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Pedal Flow Hemodynamics in Patients With Chronic Limb-Threatening Ischemia

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Abstract

Ankle-brachial index (ABI) and duplex ultrasound (DUS) are accepted standardized tests performed on patients with suspected peripheral arterial disease. In the nondiabetic patient, ABIs can be a reliable test for disease above the level of the ankle. Toe brachial index (TBI) is also an accepted modality to test for small vessel disease. However, ABIs and TBIs fall short in providing a complete evaluation of arterial flow especially in pedal arteries in the setting of noncompressible arteries. Direct duplex ultrasonography can provide a comprehensive evaluation of arterial flow hemodynamics in the lower extremity. However, we wanted to understand the role of arterial collateral flow to the foot in the setting of tibial vessel occlusion. Using DUS, we sought to define the changes that occur in the arterial flow hemodynamics in the foot in relation to occlusions of specific tibial inflow vessels.

Keywords

pedal acceleration time, pedal flow, pedal hemodynamics, pedal arch, chronic limb-threatening ischemia

Introduction

Ankle-brachial index (ABI) and duplex ultrasound (DUS) are accepted standardized tests performed on patients with suspected peripheral arterial disease (PAD).[1] In the nondiabetic patient, ABIs can be a reliable test for disease above the level of the ankle. Toe brachial index (TBI) is also an accepted modality to test for small vessel disease. However, ABIs and TBIs fall short in providing a complete evaluation of arterial flow especially in pedal arteries in the setting of noncompressible arteries.[2] Direct duplex ultrasonography can provide a comprehensive evaluation of arterial flow hemodynamics in the lower extremity. It is current practice for vascular technologists to evaluate arterial flow in the lower extremities down to the level of the ankle. We then rely on physiologic testing to provide additional information about the foot. This information is limited and often not reliable. Our group previously studied the role of pedal acceleration time (PAT) in the evaluation of patients with PAD.[3] During this process, we repeatedly observed patients with normal or adequate PAT values in the setting of proximal tibial artery occlusions. However, the directionality of flow was sometimes reversed in an otherwise patent pedal artery with normal and abnormal PAT. We wanted to understand the role of arterial collateral flow to the foot in the setting of tibial vessel occlusion. Using DUS, we sought to define the changes that occur in the arterial flow hemodynamics in the foot in relation to occlusions of specific tibial inflow vessels.

Our group has previously identified 4 locations and recommends vascular technologist obtain a PAT in all locations. Techniques of performing an arterial DUS study on the foot and obtaining PAT have been previously described.[4] PAT is felt to be an invaluable data point to indicate the severity of more proximal disease, help in the decision-making process for intervention or surgical decisions, and possibly be a predictor in wound healing.

Anatomy

The tibial vessels are well understood among the vascular community and remain standard practice to image all 3 runoff vessels from the origin to the level ankle. Historically, vascular technologists stop imaging at the level of the ankle and do not provide a comprehensive evaluation of the pedal circulation. Nor do they evaluate the collateral pathways from the peroneal artery. Ultrasound technology has greatly improved to the point that we can optimize our duplex imaging and can now visualize the communicating arteries. We feel the collateral pathways in the distal segment can be appreciated by DUS with the advancements in imaging technology.

The peroneal artery has multiple important collateral pathways to the anterior tibial artery (ATA) and posterior tibial artery (PTA). The posterior communicating artery (PCA) and the lateral calcaneal branch (LCB) both communicate from the

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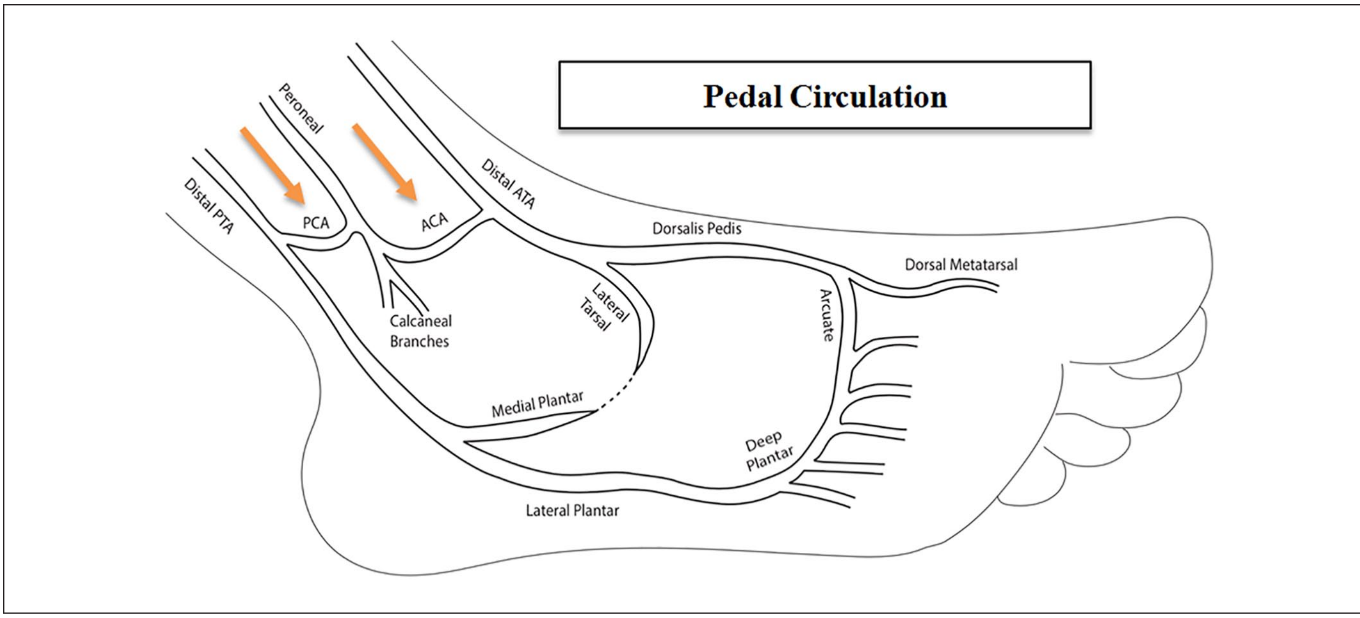

Figure 1. Anatomy of the anterior communicating artery (ACA) and posterior communicating artery (PCA).

peroneal artery to the PTA (Figure 1). The anterior communicating artery (ACA) communicates from the peroneal artery to the distal ATA. Depending on the need for flow distribution to the foot, these communicating arteries can have either antegrade or retrograde flow patterns. We observed a correlation with arterial duplex imaging and standard angiography.

The pedal arch anatomy can be described in two views, the dorsal and plantar view. From the dorsal view, the ATA crosses the ankle mortis and becomes the dorsalis pedis artery (DPA). At the proximal dorsal foot, the DPA gives rise to the medial and lateral tarsal artery that courses to the medial and lateral foot. At mid dorsal foot the DPA continues distal and bifurcates to the dorsal metatarsal artery (DMA) and the arcuate artery (AA) (Figure 2). The DMA continues to provide perfusion to the toes. From the plantar view, the distal PTA, below the level of the medial malleolus, bifurcates to the medial plantar artery and lateral plantar artery. The lateral plantar artery bifurcates to the deep plantar artery and plantar metatarsal artery located at the middle anterior foot (Figure 3). The plantar metatarsal arteries provide perfusion to the toes.

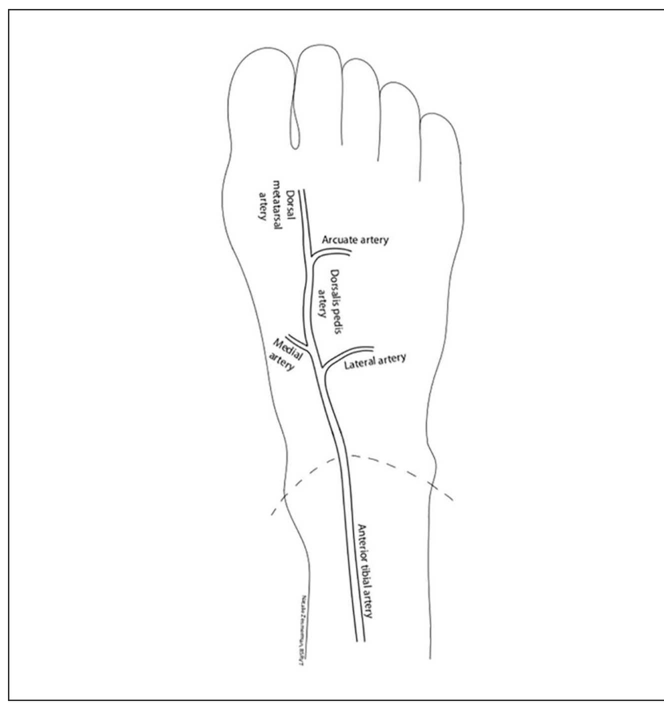

Figure 2. Ultrasound view of the anterior circulation of the pedal circulation.

Methods

A 12-month retrospective chart review of a prospectively maintained database was reviewed. All studies were performed at PeaceHealth Thoracic and Vascular Surgery in our Intersocietal Accredited Commission Vascular Laboratory by Registered Vascular Technologists. Thirty patients with confirmed PAD with prior complete arterial duplex imaging were evaluated. All patients in this cohort had multiple comorbid conditions and documented diabetes (Table 1). ABIs and TBIs were deemed unreliable due to medial wall calcification or unobtainable toe waveforms. Patients with prior revascularization procedures were included.

Duplex imaging of the infrainguinal and infrageniculate arteries as well as pedal arteries was performed with the patient in a supine position. A Philips Epic 5 DUS system (Philips Healthcare, Andover, MA) and linear array transducer with

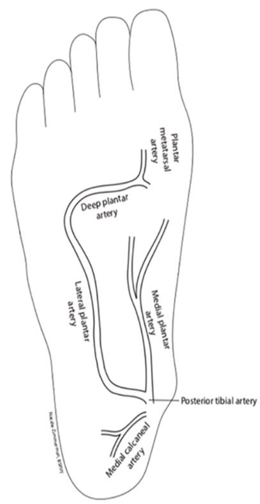

Figure 3. Ultrasound view of the posterior circulation of the pedal circulation.

Figure 4. Performed at the bedside of the patient in standard fashion.

Table 1. Incidence of Comorbid Conditions in 30 Patients.

Mean age	76.1 ± 9.4
Gender	65% male 35% female
Tobacco use	52%
Diabetes	100%
Coronary artery disease	28%
Hypertension	66%
Hyperlipidemia	70%
Renal disease	12%

pulsed-doppler frequencies between 3 and 12 MHz was used to measure PAT in the plantar circulation. A 12 to 15 MHz probe (hockey stick) is used for the anterior circulation. In long axis (indicator on the probe to the patient's head), the entire ATA, DPA, AA, and first DMA doppler waveform and flow direction were obtained. In long axis (indicator on the probe to the patient's heel), the entire PTA, peroneal, medial, lateral, and deep plantardoppler waveform and flow direction were obtained. The entire peroneal artery was also evaluated. This technique is performed at the side of the patient similar to a standard arterial duplex examination (Figure 4).

Results

Thirty patients with documented diabetes (Table 2) and a PAT greater than 225 milliseconds in the pedal arteries were reviewed. All 30 limbs had documented widely patent inflow and outflow with isolated disease in the popliteal artery and tibial arteries by DUS and angiography.

Based on the DUS results, we found that 14 patients had retrograde flow in the AA indirectly suggesting a more proximal obstruction in the ATA or DPA with no patent ACA (Figure 6A) This was correlated and confirmed with angiography

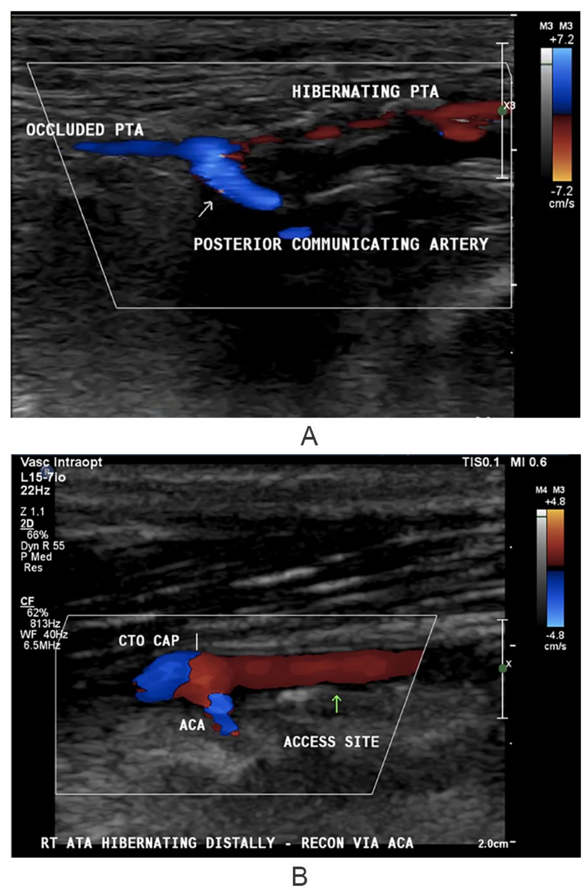

Figure 5. (A) Ultrasound view demonstrating a patent posterior communicating artery from the peroneal artery to the posterior tibial artery; (B) ultrasound view demonstrating a patent anterior communicating artery from the peroneal artery to the anterior tibial artery.
Note. ACA = anterior communicating artery.

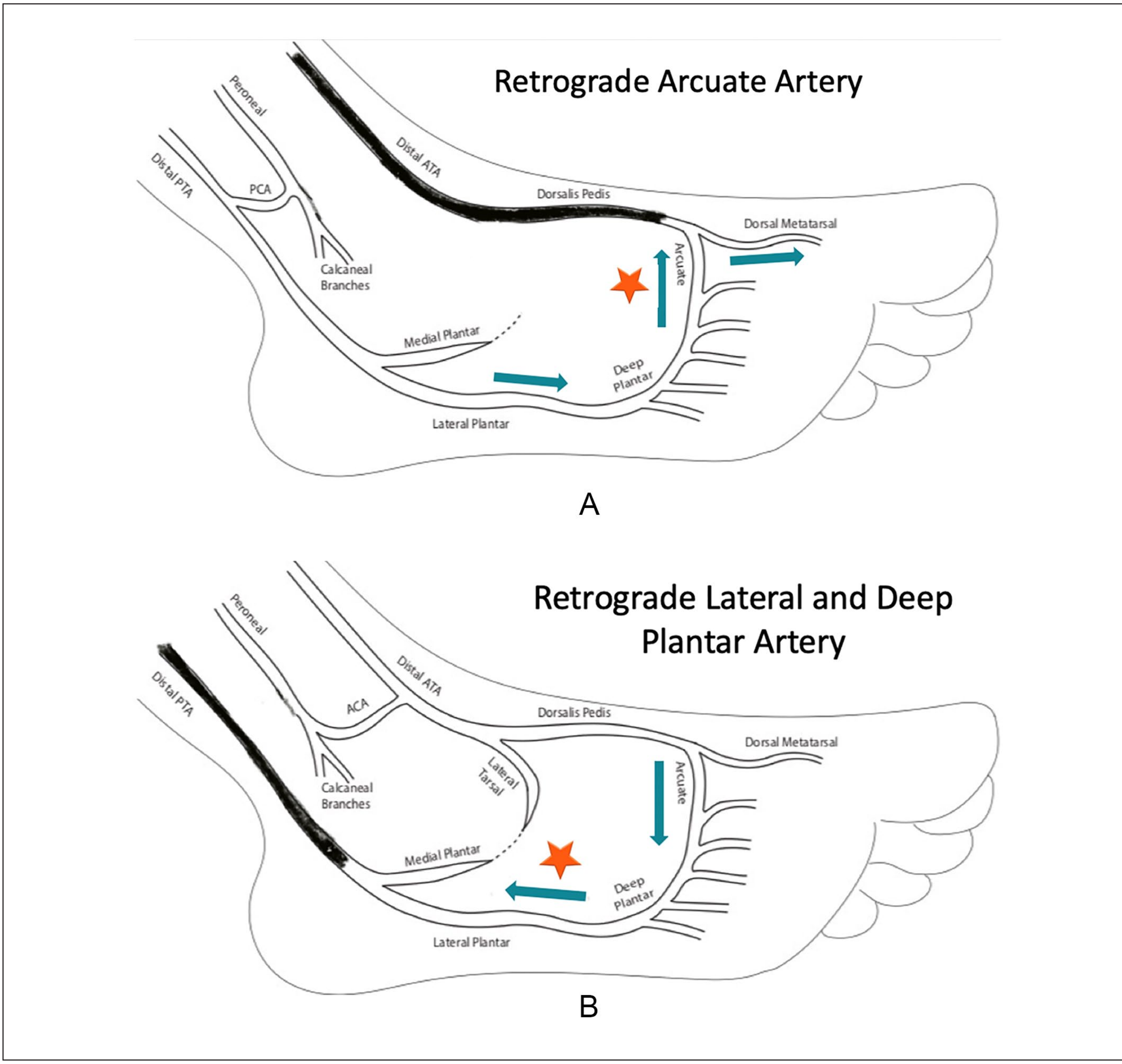

Figure 6. (A) Occlusion of the ATA and dorsalis pedis artery with indirect flow to the anterior circulation via the posterior circulation (note the retrograde flow in the arcuate artery); (B) occlusion of the PTA with indirect flow to the posterior circulation via the anterior circulation (note the retrograde flow in the deep and lateral plantar arteries).
Note. PTA = posterior tibial artery; PCA = anterior communicating artery; ATA = anterior tibial artery; ACA = anterior communicating artery.

documenting an occlusion of the ATA and DPA. Similarly, we found that 12 patients had retrograde flow in the lateral and deep plantar arteries indirectly suggesting a more proximal obstruction in the PTA with no patent PCA (Figure 6B). This was correlated and confirmed with angiography documenting an occlusion of the PTA with no PCA appreciated on angiography. Four patients had single vessel runoff via the peroneal artery with patent ACA and PCA filling the patent hibernating ATA and PTA. Antegrade flow in the AA and plantar arteries was documented by DUS.

Discussion

Collateral flow (ACA, PCA, and LCB) in the distal lower leg and foot stay dormant until the predominant and inline arterial supply pathways become diseased or may be patent in the

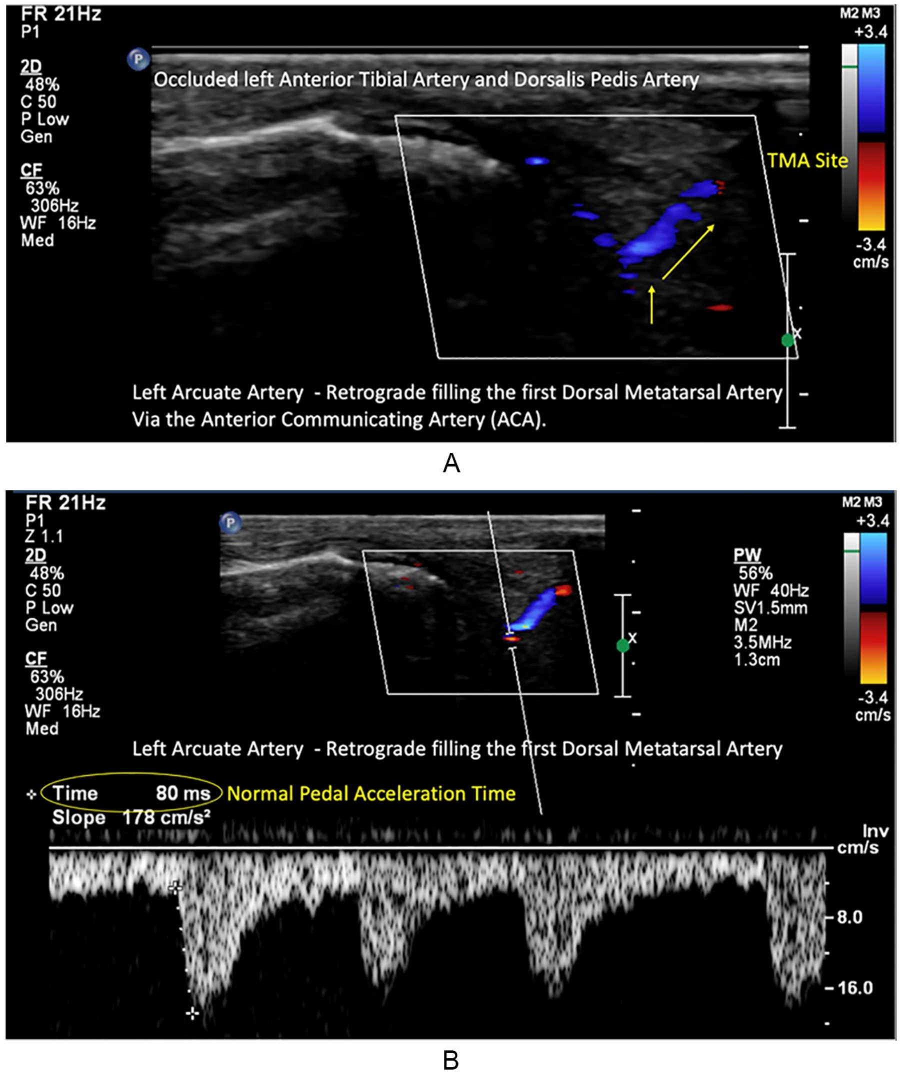

Figure 7. (A) Color doppler indicating retrograde flow in the arcuate artery; (B) spectral doppler indicating retrograde flow in the arcuate artery via the deep plantar artery (plantar circulation).

instance of anatomical variations of atretic pedal arteries. In the setting of chronic limb-threatening ischemia (CLTI), these collateral pathways play a vital role in foot perfusion and may ultimately aid in wound healing and limb salvage. In situations of rest pain, tissue loss, and/or flap failure, it is paramount for the vascular technologists to image distal to the occlusion of the tibial vessels to evaluate flow patterns within the pedal arterial bed. Evaluating collateral pathways may also provide information about flow distribution to aid the specialists in decision-making. For example, if the peroneal artery is patent and the PTA is occluded in the proximal and mid segment, the distal PTA may reconstitute via the PCA (Figure 5A), thus providing indirect flow to the pedal circulation. In addition, if the distal ATA or PTA is patent, this may be a possible access site for retrograde tibial access in the setting of CLTI (Figure 5B).

The importance and application of this information is essential the setting of wound healing and has lead our group to study wound healing when there is indirect perfusion to the wound. Many believe direct inline angiosomic flow is needed for wound healing.[5] Our group has experienced that indirect profusion may be predictive for wound healing similar to the findings of reported by Ricco et al.[6]

Conclusion

This article is the first to document patency in the PCA, ACA, and LCB by direct duplex imaging and provide an understanding of the collateral pathways to the foot. Based on our review of the 30 feet studied with varying infrageniculate disease, confirmed by angiography, we can conclude that when

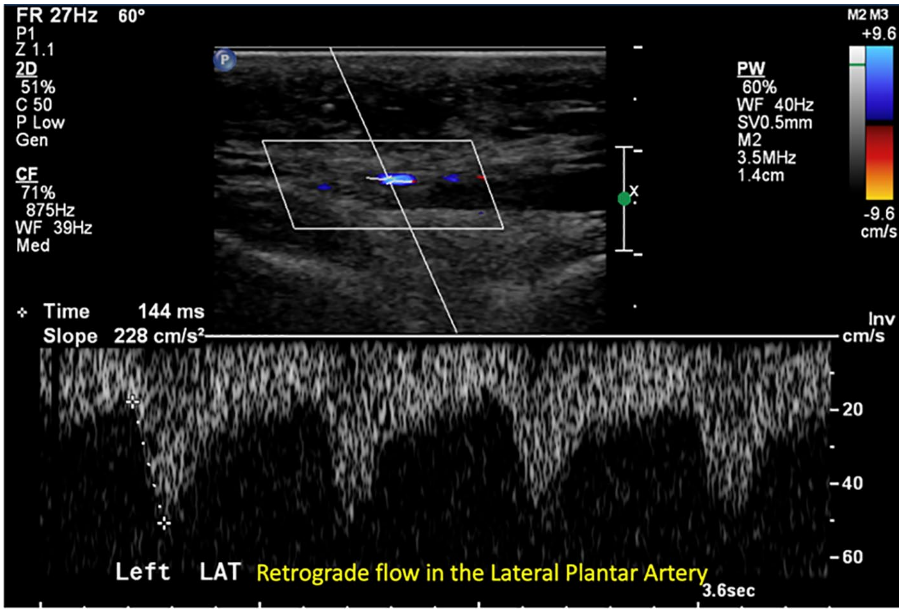

Figure 8. Spectral doppler indicating retrograde flow in the lateral plantar artery via the arcuate artery (anterior circulation).

Table 2. Thirty Limbs Retrospectively Reviewed.

14	Retrograde arcuate artery—Occluded ATA and atretic DPA with no ACA.
12	Retrograde lateral and deep plantar—Occluded PTA with no PCA
4	Antegrade arcuate artery, medial, lateral, and deep—Occluded PTA, ATA with patent peroneal artery. Patent ACA and PCA
Total: 30 limbs	

Note. ATA = anterior tibial artery; DPA = dorsalis pedis artery; ACA = anterior communicating artery; PTA = posterior tibial artery; PCA = posterior communicating artery.

retrograde flow is identified in the AA, one should be suspicious of more proximal obstruction in the anterior circulation (Figure 7A and B). Similarly, when retrograde flow is identified in the lateral and/or deep plantar artery, one should be suspicious of more proximal obstruction in the posterior circulation (Figure 8). We understand that retrograde flow in the pedal circulation may not be a negative finding but more of an understanding of flow distribution in the foot. Understanding PAT and flow direction may be vital in surgical decisions and is encouraging to have an additional data point to rely on when our current methods fail. Documenting collateral pathways between the peroneal artery, PTA, and ATA is helpful to understand the flow distribution to the angiosome that may be of concern. The information outlined in this article could be promising as it demonstrates that robust flow within these pathways may provide enough profusion for symptom resolution in patients with CLTI.

In conclusion, duplex imaging has improved our understanding of the arteries in the foot tremendously. We have observed certain changes in the arterial flow dynamics of the foot in patients with tibial occlusions. Perhaps adequate PAT can be achieved even in the setting of tibial occlusive disease as long as appropriate collateral flow is maintained to the foot. Our goal for the future is to be able to apply this knowledge involving arterial flow hemodynamics in CLTI patients in order to determine the adequacy of arterial flow to the area of the wound. In essence, we hope to define specific DUS-based angiosomic areas on any given patient's foot.

Declaration of Conflicting Interests

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Supplemental Material

Supplemental material for this article is available online.

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