

Pedal Loop Reconstruction: Valuable in Limb Salvage

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Abstract: Critical limb-threatening ischemia is a prevalent and comorbid condition associated with increased mortality, risk of amputation, and impaired quality of life. Revascularization is the cornerstone of management; however, it has been demonstrated that even in patients with patent femoral-distal bypass, amputation rates can be up to 15%. Pedal arch interruption was seen in almost all these patients. Pedal artery revascularization has been associated with improved wound healing and limb salvage. Further studies and registries are warranted to confirm long-term benefits and efficacy.

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Critical limb-threatening ischemia (CLTI) is associated with mortality, amputation, and impaired quality of life.¹ It affects approximately 8 million people in the United States, may impact up to 12% to 20% of the adult population, and is on the rise, mainly due to the increased prevalence of diabetes mellitus (DM) in the United States.² Within 1 year of diagnosis, 25% or more will progress to a major amputation, and 25% will die due to comorbid conditions. CLTI is a clinical syndrome defined by peripheral arterial disease combined with rest pain, gangrene, or lower limb ulceration over 2 weeks.¹ Revascularization is the foundation of therapy for this condition, to re-establish blood flow and oxygenation to improve the likelihood of healing with an endovascular approach, which is often preferred due to lower morbidity and mortality. However, which territories to revascularize and to what extent continue to be debated. Studies have demonstrated up to 15% major amputation risk in CLTI patients with patent femoral-to-distal popliteal bypass, in which plantar arch artery interruption was a significant finding in almost all amputees.³⁻⁶ In an attempt to further improve outcomes, it became evident that further revascularization below the ankle level would often be indicated, especially in patients with DM.

Literature Review

Plantar arch revascularization was initially described in 2006 as a direct approach for pedal arch reconstruction, which extends the limb arterial revascularization distally and provides direct perfusion to areas of ischemia.⁷ Prior studies described the benefits of lower extremity revascularization based on angiosomes,⁸⁻¹⁰ revealing a positive impact on CLTI. However, successful direct angiosome revascularization (DAR) can only be achieved in 50% to 55% of patients. Furthermore, recent studies have found a more impactful correlation between the quality of pedal artery revascularization (PAR) in wound healing rather than DAR.¹¹ Manzi et al evaluated 1331 consecutive patients with CLTI who were treated using below-the-knee (BTK) percutaneous transluminal angioplasty, and 135 (10.1%) underwent PAR. The study

demonstrated that PAR was feasible; it had a technical success of 85%, was safe, and appeared to provide positive clinical results at both acute and midterm follow-up.¹²

Kawarada classified the pedal arch into 4 types and demonstrated that arch status was an independent predictor of wound healing.¹³ The authors concluded that PAR was crucial to allow for complete wound healing.

Troisi et al evaluated the impact of pedal arch status and DAR on clinical outcomes in diabetic patients with foot wounds undergoing endovascular revascularization.¹⁴ Ninety-three diabetic patients with foot wounds underwent endovascular revascularization of at least 1 BTK vessel. Patients were divided into 3 groups according to pedal arch status: complete pedal arch (CPa), incomplete pedal arch (IPa), and absent pedal arch (aPa). Healing within 3 months and 1-year outcomes in terms of freedom from minor amputation, limb salvage, and survival were evaluated based on DAR and pedal arch status. They concluded that DAR is not a predictor of good outcomes in diabetic patients undergoing the endovascular procedure. Pedal arch patency seems to be a pivotal factor in obtaining good outcomes regarding wound healing and limb salvage.

The RENDEZVOUS registry sought to investigate the clinical implications of pedal arch angioplasty (PAA) for CLTI patients presenting with infrapopliteal and pedal artery disease. Two hundred and fifty-seven consecutive patients with de novo infrapopliteal and pedal artery disease were retrospectively reviewed from a multicenter registry. Patients were divided into 2 groups according to whether or not PAA was performed. The rate of wound healing was significantly higher, and the PAA group's wound healing time was significantly shorter. The authors concluded that this aggressive strategy might become a salvage procedure for patients with CLTI presenting with pedal artery disease.¹⁵⁻¹⁶

Ismail et al assessed 60 consecutive diabetic CLTI patients divided into 3 groups based on pedal arch status. Fifteen (25%) patients had CPa, 26 (43.3%) had IPa, and 19 (31.7%) had aPa. Limb salvage rates were significantly higher in patients with CPa (100%) compared with IPa or aPa (88.5% and 68.4%, respectively;

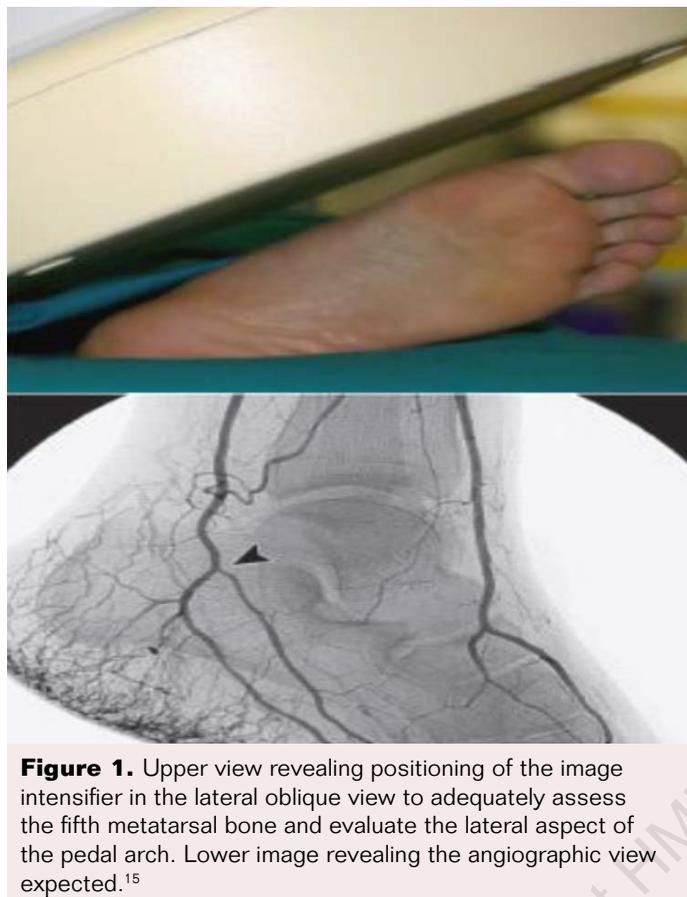


Figure 1. Upper view revealing positioning of the image intensifier in the lateral oblique view to adequately assess the fifth metatarsal bone and evaluate the lateral aspect of the pedal arch. Lower image revealing the angiographic view expected.¹⁵

$P=.01$). Healing time was also faster in the CPa group (3.4 vs 4 vs 6.1 months; $P=.02$).¹⁷

Similarly, Jung et al performed a retrospective analysis of patients undergoing endovascular interventions in CLTI patients, divided the patients with PAR and without PAR, and performed a propensity score matching. They also found that successful PAR significantly improved wound healing in patients with CLTI.¹⁸

Incorporating PAR in Clinical Practice

A patent plantar arch provides blood flow to the forefoot and calcaneal region.¹⁹ As such, PAR has a clear benefit in CLTI regarding wound-healing benefit, as well as a possible direct impact in decreasing the requirement of major amputation.¹⁸ The benefit of PAR continues to demonstrate improved wound healing.

PAR is recommended for patients with advanced disease (Rutherford classification 5–6) and those with nonhealing wounds on distal lower extremities that reveal evidence of incomplete foot arch patency. It is also an alternative approach for retrograde vascular access into tibial vessel recanalization in arteries with chronic total occlusion. This knowledge may further aid operators in certain challenging cases, as we will describe. Approaching PAR requires knowledge of anatomy and preparation. Below, we discuss certain aspects of our methodology.

Understanding the anatomy is crucial in performing successful PAR and avoiding complications.

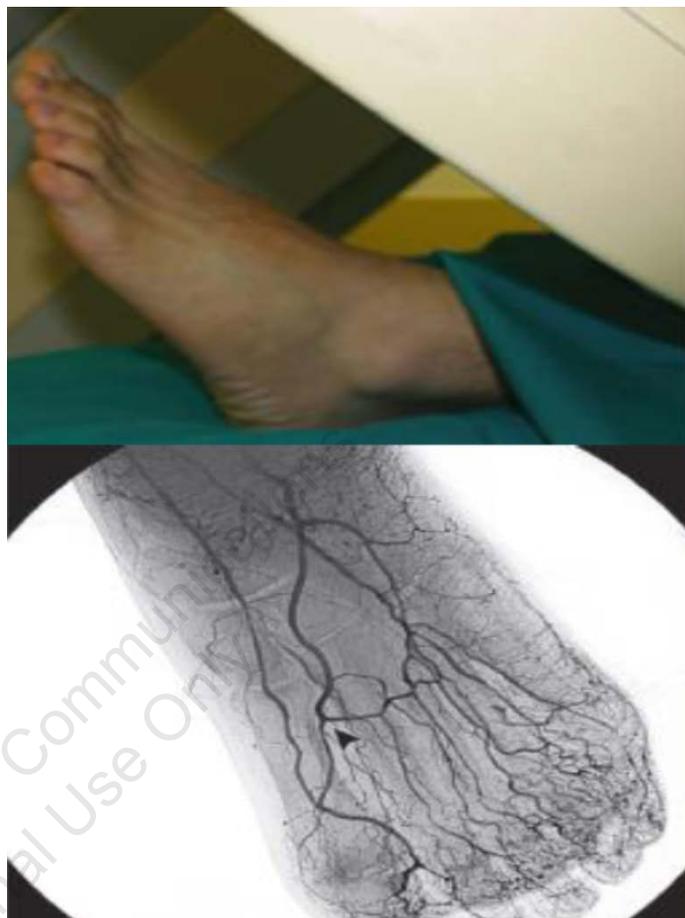


Figure 2. Upper view revealing the anterior-posterior positioning of the image intensifier required to visualize the anterior pedal arch vessels directly and evaluate the distal branches into the foot and toes. Lower image revealing the angiographic view expected.¹⁵

Anterior Circulation

The anterior tibial artery, which is usually the first branch of the popliteal artery, passes between the tibialis anterior and extensor hallucis longus muscles. At the ankle level, the anterior tibial artery crosses under the extensor retinaculum just lateral to the tendon of the extensor hallucis longus muscle. As it reaches the dorsum of the foot, it becomes the dorsalis pedis artery. It extends into the first metatarsal space, branching into the arcuate artery to supply the toes. Then, it turns sharply to join the perforator branches of the posterior plantar circulation and the pedal arch.

Posterior Circulation

The posterior tibial artery begins as 1 of the 2 branches of the tibioperoneal trunk. As it traverses posterior to the malleolus, it becomes the common plantar artery. This artery then divides into the medial and lateral arteries. The lateral plantar artery joins the anterior circulation by communicating with the dorsalis pedis at the first plantar space. The medial plantar artery crosses directly along the medial aspect of the plantar surface of the forefoot.



Figure 3. Wire bends are essential to travel vessels and cross lesions. Sharp bends are needed at calcific and chronic total occlusion stenosis, as well as short bends near the wire tip to preserve crossing force.

It ends at the first metatarsal space, which becomes the hallux digital arteries.²⁰

Plantar Arch Angiography

Upon angiographic evaluation, we can assess the pedal arch disease burden and further classify it based on the patency of the anterior or posterior circulation.¹³ Two views should be performed in all cases using digital subtraction angiography with prolonged imaging to allow late collateral filling. In the lateral oblique view, the fifth metatarsal bone must be separated to properly visualize the common plantar artery and its bifurcation, the dorsalis pedis, and its connection to the pedal arch via the deep perforating artery (**Figure 1**).²¹ The anterior-posterior view is also required to visualize the anterior pedal arch vessels directly and evaluate the distal branches into the foot and toes.²¹ This is essential for visualization of the transmetatarsal artery access required for access in complex cases of CLTI (**Figure 2**).²²

After angiograms are obtained, the pedal arch can be classified into several types. Type 1 has both dorsalis pedis and plantar arteries patent. Type 2A has only a dorsalis pedis artery patent. In type 2B, only the plantar artery is patent. In Type 3, both dorsalis pedis and plantar arteries are occluded.¹³

Before any intervention, thorough evaluation and outlining are required for successful pedal revascularization. The first step is acquiring and reviewing the angiograms and ensuring the correct anatomic landmarks are visualized.

The vascular access will depend on the complexity of the disease as well as the approach. Usually, an antegrade approach is attempted through the common femoral artery, and a 5 to 6 Fr sheath can be inserted. A 6 Fr sheath allows flexibility in using 2 wires with support catheters simultaneously for complex occlusive disease. After vascular access, angiography is performed to evaluate anatomy and disease. Navigation and wiring through calcified occlusions could become challenging. An initial 0.018" support catheter can be attempted, with advancement with a 0.014" wire. The 0.018" support catheter allows more flexibility for wire exchanges and is better for selective angiography. The support catheter can be exchanged for a 0.014" system when traversing the plantar arch. Depending on stenosis severity,



Figure 4. Distal transmetatarsal access obtained as retrograde access. Angiographic views may be used to achieve access.

calcifications and tortuosity may require different wires to approach and cross stenosis. Our initial wire is often the Regalia (Asahi Intecc), which offers excellent torqueability, steerability, and tip resilience. A double bend is helpful to traverse the plantar arch. A wire escalation strategy can then be attempted if initial attempts are unsuccessful (**Figure 3**).

If antegrade wire escalation fails, a retrograde true lumen crossing approach could be attempted. Again, operator familiarity with wiring and wire escalation is essential. If the stenosis is not crossed, a possible controlled antegrade and retrograde tracking approach would be another option. A retrograde approach through the distal transmetatarsal access could be pursued with challenging cases (**Figure 4**).



Figure 5. Severe peripheral artery stenosis of the anterior tibial artery with areas of occlusion, with flush occlusion of the posterior tibial artery.

Percutaneous balloon angioplasty is the primary therapy delivered to the vessel. Prolonged inflations (120 to 180 seconds) are associated with fewer dissections and improved outcomes.¹⁹ In some cases where a low-profile balloon cannot advance, atherectomy can be carefully utilized. Atherectomy can also be considered in select cases to achieve adequate vessel expansion.

In **Figure 5** and **Figure 6** we illustrate a case where PAR was performed and the arch was utilized for a retrograde crossing of a flush occlusion of the posterior tibial artery. The patient in our case was referred for CLTI with nonhealing wounds in the toes and heel. The anterior tibial artery was recanalized during the initial procedure using laser atherectomy and angioplasty. Then using an antegrade approach, the anterior tibial artery was wired into the dorsalis pedis, across the arch, and retrograde up the posterior tibial artery into the tibioperoneal trunk and externalized in the popliteal artery. This allowed for recanalization of the anterior and posterior tibial artery with a complete plantar arch on the final angiogram, leading to wound healing.

Summary

Pedal arch loop reconstruction has been demonstrated to impact a patient's wound healing directly and has also been associated with decreased risk of limb amputation. Further studies are warranted to confirm the long-term benefits of pedal revascularization. PAR can be performed safely in patients with CLTI, allowing for improved wound healing and improving the patient's quality of life. Understanding the anatomy, evaluating specific angiographic views, and developing various access techniques can reduce complications and increase intervention success. ■

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Figure 6. Final angiographic views revealing patent anterior and posterior tibial arteries, and successful retrograde intervention with complete reconstitution of the pedal arch.

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