The world is facing an epidemic of diabetes, consequently in the next years critical limb ischemia due to diabetic artery disease will become a major issue for vascular and endovascular operators. Revascularization is a key therapy in these patients because reestablishing an adequate blood supply to the wound is essential for healing avoiding a major amputation. In this paper, we summarize our experience in endovascular treatment of diabetic critical limb ischemia, focusing of the main technical challenges in treating below-the-knee vessels. We describe the following topics: 1) targets of the revascularization therapy: "complete" versus "partial" revascularization and the concept of wound related artery. Every procedure must be tailored on technically realistic strategies and on the general patient status; 2) the antegrade femoral access using both, the X-ray and the ultrasound guided techniques; 3) the chronic total occlusions crossing strategy proposing a step-by-step approach: endoluminal, subintimal, retrograde approaches. Particular attention has been given to the different retrograde approaches: pedal-plantar loop technique, trans-collateral approaches and the different types of retrograde puncture. For each step we provide a complete description of the technical details and of the suitable devices. Eventually we in brief describe: 3) acute result optimization and 4) prevention of restenosis.

Key words: Diabetes mellitus - Critical limb ischemia - Angioplasty.

The world is facing an epidemic of diabetes, consequently in the next years critical limb ischemia (CLI) due to diabetic artery disease will become a major issue for vascular and endovascular operators.\textsuperscript{1, 2} Revascularization is a key therapy in these patients because reestablishing an adequate blood supply to the wound is essential for healing avoiding a major amputation.\textsuperscript{3, 4} The obstructive atherosclerotic pattern of CLI in diabetic patients is characterized by a multilevel disease, specific involvement of below-the-knee (BTK) arteries, calcifications and prevalence of chronic total occlusions (CTOs) over stenosis.\textsuperscript{2, 6} Due to the prevalent involvement of BTK vessels disease in diabetic patients, this review will basically focalize on BTK vessel angioplasty. Concomitant neuropathy is frequent in diabetic CLI leading to reduced pain perception, for this reason the majority of diabetic patients with CLI come too late to vascular consultation, presenting with gangrene and/or infection.\textsuperscript{7} Diabetic patients with CLI have multiple comorbidities such as coronary heart disease and renal failure,\textsuperscript{4, 8} consequently CLI in diabetics is often a dramatic condition, jeopardizing not only the limb but also the life of the patient. The first imperative of revascularization is to tailor the procedure on the patient, balancing between two sometimes conflicting principles: on one hand revascularization must be as complete as possible, using all the techniques and devices able to guarantee the best and durable blood supply to the wounds; on the other hand the procedure must be as “soft” as possible, reducing to the minimum the
patients’ stress, contrast dye administration, fluid infusion, and respecting the extreme fragility typical of CLI diabetic patients.

**Targets of the revascularization therapy**

Peregrin et al. analyzed the clinical success of percutaneous transluminal angioplasty (PTA) in diabetic patients with CLI taking into account the number of BTK vessels successfully treated. They found that “complete” revascularization is better than “partial” revascularization: limb salvage rate at one year increased from 56% without direct blood flow to the foot (0 BTK vessels open), to, respectively, 73%, 80% and 83% with 1, 2 or 3 BTK vessels open.

Faglia et al. also demonstrated that PTA of tibial arteries had a better outcome than PTA of the peroneal artery alone. Healing is a blood flow dependent phenomenon and the first principle guiding our revascularization strategy must be giving to the foot the best possible blood supply (Figure 1).

Another emerging concept is the “wound related artery” (WRA) revascularization: following the angiosome concept, a successful angioplasty of the artery directly feeding the wound region leads to higher rate of limb salvage and wound healing. Neville demonstrated that revascularization of the artery directly feeding the ischemic angiosome leads to a higher rate of healing and limb salvage. This appealing concept must be cautiously apply for many reasons:

1. not every wound, especially in case of deep infection, is confined into a single angiosome space; patients with extensive tissue damage who are candidates to forefoot amputations (rays, transmetatarsal, Lisfranc, Chopart amputations) cannot be classified on the basis of an angiosome-oriented revascularization. Forefoot amputations often inter-
rupt the perforating metatarsal branches connecting the dorsum and the plantar vessels, separating the two systems: in these cases the revascularization should be as complete as possible, supporting the surgical wound healing;

2. direct revascularization could have a different value depending on the presence or not of a good distal distribution network. Varela et al. demonstrated that the restoration of blood flow to the ulcer through collateral vessels (pedal and distal peroneal branches) provided similar results to those obtained through its specific source artery in terms of healing and limb salvage. Figure 3 shows a single residual BTK vessel, a peroneal artery, providing optimal distal collateralization to the foot with intense tissue blush in the heel ulcer. On the other hand patients with diffuse disease of the small distal vessels (diabetic and end-stage-renal-disease patients, see Figure 2) could need for healing a direct blood flow to the WRA; 

3. all of the studies comparing direct and indirect revascularization are retrospective: we can assume that the operators focused on traditional optimal technical targets rather than the WRA but we don’t know if the same patients would have been technically revascularizable following an angiosome-oriented approach. It is possible that in the “indirect revascularization” groups there was a propensity to collect patients with the most technically challenging disease and the differences in the outcomes may simply reveal basal differences in the extend and type of obstructive disease.

Table I summarizes the concept of complete and WRA revascularization. Complete and WRA revascularization must not be uncritically pursued: the procedure must be tailored on technically realistic strategies and on the general patient status.

The antegrade femoral access

In the majority of diabetic patients with CLI, the obstructive disease involves below-the-groin vessels, sparing the iliac and the common femoral artery (CFA) and enables the antegrade femoral approach. In diabetic CLI this is the favored approach because
it provides adequate device control, maximizes angiographic resolution, and enables access to foot vessels to achieve complete and WRA revascularization.\textsuperscript{10, 24, 25} Despite these positive characteristics of the antegrade access, the controlateral approach is still considered by many Authors the standard approach because the antegrade access is more technically demanding; it is fraught by an increased risk of access site failure or complications and requires an adequate learning curve.\textsuperscript{26-29} The antegrade femoral puncture can be in the CFA or in the proximal superficial femoral artery (SFA) without an increase in morbidity.\textsuperscript{30}

**X-ray guided technique**

Our experience with the antegrade femoral puncture as first choice approach in below-the-groin vessel disease started in 2000. In the very first 1012 cases performed in the period 2000-2008, we had 27 major complications (2.7%): 25 hematomas requiring blood transfusion (17 groin hematomas, 6 retroperitoneal hematomas, 1 abdominal wall hematoma, 1 scrotal hematoma), one SFA pseudoaneurism, and one acute CFA thrombosis; 7/27 of these complications required surgical treatment (Table II), while the others 20/27 were successfully managed by medical treatment. Figure 4 shows our learning curve, demonstrating that starting without the supervision of an operator with anterograde expertise needs about 200 cases to lower the complication rate to

<table>
<thead>
<tr>
<th>Targets in CLI revascularization.</th>
<th>Medical treatment</th>
<th>Surgical treatment</th>
<th>Puncture above half line of the femoral head</th>
<th>Puncture below half line of the femoral head</th>
</tr>
</thead>
<tbody>
<tr>
<td>Complete revascularization</td>
<td>1 vessel better than 0</td>
<td>2-3 vessels better than 1</td>
<td>Tibials better than peroneal</td>
<td></td>
</tr>
<tr>
<td>Wound related artery revascularization</td>
<td>Direct revascularization, bypass or PTA, better than indirect revascularization</td>
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</table>

**Table I.**

**Table II.**—Major complications of 1012 procedures (2000-2008 years).

<table>
<thead>
<tr>
<th>Complication</th>
<th>Medical treatment</th>
<th>Surgical treatment</th>
<th>Puncture above half line of the femoral head</th>
<th>Puncture below half line of the femoral head</th>
</tr>
</thead>
<tbody>
<tr>
<td>Groin hematoma</td>
<td>14</td>
<td>3</td>
<td>4</td>
<td>13</td>
</tr>
<tr>
<td>Abdominal wall hematoma</td>
<td>1</td>
<td>-</td>
<td>1</td>
<td>-</td>
</tr>
<tr>
<td>Scrotal hematoma</td>
<td>-</td>
<td>1</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Pseudoaneurism</td>
<td>-</td>
<td>1</td>
<td>-</td>
<td>1</td>
</tr>
<tr>
<td>Retroperitoneal hematoma</td>
<td>5</td>
<td>1</td>
<td>6</td>
<td>-</td>
</tr>
<tr>
<td>Acute femoral thrombosis</td>
<td>-</td>
<td>1</td>
<td>-</td>
<td>1</td>
</tr>
<tr>
<td>Total</td>
<td>20</td>
<td>7</td>
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standard levels.⁴⁻²⁸ Figure 5 shows the complication rate according to the size of the introducer sheath. The analysis of these complicated cases showed a strong relation with the puncture site (Figure 6) indicating an X-ray guided puncture as a correct approach in reducing complication rate.⁴⁻³³ A too high puncture is highly problematic for manual compression hemostasis because the CFA is going deeply

![Figure 4.—Antegrade femoral approach complications.](image1)

![Figure 5.—Antegrade femoral approach complications according to sheath size.](image2)
into the external iliac artery and the puncture may be above the inguinal ligament, which represents the best barrier against retroperitoneal bleeding. A too low puncture into the SFA can impair manual compression hemostasis because the artery is going deeply into the muscle and is not surrounded by the connective groin tissue that is the best environment for a fast and sure hemostasis. Table III summarizes our standard approach to antegrade femoral artery puncture: the combination of fluoroscopy to identify entry point and soft tissue compression to improve puncture geometry are critical for a safe femoral arterial access.  

In the antegrade femoral approach our standard sheath introducer system is a 4 French, highly flexible and unkinkable sheath, 11 cm long (Avanti®, Cordis, USA). Only in case of heavy calcified BTK vessels where the balloons are unable to cross the lesion we exchange the short sheath with a 90 cm long, 4 or 5 French, hydrophilic sheath (Flexor® Shuttle SL, Cook Medical, USA) advancing the distal sheath tip as close as possible to the uncrossable lesion to increase the pushability and crossability of wires and balloons (Figure 7).

The antegrade femoral access: ultrasound guided technique

Yeow et al. primarily described antegrade puncture of the CFA using ultrasounds (US). Ultrasounds allow recognizing anatomical variations and atheromatous disease involving the CFA bifurcation and the proximal SFA and deep femoral artery (Figure 8). The US guided technique permits to identify the correct arterial puncture site, guiding the needle during puncture and the selective wiring of the SFA.

Marcus et al. demonstrated that antegrade puncture of the SFA under US guidance is an excellent technique in patients with “hostile groin”, obesity or scarred groin, reducing fluoroscopy time, radiation burden and vessel complications.

Finally, an accurate selection of the puncture site,
proach, subintimal, trans-collateral, pedal-plantar loop technique and retrograde puncture of the vessel beyond the CTO. Figure 9 summarizes the role of these different techniques in a step-by-step approach.37

Table III.—X-ray guided antegrade femoral puncture.

| Groin evaluation and local anesthesia | – Accurate palpation of the groin in order to identify the inguinal ligament and the best femoral pulse
| – Take time to examine the groin of the patient: identify the best target
| – In case of obesity, a bandage is passed around the abdomen and retracted in order to enable a better access to the groin.
| – Move the skin under your fingers: try to avoid too much tissue between your needle entry point and the artery
| – Do local anesthesia exactly where you want to do the antegrade puncture: begin at the distal edge of the inguinal ligament in direction of the distal region
| – Let the needle in place as a marker for X-ray evaluation
| X-ray evaluation | – Check with X-Ray the needle position in relation with the femoral head
| – Use an antero-posterior projection
| – Your target is near the inferior edge of the femoral head
| – The artery is often visible due to calcification and the procedure can be done under fluoroscopy
| – Take care to avoid exposition of your fingers under the direct X-ray beam
| Needle puncture | – Puncture the artery with an angiographic 19 Gauge needle
| – Make a little skin cut using the tip of the scalpel where you want to insert the needle, so to have the needle movements free
| – Remember that when the needle is >3 cm deep you probably have crossed by side the SFA and are close to the deep femoral artery
| Wire advancement | – Try to advance a 0.035” atraumatic wire with a 45° angulated soft tip. Do not use a straight or a U shaped tip wire.
| – Check the wire movements using an omolateral oblique view 25°-30°: this projection generally opens the common femoral artery bifurcation
| – Be delicate and careful: try to engage the SFA using a combination of needle angulation (upward, downward, left, right) and wire manipulation
| – In case of doubt take a bare needle angiogram of the femoral bifurcation slowly injecting few mL of diluted contrast dye; avoid strong injection!
| – The puncture can be into the CFA or the SFA: in this case it is important not to have disease immediately above the entry point
| Sheath positioning | – When the wire is into the SFA advance a 4 French sheath
| – Use a very flexible sheath because the sheath often undertakes a “U” shaped position and most of the sheaths kink
| – Inject slowly one mL of contrast dye to check your position: in case of proximal SFA disease, the sheath could be entrapped into a closed endoluminal space. In this case let the wire inside the sheath to maintain position, withdraw the sheath to the femoral bifurcation and take a picture of the vascular anatomy
| – Remember that you are injecting contrast dye into the SFA: in case of distal obstruction the injection must be strong in order to give contrast dye backward into the profunda femoris and internal iliac, because collaterals to the distal vessels could come from these arteries
| Closure technique | – In the majority of the patients, the procedure can be concluded maintaining the 4 French sheath approach: in these cases the hemostasis is always obtained using manual compression
| – An upgrade to bigger size sheaths (6-8 French) is necessary only in case of thromboaspiration, treatment of popliteal artery bifurcation using the kissing balloon technique, atherectomy and deployment of 6-8 French compatible stents. In this cases the bigger sheath is positioned not necessarily through the 4 French sheath site, but where the vessel diameter is ≥ 6 mm, in order to close the procedure using a closure device (Angio-Seal™ STS Plus, St. Jude Medical, USA)

Table IV summarizes our standard approach to US-guided antegrade femoral access.

avoiding atheromatous plaques, is an important requisite to deploy safely a closure device (Figure 8). The CTOS crossing strategy: a step-by-step approach

The first step in percutaneous recanalization is to cross the long CTOs typical of diabetic CLI. Different techniques are now available: endoluminal approach, subintimal, trans-collateral, pedal-plantar loop technique and retrograde puncture of the vessel beyond the CTO. Figure 9 summarizes the role of these different techniques in a step-by-step approach.37

The exploring system

It is incorrect to indicate a single type of catheter or wire as a systematic approach, because every operator can be familiar with different diagnostic and support catheters and wires and the same task can
be done using different devices, depending on the operator’s experience. Therefore, the following description merely reflects our personal experience.

Our standard approach resembles the traditional coronary angioplasty method: the guiding catheter is substituted by a hydrophilic, 4 French, 100 cm long, diagnostic, Berenstein catheter (Tempo® Aqua, Cordis, USA). The proximal luer lock of the Berenstein catheter is connected to a standard Y-shaped connector, the other luer lock of the Y-shaped connector is connected to a stopcock and a syringe for contrast injection. Using an inserter, several types of 0.014” and 0.018” wires can be inserted into the catheter and advanced into the vessel tree (Figure 10). Sliding on the wire the Berenstein catheter is advanced to the proximal edge of the stenosis or the CTO. In the proximal arched segment of anterior tibial artery a gentle rotation and push of the Berenstein catheter generally permits the crossing of the bends and the distal advancement of the catheter.

Small injections of diluted contrast dye (1-2 mL) through the lateral side of the Y-shaped connector obtain highly selective angiographic images of the vessel around the distal catheter tip, orientating our

Figure 7.—Example of use of a long sheath for uncrossable lesion. A) Basal angiographic study: the target lesion is a short occlusion of mid-anterior tibial artery (gray arrow); B) a low profile, one marker, over-the-wire balloon is unable to cross the lesion (black arrow); observe how, pushing the balloon, the shaft loses force in the anterior tibial bend (white arrows); C) a 90-cm long, 4 French sheath was positioned above the lesion, now the balloon is able to cross easily the thigh occlusion (black arrow); D) final result after balloon angioplasty.
Figure 8.—Example of US-guided femoral puncture. A) Correct ultrasound scan plane shows the CFA and the femoral bifurcation; B) progression of the 19 Gauge needle (white arrowheads) in the soft cutaneous tissue; C) single-wall CFA (*) puncture; D-F) guidewire (*) deployment through the needle and selective SFA wiring; G-I) anchor deployment under US guidance (*).

Table IV.—Ultrasound guided antegrade femoral puncture.

<table>
<thead>
<tr>
<th>Description</th>
<th>Details</th>
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<tbody>
<tr>
<td>Ultrasound evaluation</td>
<td>The high-frequency (7.5-MHz) linear probe is covered with a sterile plastic cover and coupling gel inside. Sterile gel or saline can be applied outside of the protective covering as coupling agent</td>
</tr>
<tr>
<td>Local anesthesia</td>
<td>Local anesthesia is performed in the subcutaneous tissue under US guidance, through the supposed route of the needle</td>
</tr>
<tr>
<td>Needle puncture</td>
<td>The 19 Gauge needle is introduced, parallel to the US beam with a 45° angle, in order to visualize needle movements in real time. When needle reaches the vessel wall, a single-wall technique puncture is performed</td>
</tr>
<tr>
<td>Wire advancement</td>
<td>After the evidence of pulsatile arterial back-flow, a 0.035&quot; wire with a 45° angulated soft tip is inserted through the needle</td>
</tr>
<tr>
<td>Closure technique</td>
<td>At the end of the procedure, a closure device (Angio-Seal™ STS Plus, St. Jude Medical, USA) can be deployed avoiding manual compression. The US-guided closure device deployment guaranties the correct positioning of the distal anchor, avoiding atheromatous plaques</td>
</tr>
</tbody>
</table>
Figure 9.—Step-by-step approach in CTOs.

- Antegrade approach
  1. Endoluminal
  2. Subintimal

- Retrograde puncture
- Transcollateral
  1. Pedal-plantar loop technique
  2. Trans-collateral approach

Failure?

Figure 10.—The exploring system. A) 4 French, hydrophilic, diagnostic Berenstein catheter; B) Y-shaped connector; C) stopcock; D) syringe with diluted contrast dye; E) inserter; F) wire.

Figure 11.—Example of endoluminal approach in a long occlusion. A) Basal angiographic study: long occlusion of anterior and posterior tibial arteries; B, C) a 0.014” hydrophilic wire, supported by a Berenstein catheter, crosses the occlusion; D, E) the same wire is now supported by an over-the-wire, low profile balloon and reaches easily the open distal lumen; F) final result after balloon angioplasty.
crossing strategy. In case of failure of the Berenstein catheter in advancing into a diseased vessel or into a subintimal space the diagnostic catheter is replaced by a support catheter (CXI, Cook Medical, USA) or by an over-the-wire, low-profile, 0.014” balloon (Armada 14 XT, Abbott, USA).

Endoluminal approach

The endoluminal approach is our first line approach in every type of lesion, irrespective of the length of the lesion. It is often possible to cross very long BTK CTOs maintaining a likely endoluminal position (Figure 11). The operator must gently rotate and push the wire in an attempt to cross the lesion. The only explanation of the frequent success of this “sliding strategy” is the presence of a soft inner pathway into the occluded arterial lumen, surrounded by stiffer walls, where a soft tip, lubricious wire is able to cross.

Our first choice wire is a soft tip, 0.014”, hydrophilic wire (PT2™, Boston Scientific, USA; Hi-Torque Pilot 50-150, Abbott, USA). Recently a new family of 0.014” nitinol wires (Hi-Torque Command, Abbott, USA) have demonstrated, in our experience, a superior resistance to deformation reducing the mean number of wires used per procedure.

In case of failure (the wire is unable to advance or clearly goes into the subintimal space, collateral vessels or outside), we decided to change our strategy depending on the type and length of the lesion.

In case of short CTOs, where the distal open lumen is clearly visible few cm below, we prefer to pursue the endoluminal approach using the coronary parallel wires technique. We let the soft tip wire in place, in the wrong direction, and advance a new CTO dedicated, 0.014” wire (Conquest Pro, Hasahi, Japan). We change from a “sliding strategy” (the wire tip slides through the inner, tortuous, soft pathway, if present) to a “perforating strategy” (the operator directs the wire tip through the obstructing material towards the distal open lumen). In case of “sliding” the direction is determined by the vessel, in case of “perforating” the direction is given by the operator; using this technique multiple oblique views are necessary, multiple attempts, different wires and a lot of patience (Figure 12).

Figure 12.—Example of parallel wire technique in a short CTO. A) Basal angiographic study: the target lesion is a short CTO of anterior tibial artery; B) digital subtraction imaging of the CTO (white arrows); C) a 0.014” hydrophilic, soft tip wire, supported by a Berenstein catheter, goes in the wrong direction; D, E) a new CTO dedicated wire, parallel to the first one, crosses the occlusion; F) final result after balloon angioplasty.
In case of long CTOs, where the endoluminal attempt has clearly failed, we shift to the subintimal approach because it is quite impossible to cross long segments of vessel using a “perforating strategy”.

**Subintimal approach**

In case of failure of the endoluminal approach, the subintimal approach can be safely and effectively used in order to achieve a successful revascularization.\(^4\) The performance of a successful subintimal revascularization requires multiple steps:

1. identification of a “good distal target vessel”.

Similarly to the identification of a good landing zone for a distal bypass, subintimal angioplasty needs a good distal distribution system to maintain an adequate flow rate into the new subintimal lumen. This crucial step starts with the angiographic study of the foot vessels: the better the quality of the distal vessel, the greater the chances of a successful recanalization.\(^4\) An adequate imaging of the distal vessels

Figure 13.—Examples of extreme subintimal angioplasty. A) Basal angiographic study: “desert foot” only a tarsal artery and a faint image of the plantar arch is visible; B-D) subintimal loop technique in plantar arteries (0.035” Terumo wire); E) the Berenstein catheter arrived at the distal plantar arch; F) balloon dilatation; G) final result after balloon angioplasty.
can be difficult to obtain, especially in patients with multilevel vessel disease. In these cases very long X-ray movies, waiting for late opacification and very distal injection through the exploring catheter at the ankle level can help in identifying a good distal target vessel. Lastly, we must consider that, unlike bypass surgery, in some cases the very distal plantar arch can represent a successful landing zone for a subintimal angioplasty.\(^{32-44}\) (Figure 13);

2. enter the subintimal space. When the selected artery presents a good stump, the access to the subintimal space can be done by pushing and rotating the Berenstein catheter and/or advancing the looped wire.\(^{45}\) This maneuver is not feasible in cases where the stump is very short or the ostium of the artery completely hidden. In these situations, a roughly pushing of the catheter or loop could damage the main artery. We prefer to cross the ostium of the occluded artery using a more delicate approach with CTO dedicated wires and parallel wires technique, shifting to the looped-wire technique only after definitive demonstration of the correct subintimal position of the wire (Figure 14);

3. dissection of the subintimal space. Once we
get into the subintimal space, our preferred strategy is to continue the dissection using the described Berenstein catheter supporting the 0.035”, hydrophilic, looped wire (Radiofocus® Guide Wire M, half stiff type, angled J, r:1.5 mm, Terumo, Japan), from SFA to BTK and foot vessels. This approach reflects personal habits because many operators prefer 0.018” wires (V-18™ Control Wire, Boston Scientific, USA) or 0.014” wires (Hi-Torque Pilot or Command, Abbott, USA), especially in the small BTK and foot vessels. It is important to maintain the loop short and thin. In case of difficulty in advancing the catheter, which may be entrapped into the thick subintimal space, the 0.035” is exchanged with a 0.014” wire, a low profile balloon is advanced and inflated to dilate the subintimal space. In some cases it is impossible to proceed with the loop, even applying some force; in this case one must retract the wire, change the position of the catheter tip and try to re-establish a new loop in another direction. Bifurcation can be treated changing the direction of the subintimal dissection (Figure 15);

4. re-entry into the true distal lumen. One of the major issues of the subintimal approach is how and where to re-enter into the true distal lumen, the main imperative being not to damage the healthy

![Figure 15.—Example of subintimal angioplasty of a bifurcation. A) basal angiographic study: BTK vessels occlusion; B) subintimal dissection of anterior tibial artery (0.035” hydrophilic wire); C) subintimal dissection of peroneal artery; D) subintimal dissection of posterior tibial artery; E) final result after balloon angioplasty.](image-url)
distal vessel, which might be the target for a surgical bypass. The traditional way to re-enter consists in a simple pushing of the looped wire towards the patent distal vessel. Bolia said “this is actually not a real step but only a phase that you are not able to control”. This blind maneuver is appropriate when the open distal lumen is far from a hypothetical landing zone of a distal bypass and there is not calcium or a very low calcium burden. In case of calcified vessel or poor landing zone or an open distal vessel suitable for a surgical anastomosis (popliteal, dorsalis pedis, distal posterior tibial arteries etc.) this maneuver can be dangerous due to the risk of dissecting and damaging the distal artery without entering into the true lumen and precluding a rescue bypass. In these cases we prefer to change approach using a CTO dedicate wire (Figure 16) or a retrograde approach (Figure 17).

**Retrograde approaches**

In some cases the antegrade approach of a CTO is unsuccessful basically because of these events: 1) inability to correctly identify the origin of an occluded tibial artery; 2) rupture or loss of the antegrade vessel pathway; 3) inability to re-enter into the true distal patent lumen due to limited distal “landing” zone or vessel calcification; 4) high risk to damage, continuing the antegrade subintimal dissection, the distal target vessel which could be the only landing zone of a distal bypass.

In these situations, the problem cannot be solved

![Figure 16.—Example of re-entry into the true distal lumen using a CTO dedicated wire. A) Basal angiographic study: posterior tibial artery occlusion; B) subintimal dissection of posterior tibial artery (0.035" Terumo wire); C) angiogram from the tip of the Berenstein catheter: the true lumen is very close to the subintimal space; D, E) a 0.014” CTO dedicated wire (Conquest Pro 12, Asahi, Japan) enters the true distal lumen; F) balloon dilatation; G) final result after balloon angioplasty: the distal healthy vessel was not touched.](image-url)
persevering with an antegrade approach, the only way is to switch to retrograde techniques. The technical options for retrograde approaches are different so, after a careful angiographic evaluation of the distal vessel network, we can choose to apply the pedal-plantar loop technique, the transcollateral approach or a retrograde puncture.

Once applied a retrograde approach, the main problem is the rendezvous with the antegrade approach, because different subintimal planes can separate the antegrade and retrograde wires. The Safari technique and the kissing antegrade and retrograde balloon technique 49-51 can help in connecting the two opposite approaches.

**Pedal-plantar loop technique**

The pedal-plantar loop technique is based on the creation of a loop from the dorsal to the plantar circulation (or vice versa) by means of the wire and balloon tracking through the pedal arch of the foot.52, 53 The aim of the technique is to restore a direct ar-

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**Figure 17.—Example of respecting the distal landing zone using a retrograde approach.** A) Basal angiographic study: the “good distal target vessel” is the dorsalis pedis artery, which is supplied by a tortuous hypoplastic anterior tibial artery; B) subintimal dissection of the anterior perforating branch of the dominant peroneal artery: the loop is into the subintimal space; the calcifications reduce the probability to re-entry into the true lumen with high risk of dissection and damage of the dorsalis pedis; C) retrograde puncture of the proximal dorsalis pedis; D) reverse to antegrade approach and distal angiogram injecting from the tip of the balloon catheter: dorsalis pedis is perfect, the only sign of the retrograde puncture is the leaking from the small hole (black arrow); E) final result after balloon angioplasty: the distal healthy vessel was not touched.
terial in-flow from both tibial arteries achieving a complete BTK and below-the-ankle revascularization. Before apply the loop technique the operator must carefully analyze the vascular situations from a pathophysiological point of view.

It is essential to emphasize that a direct blood flow through one tibial artery with a good distal distribution system into the foot vessels can be a good and conclusive result of the revascularization for the majority of the patients and that a good distal distribution system must always be respected and, if possible, not touched. The prosecution of the procedure with complex techniques aimed to an extra-improvement of the blood supply must be cautiously considered: the benefit of opening the opposite tibial vessel must be balanced with the risk of damaging, crossing with wires and balloons, the forefoot distribution system.

A different situation is the diffuse disease involving the foot vessels (desert foot), typical of diabetic and end-stage-renal-disease patients, where opening the distal distribution system, if possible, becomes essential for wound healing.

The technique consists in one of the following approaches: 1) antegrade recanalization of the anterior tibial artery and the pedal artery, including the pedal arch, followed by retrograde recanalization of the lateral plantar artery and then of the posterior tibial artery (Figure 18); 2) antegrade recanalization...
of the posterior tibial artery and the lateral plantar artery, including the pedal arch, followed by retrograde recanalization of the pedal artery and then of the anterior tibial artery.

A combination of other technical possibilities, such as antegrade subintimal recanalization of the tibial artery followed by a re-entry on the foot artery or a retrograde subintimal recanalization of the

Figure 19.—Example of peroneal artery branches angioplasty. A) Basal angiographic study: the peroneal artery is the only open BTK vessel; after failure of treatment of anterior and posterior tibial arteries we decided to treat the anterior perforating branch of peroneal artery; B) lateral projection demonstrating a thin vessel connecting peroneal and dorsalis pedis arteries (black arrows); C) antero-posterior projection: the collateral vessel is tortuous and gives blood to the dorsalis pedis and tarsal arteries; D) final result after balloon angioplasty.
foot and tibial arteries, followed by a re-entry at the origin of the tibial vessel, could help to reach both, technical and clinical success.

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 atherosclerotic disease, providing high rate of acute success, intended as the ability to cross the lesions and inflate the balloon, achieving adequate angiographic results, without periprocedural complications.

**Transcollateral approach**

In many cases of extreme vascular intervention, it is not possible to perform regular antegrade or retrograde recanalization of the occluded tibial and foot arteries. The only solution, if possible, is to recourse to unusual techniques as the transcollateral approach, consisting in using the natural vessel anastomoses to recanalize tibial or foot arteries.

Different collateral vessels can be used for this purpose:

1. the “deep arch” of the foot (interconnecting the medial plantar artery with the lateral tarsal branch) can be used to recanalize the dorsal or planter circulation or the pedal arch, through the tarsal branches;
2. distal peroneal artery branches can be used to reach tibial and foot arteries. It is important to note that angioplasty of a distal perforating peroneal branch can be sufficient alone to give a new direct blood flow line to an open foot vessel (Figure 19).

**Retrograde puncture**

This strategy consists in a direct percutaneous retrograde puncture of a distal patent vessel, followed by the insertion of wires and catheters with the aim to achieve the proximal open lumen were the antegrade approach failed. When antegrade and retrograde devices are connected, the procedure can continue with a standard antegrade angioplasty and hemostasis of the distal puncture site. A retrograde puncture can be done in every segment of the below-the-groin vessel, from the SFA to the foot vessels (Figure 20), providing good technical and clinical results.

Key points in retrograde puncture:

1. choice of the puncture site. Accurate angiographic evaluation using different oblique views is necessary to identify the best target vessel. Table V describes some radiological and technical details;
2. vasodilators. Especially for the distal vessels, the use of vasodilator (nitroglycerine, verapamil) is essential in avoiding spasm of the vessel. Vasodilators can be administered intra-arterially, as close as possible to the puncture site, and subcutaneously around the needle entry point;
3. puncture technique. The puncture is performed with a 21 Gauge needle, under fluoroscopic guidance with contrast medium injection and at the maximum magnification. Mustapha et al. described also the US-guided technique. The length of the needle must be chosen according to the depth of the target vessel (Table V). The operator must keep in mind the concept of parallax technique: the needle should be advanced by maintaining a perfect overlap with the target vessel (Figure 21). Once chosen the correct projection for the puncture, a 90° angulated projection can be useful to check the distance of the needle to the target vessel;
4. sheath. In SFA and popliteal artery a 4F sheath is sometimes necessary to permit retrograde approach with the support of a 4 French catheter. In BTK vessels we avoid standard sheaths and prefer to use a sheathless approach or the Micropuncture® Introducer Set (Cook Medical, USA), containing a micro sheath;
5. retrograde crossing strategy. Every 0.014” and 0.018” wire can be used for retrograde crossing of the CTO. We generally prefer to start with a 0.018” wire, because of the enhanced support, but other types of wires can be selected according to the different situations. Low profile, support catheters (CXI, Cook, USA) are very useful for wire support, orientation and exchange.

**Stent puncture**

In a long-term follow up the most important complication of stenting in the femoro-popliteal tract is the in-stent re-stenosis and occlusion. Many of these patients present recurrent limb-threatening ischemia or sever disability, requiring a new revascularization. Endovascular approach of in-stent occlusion is often difficult or impossible, due to inability to enter the true stent lumen. Using antegrade or retrograde technique the wire at the edges of the occluded stent can progress in the surrounding subintimal space, leading to the impossibility to intraluminally cross the occluded stent. This situa-
In these cases, the direct stent puncture technique can be an alternative solution for endoluminal stent recanalization, with a good acute result but an extraordinary metal and mechanical burden on the artery, precluding a good long term result.

This novel approach consists of a retrograde di-

Figure 20.—Example of retrograde puncture of metatarsal vessel. A) Basal angiographic study: stenosis in the middle tract of the anterior tibial artery, occlusion of the peroneal and posterior tibial arteries. On the foot, plantar arteries occlusion and dorsal tarsal branches with anatomical variation for the absence of the pedal artery; B) under fluoroscopic guidance retrograde puncture of the first dorsal digital branch and wire advanced into the lateral plantar and posterior tibial arteries; C) final result after balloon angioplasty: patency of the anterior tibial artery and posterior tibial arteries. On the foot, patency of the dorsal tarsal branches and patency of the lateral plantar artery, with direct blood flow to the forefoot.
Table V.—Retrograde approaches: technical tips.

<table>
<thead>
<tr>
<th>Artery</th>
<th>Preferred oblique view</th>
<th>Preferred segment</th>
<th>Skin puncture site</th>
<th>Needle length</th>
</tr>
</thead>
<tbody>
<tr>
<td>SFA</td>
<td>Controlateral, 30-45°;</td>
<td>Distal</td>
<td>Medial aspect of the thigh at the level of the</td>
<td>9-15 cm</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>superior edge of the rotula</td>
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</tr>
<tr>
<td>Popliteal</td>
<td>Antero-posterior</td>
<td>Medium-distal</td>
<td>Posterior aspect of the knee</td>
<td>7-9 cm</td>
</tr>
<tr>
<td></td>
<td>Maintain the supine</td>
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<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>position with the knee</td>
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</tr>
<tr>
<td></td>
<td>gently flexed and</td>
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<td></td>
</tr>
<tr>
<td></td>
<td>rotated</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Anterior</td>
<td>Omolateral 20-40°</td>
<td>Every segment</td>
<td>Antero-lateral aspect of the leg</td>
<td>4-7 cm</td>
</tr>
<tr>
<td>tibial</td>
<td>Lateral</td>
<td>Distal, retromalleolar segment, proximal plantar arteries</td>
<td>Medial aspect of the ankle</td>
<td>4-7 cm</td>
</tr>
<tr>
<td>Posterior</td>
<td>Omolateral 20-40°</td>
<td>Every segment</td>
<td>Antero-lateral aspect of the leg; the needle crosses the interosseus membrane</td>
<td>7 cm</td>
</tr>
<tr>
<td>tibial</td>
<td>Lateral</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Peroneal</td>
<td>Omolateral 20-40°</td>
<td>Every segment</td>
<td>Antero-lateral aspect of the leg; the needle crosses the interosseous membrane</td>
<td>7 cm</td>
</tr>
<tr>
<td></td>
<td>Lateral</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dorsalis pedis</td>
<td>Antero-posterior</td>
<td>Every segment</td>
<td>Dorsum of the foot</td>
<td>4 cm</td>
</tr>
<tr>
<td>Foot arteries</td>
<td>Antero-posterior</td>
<td></td>
<td>Dorsum of the foot</td>
<td>4 cm</td>
</tr>
<tr>
<td></td>
<td></td>
<td>– First metatarsal artery</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>– Tarsal arteries</td>
<td></td>
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<td></td>
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<td>– Collaterals</td>
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</tr>
</tbody>
</table>

Figure 21.—Example of retrograde puncture. A) Basal angiographic study: BTK vessel occlusion; B) loss of direction in the tibioperoneal trunk; C) retrograde puncture of the medial plantar artery; D) the needle enters the artery: observe the perfect overlapping between needle and artery; E) the wire advances into the artery; F-G) the wire enters the tip of the antegrade Berenstein catheter; H) final result after balloon angioplasty.
wire creating a looped tip, in order to avoid accidental extra-luminal passage through the struts or fractures. A 4 French, 10-12 cm long sheath is positioned. A 4 French diagnostic catheter and a loop shaped wire is retrogradely advanced into the occluded stent segment and the patent distal artery. No bleeding in the puncture site.

The patient is in a supine position with a standard antegrade or contralateral femoral approach; the skin area in correspondence of the stent is prepared for puncture. Under US (7.5 MHz, linear probe) and/or fluoroscopic guidance, a retrograde direct puncture of the occluded stent is performed (19 Gauge needle); different oblique projections are used to ensure that the needle tip is positioned precisely in the occluded stent lumen (Figure 22).

The operator inserts a 0.035” or 0.018”, non hydrophilic, angled wire and immediately manages the wire creating a looped tip, in order to avoid accidental extra-luminal passage through the struts or fractures. A 4 French, 10-12 cm long sheath is positioned. A 4 French diagnostic catheter and a loop shaped wire is retrogradely advanced into the occluded stent.

On approaching the antegrade catheter, the retrograde guide-wire is retrieved to straight the tip and engage the antegrade catheter. Once successfully engaged, the wire is externalized to the groin and, maintaining the wire under tension, the antegrade catheter is advanced to the distal sheath; a new 0,018” wire is antegradely inserted and advanced beyond the intra-stent sheath through the distal occluded stent segment and the patent distal artery.
Standard antegrade angioplasty follows inflating the intra-stent balloon for 5 minutes after removing the intra-stent sheath.

Direct stent puncture technique has demonstrated good technical (98.2%) and clinical (94.4%) success, with a low rate of complications (7.5%).

There are not studies comparing results using different inflation times in BTK vessel angioplasty. Bailout stenting in case of flow limiting dissection or poor result is recommended. Atherectomy, cryoplasty, laser, scoring balloons, cutting balloons, are all promising devices, which value have to be clarify, especially regarding the cost-to-benefit ratio.

Acute result optimization

Long, thin-profiled, high pressure balloons are the key point in BTK vessel angioplasty. Due to the extreme length of the BTK vessel lesion, we prefer long, tapered balloons (Amphirion Deep, Medtronic Invatec, USA). Traditionally a 1-2 minutes inflation is recommended, longer time in case of dissection.

Prevention of restenosis

Restenosis remains one of the main problems of percutaneous revascularization in below-the-groin vessels. Restenosis is higher for small arteries and long lesion, reaching a 69% rate in BTK vessel three month after PTA. Figure 23 shows

![Figure 23.—Mean length of the treated lesion in 27 studies regarding BTK vessel angioplasty. AMS: absorbable metal stent; BMS: bare metal stent; DEB: drug eluting balloon; DES: drug eluting stent; EES: everolimus eluting stent; PES: paclitaxel eluting stent; POBA: plain old balloon angioplasty; SES: sirolimus eluting stent; UB: uncoated balloon.](image-url)
the length of treated lesions in studies regarding the patency after BTK angioplasty performed with balloon expandable stents, nitinol self-expandable stents and plain old uncoated and drug-coated angioplasty balloons.\(^{15, 24, 75-98}\) All the studies involving stents have selected patients with very short lesions, completely different from the patients enrolled in studies concerning balloon angioplasty. The good results in terms of prevention of restenosis by stenting, particularly DES, are confined to short BTK lesions (<5 cm) that are a minority of the lesions seen in diabetic CLI patients. In long, diffuse lesions (majority of CLI patients), the optimal endovascular treatment remains the balloon angioplasty with dedicated BTK balloons and bailout stenting. In these type of lesions, DEBs are promising devices in the prevention of restenosis.\(^{97, 98}\)Apart from these data, it is well known that patency after BTK PTA and limb salvage are not strongly correlated\(^{99, 100}\) therefore further studies are needed to clarify the importance of BTK vessels patency in terms of wound healing time, re-ulceration rate, time-to-walking, target vessel revascularization and cost-to-benefit ratio.

References

25. Faglia E, Dalla Paola L, Clerici G, Clerissi J, Graziani L, Fusaro M. Peripheral angioplasty as the first-choice revascularization procedure in diabetic patients with critical limb ischemia: prospective study of 993 consecutive patients hospitalized and


57. Palena LM, Manzi M. Extreme below-the-knee interventions: retrograde transmetatarsal or transplant arch access for foot


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