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Endovascular treatment of diabetic foot ischemic ulcer – Technical review

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ABSTRACT

This article is a technical review of the common techniques used in the treatment of lower-limb occlusive arterial disease associated with diabetes. The techniques described here reflect the author's own practice and are methods that the author finds helpful in avoiding complications and in making the technical aspects of the procedures easier.

Introduction

Diabetic foot ulcer

Diabetes is the fastest-growing chronic disease worldwide.[1] It is estimated that up to 1,000,000 Australian people have diabetes and another 700,000 have undiagnosed diabetes. The incidence of this disease is also rapidly increasing in developing countries.[2] Diabetes is a chronic condition that affects most organs of the body. Stroke, ischemic heart disease, kidney disease, and peripheral arterial disease are common in patients with diabetes. The first presentation of peripheral arterial disease in patients with diabetes is often foot ulceration. Foot ulcer in diabetes has a neuropathic or neuroischaemic etiology. Prompt treatment of arterial circulation disturbances allows wound healing and prevents limb loss. This article is an update on the technical aspects of the endovascular techniques used in the treatment of peripheral arterial disease in patients with diabetes.

Technical description

Endovascular treatment of arterial disease in diabetes

Patients with diabetes present with a disorder predominantly affecting the tibial and foot arteries. In this condition, there is a paucity of collateral circulation amongst the territories supplied by the individual tibial arteries.[3] The arteries are often extremely calcified, with a significant amount of medial calcification. The treatment of arterial occlusive disease can be divided into case planning, crossing the lesion, and lesion preparation and treatment.

Case planning

Case planning is crucial to treatment success. Preoperative imaging should be carefully analyzed as a mandatory part of case planning. Comorbidities, symptoms, and areas of ulceration should be taken into account when setting the treatment goals.

Ultrasound

Ultrasound is an essential modality during lower-limb arterial intervention. Generally, a 5- to 13-MHz linear probe is used (Fig. 1). Ultrasound allows safe access to the femoral artery by avoiding excessively high or low puncture, which can result in false aneurysm formation. It is also used to guide the closure device for a safe closure of the artery on completion of the procedure.[4] Intraoperatively, it can be used to assist the guiding catheter and wire across a chronic total occlusion (CTO). The wire and catheter can be redirected toward the central lumen of the

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Abbreviations: CIA, common iliac artery; CFA, common femoral artery; PFA, profunda femoris artery; SFA, superficial femoral artery; AT, anterior tibial artery; PT, posterior tibial artery; PR, peroneal artery; CTO, chronic total occlusion; IVUS, intravascular ultrasound.

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Fig. 1. Ultrasound and linear probe used in lower-limb arterial intervention.

vessel if they are found to be in the subintimal plane (see Figs. 2–8).

Computed tomography angiography (CT angiography)

The most appropriate access site and approach can be determined from computed tomography angiography. The lesion requiring treatment is assessed for calcification, eccentricity, shape of the CTO cap in the entry zone, and the distal re-entry zone into the distal target vessel should be assessed for diffuse disease that may cause difficulty with re-entry into the true lumen. Anatomical variations are common in lower limb arteries and a good understanding of these variations is crucial to successful lower limb revascularization. Variations in the anatomy of the occluded tibial vessels can be assessed by following the calcification along the wall of the tibial vessels on either CT angiogragram or conventional angiogram.

Anatomical variations

Popliteal bifurcation variants. Anatomical variation of popliteal trifurcation is present in about 10% of patients. The most common pattern is bifurcation of the popliteal artery into the anterior tibial artery and tibioperoneal trunk artery below the knee. The peroneal artery and posterior tibial artery are two terminal branches of the tibioperoneal trunk artery.

Anatomical variations of the popliteal bifurcation can be divided into three types (Figure 2).[5] In type 1, the popliteal artery bifurcates below the knee joint. In type II, the popliteal artery bifurcates above the knee joint. In type III, the anterior or posterior circulation becomes the dominant supply of the foot and one of the tibial arteries is hypoplastic.

Type I - division of the popliteal artery (PA) below the knee joint
Type I-A: division into the anterior tibial artery (AT) and a common trunk for the peroneal artery (PR) and the posterior tibial artery (PT)
Type I–B: division into the AT, PT, and PR, all within 5 mm of each other
Type I–C: division into the PT and a common trunk of the AT and PR
Type II - division of the PA at or above the knee
Type II-A1: AT branches off first and follows an abnormal course
Type II-A2: AT branches off first and follows a medial course
Type II-B: PT branches off first
Type II-C: PR branches off first
Type III - dominant anterior or posterior circulation with hypoplasia of a branch
Type III-A: PT hypoplasia or aplasia with PR continuing as distal PT into the foot
Type III-B: AT hypoplasia or aplasia with PR continuing as dorsalis pedis into the foot
Type III-C: both AT and PT hypoplasia or aplasia with PR supplying the foot via the anterior and posterior communicating branches

Foot artery anatomical variations. The anterior circulation of the foot is supplied by the dorsalis pedis artery, and the posterior circulation is supplied by the medial and lateral plantar arteries. The anterior and posterior circulation have many collateral connections in a normal healthy person. The collateral connections can be poor in patients with diabetes, leading to non-healing of wounds unless the appropriate angiosome artery is revascularized.[6] The dorsalis pedis and lateral plantar arteries connect via the deep perforating branch of the dorsalis pedis artery to form the plantar loop. The dorsalis pedis artery branches into the lateral and medial malleolar arteries, lateral and medial tarsal arteries, arcuate arteries, deep perforating branch, and the dorsal great toe metatarsal artery. The arcuate artery, in turn, gives off the second, third, and fourth dorsal metatarsal arteries. Dorsal metatarsal arteries form collateral connections with plantar metatarsal arteries, which are branches of the plantar arch. The variation is greater with the dorsalis pedis artery than with the plantar arteries. The great toe can be supplied by the dorsalis pedis artery via the dorsal first metatarsal artery, medial plantar artery, or first plantar metatarsal artery of the plantar arch (lateral plantar artery). The distal dorsalis pedis artery is often absent (30%), creating a lateral plantar dominant pedal arch.[7] In these cases, the medial and lateral tarsal arteries can be hypertrophied and can develop large collaterals to the plantar arch. The pedal arch can also be dorsalis pedis artery dominant, where the lateral plantar artery is atrophic. The dorsalis pedis and lateral plantar arteries can equally contribute to the pedal arch, creating a codominant pedal arch. In the case of dominant circulation from one territory, the plantar arch may not form a complete loop around the foot. Knowledge of anatomical variations of the popliteal and pedal circulation can help reduce injury to the lower-limb arteries during the procedure and optimize the successful revascularization of the foot. It may be necessary to perform planning angiography before the intervention to optimize procedural success, especially in the pedal arch.

CTO cap assessment

Assessment of the CTO involves assessing the duration of occlusion, presence of collaterals, length of the CTO, calcification within the lesion, tortuosity along the CTO and at the entry and exit sites, and shape (convex or concave) of the CTO cap. The duration of lower-limb CTO is usually difficult to determine, as, unlike in coronary CTO, occlusion is not necessarily associated with significant deterioration of symptoms, especially in patients with a more sedentary lifestyle. Longer length, presence of calcification, and tortuosity all increase the complexity of the procedure. The presence of collaterals at the origin of the occlusion will make entry into the CTO difficult, as the wire will preferentially slide down the collaterals. The collaterals should be assessed as a possible channel for trans-collateral retrograde recanalization if antegrade crossing is difficult. During angiography, sufficient time should be allowed for the contrast to retrogradely fill the distal reconstituted artery, to fully assess the true length of the occlusion. A blunt cap will be more challenging to enter with a wire from the antegrade direction than a tapered cap. Determining the shape of the cap at the origin and distal end of the CTO can help determine the best direction for crossing the CTO (Figure 3).[8] Reconstituted artery distal to the CTO should also be assessed for significant diffuse disease that would make re-entry into the true lumen difficult.

Positioning and draping

All potential access sites should be surgically prepared and draped into the sterile field to facilitate conversion of the strategy during the procedure. For lower-limb recanalization, this often means draping both the groins and the symptomatic leg in the surgical field. A clear plastic bag or a large-sized glove can be used to exclude ulcers or gangrenous tissues from the sterile field.

Angiography

Multiplanar view

Angiography in a single plane is mostly used during lower-limb

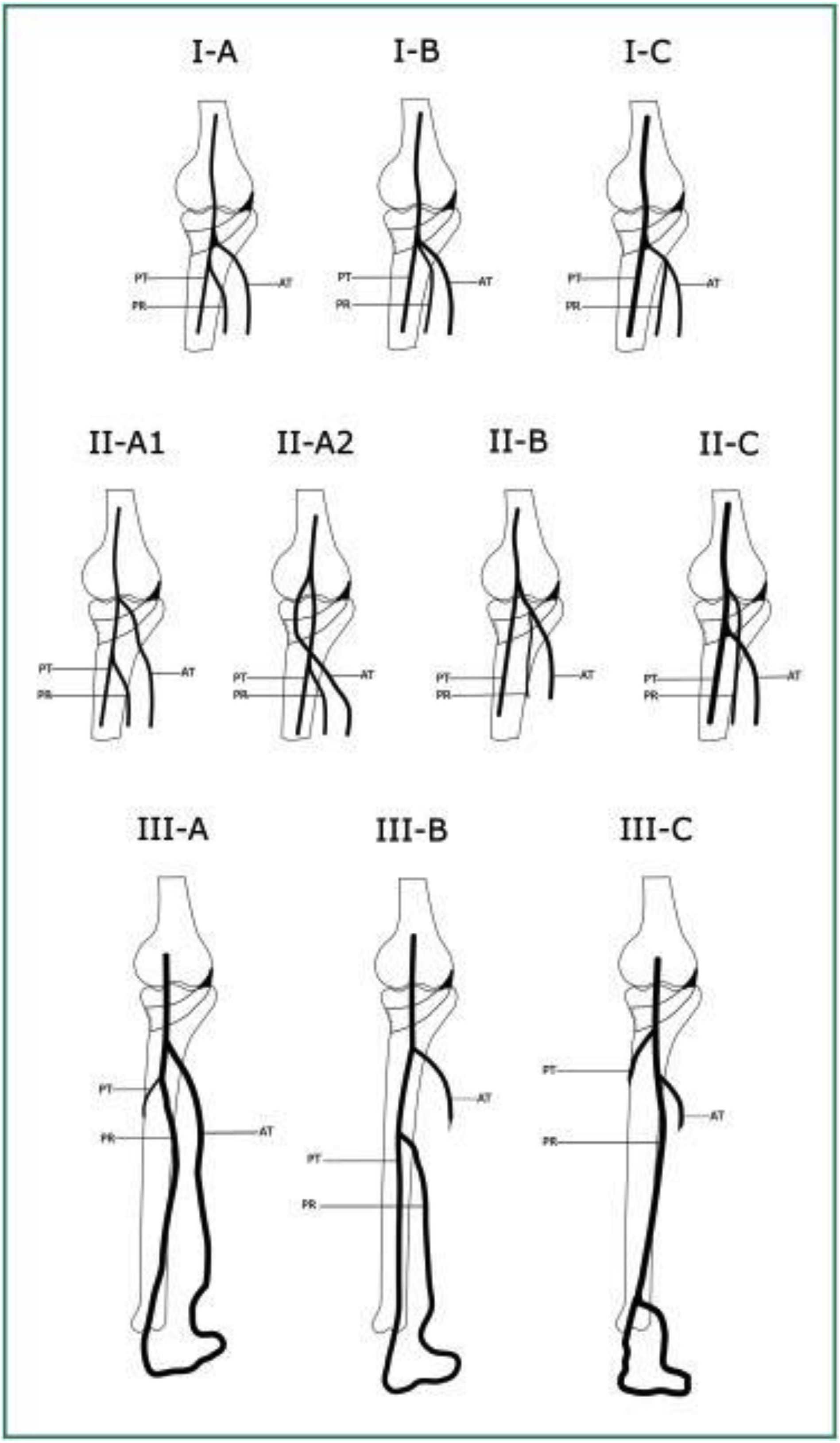


Fig. 2. Anatomical variations of popliteal trifurcation reproduced with permission from Demirtas, H., et al., Anatomic variations of popliteal artery: Evaluation with 128-section CT-angiography in 1261 lower limbs. Diagn Interv Imaging, 2016. 97(6): p. 635–42. Copyright © 2016 Elsevier Masson SAS. All rights reserved.

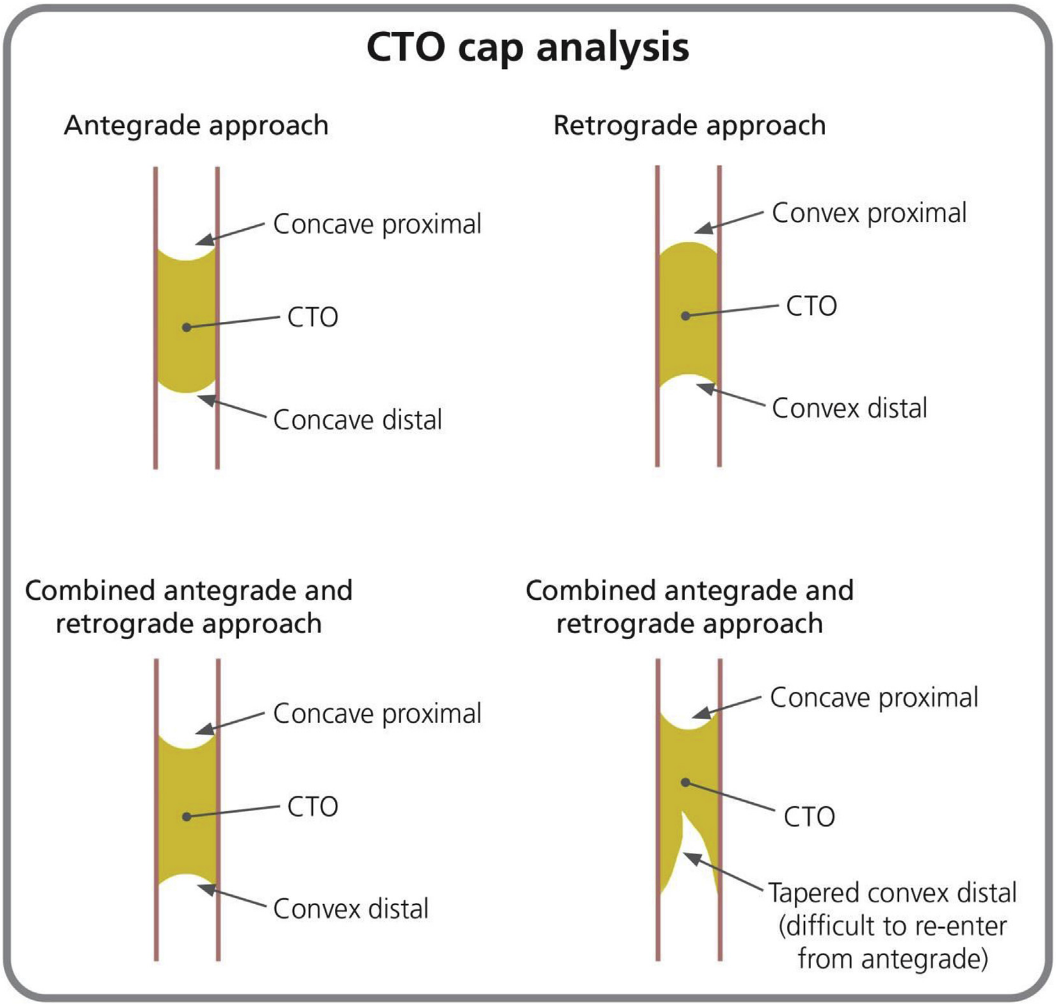


Fig. 3. Chronic total occlusion (CTO) cap analysis.

arterial intervention; however, if there is any doubt about the presence of a lesion, adequacy of treatment, or whether the wire is located in the distal true lumen, then images should be acquired in a different plane for further confirmation. An eccentric plaque located on the posterior wall of the artery may appear normal on a single anterior posterior projection. Eccentric lesions can only be recognized in oblique projections.

Contrast injection close to the lesion requiring assessment

The catheter or sheath should be placed as close as possible to the CTO to allow accurate assessment of the lesion and the distal runoff vessels. Placement of the catheter far from the lesion will make the contrast too dilute for a useful assessment of vessels distal to the occlusion. Selective injection via the collateral circulation, such as large collateral or profunda arteries, can be useful in the assessment of the patency of distal vessels. Dual source injection via a straight support catheter using 3-mL syringes in the anterior tibial and posterior tibial arteries simultaneously can be useful in the assessment of the pedal arch. Pedal arch intervention is best staged with a planning angiogram before the intervention to allow for a detailed identification of anatomical variations in the pedal plantar loop pathways.

Access

Obesity

In obese patients, the abdominal pannus should be taped upward using a large Opsite dressing, bringing the pannus toward the chest. A long, 9-cm, 18G puncture needle can be useful for reaching arteries in a deep location. Antegrade puncture in the common femoral artery (CFA) is relatively contraindicated, as the sheath is likely to be kinked by the abdominal apron during the procedure. Puncturing the proximal superficial femoral artery (SFA) may be an option if it is not occluded. Retrograde access from the contralateral CFA is the usual access option for obese patients. Tibial or pedal access using a low-profile sheath, such as Terumo Glidesheath Slender, can also be an option. Balloon, stent, or an atherectomy device can be delivered in a retrograde fashion toward the target lesion from a tibial or pedal access. The downside of these sheaths is that they are flimsy and can be damage by multiple exchanges of equipment. Hemostasis of the arteriotomy at the access site can be problematic with a large sheath after the procedure, as use of a closure device in these small arteries is contraindicated. A generous amount of glyceryl trinitrate or verapamil should be administered intra-arterially and topically to avoid spasm and subsequent thrombosis of the access vessel.

Scarred groin

Access through a scarred groin is common in endovascular procedures, as many of the patients undergoing the procedure have had a prior surgical intervention. There are two ways to access a scarred groin. The first approach is using a 4F introducer without the sheath after needle puncture and placement of a 0.035-in short-sheath guidewire in the artery. The 0.035-in short-sheath guidewire should be exchanged for a stiff guidewire, providing strong support to the advancing sheath without

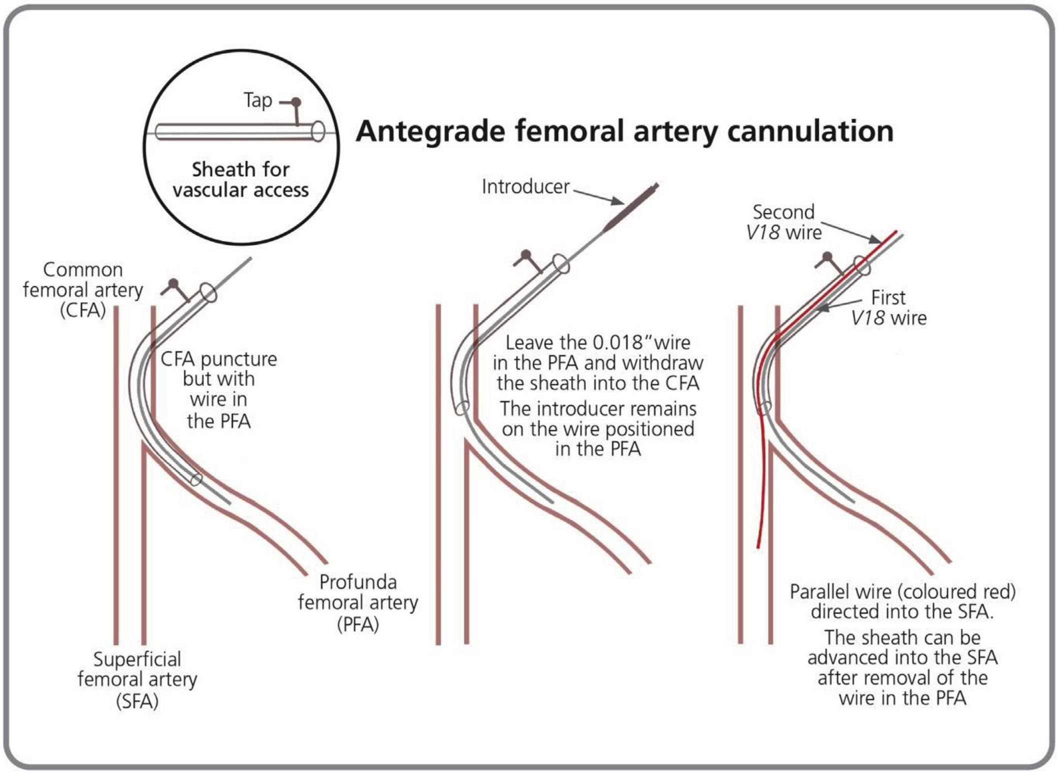
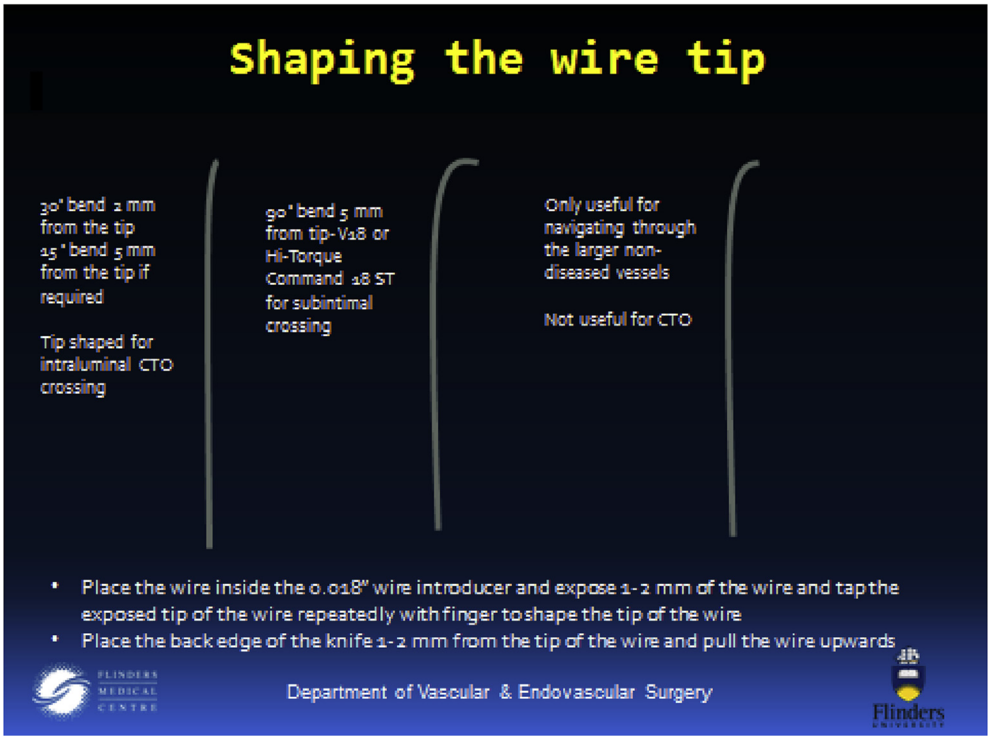


Fig. 4. Antegrade femoral access with the double-wire technique.



Shaping the wire tip

30° bend 1 mm
from the tip
15° bend 5 mm
from the tip if
required

Tip shaped for
intraluminal CTO
crossing

90° bend 5 mm
from tip- V18 or
Hi-Torque
Command 18 ST
for subintimal
crossing

Only useful for
navigating through
the larger non-
diseased vessels

Not useful for CTO

- Place the wire inside the 0.018" wire introducer and expose 1-2 mm of the wire and tap the exposed tip of the wire repeatedly with finger to shape the tip of the wire
- Place the back edge of the knife 1-2 mm from the tip of the wire and pull the wire upwards

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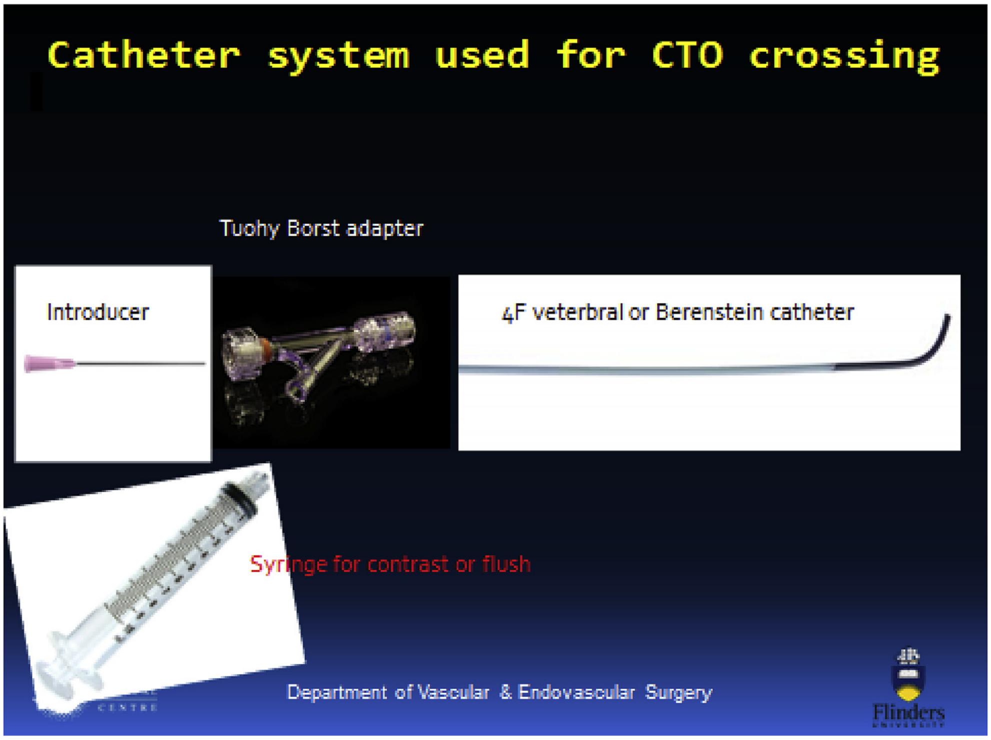
Fig. 5. Shaping the wire tip.

kinking in the scar tissue such as Hi-Torque Supracore wire (Abbott) before placement of a larger sheath. The second approach is to access the artery using a micro-puncture kit. The micro-puncture kit introducer is removed and a Hi-Torque Supracore wire (Abbott) is inserted through the micro-puncture sheath into the artery. The Hi-Torque Supracore wire provides strong support for the placement of the sheath through the tough scar without the risk of kinking the wire. Dilatation of the subcutaneous tract with an introducer that is 2F larger than the intended sheath is advisable before insertion of the sheath. Hydrophilic sheaths, such as the Cook sheath, are easier to insert through a scarred groin than



Catheter system used for CTO crossing

Tuohy Borst adapter

Introducer

4F veterbral or Berenstein catheter

Syringe for contrast or flush

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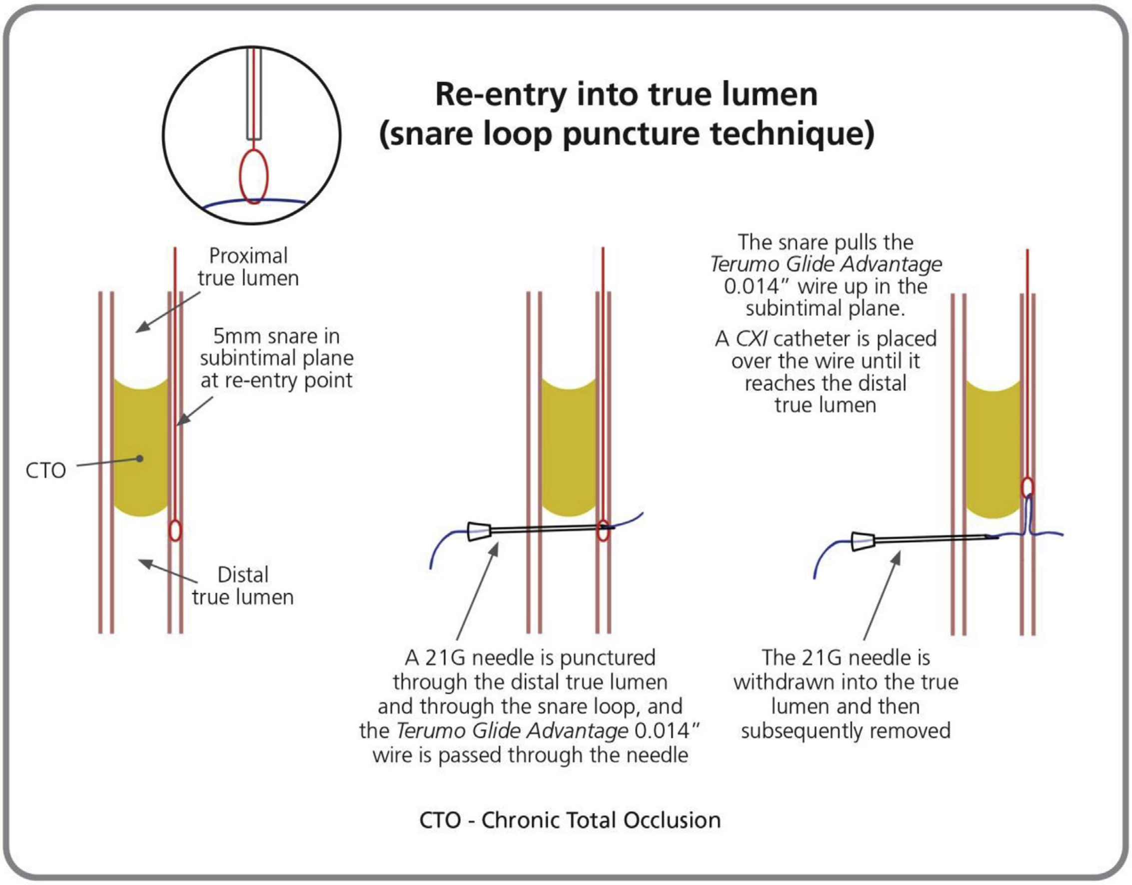
Fig. 6. Catheter system used for CTO crossing.



Re-entry into true lumen (snare loop puncture technique)

The snare pulls the *Terumo Glide Advantage* 0.014″ wire up in the subintimal plane.

A *CXI* catheter is placed over the wire until it reaches the distal true lumen

A 21G needle is punctured through the distal true lumen and through the snare loop, and the *Terumo Glide Advantage* 0.014″ wire is passed through the needle

The 21G needle is withdrawn into the true lumen and then subsequently removed

CTO - Chronic Total Occlusion

Fig. 7. Re-entry into the distal true lumen (snare loop puncture technique).

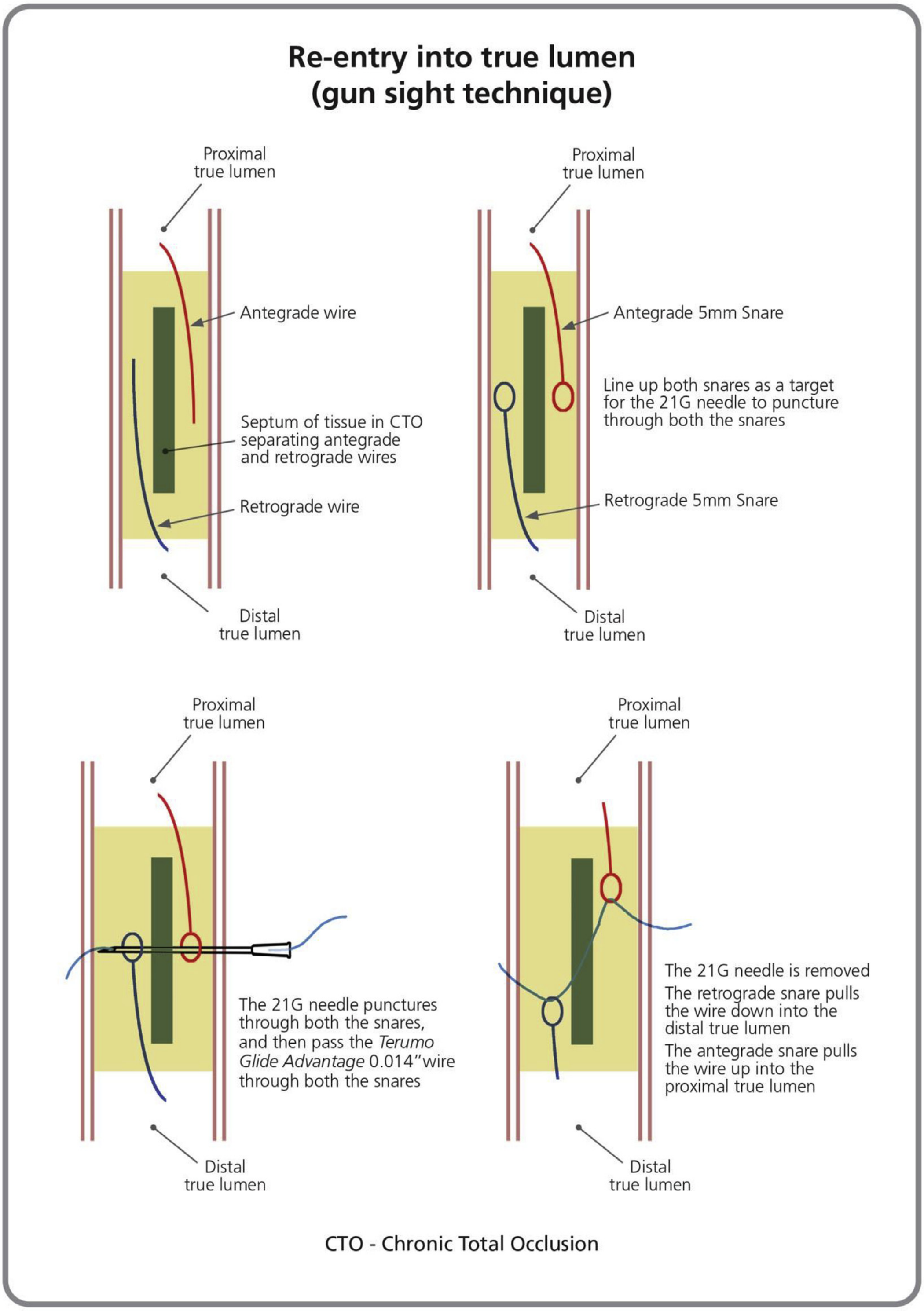


Fig. 8. Re-entry into the distal true lumen (gun-sight technique).

non-hydrophilic sheaths. The sheath and surrounding tissue should be wet with saline to reduce friction with the scar tissue in the groin.

Aortic bifurcation/previous aortobifemoral bypass graft

Contralateral access is often established in the treatment of diseases involving the proximal SFA and popliteal artery. The aortic bifurcation can have a very acute angle. Iliac arteries are often tortuous, and there may also be a prior stent placed in the iliac artery, making crossing the aortic bifurcation difficult. Crossing a difficult aortic bifurcation can be made easier by using an appropriately sized balloon (slightly smaller than the common iliac artery [CIA]) as an anchor for the wire. A 6F or 7F sheath is placed in the CIA of the access side. The aortic bifurcation is crossed with a Terumo Glidewire in combination with an Universal Flush (UF) or Rosch inferior mesenteric (RIM) catheter. The UF or RIM catheter is then exchanged for a 4F Bern catheter. The Glidewire is then exchanged for a Supracore wire. Thereafter, an appropriately sized balloon is inflated in the CIA, and the sheath is advanced over the wire and balloon as the balloon is deflated. The balloon is then inserted further along into the external iliac artery, and the sheath can again be advanced over the deflating balloon to reach the CFA. The balloon anchors the wire in place and prevents the wire from buckling into the aorta during sheath advancement. It also centers the advancing sheath and prevents its edge from catching on the side wall of the iliac artery.

In a very difficult aortic bifurcation crossing, bilateral retrograde groin access can be useful. The side with the sheath intended for passage of the equipment for treatment has an appropriately sized sheath (6F or 7F) placed in the CIA and a snare (15–20 mm) placed in the distal aorta. The contralateral CFA is accessed with a micro-puncture kit, and a 3F micro-puncture sheath is placed in the CFA. A 180-cm, 0.035-in Terumo Glidewire is then advanced through the micro-puncture sheath and snared using the snare placed in the aorta to establish through-and-through access. Two artery clips are placed on both ends of the wire adjacent to the sheaths. The treatment sheath is simultaneously pushed from the ipsilateral groin and pulled down from the contralateral groin. This simultaneous push-and-pull technique allows crossing of almost all aortic bifurcations, except those with iliac stents protruding into the distal aorta.

Antegrade femoral artery access

Antegrade CFA access is ideal in the treatment of tibial and pedal arterial disease of the ipsilateral leg. Advancing the wire into the SFA rather than the profunda femoris artery (PFA) can be problematic. Redirection of the wire from the PFA into the SFA has the risk of complete loss of access, and troublesome bleeding can result. This problem can be mitigated by using the profunda balloon occlusion technique or the double-wire technique (Figure 4). The double-wire technique can be performed with a 4F sheath. The profunda balloon occlusion technique requires a 6F sheath. Needle access in the CFA is obtained. If the wire progresses down the PFA, two 0.018-in wires, such as V18, are prepared. One of the 0.018-in wires is advanced down the PFA and a 4F balloon can be inflated close to the origin of the PFA. Thereafter, the sheath is pulled back gradually until it is clear of the PFA origin. Another V18 wire can be used to access the SFA through a separate puncture in the sheath. The sheath can then be advanced over the SFA wire after the removal of the wire and balloon in the PFA. The double-wire technique is similar, but performed with two 0.018-in wires without the use of the profunda occlusion balloon. The sheath introducer should always be left on the wire located in the PFA to allow rapid re-insertion of the sheath in the event that the sheath accidentally dislodges out of the CFA.

Retrograde access

Retrograde access has revolutionized the treatment of CTO lesions in the lower extremities. Lesions that cannot be crossed in the antegrade direction often can be relatively easily crossed in the retrograde direction. Retrograde access can also be very helpful when the occlusion is flushed at the origin of the tibial vessels, making the identification of the branch point impossible. Retrograde access can be established in the foot arteries (dorsalis pedis, plantar artery, and first dorsal metatarsal artery), tibial and peroneal arteries, popliteal artery, and SFA. The pedal artery can also be cannulated in antegrade direction, and the wire can be navigated through the pedal plantar arch to reach the tibial artery in a retrograde fashion. The popliteal artery can be accessed through the anterolateral, medial, and posterior approaches. The posterior approach has the inconvenience of having to turn the patient to a prone position or having the leg in a “frog position” for puncture. The anterolateral approach has the advantage of performing the puncture in the normal supine position. The C-arm is positioned in the ipsilateral oblique projection to allow adequate separation of the tibia and fibula with the popliteal artery away from bony structures. A 21G 7-cm needle is aligned with the below-the-knee popliteal artery and punctured through the interosseous membrane to reach the popliteal artery. An intermittent orthogonal view is obtained to check the depth of the needle during the puncture.

Tibial artery retrograde puncture can be guided by either ultrasound or fluoroscopy. Ultrasound-guided puncture is easier for superficial vessels, although the presence of hematoma may make images difficult to interpret. Fluoroscopy has the disadvantage of radiation exposure, especially to the hands and fingers; however, the images are not affected by hematoma. Digital subtraction images are not generally helpful in retrograde puncture of tibial vessels, as any movement of the leg will result in severe degradation of images. Real-time non-subtracted angiography images are usually used to guide the puncture. Vessels filled with contrast can be seen indented by the needle as the needle punctures the artery. An occlusion balloon can be placed in the popliteal position to allow a fairly static column of contrast to outline the artery and to allow more time to puncture the artery. Access to the distal anterior tibial artery or the dorsalis pedis artery can be assisted by plantar flexion, and access to the posterior tibial artery can be assisted by dorsiflexion. These maneuvers straighten the path of the artery and also reduce the mobility of the artery. The tibial artery is often very calcified and difficult to puncture, as the needle causes the artery to move and roll around. This can be assisted by fixation of the artery with two extra needles placed in a cross configuration beside and underneath the artery to be punctured.[9] A deeper tibial artery that is calcified can present significant resistance to a 21G needle, causing the needle to bend while it penetrates the wall of the artery. This can be prevented by placing the 21G needle coaxially through a shorter 18G needle. Tibial artery access near the ankle region can be used as a last resort through open surgical exposure of the artery. The arteries near the ankle are relatively superficial and therefore can be surgically exposed through a small incision. Doppler ultrasound can be used to locate the artery before the surgical exposure. Finally, if there is a very long-segment CTO, such as one that involves the femoral popliteal segment and tibial arteries concurrently, the CTO can be tackled in a segmental fashion with multiple access points in the leg.

Lesion crossing

Many commercially available crossing devices have been recommended as specialist CTO crossing devices. These devices are often expensive and not necessarily available in many countries. This review will concentrate on using a wire and catheter support system for crossing the lesion.

Intraluminal tracking

Intraluminal tracking is the preferred approach for crossing the lesion in arterial occlusive disease. Arterial stenosis is generally easily crossed with a guidewire with a hydrophilic coating, such as V18 or Command wire. Tight stenosis is best crossed with a 0.018- or 0.014-in guidewire. A 0.014-in wire has a smaller profile and allows crossing very tight stenoses; however, it does not provide as good a support for the subsequent delivery of balloon, stent, or atherectomy device as the 0.018-in wire. A 0.035-in wire is best avoided, as this is too large for the stenosis and can cause complete occlusion of the stenosis. To achieve the best results with intraluminal tracking, the guidewire tip should be shaped with a 30° bend 1 mm from the tip (Figure 5). The guidewire should be gently rotated alternately clockwise and counterclockwise to navigate through the lesion. Significant bending of the guidewire tip should be prevented during the crossing. The author uses a tri-axial system consisting of a long 6F 55-cm sheath and a 4F 100-cm Bernstein catheter (Cordis) with a Tuohy-Borst connector at the end (Figure 6). A 2.3F or 2.6F 150-cm CXI catheter (Cook Medical) can be inserted coaxially through the 4F Bernstein catheter to provide maximum support for the guidewire. A small amount of contrast (1–2 mL) can be used to check the position of the wire without removal of the guidewire if a 0.018-in wire is used inside the 4F catheter; however, this is not possible if the 2.6F CXI catheter is also inside the Bernstein catheter. The 4F Bernstein catheter and 2.6F CXI catheter should be moved stagewise as close as possible to the tip of the guidewire, to support the guidewire during the crossing.

It is often possible to cross the CTO through intraluminal tracking if there is no significant calcification or complete obliteration of the artery (scarring after vessel thrombosis). A CTO often has internal microchannels that allow the passage of a 0.014- or 0.018-in wire. As microchannels within CTO lesions are not linear structures, the use of a CTO wire that can navigate through microchannels, fibrous tissue, and plaque consisting of lipid and calcium is optimal. The author prefers the Astato 20 and 30 wires for this purpose. The CTO wire should be shaped similarly, with a 30° bend 1 mm from the tip. A two-handed approach is required for this maneuver, with the left hand advancing and retracting the wire a few millimeters at a time and the right hand gently rotating the guidewire alternately clockwise and counterclockwise. The CTO guidewire is exchanged for a floppy-tip 0.018- or 0.014-in guidewire after crossing the lesion, to avoid damage to distal normal vessel.

Subintimal crossing

Subintimal crossing is used when intraluminal crossing has failed, and may be considered a first-line approach if the lesion is calcified and long. A small amount of contrast can be used to check the progress along the subintimal plane. The contrast should be completely aspirated after checking. Large amounts of contrast should be avoided especially near the re-entry zone, as this can cause compression of the distal true lumen, making re-entry into the true lumen difficult. The track should not be dilated before re-entry into the distal true lumen. Balloon dilatation of the subintimal track can result in blood flow into the subintimal channel, causing distal true lumen collapse. The author, however, occasionally dilates the subintimal track with a small 3mm balloon before re-entry into the distal true lumen because there is significant difficulty in crossing a subintimal plane from extensive calcification impeding the movement of the support catheter and guidewire. A tri-axial support system consisting of a 6F sheath (55 cm), coaxial 4F sheath (90 cm), and 4F Bernstein (100 cm) catheter with a stiff Glidewire can be used to cross a difficult-to-cross subintimal track. Spontaneous re-entry into the distal true lumen is often achieved with a soft Glidewire, V18 wire, or 0.018-in Command-ST wire. The wire needs to be gently rotated to keep the subintimal loop small while the wire is being pushed through the occlusion toward the distal true lumen. A stiff Glidewire should be avoided when approaching the distal re-entry site, as it can result in vessel perforation. The personal preference of the author is the 0.018-in Command ST wire, as the tip of this wire is resistant to damage and the wire can easily navigate through the distal true lumen without damaging the true lumen. The wire position in the distal true lumen should be checked before balloon angioplasty or stent implantation. This can be performed by injecting a small amount of contrast after wire removal. Alternatively, the position of the wire can be checked by injecting contrast from the sheath in two orthogonal projections.

Re-entry into the true lumen

In a small proportion of patients, distal true lumen re-entry could not be achieved. Several strategies can be used to re-enter the distal true lumen. An Outback re-entry catheter (Cordis) and Pioneer re-entry catheter (Philips) can be used. These re-entry devices have a curved needle that allows a sharp puncture back into the true lumen. The Outback re-entry catheter uses fluoroscopy to guide needle re-entry, whereas the Pioneer re-entry catheter uses intravascular ultrasound (IVUS) to guide re-entry. The IVUS is incorporated into the re-entry catheter. It can visualize the thickness of the subintimal membrane between the true lumen and the false lumen, and allows making a re-entry puncture in a location with the least calcification and where the subintimal membrane is the thinnest. Optimal functioning of the re-entry catheter requires support of the subintimal space to allow puncture back into the distal true lumen. The subintimal space therefore needs to be small for effectively supporting the re-entry catheter. An aggressive attempt to re-enter the distal true lumen with a wire, especially the 0.035-in Glidewire, followed by use of the re-entry device is not likely to be successful. An alternative technique (snare loop puncture technique) has been described by a Spanish group (Figure 7).[10] A 5-mm goose neck snare is placed in the subintimal space after a failed re-entry into the distal true lumen. Thereafter, an 18G or 21G needle is used to puncture through the distal true lumen and through the snare, and a 0.018-in V18 wire is placed through the needle. The needle is then withdrawn while leaving the wire in place. The snare is closed, and the V18 wire is externalized through the femoral sheath. A 4F Bernstein catheter is advanced over the V18 wire to reach the distal true lumen. Once the catheter is inside the distal true lumen, the V18 wire is removed and a new wire is placed through the Bernstein catheter from the antegrade direction to reach the distal true lumen.

The retrograde technique for crossing CTO lesions has improved the CTO crossing rate to nearly 100%. In a small percentage of patients, crossing the CTO remains problematic despite the use of both antegrade access and retrograde access. This is because the antegrade and retrograde wires are in different subintimal planes; thus, the two subintimal planes are not connected. Several techniques can be utilized to connect the two subintimal planes. Two balloons, one each in the antegrade and retrograde channels, can be used to disrupt the subintimal membrane. The balloon ends should be placed with a 1–2 mm gap. The wires will also need to be withdrawn from the ends of the balloon before inflation. Failure to do so will result in failure of the balloons to disrupt the subintimal membrane, as the movement of the balloons are restricted by the wires.

Combined use of a re-entry catheter with a retrograde or antegrade balloon or snare can also be an option in the event that a kissing balloon is not able to disrupt the subintimal membrane. The re-entry catheter is used to puncture the inflated balloon or snare, and a 0.014-in wire, such as V14, can be advanced into the balloon or snare and brought into the distal true lumen, thereby achieving CTO crossing.

The gun-sight technique is a powerful technique that allows two separate subintimal planes to meet (Figure 8).[11] Two 5-mm snares are used, one each in the antegrade and retrograde directions. A 21G long needle is used to traverse both snares after both snares have been lined up as a single target for the needle. The needle passes through both snares, and a 0.014-in Terumo Glide Advantage wire is passed through the needle back end first. The needle is then withdrawn from the wire and the relatively flexible back end of the 0.0140-in Terumo Glide Advantage wire is externalized at the CFA. The floppy end is externalized at the distal access sheath, thus achieving through-and-through access.

Crossing a stent

A stent previously placed in a leg presenting for CTO intervention is not uncommon. In such cases, the stent is often occluded and needs to be recanalized. The best way to cross an occluded stent is to push forward a wire with a J-tip formed at the end once it has entered the stent lumen. This will prevent the wire from going through the interstices of the stent. It is sometimes necessary to directly puncture the stent in a retrograde fashion to allow access to the occluded stent lumen. This is best accomplished with a 18G needle and a stiff Glidewire for an SFA stent. A stent in the below-the-knee position should be punctured with a 21G needle in combination with a V18 wire. The stiff wire allows sufficient support for placement of a 4F sheath or a micro-puncture sheath.

Lesion preparation and treatment

Treatment of peripheral arterial lesions has undergone significant changes in the last few years. The current trend is to perform atherectomy followed by drug-coated balloon angioplasty, and to insert a stent only if there is significant dissection or residual stenosis. Atherectomy can be performed with laser, directional atherectomy device, or rotational atherectomy device. All these devices remove a certain amount of plaque and modify the plaque, allowing easier balloon angioplasty of the lesion. There is less dissection observed following balloon angioplasty after atherectomy. Stent placement is still required in a small proportion of patients. Most atherectomy procedures have a potential risk of embolization, especially in long lesions. Placement of a filter is advisable when treating long lesions even with devices that aspirate simultaneously, such as the Jetstream atherectomy device.

Balloon angioplasty is still the mainstay of treatment of peripheral arterial lesions. Calcified lesions may impede the crossing of a balloon catheter, thus hindering the angioplasty procedure. A low profile short and small 2 × 40-mm balloon can be used to predilate difficult-to-cross lesions, and follow by angioplasty with a larger-diameter balloon sized to the artery. The balloon should be pushed forward with a slight jabbing motion, as static friction is a greater stopping force than kinetic friction. Strong support is required for the balloon to cross a difficult-to-cross lesion. This can be achieved with a 4F sheath that is longer than the outer 6/7F sheath placed coaxially. The balloon placed inside the 4F sheath will have strong support for crossing the lesion.

Two wires can be placed side by side across the lesion, and "seesaw balloon dilatation" with the leading edge of the balloon can help the balloon in crossing the calcified lesion. Other methods that can be used to modify a calcified lesion in order to allow balloon crossing includes gradual dilation with a tapered low-profile crossing microcatheter (e.g., CXI, Cook Medical; VIANCE, Medtronic), rotational atherectomy (e.g., Jetstream), excimer laser atherectomy device (e.g., Turbo Elite, Spectranectics), and lithoplasty device (e.g., CROSSER CTO crossing catheter, Bard). Pickling is a technique that uses the back end of the wire to jack hammer the calcified lesion in order to modify the lesion. Similarly, external piercing of a calcified plaque with an 18G or 21G needle can modify the plaque to allow balloon crossing and, thereby, balloon angioplasty. The needle is poked and rotated into the lesion at multiple locations to cause fracture of the calcified plaque in multiple locations.

Stent placement is performed when balloon angioplasty yields a suboptimal response. Calcified lesions can be modified before angioplasty with rotational, directional, or laser atherectomy devices. Intravascular lithoplasty (Shockwave Medical) also induces multiple fractures in the calcified plaque, thereby modifying the plaque. A cheaper alternative is the PIERCE technique, in which a needle is used to create fractures in the plaque. Some lesions can still be resistant to angioplasty despite the availability of lesion-modifying equipment and techniques. In lesions resistant to angioplasty in which the calcified plaque could not be modified, the plaque/vessel can be intentionally ruptured with a balloon-expandable covered stent and relined with the SUPERA stent (Abbott) once an adequate diameter has been achieved.

When to stop & fight another day?

Lower-limb arterial interventions can be complex procedures requiring many hours of surgery. Termination of the procedure should be considered if the patient is uncomfortable under local anesthesia. It is better to stop, think, and plan for reintervention in this scenario. An uncomfortable patient is likely to move and cause problems with imaging, thus making the procedure extraordinarily difficult. The procedure may have already required the use of large volumes of contrast, which has the risk of causing acute kidney injury. Pedal arch intervention is best staged, as there are many anatomical variations that will need to be carefully studied before the procedure. Planning an intervention not only involves understanding the anatomy and the lesion, but may also require ensuring the availability of the appropriate equipment for the procedure. The patients' medical comorbidities and how these influence the outcome should be factored into the decision-making process, and appropriate treatment goals need to be clearly established before starting the intervention.

Conclusion

Interventions for peripheral arterial disease have significantly developed over the last few years. Many technical advances have been made, leaving very few CTO lesions that cannot be treated with an endovascular approach. Complex endovascular procedures require careful planning for a successful treatment.

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