Techniques for Successful BTK Revascularization

An overview of BTK vessel anatomy, related angiosomes, and techniques for optimal outcomes.

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The worldwide prevalence of peripheral artery disease (PAD) affects 12% of the adult population and up to 20% of individuals aged 70 years or older. Its incidence continues to increase, mainly due to the uncontrolled epidemic of obesity and diabetes mellitus caused by calorie-rich diets and sedentary lifestyles, combined with poorly controlled hypertension and failed attempts at controlling tobacco use.[1-3] Critical limb ischemia (CLI) represents the end stage of PAD.

In patients with diabetes, the risk of PAD is three- to fourfold higher and tends to be more aggressive than in patients without diabetes, with a major amputation rate that is 5 to 10 times higher. Typical infrapopliteal (IP) diabetic disease is characterized by a long, multilevel, and multivessel process that involves all three IP arteries.[4,5] The presence of isolated IP disease is mainly seen in the elderly (> age 80 years) and dialysis-dependent patients.[6] These patients have a higher risk for amputation and shorter amputation-free survival compared to those with combined femoropopliteal and IP disease.[7]

This article provides a review of the below-the-knee (BTK) anatomy, angiosome concept, and target selection for revascularization, as well as a technical review of crossing strategy and device selection.

BTK VESSEL ANATOMY

Leg Vessel Distribution

The vascularization of the foot is supplied by three tibial vessels: the anterior tibial artery (ATA), posterior tibial artery (PTA), and peroneal artery (PA). The distribution of the three leg vessels at the ankle level presents a high variability. Similar to the anatomic classification of the coronary distribution, the ankle distribution patterns can be classified as *balanced circulation, anterior dominant PA, posterior dominant PA,* and *single PA.*

Balanced Circulation. In balanced circulation, ATA and PTA are codominant arteries, their course in the leg is straight, and at the ankle level, they directly originate from the dorsalis pedis and plantar arteries, respectively. The PA is a small, terminal artery (Figure 1).

Anterior Dominant PA. In the anterior dominant PA pattern, the ATA is absent or hypoplastic. Typically, it is a thin vessel with a tortuous course into the leg, ending at the mid or distal leg. The PA is large in size, and at the ankle, it moves anteriorly and keeps the position of the ATA, directly generating from the dorsalis pedis artery (DPA) (Figure 2).

Posterior Dominant PA. In the posterior dominant PA pattern, the PTA is absent or hypoplastic. Like the ATA, the PTA is also typically a thin vessel with a tortuous course into the leg, ending at the mid or distal leg. At the ankle, the larger PA moves posteriorly and keeps the position of the PTA, directly generating from the plantar arteries (Figure 3).

Single Dominant PA. In the single dominant PA pattern, both tibial arteries are hypoplastic and the PA is the only leg vessel supplying the foot. In our experience, the DPA is a thin vessel, whereas the plantar arteries are dominant (Figure 4). This is a less common pattern.

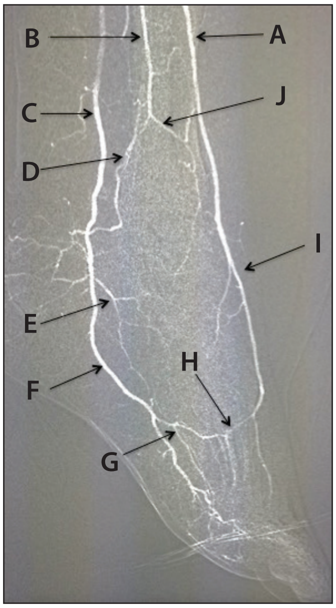


Figure 1. Vessel distribution and balanced circulation at the ankle level: ATA (A); distal PA (B); PTA (C); posterior communicating branch of the PA (D); MPA (E); LPA (F); plantar arch (G); deep perforating artery (H); DPA (I); and anterior perforating branch of the sPA (J).

Foot Vessel Distribution

Two principal circulatory pathways, the dorsal and the plantar

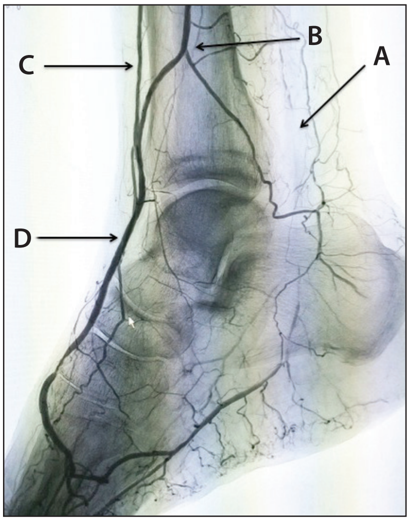


Figure 2. Anterior dominance of the PA: occluded PTA (A); dominant PA (B); hypoplastic ATA (C); DPA (D).

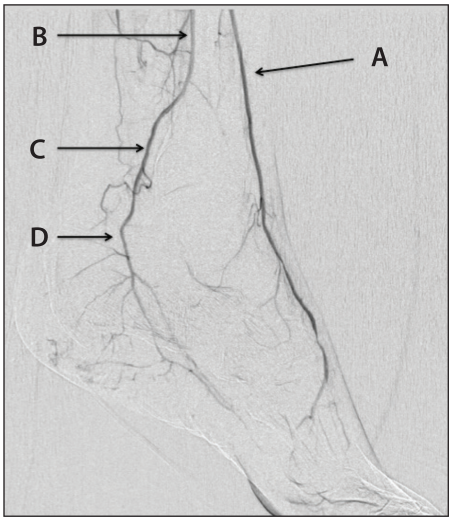


Figure 3. Posterior dominance of the PA: ATA (A); patent PA (B); retromalleolar part of the PTA (C); common plantar artery (D).

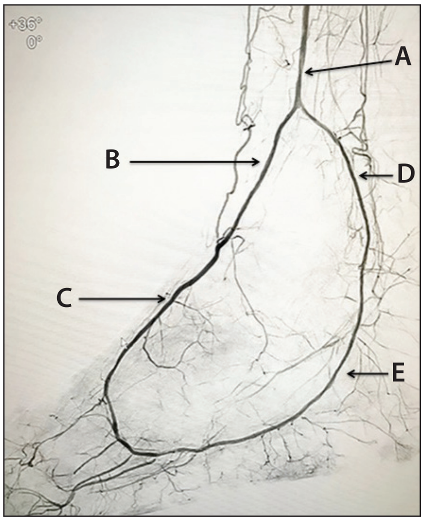


Figure 4. Single dominant PA: PA (A); anterior perforating branch of the PA (B); DPA (C); posterior branch of the PA (D); plantar arteries (E).

circulations, comprise the vascular anatomy of the foot. Both circulatory pathways, together with the PA branches, supply different regions of the foot.[8,9]

Dorsal Distribution. The main vessel of the dorsal circulation is the DPA. The DPA branches off to the medial tarsal, lateral tarsal, and arcuate arteries. At the level of the first metatarsal space, just distal to the origin of the first metatarsal artery (which mainly supplies the first toe), the DPA curves in the plantar direction. This arterial segment, called the *deep perforating artery,* communicates with the plantar arch and plantar circulation. The dorsal circulation supplies the dorsal part of the foot and the first and second toes.

Plantar Distribution. The distal PTA, also known as the *common plantar artery,* bifurcates into the medial and lateral plantar arteries. The medial plantar artery (MPA) becomes the first plantar metatarsal artery. The lateral plantar artery (LPA) is continuous with the plantar arch where it communicates with the anterior circulation via the deep perforating artery. The plantar circulation supplies the plantar part of the foot and the third, fourth, and fifth toes.

Foot Vessel Network

The anatomic anastomosis between the dorsal and plantar circulations influences the distal runoff and the revascularization strategies. The main pedal-plantar connection is called the *pedal-plantar loop,* which consists of the anastomosis of the DPA in the first metatarsal space to the plantar arch and LPA via the deep perforating artery. The deep pedal arch, the proximal pathway between the superficial branch of the MPA and the medial tarsal artery, is often narrow; however, it could become predominant in cases of pedal-plantar loop occlusion or forefoot amputation.

Anatomic Variability of Foot Vessel Distribution

The most frequent anatomic variants of the foot arteries have been described in the literature.[10] Similar to the ankle distribution, we propose a classification of the foot distribution patterns as balanced circulation, dominant DPA, and dominant LPA. Other abnormalities include the tarsal loop and the absence of a pedal-plantar loop.

Balanced Circulation. In balanced circulation, the DPA and LPA are codominant arteries. They present at a similar diameter and communicate with each other through the plantar arch (Figure 5).

Dominant DPA. DPA dominance consists of the absence of plantar arteries or the presence of hypoplastic plantar arteries (Figure 6). In this pattern, the first metatarsal artery is supplied by the DPA.

Dominant LPA. In this variation, the DPA is absent or hypoplastic and the connection between the dorsal and plantar circulation is not present or could be supplied by thin tarsal branches. Absence of the DPA has been reported in 6% to 12% of patients (Figure 7).[10]

Tarsal Loop. This pattern is correlated to the absence or hypoplasia of the DPA. In this group, the tarsal artery becomes dominant and develops an anastomosis to the plantar circulation (Figure 8).

Absence of the Pedal-Plantar Loop. In this variation, the dorsal and plantar circulations are completely separate; this presentation is very rare.

Angiosomes of the Foot and Ankle

An angiosome can be defined as vascular territories of skin and underlying muscles, tendons, nerves, and bones based on segmental or distributing arteries.[11-13] The foot and ankle angiosomes are correlated to the principal BTK arteries, which are described within the following groups.

Dorsal angiosome. The entire dorsal part of the foot is functionally connected in a single angiosome that is supplied by the dorsal circulation. The principal vessel in this angiosome is the DPA, which prolongs the ATA and branches off to the medial and lateral malleolar arteries, medial and lateral tarsal arteries, and arcuate artery. The DPA and its branches also supply the dorsum of the foot and toes, as well as the upper anterior perimalleolar vascularization (Figure 9).

Plantar angiosomes. The posterior and plantar circulation is supplied by the PTA, which feeds three different angiosomes. The medial calcaneal artery is the first vessel of the posterior circulation that originates from PTA; this branch supplies the medial malleolar region and the medial plantar heel (Figure 10). The angiosome supplied by the medial plantar artery includes the medial plantar instep. The medial plantar artery has a superficial branch, which perfuses the dorsum of the foot and is often connected to the anterior circulation through the medial tarsal arteries. Furthermore, its deep branch might be connected to the first plantar metatarsal artery, which supplies the first toe (Figure 11). The LPA communicates with the dorsal circulation through the plantar arch and deep perforating artery. The plantar metatarsal arteries originate from the plantar arch and feed the digital artery in the forefoot, which, in combination with the lateral plantar surface, constitutes the lateral plantar angiosome (Figures 12 and 13).

Peroneal angiosomes. At the level of the malleolus, the PA bifurcates into anterior perforating and lateral calcaneal branches, each of which supplies a specific angiosome. The anterior branch of the PA supplies the anterolateral ankle angiosome, and the calcaneal branch of the PA supplies the lateral heel angiosome (Figure 14).

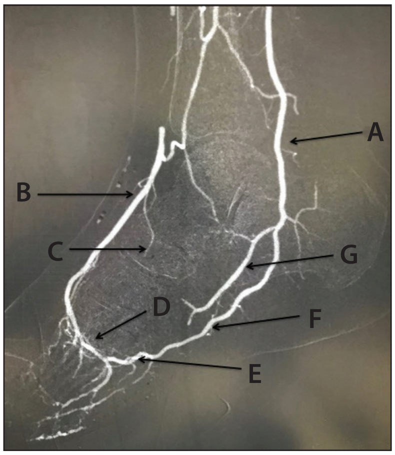


Figure 5. Balanced circulation: common plantar artery (A); DPA (B); lateral tarsal artery (C); deep perforating artery (D); plantar arch (E); LPA (F); MPA (G).

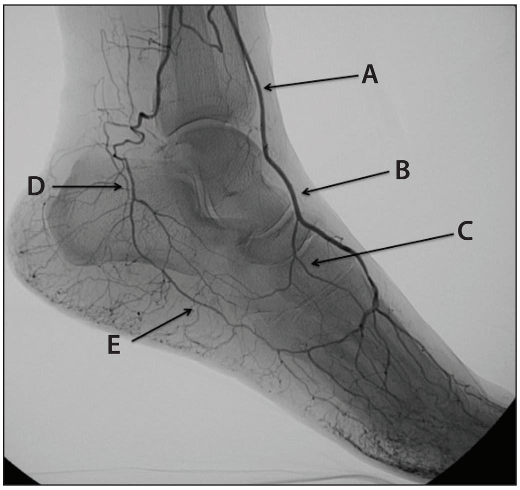


Figure 6. Dominant DPA: ATA (A); dominant DPA (B); lateral tarsal branch (C); common plantar artery (D); hypoplastic LPA (E).

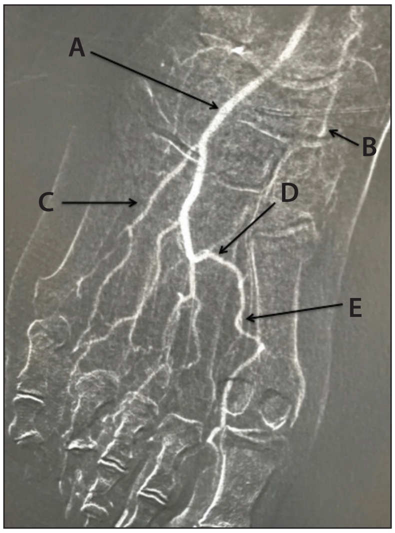


Figure 7. Dominant LPA: LPA (A); MPA (B); fifth metatarsal artery (C); plantar arch (D); first metatarsal artery (E).

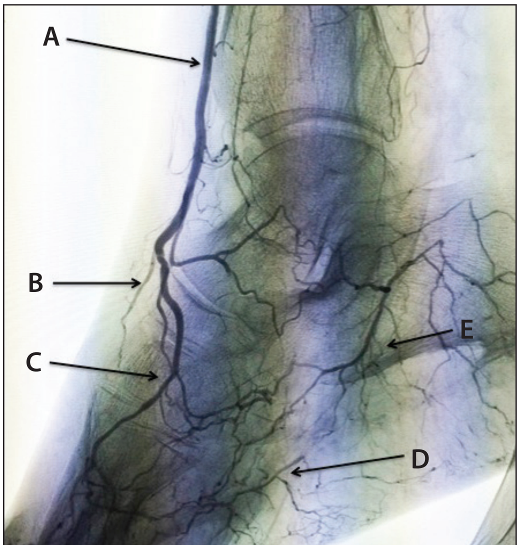


Figure 8. Tarsal loop: ATA (A); hypoplastic DPA (B); tarsal plantar loop (C); distal LPA (D); MPA (E).

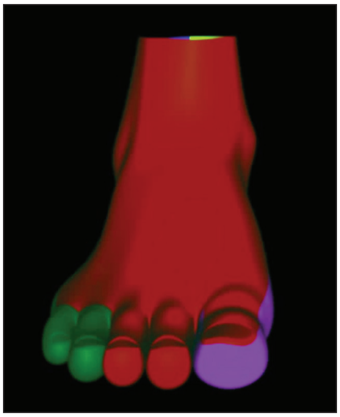


Figure 9. Anterior pedal angiosome. The dorsum of the foot is supplied by the anterior circulation (red).

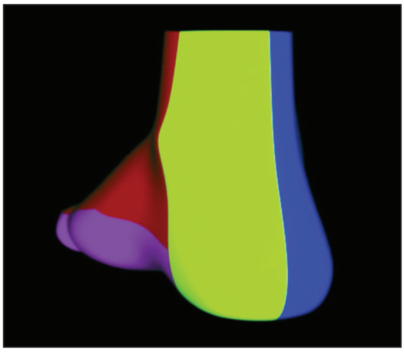


Figure 10. The medial calcaneal angiosome (yellow) through the medial calcaneal artery of the posterior circulation that originates from the PTA. This branch supplies the medial malleolar region and the medial plantar heel.

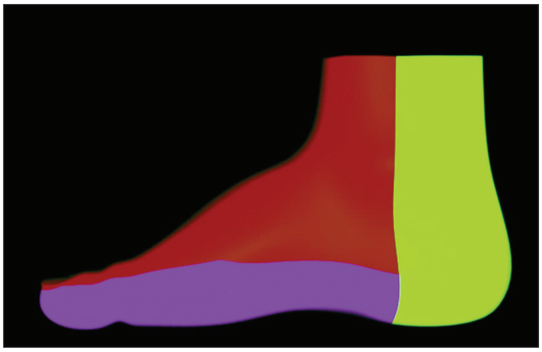


Figure 11. Medial plantar angiosome (violet) from the MPA. Its deep branch might be connected to the first plantar metatarsal artery, which supplies the first toe.

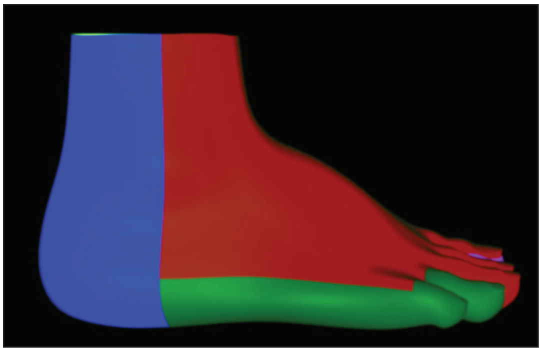


Figure 12. The LPA angiosome (green), which feeds the lateral part of the foot and the fourth and fifth toes.

Figure 13. Overview of all the plantar angiosomes: lateral plantar angiosome (green); medial plantar angiosome (violet); medial calcaneal angiosome (yellow) from the PTA; lateral calcaneal angiosome (blue) from the PA.

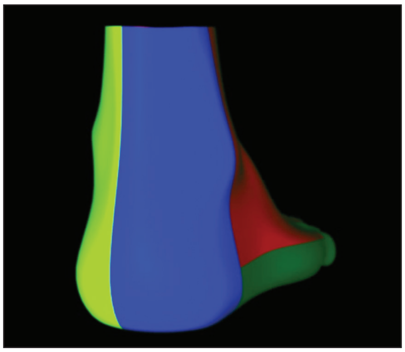


Figure 14. The lateral calcaneal angiosome (blue) from the PA, which feeds the external part of the heel and the external malleolar region.

TARGETS IN CLI REVASCULARIZATION

Revascularization is a mainstay therapy in patients with CLI because reestablishing an adequate blood supply to the wound is essential for healing and avoiding major amputation.[14,15] The targets of revascularization can be summarized by two concepts: "complete" and "wound-related artery" revascularization.

Complete Revascularization

Peregrin et al analyzed the clinical success of percutaneous revascularization in patients with diabetic CLI based on the number of patent leg vessels.[16] They demonstrated that "complete" revascularization is better than "partial" revascularization, as the limb salvage rate at 1 year increased from 56% without direct blood flow to the foot (0 leg vessels open), to 73%, 80%, and 83% with one, two, or three leg vessels open, respectively. Faglia et al also verified that angioplasty of tibial arteries had a better outcome than angioplasty of the PA.[17] Healing is a blood flow–dependent phenomenon, and the first principle guiding our revascularization strategy must be providing the foot with the best possible blood supply. This statement is particularly true in patients with extensive tissue damage and infection, where the lesion is not confined into a single angiosome space but spreads over contiguous foot spaces and angiosomes.

Wound-Related Artery Revascularization

In the last several years, the concept of angiosome-oriented revascularization has gained a wide consent because it was clearly demonstrated that successful revascularization of the artery directly feeding the wound region leads to a higher rate of limb salvage and wound healing.[13,18-24] Direct revascularization has a different value that depends on the capacity of the outflow distribution network. Varela et al demonstrated that the restoration of blood flow to the wound through distal collateral vessels (pedal and peroneal branches) could provide similar results to those obtained through its specific source artery in terms of healing and limb salvage.[25] On the other hand, patients with diffuse disease of the small distal vessels (patients with diabetes and end-stage renal disease) could require direct blood flow to the wound-related artery for healing.[26]

The wound-related artery concept has particular importance in case of surgical wounds: forefoot amputations (rays, transmetatarsal, Lisfranc, Chopart amputations) often interrupt the perforating metatarsal branches connecting the dorsum and the plantar vessels, separating the two systems. In these cases, revascularization should supply the surgical flap, supporting the surgical wound healing. Foot vessel evaluation and treatment represent the key points in the revascularization strategy in CLI patients (Figure 15).

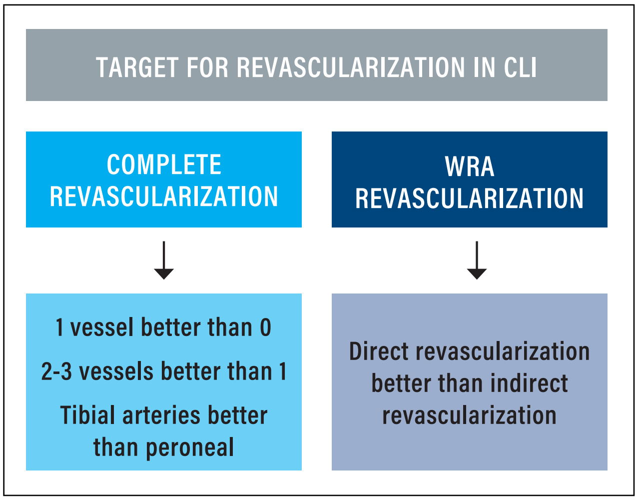


Figure 15. Flowchart of the target for CLI revascularization. WRA, wound-related artery.

TREATMENT STRATEGY IN BTK VESSELS

The first step in percutaneous recanalization is to successfully cross the vascular lesions. Recanalization can be performed using antegrade and retrograde techniques (Figure 16). To date, there are few studies regarding angioplasty and stenting of the BTK arteries.[27-38] Nonetheless, these studies have proven the principle, safety, and feasibility of using standard subintimal or intraluminal recanalization techniques in the pedal and plantar arteries for limb salvage in cases of CLI.[37] Plain old balloon angioplasty must be considered the standard technique BTK; in foot vessels, stenting is contraindicated due to the high burden of mechanical trauma that can collapse and break the stent structure.[37] The pedal-plantar loop technique and retrograde puncture of the distal forefoot vessels can increase the success rate of percutaneous revascularization of the foot vessels.

Antegrade Recanalization

The endoluminal approach should be the first choice in every type of lesion, because it is often possible to cross even long BTK lesions by maintaining the endoluminal position. It is also the preferred approach in calcified vessels. Our choice of wire is usually a shapeable-tip, 0.014-inch, hydrophilic guidewire (Savion FLX™ Guidewire, Boston Scientific Corporation) and support catheter or balloon catheter (Coyote™ ES Balloon Catheter, Boston Scientific Corporation). When traditional endoluminal revascularization fails, we then change our strategy according to the vessel lesion. In the case of calcified vessels or short-length obstructions, we prefer to pursue the endoluminal approach using the "parallel wire" technique and advanced crossing wires (Victory™ Guidewire, Boston Scientific Corporation).

In case of a long chronic total occlusion (CTO) or a noncalcified or spot-calcified vessel, we shift to a subintimal approach. The subintimal approach can be safely and effectively used to achieve a successful revascularization. It is usually performed using a 0.035- or 0.018-inch V-18™ ControlWire™ Guidewire (Boston Scientific Corporation) in the tibial vessels and a 0.018-inch V-18™ ControlWire™ Guidewire or 0.014-inch Savion FLX™ Guidewire in the foot arteries, as well as a support catheter (Rubicon™ Support Catheter, Boston Scientific Corporation) or balloon catheter (Sterling™ Balloon Catheter [Boston Scientific Corporation], Coyote™ ES). It is usually performed by pushing the

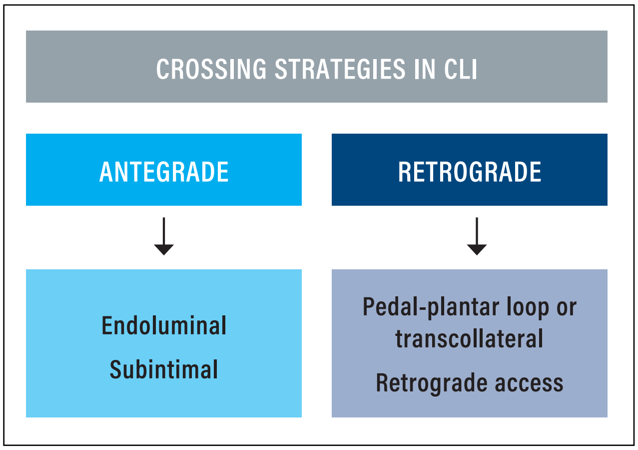


Figure 16. Flowchart of the technical strategies for crossing in CLI.

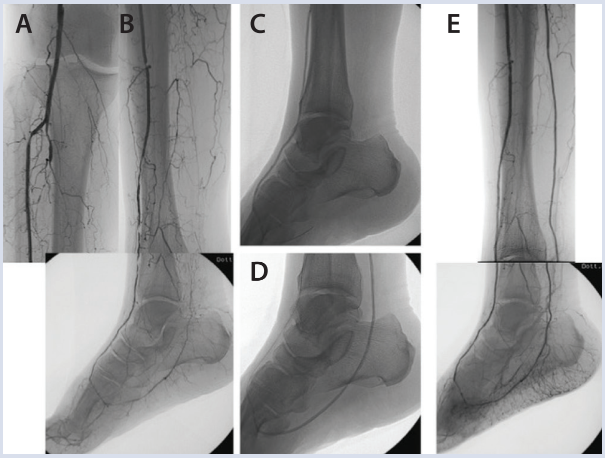
CASE REPORT

A 73-year-old man presented with CLI of his right leg and ulceration on the fourth/fifth toes and metatarsophalangeal joint. He also had a history of diabetes, hypertension, and dyslipidemia. Antegrade access was achieved in the common femoral artery, and diagnostic angiography showed BTK/BTA arterial disease, with multiple stenoses in the anterior tibial artery and occlusion of the peroneal and posterior tibial arteries. Further arterial disease was found in the lateral plantar artery as well (A, B).

We decided on an endoluminal and subintimal crossing approach with the Savion FLX™ Guidewire, which was supported with a 2- X 40-mm Coyote™ ES Balloon Catheter. This allowed us to reach and reenter the lateral plantar artery and safely navigate the plantar arch. Finally, balloon angioplasty was performed using a 2.5- X 220-mm Coyote™ ES Balloon Catheter. Endoluminal angioplasty was also performed in the anterior tibial and dorsalis pedis arteries with the same Savion FLX™ Guidewire and 2.5- X 220-mm Coyote™ ES Balloon Catheter (C, D).

The final control angiogram showed direct blood flow through the anterior and posterior tibial arteries, with direct blood flow for the dorsal and plantar circulation (E).

Due to its structure, the Savion FLX™ Guidewire allows us to combine endoluminal and subinitmal crossing, making the loop-shape tip without damaging the tip of the wire, and after reentry, straightening the wire again to allow continuous navigation of the patent distal vessel.



guidewire to create a loop shape and following the loop with a support catheter to dissect the subintimal space until the reentry point. At the reentry point, the main imperative is to avoid damaging the healthy distal vessels. We manage this by pushing the looped wire toward the patent distal vessel in a location where the patent distal lumen is straight and free from calcium. In the case of a calcified vessel, poor landing zone, or patent distal vessel that is suitable for a bypass, we preferred to approach it using an advanced crossing wire (Victory™ Guidewire) or retrograde approach.

Pedal-Plantar Loop Technique

This technical strategy aims to restore direct arterial inflow from both principal circulatory pathways of the foot, achieving complete BTK revascularization, but it can also be used to succeed in wound-related artery recanalization, crossing through the opposite patent circulatory pathway to obtain retrograde recanalization of the occluded foot vessel. It is based on the wiring and balloon tracking through the plantar arch and creating a loop from the dorsal to the plantar circulation of the foot (or vice versa).[27,28]

This technical strategy has been thoroughly tested and proven to be useful for recanalization of patients with CLI due to BTK and below-the-ankle (BTA) atherosclerotic disease,[30] providing a high rate of acute success. Before applying the loop technique, the operator must carefully analyze the vascular anatomy of the foot network. It is essential to emphasize that direct blood flow through one tibial artery (ATA or PTA) with a good distal distribution system into the foot vessels can be a satisfactory and conclusive result of revascularization for the majority of the patients.

Retrograde Percutaneous Puncture

This technical strategy is considered when antegrade recanalization fails and consists of a retrograde percutaneous puncture of the distal patent vessel followed by retrograde wiring with the objective to achieve patency of the proximal lumen of the target artery.[35,38-41] Retrograde recanalization in BTK arteries can be performed through multiple different access sites. Specifically, to perform percutaneous retrograde distal access, we offer the following suggestions:

- **Choose the puncture site.** Accurate angiographic evaluation using the correct radiological projection is necessary for tibial and foot artery puncture.
- **Avoid spasms.** Spasms can compromise the puncture and wiring of the small vessels, and pharmacological support is essential. The use of a vasodilator (nitroglycerine, verapamil) is mandatory; it can be administered intra-arterially, as close as possible to the access site and, together with lidocaine, into the subcutaneous tissue around the needle entry site.

Results from case studies are not necessarily predictive of results in other cases. Results in other cases may vary.

- **Puncture technique.** The puncture is performed with a 21-gauge needle under fluoroscopic or ultrasound guidance.
- **Retrograde crossing strategy.** We generally prefer to use a 0.018-inch V-18™ ControlWire™ Guidewire after the puncture due to its enhanced support. However, the Savion DLVR™ Guidewire (Boston Scientific Corporation) is also an option as a designated wire for support and exchange due to its 0.014-inch platform and maximum rail support. The chosen guidewire is used in combination with a low-profile support catheter, which is very useful for wire support, orientation, and exchange.
- **Reconnection with the antegrade approach.** After retrograde crossing of the occluded vessel and reaching the proximal patent arterial segment, the aim is to perform the rendezvous with the antegrade catheter.[39-41] When the rendezvous is achieved, the retrograde wire is externalized at the groin level. After reversion of the approach, final hemostasis is obtained by advancing a balloon catheter beyond the puncture site and inflating it to nominal pressure.

CONCLUSION

The first step in treating PAD in BTK or BTA anatomy is gaining knowledge of the vascular anatomy of the tibial and foot vessels, as well as the most frequent anatomic variations and the angiosome concept. The target for CLI should change in relation to the clinical baseline condition, as well as to the vascular anatomy. In regard to our toolbox, the V-18™ ControlWire™ Guidewire is preferred for an endoluminal subintimal approach in the BTK arteries, the Savion FLX™ Guidewire can be used in an endoluminal subintimal approach in the BTA vessels, and the Savion DLVR™ Guidewire is helpful for increasing support and in delivering devices BTK/BTA.

We have many techniques that support us in successful approaches to the distal arteries, and by combining these in the proper way and following clinical needs, we can achieve excellent results, saving legs and lives. ■

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