# Tibioperoneal CTOs in Patients With Critical Limb Ischemia

Using cap analysis to design and implement crossing strategies.

BY JIHAD A. MUSTAPHA, MD; LARRY J. DIAZ-SANDOVAL, MD; AND FADI SAAB, MD

Anatomically, critical limb ischemia (CLI) is characterized by multilevel and multivessel disease (eg, aortoiliac, femoropopliteal [FP], and infrapopliteal [IP]), but fewer than 10% of CLI patients have hemodynamically significant disease in all three levels.[1-3]

Among patients with infrainguinal disease (FP and IP), approximately one-third have predominantly isolated IP disease, and the remaining two-thirds have a combination of FP and IP disease.[4-7] Isolated IP disease is mainly seen in elderly (older than 80 years), diabetic, or dialysis-dependent patients.[5] These patients have higher risk for amputation and shorter amputation-free survival compared to those with combined FP and IP disease.[6]

It is presumed that this prognostic difference is at least in part secondary to the individual patient's ability to develop systems of collateral circulation. The number and quality (diameter) of these collaterals are related to the degree of disease (high-grade stenosis vs chronic total occlusions [CTOs]) and the patient's comorbidities. Advanced age, history of coronary artery disease, hypertension, smoking, and elevated LDL cholesterol levels affect the number and migratory capacity of endothelial progenitor cells, which are known to be involved in the process of collateral formation.[8]

Intact collaterals are capable of transporting a larger volume of blood to the distal reconstitution point and generating a higher emptying pressure into the main vessel, creating enough retrograde flow that "erodes" the occlusive plaque and creates a retrograde concave distal cap (Figure 1). When these collaterals are compromised (or exist in small numbers and caliber), they only transfer a small volume of blood to the distal circulation, with a low emptying pressure that is not enough to generate retrograde flow nor the "cephalic erosion" process, and therefore, the cap becomes flat (open concave angle), which is associated with a higher degree of complexity as it increases the likelihood that crossing tools will be deflected toward the arterial wall (Figure 2).

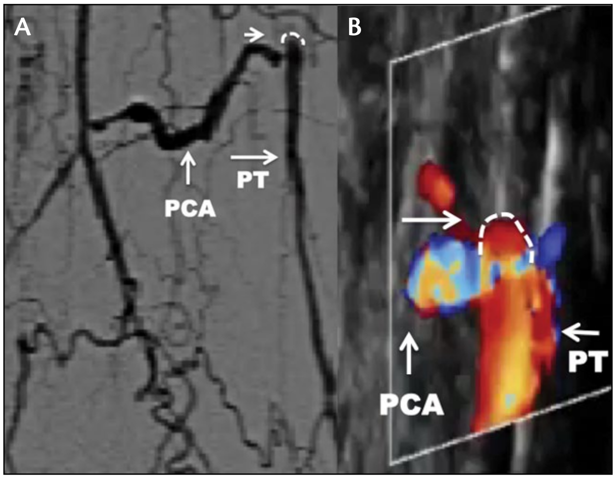

**Figure 1. Distal posterior tibial reconstitution. This cap has a retrograde concave shape. Angiogram depicting the retrograde concave shape of the PT reconstitution (small arrowhead, dashed cap) at the point that it is being fed by the PCA (A). The size of the PCA allows for sufficient volume and pressure to erode into the plaque proximally, creating the concavity of the cap. A DUS image of the concave cap being fed by the PCA (B).**

The evolution of interventional endovascular medicine has led to a rapidly growing field of IP interventions through development of new technologies such as low-profile sheaths, balloons, stents, steerable and hydrophilic guidewires, atherectomy devices, CTO crossing devices, low-profile reentry devices, extravascular ultrasound (US)[9,10] and fluoroscopy with roadmapping capabilities, among others. IP angioplasty

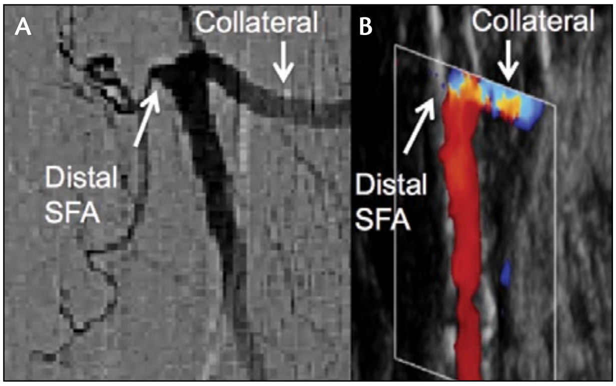


**Figure 2. Distal "flat" or open-angle concave distal SFA cap. A large collateral feeding the distal cap (A). The emptying pressure into the main vessel is low, generating a flat cap. The same image captured with DUS (B).**

and stenting have become the first-line treatment for below-the-knee (BTK) arterial occlusive disease.[11] The primary goals of CLI treatment are relief from ischemic pain, improvement of the patient's functionality and quality of life, wound healing, limb salvage, and amputation-free survival.[12] Mechanical revascularization via endovascular or surgical intervention is necessary to achieve these goals. Ultimately, comprehensive treatment of CLI patients requires the participation of a multidisciplinary team that is involved in longitudinal follow-up, even after revascularization and wound healing have been achieved, as this particular cohort of patients is always at risk for new upsets to their compromised metabolic balance.

## DIAGNOSTIC IMAGING

Modern preprocedural imaging includes multidetector CT angiography, contrast-enhanced magnetic resonance angiography, high-frequency duplex ultrasound (DUS),[12-15] and digital subtraction angiography. The choice of the optimal preprocedural imaging modality should be individualized on a case-by-case basis, and it largely depends on local expertise. In patients with advanced chronic kidney disease, sole preoperative DUS is recommended to avoid contrast-induced nephropathy and nephrogenic systemic fibrosis.[16]

The authors typically map the arterial tree with DUS in all patients with CLI and perform intraprocedural imaging with a combination of DUS and $CO_2$ angiography in patients with chronic kidney disease to minimize radiation and contrast exposure. Optimal preprocedural imaging should identify the severity and length of the IP arterial lesions, provide detailed information about the distal foot vasculature, and locate the distal point of reconstitution of the target vessels.

## INDICATIONS AND CONTRAINDICATIONS

Treatment should also focus on the diagnosis and management of the patient's cardiovascular risk factors (eg, hypertension, hyperlipidemia, diabetes, obesity, tobacco use), as well as any concomitant coronary and/or cerebrovascular disease.[12,17] In patients with impaired renal function, the alternative use of $CO_2$ should be considered, especially for imaging the supragenicular vessels, and limit the amount of contrast; however, $CO_2$ has a limited use in occluded tibials as it diffuses rather easily into the small collaterals.

The intersociety consensus for the management of peripheral arterial disease (Transatlantic Intersociety Consensus [TASC] II) classification establishes that for TASC A or B lesions, endovascular treatment is preferred, whereas with TASC D lesions, surgical vein bypass had been the gold standard until recently. However, the TASC II document states, "There is increasing evidence to support a recommendation for angioplasty in patients with CLI and infrapopliteal artery occlusion."[12] In TASC C lesions, surgery is the preferred treatment in "good-risk" patients. But it should be noted that in the absence of a suitable vein and/or adequate distal runoff vessels and in high-risk surgical patients, endovascular treatment represents the only valid therapeutic option for CLI. In real-world practice with older and fragile patients, who are poor surgical risk, have numerous comorbidities, poor inflow and/or outflow, and without suitable conduits, endovascular treatment is often the first line of treatment and should be attempted even in patients with difficult TASC C and D lesions.

## INTERVENTIONAL SETUP

Antegrade (common femoral artery [CFA]/superficial femoral artery [SFA]) and retrograde (tibial/pedal) combined arterial access should be pursued as the initial strategy to achieve complete limb revascularization, as determined by the CTO cap analysis. When concomitant ipsilateral CFA occlusive disease is present, surgical patch atherectomy and BTK revascularization can be performed simultaneously if the institution has a hybrid suite and CLI team in place. If these are not available, a contralateral puncture can be performed immediately, or soon after endarterectomy, or the endovascular treatment can be scheduled at least 2 weeks after surgery to safely facilitate the ipsilateral CFA or SFA puncture.

In nonobese patients without iliac, CFA, or very proximal SFA lesions, a direct antegrade puncture is preferable because it offers superior pushability, trackability, and torquing of the crossing devices as the entire force applied to the device is transmitted to the lesion in a unidirectional vector, allowing crossing of hard, calcified distal occlu-

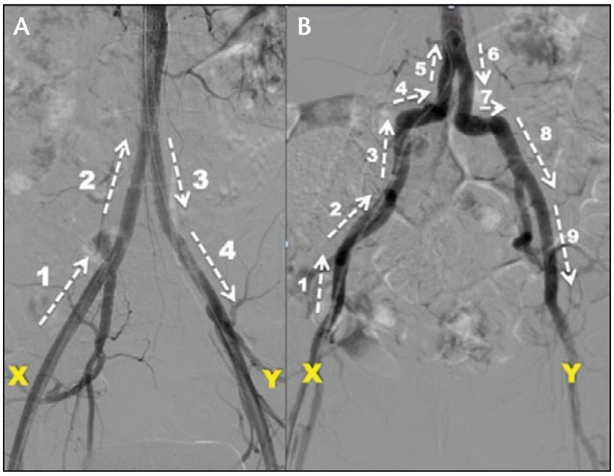


Figure 3. The dashed arrows represent the vectors into which a force applied at point X would decompose before reaching point Y. The force vector decomposes in at least four vectors with a narrow angle (A). The force vector decomposes in eight or more vectors with multiple changes in direction and narrow angles (B).

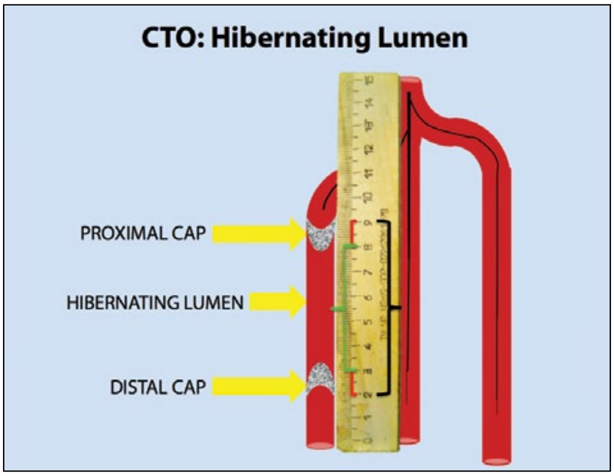


Figure 4. The illustration represents a total occlusion of the posterior tibial artery. With conventional angiography, it would seem that this occlusion is 7 cm long (black marker). However, the true occlusion is limited to the thickness of each cap, which is a total of 2 cm (red markers). The remaining 5 cm (green marker) represent the length of the hibernating lumen.

sions, as well as easier catheter and guidewire maneuvers. Antegrade access also provides the operator with the ability to perform distal injections to assess the status of the pedal vessels more accurately and to potentially treat below-the-ankle (BTA) vessels in the event of embolization, dissection, or other distal complications, which would be potentially impossible to perform with a contralateral approach.

The contralateral "up-and-over" approach is only recommended in instances when an antegrade approach is not feasible, such as in a severely diseased CFA or flush ostial SFA occlusion. This technique can be almost impossible in patients with extremely tortuous iliac arteries, hostile aortic bifurcations, "Y" prosthesis, or abdominal aortic stent grafts. When this approach is utilized, there is a deconstruction of the force vector into four (Figure 3A) to eight or more (Figure 3B) vectors, depending on the tortuosity of the aortoiliac bifurcation, resulting in very little transmission of the crossing force to the tip of the crossing device, therefore decreasing the likelihood of success. If the up-and-over maneuver is feasible, a long sheath or guide catheter is positioned into the contralateral external iliac artery, SFA, or distal popliteal to allow selective/superselective angiographic visualization of the BTK vessels.

As new techniques are being developed and brought into practice, including US-guided tibiopedal access and interventions, transcollateral tibial interventions, and digital and transmetatarsal artery access and interventions, it appears that the future holds promise with regard to the ability to intervene in these ever-increasingly complex patients.[18,19]

## IP INTERVENTION

US-guided puncture is used to facilitate precise CFA or SFA arterial access. Popliteal and tibiopedal access should also be performed under US guidance. Some authors advocate the use of fluoroscopic guidance when there are vessel wall calcifications. However, US guidance is recommended because it allows precise visualization of the needle path, vessel depth, surrounding veins and nerves, as well as the ideal puncture site along the vessel path (depending on lumen size, calcification, occluded segments, and location of accompanying veins).[10]

Baseline selective and superselective preinterventional arteriograms are obtained (preferably at a separate date preceding the intervention) in an attempt to minimize contrast and radiation exposure, as well as to aid in planning the interventional strategy (scheduling the necessary ancillary staff: US technician, anesthesia support, and assisting scrub nurse and physician for complex dual-access cases) and to set up the room for the intervention. For selective angiography, the catheter is positioned at the level of the SFA. Superselective angiography is performed with the catheter at the P3 segment of the popliteal artery or the tibial trifurcation.

In cases in which the pedal circulation is the target of the intervention, selective antegrade tibial angiography is performed, if feasible, with the aid of intra-arterial vasodilators. In general, optimal visualization of the upper- and mid-third of the tibial arteries is achieved in an ipsilateral oblique projection. Imaging of the distal

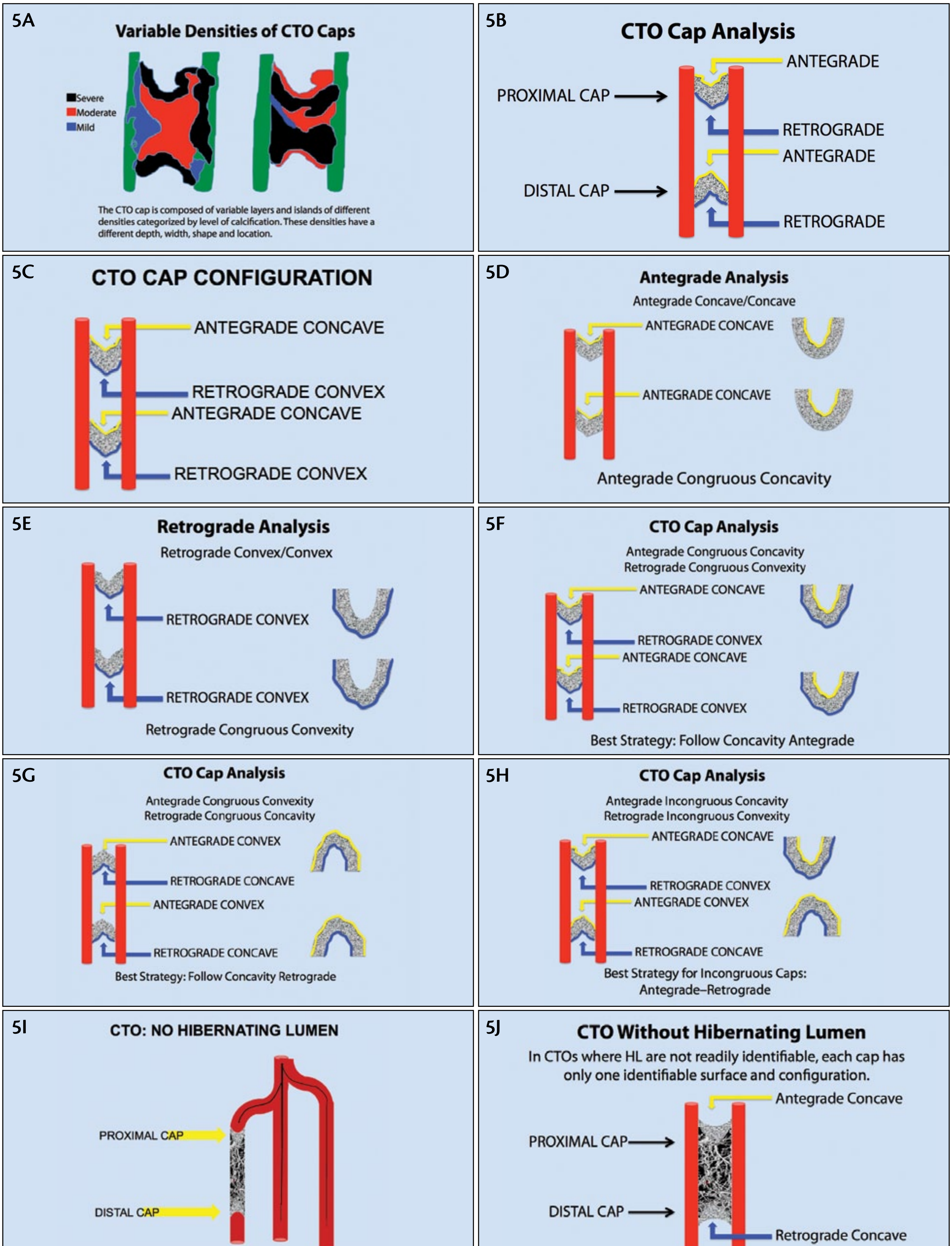


**Figure 5. Determining crossing strategy based on the type of CTO.**

tibial arteries and the foot is best achieved in a contralateral oblique projection with foot abduction that produces a lateral arteriogram of the foot. The optimal projection to visualize the common plantar artery bifurcation, the dorsalis pedis artery, and the pedal-plantar loop is the lateral oblique projection. To visualize the pedal-plantar loop and the tarsal and metatarsal arteries, an anteroposterior projection of the foot should be obtained.[20]

The target tibial vessel is generally catheterized with a 0.018-inch support catheter. Tibiopedal lesions are crossed with 0.014- or 0.018-inch guidewires. Retrograde tibial pedal access is achieved with a 2.9-F sheath (sometimes only the dilator is used) and use of an atraumatic 0.014-inch wire manipulated under US guidance. Once the CTO cap is reached, a 0.018-inch catheter is advanced, and the wire is exchanged for a CTO wire. Low-profile 2- or 2.5-mm balloon catheters may be used for wire support while "centering" the wire in the lumen. Over-the-wire balloon platforms are utilized given their superior pushability, ability to inject through, and ability to exchange wires if needed. Heavily calcified vessels represent a challenge for both intraluminal (suboptimal inflation) and subintimal (difficulty in reentering the true lumen, increased risk of rupture) angioplasty.

Data regarding the duration of balloon inflation are scarce. To our knowledge, there are no reliable studies on this topic in the literature covering peripheral endovascular interventions. Studies on coronary stenting have suggested a minimal inflation time of 25 seconds.[21] The authors traditionally use prolonged (2 minutes), low-pressure (2 to 4 atm) inflations based on a theoretical decrease in the likelihood of barotrauma to the vessel wall.

Efforts should be made to improve the tibial runoff with additional BTA angioplasty of significant distal stenosis, as the longevity of tibial artery patency may be jeopardized in the absence of adequate outflow. BTA stenting is not recommended with the currently available technology in order to allow potential future surgical bypass in an undamaged, unstented landing zone.

In patients with occluded SFAs that cannot be recanalized, antegrade popliteal access may also be considered to address tibioperoneal disease in CLI patients.[22]

## CTO CAP ANALYSIS

The choice of crossing strategy is based on the type of tibial CTO in order to ensure a higher crossing success rate. There are many anatomical variations in CTOs of the IP arteries that are beyond the scope of this article. The authors have pursued a strategy based on the study of the different types of CTO caps, which have been classified according to their configuration and the presence or absence of a hibernating lumen (HL). The HL is a segment of arterial lumen that is patent and located between two CTO caps (Figure 4) that typically have a heterogeneous distribution of calcium (Figure 5A).

When an HL is present, each CTO cap is said to have two surfaces (depending on whether the lesion is being approached in antegrade or retrograde fashion, Figure 5B).

The next step is to determine the configuration of each surface pertaining to the proximal and distal caps. These can be either concave or convex (Figure 5C). For our example, both the proximal and distal caps will be antegrade concave and retrograde convex.

Antegrade analysis is performed by comparing the antegrade surfaces of both proximal and distal caps. When the same surface of each cap has the same configuration, the lesion is termed "congruous." In this example, the lesion has antegrade congruous concavity (Figure 5D).

Retrograde analysis is performed by comparing the retrograde surfaces of both proximal and distal caps. In the example, the lesions have retrograde congruous convexity (Figure 5E).

In general, the intervention should be performed following the direction of the concavity, as this configuration increases the likelihood of central intraluminal crossing (Figure 5F). In this example, the intervention should be carried out using an antegrade approach. In tibial CTOs with retrograde congruous concavity, the best strategy is to intervene from a retrograde tibiopedal access approach (Figure 5G).

In more complex tibioperoneal CTOs, both antegrade and retrograde surfaces will exhibit different configurations (a mix of concave and convex). This is termed "incongruous concavity." In these cases, the

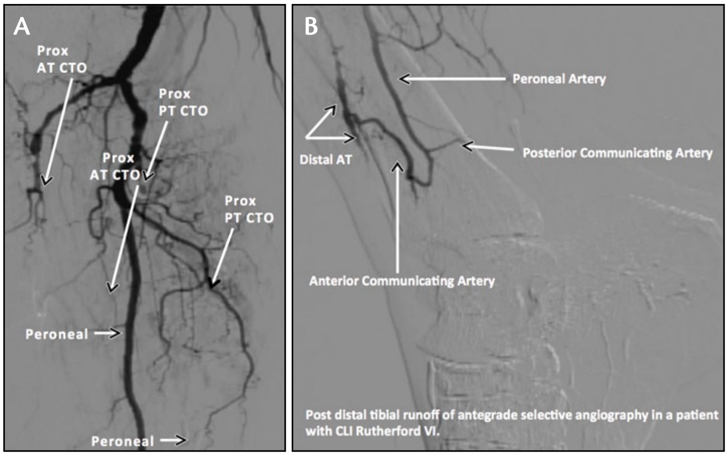


**Figure 6. A proximal CTO cap in the proximal segment of both the AT and PT (A). Distal reconstitution of the AT via the PCA.**

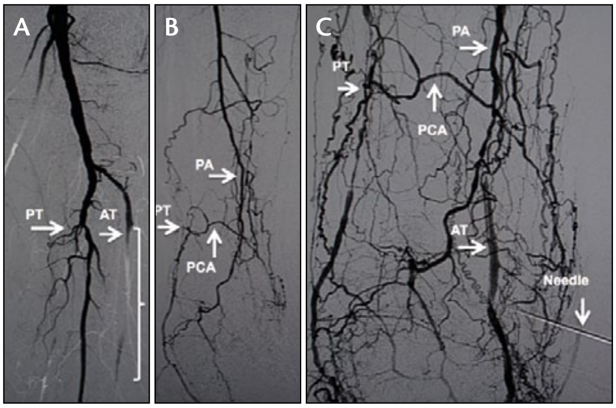


**Figure 7. Selective antegrade popliteal angiogram with runoff (A). Ostial occlusion of the PT, without clear takeoff (arrows). Proximal occlusion of the AT (arrows). Bracket: subtotal occlusion of the mid AT. Distal tibial pedal runoff from antegrade popliteal angiogram (B). Simultaneous supraselective antegrade popliteal + retrograde AT angiogram (C). For the AT, notice the wire inside the vessel from retrograde access.**

best approach is a combined antegrade-retrograde access and intervention (Figure 5H).

In lesions where there is no identifiable HL, it is presumed that the entire length of the arterial segment not highlighted by contrast is occupied by fibrous/plaque material. In these cases, each cap has only one analyzable surface and configuration (Figure 5I and 5J).

## TYPES OF TIBIAL CTOs AND CROSSING STRATEGIES

### Anterior Tibial Artery

The most common anterior tibial (AT) CTO is proximal, usually found 10 to 30 mm distal to the ostium of the tibial artery. The AT is frequently occluded at the site of the takeoff of its large anterolateral branch, preserving the proximal 10 to 30 mm of its course. The most common area for distal reconstitution is located near the anterior communicating artery (ACA), which usually fills the distal AT via the peroneal artery (PA) (Figure 6). The AT and posterior tibial (PT) are accessed with US guidance and antegrade CFA access, as well as selective tibiopedal angiography and simultaneous antegrade-retrograde selective angiography (Figure 7).

These figures illustrate the value of combined antegrade-retrograde arterial access and simultaneous bidirectional selective angiography, which significantly enhances visualization of hibernating lumens, the true length of occlusions, and the morphology of CTO caps, which provides us with an unparalleled and unprecedented ability to plan and perform endovascular interventions for limb salvage cases.

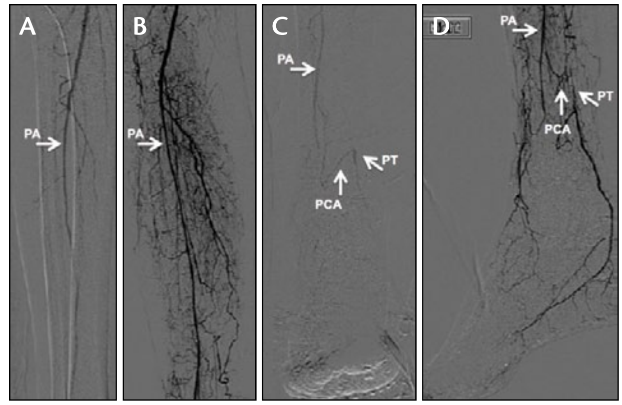


**Figure 8. Distal popliteal, TPT, and PA visualized through nonselective abdominal angiogram with runoff (A). Distal popliteal, TPT, and peroneal visualized via selective popliteal angiogram with runoff (B). The PT is occluded at the ostium. Distal PT reconstitution is seen via the PCA and visualized through nonselective abdominal angiogram with runoff (C). Distal PT reconstitution is seen via the PCA and visualized through selective popliteal angiogram with runoff (D).**

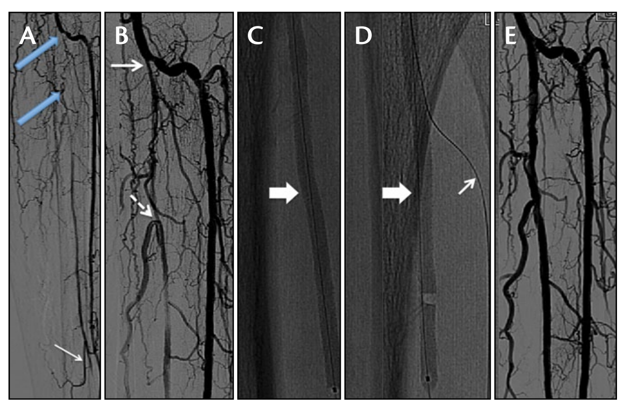


**Figure 9. Totally occluded TPT-peroneal and PT (A). The first blue arrow points to ostial TPT occlusion. The second blue arrow points to the origin of the peroneal. The thin white arrow points to the PCA feeding the distal PT from the peroneal. Reconstitution of the TPT (solid arrow) and the PT-peroneal bifurcation (dashed arrow) (B). Angioplasty of the TPT/peroneal (thick arrow) (C). Angioplasty of the TPT/peroneal (thick arrow) with a wire protecting the AT (small arrow) (D). Final angiogram after reconstruction of the TPT-peroneal (E).**

### Posterior Tibial Artery

The most common site of a proximal PT CTO is localized either at the ostium or within the first 10 mm (Figures 6A and 7A). The most common reconstitution site of a PT CTO is near the posterior communicating artery (PCA) in the distal third of the leg, above the ankle. This vessel also feeds the distal runoff via the PA (Figures 6B, 7B, 7C, 8C, and 8D).

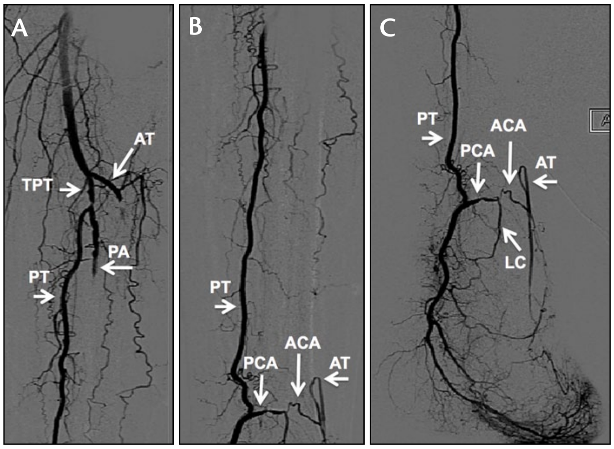


**Figure 10. CLI with one-vessel runoff via the PT. Proximal and distal thirds of the infrapopliteal vessels (A). Proximal occlusion of the AT. High-grade stenosis of the TPT. Proximal occlusion of the PA. Distal third of the infrapopliteal vessels at the ankle (B). The peroneal is not seen; however, the PCA to the PT and the ACA to the AT are seen. The lateral calcaneal branch of the peroneal (C).**

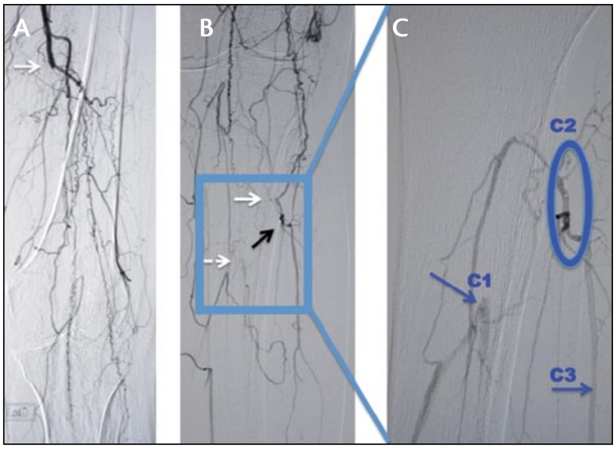


**Figure 11. Totally occluded distal SFA (arrow) and popliteal in all three segments (A). A hint of reconstitution of the AT (arrow) and its anterolateral branch (black arrow) (B). There is what appears to be a very faint reconstitution of the PT-peroneal bifurcation (dashed arrow). An amplified view of panel B (C). Reconstitution of the PT-peroneal bifurcation (C1). Brief AT reconstitution and takeoff of the anterolateral branch (oval) (C2). Magnified view of the anterolateral branch of the AT (C3).**

### Tibioperoneal Trunk and Peroneal Artery

The most common site of CTO in the TPT and PA is at the ostium of the TPT and between the ostium and first 10 mm of the PA (Figures 9A and 10A). Reconstitution of the PA is usually in its distal one-third and mostly fills retrograde via the ACA, PCA, or both. These branches allow the PA to communicate with the AT and PT respectively (Figures 9 and 10).

## CROSSING TECHNIQUES

The preferred access strategy for successful tibial CTO crossing is a combination of antegrade CFA or SFA with retrograde single or double tibial access (AT, PT, or a combination), depending on the CTO cap analysis previously discussed.

### Tibial CTO Crossing Techniques

The best working view to cross proximal AT, PT, and PA CTOs (if working with fluoroscopic guidance) is an ipsilateral oblique view at 30°. This opens the fibula and tibia and positions the AT, PT, and PA between the bones, making the arteries and crossing devices easier to visualize. This view also shows the bifurcation of the PT and PA, which helps to more accurately identify these two vessels. It is always best to start with a supporting device when crossing tibial CTOs, such as a catheter or sheath.

The most common antegrade approach is to place a long sheath, positioning the tip near the popliteal area, and then engage the tibial artery with a variety of soft-tip wires. When treating proximal PT and PA CTOs, make sure your support catheter is within the proximal PT or PA prior to initiating the use of heavy-gram-tip wires. This technique allows you to protect the section of the distal TPT and the ostial PA (if crossing the PT) or PT (if crossing the PA) that are in close proximity. Keep in mind, the majority of these patent proximal AT, PT, and PA segments can have plaque buildup in the range of 30% to 50%, and when crossing the ostium on the way to the CTO cap, it is necessary to avoid disruption of nonocclusive plaque in the patent segment, which could lead to a devastating dissection or occlusion. To avoid this, start with a soft-tip wire with an atraumatic tip-angled catheter.

Use of wires with an excellent 1:1 torque and atraumatic tip are easily maneuvered to the proximal AT, PT, and PA CTO caps and provide enough support to advance the angled support catheter.

Once the support catheter is at the CTO cap, you can choose to initiate CTO crossing with CTO wires. If an operator has a need to limit choices to two workhorse wires for tibial CTO crossing, the authors recommend starting with a soft-tip wire and exchanging to a heavy-gram-tip wire of the operator's choice.

The following case describes a complex CTO that starts in the distal SFA/P1 segment of the popliteal artery. There was no obvious reconstitution, except

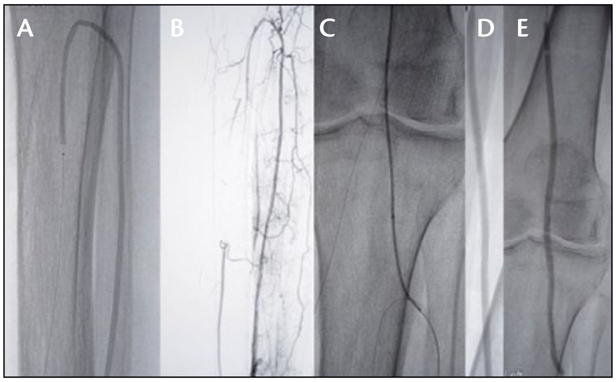


**Figure 12. Transtibial retrograde angioplasty of the AT into the peroneal artery (A). Retrograde AT angiogram shows improved tibial flow (B). Antegrade crossing of the CTO from distal SFA into the AT followed by reversal of the retrograde access to finish the intervention in an antegrade fashion (C). Extensive angioplasty of the distal SFA, popliteal, and AT (D, E).**

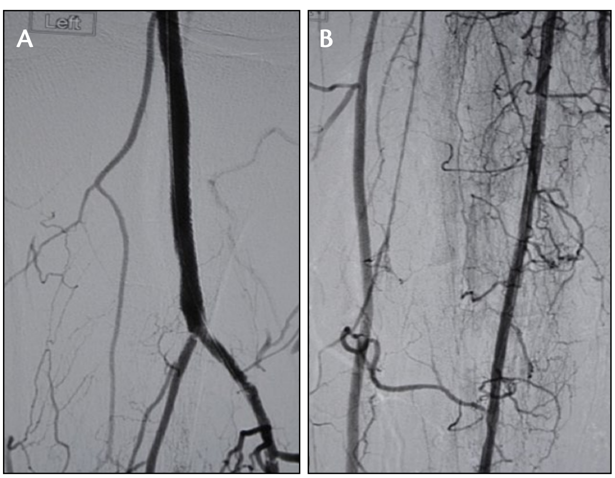


**Figure 13. Poststenting status of the popliteal to the level of the AT-TPT bifurcation (A). Two-vessel runoff to the foot via the AT and peroneal (B).**

for a very short segment of the proximal AT and what appeared to be the bifurcation of the PT and PA. Also shown is the anterolateral branch of the AT, which is typically seen when the AT has a proximal CTO, and tends to be confused for the AT itself (Figure 11).

This case represents the typical example of a patient who is referred for above-the-knee amputation. The supposed lack of tibiopedal runoff eliminates the surgical and endovascular options. Detailed US mapping of the tibial vessels was performed, and segments of "patent lumen" were seen in all the distal vessels. Next, US-guided antegrade CFA access and retrograde AT access were achieved. A Micropuncture pedal access sheath (Cook Medical) was placed in the AT, and heparin (60 U/kg) and nitroglycerin (200 µg) were administered. A 0.014-inch soft-tip wire was manipulated from the retrograde AT sheath into the PA. This was followed by retrograde transtibial balloon angioplasty of the AT into the TPT/proximal PA (Figure 12A). Retrograde angiography revealed improved tibial runoff (Figure 12B). A 0.035-inch catheter was advanced in an antegrade fashion, and the proximal CTO cap (distal SFA) was crossed with a 6-g, 0.018-inch wire under US guidance. The catheter was advanced under US guidance into the ostium of the AT and easily crossed with the wire (Figure 12C). The retrograde wire in the AT was introduced in the antegrade catheter using US guidance, and the retrograde wire was exteriorized at the groin. The 0.035-inch catheter was removed, and then a 0.018-inch catheter was advanced in an antegrade fashion into the distal AT. The retrograde wire was removed and introduced in an antegrade fashion. The retrograde sheath was removed, and the antegrade wire was manipulated into the foot, past the point of retrograde access. Extensive antegrade balloon angioplasty was performed in the popliteal and AT using a low-profile balloon (Figure 12D and E). The results of antegrade angioplasty were suboptimal, therefore the distal SFA and entire popliteal (up to the AT/TPT bifurcation) was stented (Figure 13A). Final angiography revealed TIMI III flow through the AT and PA into the foot (Figure 13B).

### Reentry From the Tibial Subintimal Space to the True Lumen

The tibial arterial wall is thin and should be crossed primarily with a 0.014-inch wire system when possible. When crossed subintimally, re-entry is usually accomplished with US guidance and an angled 0.018-inch catheter, with a heavy-tip wire featuring a short 90° bend at the tip, or the Enteer catheter (Covidien), which is a balloon-based device. Enteer has two wire exit ports that can lead to the true lumen with a specialized angled wire that comes with the device.

## CONCLUSION

IP intervention has been shown to be safe and efficacious. As with any other interventional procedure, experience correlates with improved outcomes. Further studies with longer follow-up are necessary to answer some of the remaining questions about safety and efficacy of the next frontier in CLI therapy, which is the use of these technologies in below-the-ankle interventions. ■

*Jihad A. Mustapha, MD, is the Director of Cardiovascular Catheterization Laboratories, Metro Health Hospital, Wyoming, Michigan; and Clinical Assistant Professor of Medicine, Michigan State University CHM and COM, East Lansing, Michigan. He has disclosed that he is a consultant to Cook Medical and Covidien. Dr. Mustapha may be reached at jihad.mustapha@metrogr.org.*

*Larry J. Diaz-Sandoval, MD, is an interventional cardiologist with Metro Health Hospital, Wyoming, Michigan; and Clinical Assistant Professor of Medicine, Michigan State University CHM and COM, East Lansing, Michigan. He has disclosed that he has no financial interests related to this article.*

*Fadi Saab, MD, is an interventional cardiologist with Metro Health Hospital, Wyoming, Michigan; and Clinical Assistant Professor of Medicine, Michigan State University CHM and COM, East Lansing, Michigan. He has disclosed that he is a consultant to Cook Medical and Covidien.*

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