilities of 2 to 10 µm, which provide the necessary definition to identify the elements of a vulnerable plaque, such as the thin fibrous cap, lipid-rich core, and macrophage content. This new imaging modality is also capable of detecting fibrous cap disruption in lipid-rich plaques, the presence of intracoronary thrombus, the depth of dissections caused by balloon inflations (not fully appreciated by IVUS), cuts in the atherosclerotic plaque made by the blades of a cutting balloon, neointimal formation, and underdeployed struts otherwise missed by IVUS.[10-12] The composition of atherosclerotic plaque may be of interest for optimal treatment strategies in peripheral arteries with the introduction of cutting/scoring balloon angioplasty, intravascular cryoablation, and atherectomy.[11]

Although there have been numerous studies demonstrating OCT's diagnostic capacity in coronary arteries, there has

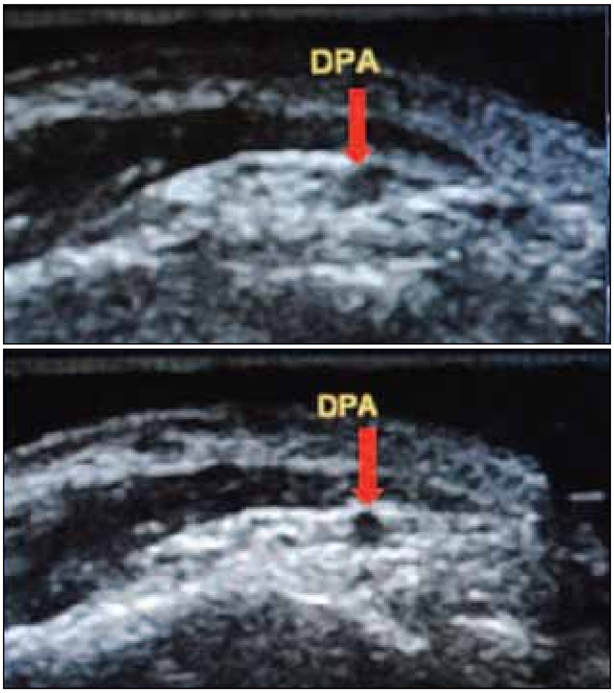

Figure 7. Off-plane ultrasound short-axis view of the dorsalis pedis (A). On-plane ultrasound short axis view of the dorsalis pedis (B).

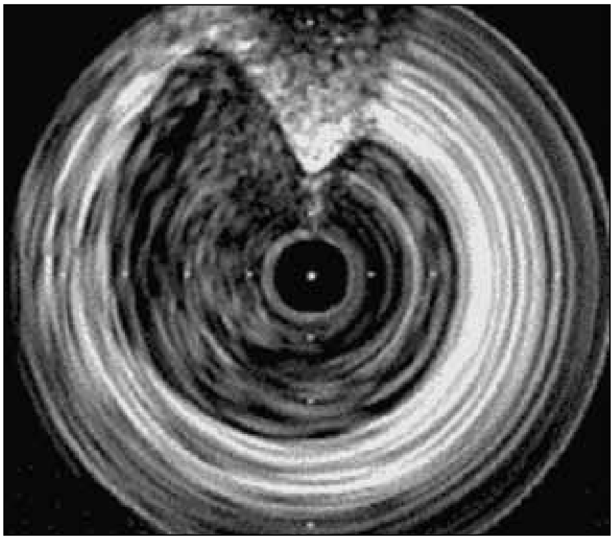

Figure 8. Example of nonuniform rotational distortion (NURD).

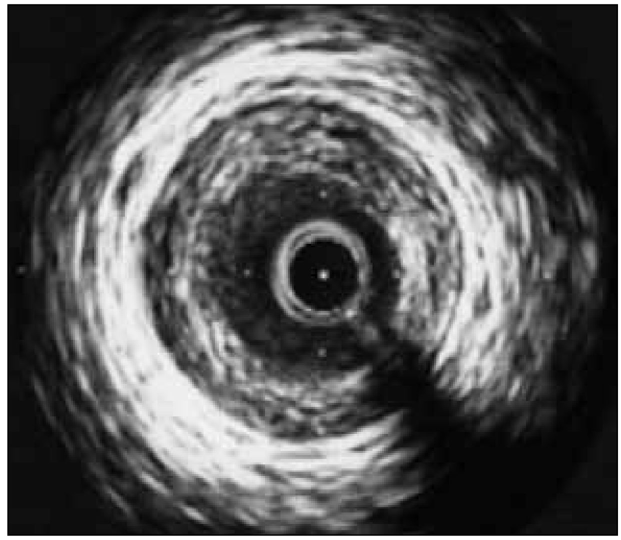

Figure 9. Example of intravascular ultrasound showing plaque burden.

been little published regarding the use of OCT in the evaluation of peripheral arteries, which are classified as either elastic (aorta and its great branches: carotid, iliacs, and pulmonary) or muscular (coronary, renal, popliteal, and tibial).[13] With this classification, it is of interest that the popliteal and tibial vessels share histologic features with the much more widely characterized and studied coronary arteries. Meissner et al showed that OCT was capable of identifying the different plaque components of ex vivo human tibial arteries with the same high sensitivity and specificity demonstrated in the coronary arteries.[14]

The NightHawk is a unique device incorporating OCT technology onto the SilverHawk (Covidien, Mansfield, MN) plaque excision platform, which enables real-time arterial wall imaging during plaque excision. A prospective, multicenter, nonrandomized study of 100 patients investigated the proximity of the catheter to the arterial wall and correlated excised tissue with OCT images collected. In this study, 89% of lesions were below the knee. The average diameter stenosis improved from 87% to 14%, and adjunctive angioplasty was used in one case. OCT predicted apposition prior to a cutting pass in 92% of patients.[15]

Although OCT has largely remained a research tool for many years, recent technological innovations have enabled US Food and Drug Administration approval for use in the coronary arteries in 2010 (St. Jude Medical, Inc., St. Paul, MN). So far, most of the available data are from coronary studies, and the drawback of low penetration in large vessels is well known, which has limited its application in PAD. With the recent move into the CLI arena, more interventional procedures are being performed in the tibial vessels, which share anatomic and histopathologic features with the coronary arteries, rendering the tibial vascular bed an attractive candidate for OCT studies that could help in identifying ideal strategies for revascularization in patients with advanced PAD and CLI.

CONNECT II, a prospective, multicenter, nonrandomized clinical trial, will evaluate the Ocelot catheter (Avinger, Inc., Redwood City, CA) in 100 patients with femoropopliteal chronic total occlusion lesions. This catheter incorporates OCT imaging technology into their chronic total occlusion atherectomy device. The company received conditional approval to conduct the study from the US Food and Drug Administration in January 2012. As it holds true for IVUS, we can only speculate what the future may bring in terms of the possible applications of OCT in limb salvage interventions.

SUMMARY

Access guided by palpation and landmarks has helped us achieve many milestones for peripheral vascular interventions, but ultrasound-guided access has transformed our thought process and approach to access from straightforward to complex peripheral interventions. This has led to a significant reduction in time to access and access site complication rates.

We find ultrasound to be significantly helpful as an imaging modality in vessels that are hard to differentiate via angiography. Ultrasound is able to show us the specification of vessel bifurcations, CTO caps, subintimal spaces, thrombus versus plaque, etc. In addition to transcutaneous ultrasound, IVUS adds significant benefit to our decision-making when treating borderline lesions defined by angiography which later are determined to be significant lesions by IVUS. OCT provides a different analytic modality of intravascular anatomical visualization. The use of OCT will help us understand and differentiate the composition of plaque morphology and superficial dissections of the treated target vessels, primarily below the knee. We see unparalleled value in utilizing imaging modalities during complex peripheral interventions from simple retrograde access via the CFA all the way to complex pedal access in limb salvage. ■

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