Chapter 22
Ischaemic Foot: Endovascular Intervention in the Distal Arteries of the Leg and Foot

Riad Alchanan and Dean Y. Huang

22.1 Introduction

Diabetic patients with critical limb ischaemia (CLI) usually have significant multilevel arterial diseases. One of the features of diabetic patients with CLI is the predominance of diffuse obstructive lesions in the distal, sub-popliteal arteries [1–3], either in isolation or concomitantly with more proximal femoro-popliteal disease, and often with compromised outflow in pedal arteries. The combination of severe arterial occlusion in the small, distal arteries with the increased blood flow requirement, necessary to achieve the healing of skin lesions or surgical incisions, makes this population particularly challenging to treat, requiring coordinated care with multidisciplinary approach [4].

The optimal revascularisation strategy for this population of patients aims to restore a direct arterial inflow from principal circulatory pathways of the foot, achieving a complete below-the-ankle revascularization [5]. Diabetic patients with CLI have a high rate of comorbidities, which increase surgical risks. The introduction of endovascular procedures in the routine of vascular surgery allowed for the expansion of therapeutic options in the diverse areas of vascular disease. Endovascular revascularization has now been widely accepted as a first line choice to treat diabetic patients with CLI [6–8]. This strategy is based on the superior perioperative safety of results compared to surgery. Results are at least equivalent to that of surgery in terms of efficacy and limb salvage rate [9–12]. Recent studies support the role of endovascular therapy in diabetic patients with CLI caused by below-the knee (BTK) and below-the-ankle (BTA) arterial occlusive disease, as percutaneous

R. Alchanan · D. Y. Huang (✉)
Department of Radiology, King's College Hospital, London, UK
e-mail: dean.huang@nhs.net

M. E. Edmonds, B. E. Sumpio (eds.), *Limb Salvage of the Diabetic Foot*,
https://doi.org/10.1007/978-3-319-17918-6_22

angioplasty for BTK and BTA vascular disease has shown to be feasible and safe in this setting [13–18], achieving successful revascularization, necessary for limb salvage and ulcer healing, and avoiding amputations. In addition to the traditional approach, alternative techniques such as pedal-plantar loop technique and retrograde percutaneous access have been shown to be beneficial in further increasing intervention success rates [19–21].

The aim of the current article is to summarize the principles of endovascular revascularisation and currently available advanced techniques to treat lesions within distal arteries of the leg and foot.

22.2 Vascular Anatomy

In the normal anatomy, the anterior tibial artery (ATA) gives rise to the anterior circulation of the foot, and the posterior tibial artery (PTA) to the posterior circulation of the foot. Both tibial arteries, together with the peroneal artery (PA), supply different regions of the foot and ankle. In the anterior circulation, the ATA continues to the dorsum of the foot as the dorsalis pedis artery at the ankle level. As an anatomic variation of the foot, the dorsalis pedis artery may be absent in 6–12% of cases. Running laterally to medially along the dorsal aspect of the foot to the first metatarsal space, the dorsalis pedis artery gives off the medial malleolar, lateral malleolar, medial tarsal, lateral tarsal, and arcuate arteries. The arcuate artery, which usually arises at the level of the tarsal-metatarsal joint and travels laterally, in turn gives rise to small dorsal digital arteries supplying the second, third, and fourth toes. At the level of the first metatarsal space, just distal to the origin of the first dorsal metatarsal artery, which mainly supplies the first toe, the dorsalis pedis artery curves in the plantar direction; this arterial segment, named the deep perforating artery, communicates with the lateral plantar artery from the posterior circulation [22]. The posterior circulation of the foot, which is supplied by the posterior tibial artery consists of three main arteries—the medial plantar, lateral plantar, and medial calcaneal arteries. The medial plantar branch feeds the medial plantar instep, and a lateral plantar branch supplies the lateral forefoot, plantar midfoot, and entire plantar forefoot. In some cases, the lateral plantar artery, through plantar arch, is the predominant artery for the first toe. The calcaneal branch supplies the medial ankle and plantar heel. The peroneal artery supplies the lateral ankle and plantar heel via the calcaneal branch and the anterior upper ankle via an anterior branch.

22.3 Anatomic Consideration for Revascularisation

Graziani et al. [23] demonstrated through angiographies of 417 diabetic patients with 2893 ischemic trophic lesions that vascular obstructive disease involved the iliac arterial system in 1% of patients, but was present in 74% of patients at the sub-popliteal level. 66% of leg lesions were obstructive and 50% were over 10 cm in length. All three arterial systems were involved in 28% of patients whereas in 55%, at least one distal artery remained patent (Fig. 22.1). The predominance of diffuse obstructive lesions in the distal, sub-popliteal arteries makes diabetic vasculopathy particularly challenging to treat (Fig. 22.1). There seems to be sufficient evidence to suggest that the establishment of at least one straight-line flow to the foot on angiographic interpretation basis (Fig. 22.2) could be the primary strategy for infra-popliteal intervention [24] but the optimal revascularisation strategy ideal should aim to achieve a complete direct revascularization of the leg arterial system below-the-knee. In 2010, Peregrin et al. [25] showed that diabetic patients with CLI had a 1 year limb salvage rate of 56% if direct patency was not obtained in at least one vessel and 73%, 80% and 83% if 1, 2 or 3 vessels became patent following revascularisation.

It has been shown that pedal arch classification is a predictor of wound healing [26]. This finding suggests that clinically driven, more distal revascularization to establish a patent pedal arch is vital to facilitate complete wound healing in terms of endovascular strategy. In a series of 42 cases involving below-the-ankle angioplasty, technical success was achieved in 88%, and the reported 2-year limb salvage rate was 81.9% [16]. Simultaneous above the ankle angioplasty in this series would have

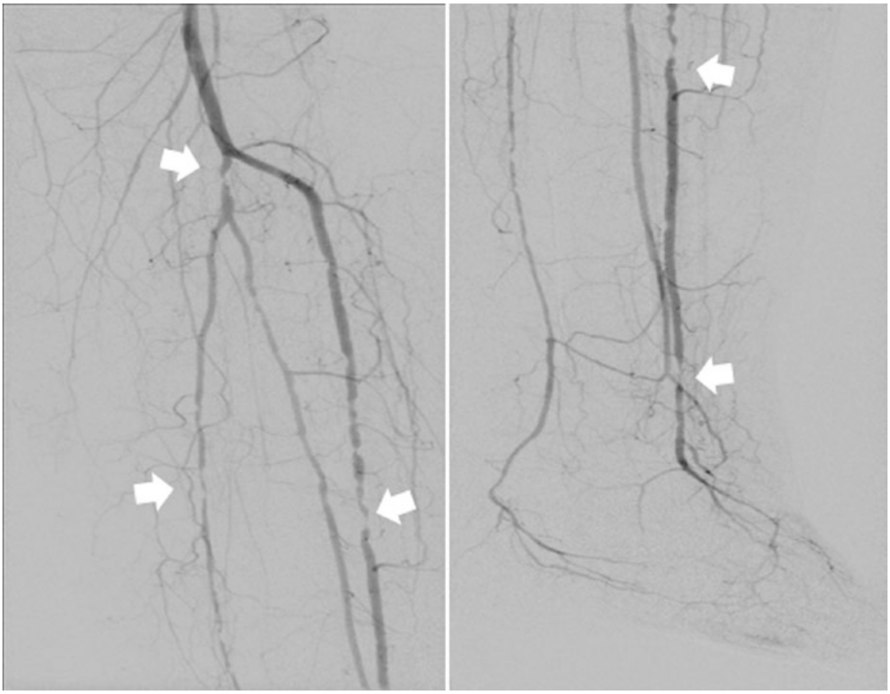

Fig. 22.1 An infra-popliteal angiogram of a diabetic patient with CLI demonstrating the typical pattern of multi-focal obstructive lesion (white arrows) in the distal sub-popliteal levels involving anterior and posterior tibial arteries

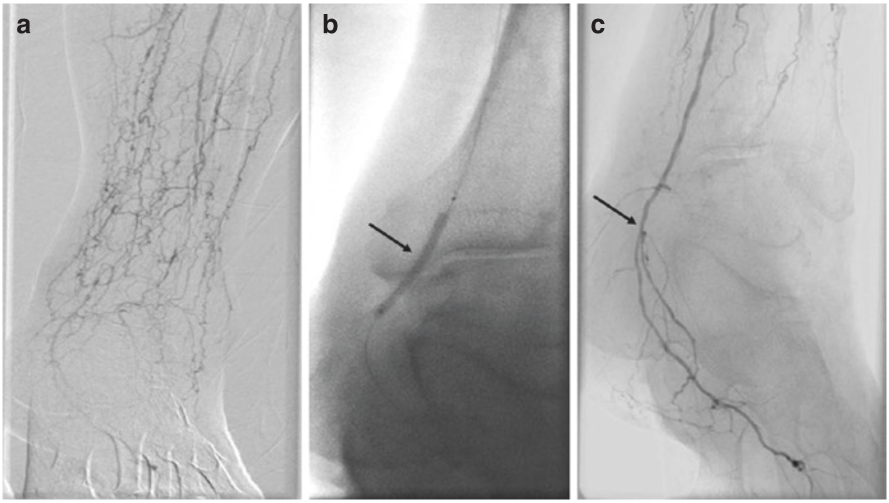

Fig. 22.2 Revascularization procedure of the posterior vascular pathway to the foot. (**a**) pre-treatment angiogram demonstrating occlusion of all calf vessels at the ankle level with an extensive collateral network with no direct straight-line flow into the foot. (**b**) Balloon angioplasty (arrow) recanalization of the posterior tibial artery. and the plantar artery was performed (**c**) Completion angiogram demonstrates establishment of straight-line flow into the foot (arrow) via the recanalized distal posterior tibial and plantar arteries

contributed to the clinical outcome but the report nonetheless reflects the feasibility and benefit of below the ankle endovascular intervention. Nakama et al. [27] further investigated the clinical impact of additional pedal artery angioplasty in patients with CLI attributed to pedal artery occlusion with insufficient 'wound blushing' after conventional above-the-ankle percutaneous revascularization. Additional dorsalis pedis angioplasty resulted in higher wound healing rate (93% vs. 60%, $p = 0.050$) and shorter time to wound healing ($p = 0.050$). The study concluded that additional pedal artery angioplasty might improve clinical outcomes (especially speed and extent of wound healing) in patients with CLI attributed to infra-popliteal and pedal artery disease and this aggressive strategy may be a salvage procedure for patients with CLI. With improved technology, it is now possible to treat even the very distal arterial lesions which might improve clinical success in selected cases. Manzi et al. [28] performed endovascular recanalization of digital branches in 24/1054 CLI patients (2.3%) and reported the technique is feasible and safe and may provide additional support to avoid amputation and healing of distal wounds on the toes.

22.4 Endovascular Devices for Endovascular Intervention in the Distal Arteries of the Leg and Foot

As current endovascular treatment with plain balloon angioplasty for patients with CLI and BTK lesions are associated with a low primary patency, high risk of restenosis and associated repeat intervention rate, there has been an evolution of newer technologies and adjunctive endovascular devices including atherectomy, cryoplasty, cutting balloons and laser [29–32]. Most experience has been published in patency-enhancing drug coating for balloons and stents More recently, review of the randomised controlled trials comparing paclitaxel-coated balloons or stents with standard balloon angioplasty or uncoated stents demonstrated a higher mortality in patients treated with paclitaxel products. These results are preliminary and the trials involved mainly claudicants and involved exclusively femoropopliteal lesions and not BTK lesions. However, current societal recommendation on the drug-eluting devices states in majority of patients undergoing lower limb recanallization, alternative to drug eluting devices should be used until more information is available. [33, 34].

22.4.1 Drug-Coated Balloons (DCB)

Drug-coated balloons impregnated with paclitaxel are available in a wide range of lengths and diameters. Liistro et al. [35] published a randomized, open-label, single-center study (Debate-BTK study) which compared the effect of a drug coated balloon with an uncoated balloon in 132 diabetic patients with CLI and a long occlusion (13.0 ± 8.0 cm) of the infra-popliteal vessels. Restenosis occurred in 20 of 74 lesions (27%) in the drug-eluting balloon group compared with 55 of 74 lesions (74%) in the PTA group ($P < 0.001$); target lesion revascularization, in 12 (18%) vs. 29 (43%; $P = 0.002$); and target vessel occlusion, in 12 (17%) vs. 41 (55%; $P < 0.001$). Twelve-month major adverse events occurred less frequently in the DCB (31%) than in the PTA (51%) group, driven mainly by a reduction in target lesion restenosis (TLR) and better ulcer healing. However, there was no difference in the rates of amputation, limb salvage, or mortality between the groups. These encouraging results have not, however, been confirmed in a subsequent multicenter, randomized IN-PACT DEEP study [36], in which low 12-month TLR rates had been observed in both the DCB and standard PTA arms without a statistically significant difference between the groups. A safety signal was activated and the INPACT-DEEP study was stopped prematurely as a result of a high amputation rate of 8.8% in the DCB group vs. 3.6% of the PTA group ($p = 0.08$) which were observed at 12 months . No definitive reason has been provided to explain the lack of efficacy and safety outcomes, but it has been hypothesized that potential disease and device and/or procedure-specific factors might have contributed to the observed outcomes [37]. Subsequently, the BIOLUX P-II study [38] was published comparing the Passeo-18 LUX DCB vs. standard angioplasty for infra-popliteal lesions (lesion length 11.4 ± 8.7 cm). Low and comparable restenosis rates at 6 months of follow-up were observed in both groups (DCB 17.1% vs. PTA 26.1%, $p = 0.298$), indicating no clear benefit of the drug coating in DCB group. Steiner et al. [39] reported in the 220 BTK interventions (144 [69.3%] of patients were diabetic patients). In 19 (8.6%) patients, angioplasty was extended into the pedal arch. This retrospective analysis of a real-world, single-center experience treating BTK peripheral arterial disease with the Lutonix 014 DCB found no unanticipated device events. However, the retrospective nature and lack of the control arm are major limitations of this study.

The use of DCB is not technically complex and it may yet play an important role as a possible solution for re-stenosis in the BTK, but it is not possible at present to propose the first line use of DCB technology in treating BTK disease in diabetic patients with CLI. It is also worth noting that DCB study data in general are strictly device specific. Different DCBs by various manufacturers exhibit substantial disparities with respect to paclitaxel concentrations and excipients, which potentially influence biological effects and subsequent anti-restenotic properties in the vessel wall [40].

22.4.2 Drug-Eluting Stents (DES)

The usefulness of PTA is frequently limited by elastic recoil and high rates of flow–limiting dissection and stent placement may improve radiological and clinical results in such cases (Fig. 22.3). However, stenting may also stimulate neointimal hyperplasia which results in re-stenosis. Primary bare metal stent (BMS) implantation showed no advantage over PTA. Randomized trials of DESs have demonstrated a potential role regarding vascular restenosis, target lesion revascularisation, wound healing, and rate of amputations [41–44]. However, it is worth noting that in these trials the lesions selected were shorter lesions with less calcifications and may not reflect "real world" diabetic BTK lesions. In the IDEAS trial [45],

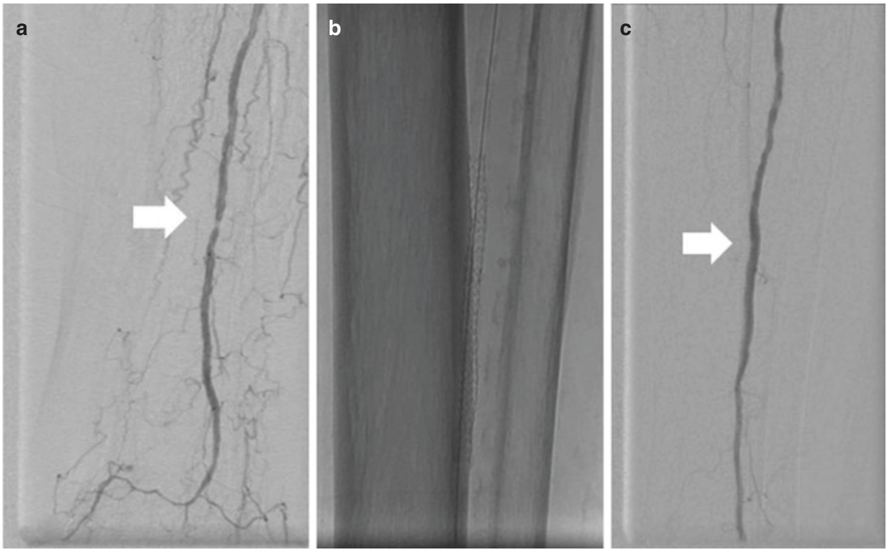

Fig. 22.3 Placement of a DES. (**a**) Angiogram of the peroneal artery demonstrates persistent elastic recoil of a focal stenosis (white arrow) following previous balloon angioplasty. (**b**) A DES was deployed across the stenosis. (**c**) Completion angiogram demonstrating patency across the stenosis (white arrow)

DES proved their superiority vs. PCB in long BTK lesions (107 ± 40.1 mm) but this is a single-center study with a relatively small number of patients and overall follow-up was limited to 6 months. Spiliopoulos et al. [46] reported 214 diabetic patients with CLI and BTK disease (679 lesions) treated with DES in a period of ten years. Survival rates at 1, 5, and 10 years were 90.8%, 55.5%, and 36.2% and amputation-free survival was 94.9%, 90.4% and 90.4%, respectively,. Although a valid control group was not available to provide a comparison with other techniques, DESs proved their potential role in the very demanding field of diabetic CLI revascularization in this retrospective analysis. DES trials have yet to show enough clinical or economic benefit for primary DES stenting in diabetic patients with long lesions but it would be interesting to try to determine if a specific subgroup of diabetic patients with CLI could benefit from use of DES. Further quality trials assessing long-term clinically relevant outcomes [47] and safety may lead to a change in future practice.

22.5 Operator Factor in Endovascular Intervention in the Distal Arteries of the Leg and Foot

Although often the latest advance in technology will grab the headlines, it is worth remembering that endovascular technique is a specialized technique that regardless of tools used, well trained, experienced, and dedicated operators are expected to offer the best outcomes.

Variation among practice patterns and specialists has been evaluated in many areas of medicine. Medicare data show that endovascular lower-extremity revascularization by less experienced operators results in more transfusion and intensive care unit (ICU) use, longer hospital stay, more repeat revascularization procedures or amputations, and higher costs compared with procedures performed by interventional radiologists [48].

22.6 Conventional Techniques of Endovascular Intervention in the Distal Arteries of the Leg and Foot

Antegrade access remains the first-choice approach for the treatment of BTK and BTA lesions as it allows excellent guide-ability of the guidewire and good pushability of the catheter balloons through long complex atheromatous, often occluded, BTK lesions [49]. Retrograde contralateral femoral ‘crossover’ across the aortic bifurcation is used if there is associated iliac disease or in the presence of morbid obesity and proximal iliac or common or proximal superficial femoral disease.

The first line technique remains the transluminal crossing method [50]. An introducer (45 cm) can be advanced to the lower popliteal artery providing additional

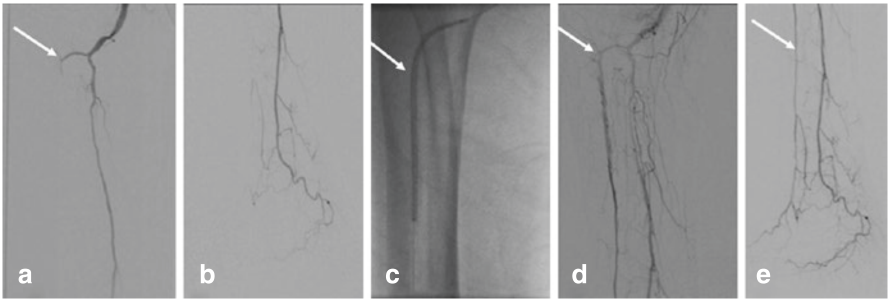

Fig. 22.4 Antegrade approach of crossing of a long anterior tibial artery occlusion. (**a** and **b**) Pre-treatment angiogram demonstrates a full-length occlusion of the anterior tibial artery (arrow). (**c**) A guide wire was successfully navigated through the occlusion intraluminally with a combination of drilling techniques and balloon angioplasty was performed (arrow). (**d** and **e**) Completion angiogram demonstrates restored patency of the anterior tibial artery (arrow)

support. The procedure is started with a drilling motion of the guide-wire, with rotating of the guidewire with alternating clockwise and anticlockwise movements, with gentle push and with a short and low profile coaxial catheter balloon as a support catheter, in the direction of recanalization through areas of lower resistance in the stenosis or occlusion (Fig. 22.4).

On failure of navigating the guidewire through intraluminal path, an attempt can then be made to cross the occlusion using a subintimal approach [51]. In principle, an intentional subintimal plane is initiated proximal to the lesion to bypass the entire diseased area and to exit into a disease–free segment just distal to the lesion. The failure of this technique is mainly due to the guide-wire not being able to re-enter to the true lumen beyond the occlusion, and the failure rate is increased in vessels with significant calcification. Inflation of a balloon next to the assumed re-entry area could be used to traumatically cross the dissection membrane and potentially allow a guidewire to be navigated through into the true lumen.

22.7 Alternative Techniques of Endovascular Intervention in the Distal Arteries of the Leg and Foot

The technical failure rate using the traditional antegrade approach is around 20% with modern devices. Fortunately, the threshold of what can be treated with endovascular procedures is shifting. When conventional techniques fail, a number of alternative techniques can be pursued to restore blood flow to the foot. When applying these advanced techniques, the principle of a ‘step-by-step approach’ should be taken, starting from conventional technique and progress to more advanced techniques if clinically indicated following a balanced assessment of function and degree of collateralization in the vascular territories, as well as consideration of risk of compromising other potential alternative surgical and endovascular options should advanced endovascular techniques fail. Time and effort should be prioritized to do what is realistic in order not to prolong procedure time and potentially increase risk of complication on attempting unrealistic targets.

22.7.1 Retrograde Pedal Access

This procedure requires combining a conventional ipsilateral femoral approach with direct puncture of the leg vessel distal to the obstruction where it is still patent from rich collateral supply but could not be reached through an antegrade approach in order to cross the occlusion backwards (Fig. 22.5). Various groups have shown good technical and clinical success confirming that a retrograde approach to the vessel leads to high success rate of revascularization when the antegrade approach fails, probably because the distal part of an occlusion generally consists of less fibrotic or calcified tissue, thus allowing an easier passage across the occlusion. Sabri et al. [20] suggested that retrograde pedal access is a viable revascularization technique for achieving limb salvage in patients with CLI in whom antegrade revascularization has failed and surgical bypass is not a viable option. In 124 diabetic patients with CLI (12% of 1035 people treated) in which antegrade recanalization failed,

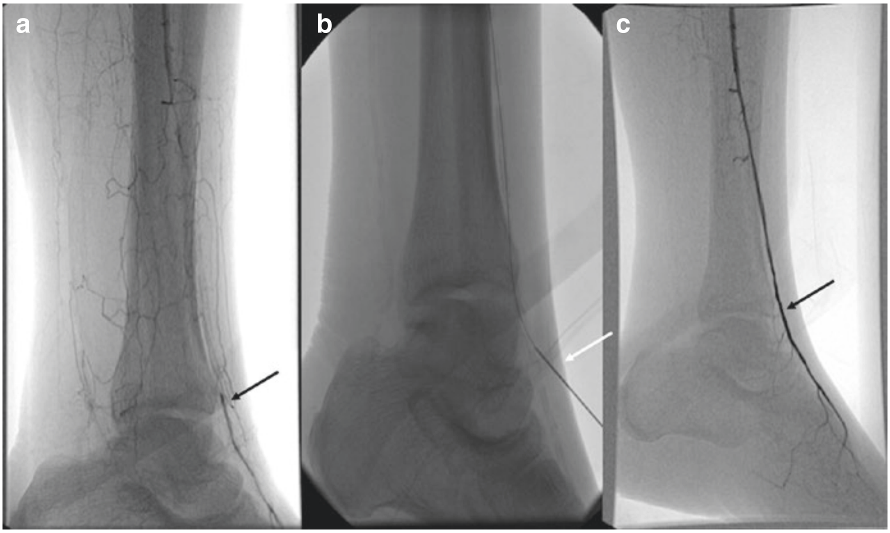

Fig. 22.5 Retrograde pedal access. (**a**) Pre-treatment angiogram demonstrates an occluded distal anterior tibial artery with a patent dorsalis pedis artery (black arrow) which could not be reached via an antegrade approach. (**b**) A direct puncture of the patent distal anterior tibial artery was performed under ultrasound guidance and a guide wire was passed through the occlusion in a retrograde fashion successfully (white arrow). (**c**) Completion angiogram demonstrates restored patency of the distal anterior tibial artery (black arrow) following balloon angioplasty over the guide wire from the ipsilateral femoral approach

Gandini et al. [52] reported a technical success rate of 96% using this dual approach with a limb salvage rate of 83% at 6 months and a 10% mortality rate during clinical follow-up, with 26% repeat procedure and 16% amputation rates. The technical success of this approach using retrograde puncture after antegrade failure is estimated to be around 80% [53, 54]. Access vessel thrombosis has been reported [55], which has created some concerns about the use of pedal arteries as access. However, lower profile, dedicated pedal access sheath and intra-arterial vasodilators can be used to minimize the risk of vasospasm and access site thrombosis.

22.7.2 The Pedal Plantar and "Trans-collateral LOOP" Techniques

The pedal plantar loop technique [19, 52, 56] and the trans-collateral approach [57] consist of using natural anastomosis to optimize pedal flow or to allow access to recanalize a tibial or foot artery via the plantar arcade or a sufficiently well-developed collateral supply. It is based on the technique of successfully advancing a wire followed by a balloon through the plantar arch, or a different anastomosis such as the "deep arch" of the foot which links the medial plantar artery with lateral tarsal branch of the dorsalis pedis artery, recreating a loop or patent communication from the dorsal to the plantar circulation of the foot (or vice versa). The technique can be utilized to optimize pedal flow to achieve a complete below-the-ankle revascularization with the hope of improving perfusion of the forefoot by restoring missing connections in the toes and heels (Fig. 22.6). It can also be used to perform recanalization, crossing through the opposite patent circulatory pathway to obtain a retrograde recanalization of the occluded foot vessel (Fig. 22.7). Manzi et al. described a technical success rate of 85% in 135 patients (10.1% of a population of patients

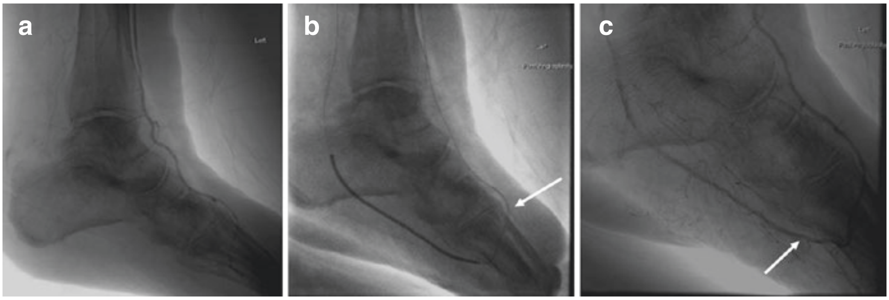

Fig. 22.6 Pedal plantar loop angioplasty. (**a**) Initial angiogram demonstrates poor flow through the pedal arch and an occluded distal posterior tibial artery. (**b**) A guide-wire was negotiated through the pedal plantar arch via an antegrade approach through the anterior tibial artery and balloon angioplasty was performed though the plantar arch to optimize pedal arch flow (arrow). (**c**) Completion angiogram demonstrated improved flow through the pedal plantar arch (arrow) following angioplasty

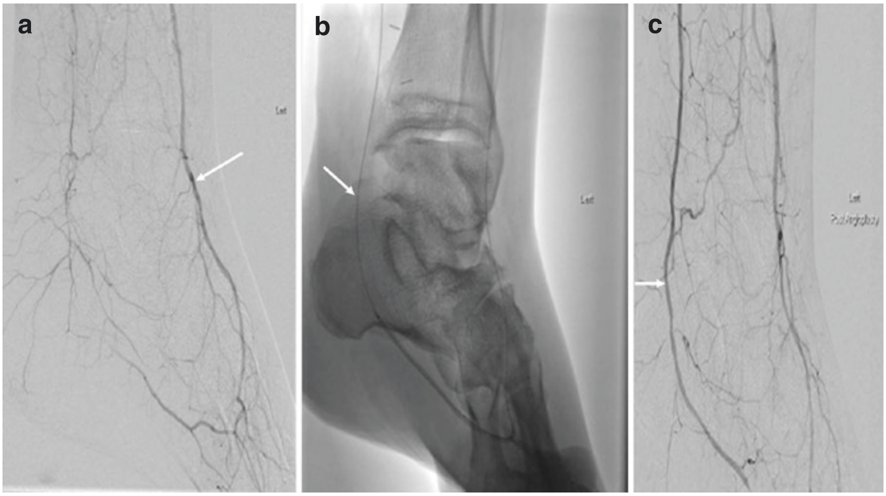

Fig. 22.7 Retrograde recanalization of the distal posterior tibial artery with pedal plantar technique. (**a**) Pre-treatment angiogram demonstrates an occluded distal posterior tibial artery. The anterior tibial artery (arrow) and the pedal plantar arch is patent. (**b**) A retrograde recanalization of the occluded distal posterior tibial artery (arrow) was performed following a successful retrograde crossing of the occlusion through the opposite patent anterior circulatory pathway and the plantar arch. (**c**) Completion angiogram demonstrates restored patency of the distal posterior tibial (arrow) and plantar arteries

treated via an endovascular approach for CLI over a period of 2 years), and clinical improvement in functional status was obtained and maintained after an average of 12 months, with a significant improvement of transcutaneous oxygen tension after 15 days [19].

22.7.3 Metatarsal Angioplasty and Direct Metatarsal Artery Puncture

With the advances in guide wire and catheter technology, it is now possible to perform angioplasty in the very distal, metatarsal arteries to restore direct line flow to non-healing toe ulcers (Fig. 22.8). In addition, Palena and Manzi reported the feasibility to directly puncture the first metatarsal artery or the plantar arcade, following local anesthesia and local administration of antispastic verapamil, to undertake retrograde recanalization of the foot and lower leg arteries. Through this approach, the group reported a technical and clinical success rate of 85% at 6 months in 28 patients, with an associated increase in tcPO2 with 71% of patients alive and not amputated at 6 months [58, 59].

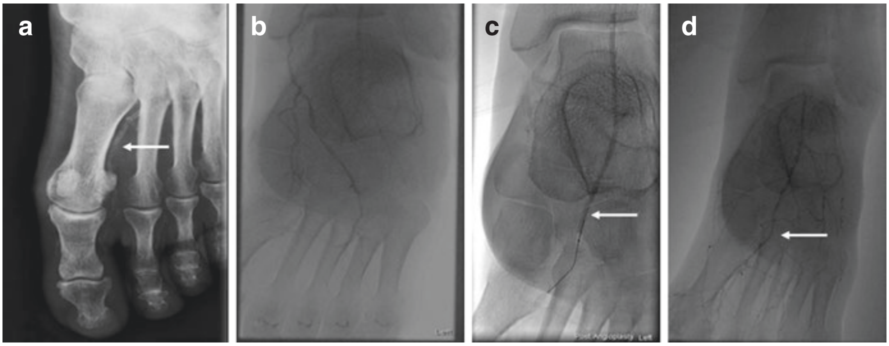

Fig. 22.8 Metatarsal artery angioplasty. (**a**) Radiograph of the right big toe demonstrates a heavily calcified first metatarsal artery (arrow). Clinically, a non-healing ulcer persists at the big toe despite previous successful tibial revascularization. (**b**) Foot angiogram demonstrates an occluded distal dorsalis pedis and first metatarsal arteries. (**c**) Crossing of the distal dorsalis pedis and first metatarsal occlusion was performed successfully and this is followed by balloon angioplasty (arrow) of the dorsalis pedis and first metatarsal arteries. (**d**) Direct vascular flow is restored into the big toe(arrow) where the non-healing ulcer is present

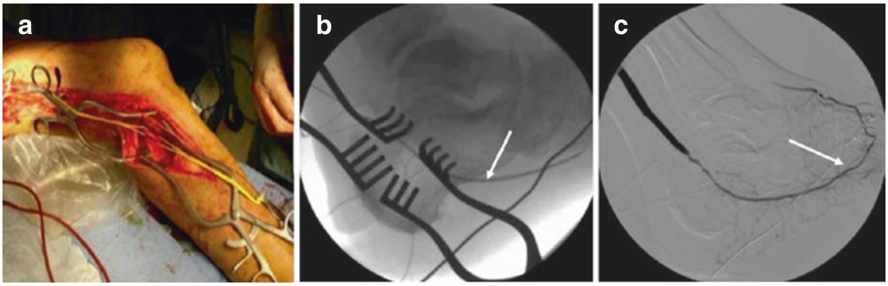

Fig. 22.9 Plantar arch angioplasty through a Critical limb ischemia (CLI):endovascular intervention in distal arteries of leg and foot:hybrid approach. (**a**) An ultra-distal surgical bypass procedure was performed with the distal anastomosis at the common plantar artery. There is, however, poor distal outflow into the lateral plantar artery and foot arch. (**b**) Through access at the distal anastomosis at the time of bypass operation, a guidewire was passed through the plantar arch and balloon angioplasty (arrow) was performed to optimize bypass graft outflow. (**c**) Completion angiogram demonstrates a good graft outflow into the optimized plantar artery and the pedal plantar arch (arrow)

22.7.4 Hybrid Procedures

Another strategy is a hybrid approach, with angioplasty of pedal arteries in the ultra-distal bypass group (Fig. 22.9) [60, 61]. Combined therapy with a hybrid approach simplifies the procedure and allows the one-step treatment of patients with complex vascular disease.

22.8 Conclusion

One of the features of diabetic patients with CLI is the predominance of diffuse obstructive lesions in the distal, sub-popliteal arteries. The range of technical endovascular revascularization possibilities for crural and pedal artery disease has increased considerably. Technical success rate and clinical outcomes for endovascular revascularization techniques are encouraging although this is dependent on the local resources and expertise. The rapid pace of development of various endovascular devices and advanced techniques allow the interventionists to treat increasingly complex and distal patterns of disease. However, a recent meta-analysis has found an increased risk of death at 2 and 5 years after the use of paclitaxel- coated balloons and stents in the femoro-popliteal artery and this is still under discussion at the present time [62]. Revascularization strategy should be individualized through a multidisciplinary process, with a step-by-step technical approach, to facilitate clinically driven, more distal revascularization aiming to establish a patent pedal arch flow, which could be vital to facilitate complete wound healing and achieve limb salvage.

References

1. Andresen JL, Rasmussen LM, Ledet T. Diabetic macroangiopathy and atherosclerosis. Diabetes. 1996;45:S91–4.
2. Van Dieren S, Beulens JW, van der Schouw YT, Grobbee DE, Neal B. The global burden of diabetes and its complications: an emerging pandemic. Eur J Cardiovasc Prev Rehabil. 2010;17(Suppl 1):S3–8.
3. Apelqvist J. Diagnostics and treatment of the diabetic foot. Endocrine. 2012;41:384–97.
4. Huang DY, Wilkins CJ, Evans DR, Ammar T, Deane C, Vas PR, et al. The diabetic foot: the importance of coordinated care. Semin Interv Radiol. 2014;31(4):307–12.
5. Aiello A, Anichini R, Brocco E, Caravaggi C, Chiavetta A, Cioni R, et al. Treatment of peripheral arterial disease in diabetes: a consensus of the Italian Societies of Diabetes (SID, AMD), Radiology (SIRM) and Vascular Endovascular Surgery (SICVE). Nutr Metabol Cardiovasc Dis. 2014;24(4):355–69.
6. Soderstrom MI, Arvela EM, Korhonen M, Halmesmäki KH, Albäck AN, Biancari F, et al. Infrapopliteal percutaneous transluminal angioplasty versus bypass surgery as first-line strategies in critical leg ischemia. Ann Surg. 2010;252:765–73.
7. Kudo T, Chandra FA, Kwun WH, Haas BT, Ahn SS. Changing pattern of surgical revascularization for critical limb ischemia over 12years: endovascular vs. open bypass surgery. J Vasc Surg. 2006;44:304–13.
8. Faglia E, Clerici G, Clerissi J, Gabrielle L, Losa S, Mantero M, et al. Early and five-year amputation and survival rate of diabetic patients with critical limb ischemia: data of a cohort study of 564 patients. Eur J Vasc Endovasc Surg. 2006;32(5):484–90.
9. Adam DJ, Beard JD, Cleveland T, Bell J, Bradbury AW, Forbes JF, et al. Bypass versus angioplasty in severe ischaemia of the- leg (BASIL): multicentre, randomised controlled trial. Lancet. 2005;366:1925–34.
10. Hunt DL. Diabetes: foot ulcers and amputations. BMJ Clin Evid. 2009;2011:06025.

11. Park SW, Kim JS, Yun IJ, Hwang JJ, Lee SA, Chee HK, et al. Clinical outcomes of endovascular treatments for critical limb ischemia with chronic total occlusive lesions limited to below-the-knee arteries. Acta Radiol. 2013;54(7):785–9.
12. Werneck CC, Lindsay TF. Tibial angioplasty for limb salvage in high-risk patients and cost analysis. Ann Vasc Surg. 2009;23(5):554–9.
13. Manzi M, Palena L, Cester G. Endovascular techniques for limb salvage in diabetics with crural and pedal disease. J Cardiovas Surg (Torino). 2011;52(4):485–92.
14. Hering J, Angelkort B, Keck N, Wilde J, Amann B. Long-term outcome of successful percutaneous transluminal angioplasty of the fibular artery in diabetic foot syndrome and single- vessel calf perfusion depends on doppler wave pattern at the forefoot. Vasa. 2010;39:67–75.
15. Zhu YQ, Zhao JG, Liu F, Wang JB, Cheng YS, Li MH, et al. Subintimal angioplasty for below-the-ankle arterial occlusions in diabetic patients with chronic critical limb ischemia. J Endovasc Ther. 2009;16:604–12.
16. Abdelhamid MF, Davies RS, Rai S, Hopkins JD, Duddy MJ, Vohra RK. Below-the-ankle angioplasty is a feasible and effective intervention for critical leg ischaemia. Eur J Vasc Endovasc Surg. 2010;39(6):762–8.
17. Acín F, Varela C, López De Maturana I, de Haro J, Bleda S, Rodriguez-Padilla J. Results of infrapopliteal endovascular procedures performed in diabetic patients with critical limb ischemia and tissue loss from the perspective of an angiosome-oriented revascularization strategy. Int J Vasc Med. 2014;2014:270539.
18. Ferraresi R, Centola M, Ferlini M, Da Ros R, Caravaggi C, Assaloni R, et al. Long-term outcomes after angioplasty of isolated, below-the-knee arteries in diabetic patients with critical limb ischaemia. Eur J Vasc Endovasc Surg. 2009;37:336–42.
19. Manzi M, Fusaro M, Ceccacci T, Erente G, Dalla Paola L, Brocco E. Clinical results of below-the-knee intervention using pedal-plantar loop technique for the recanalization of the foot arteries. J Cardiovasc Surg (Torino). 2009;50(3):331–7.
20. Sabri SS, Hendricks N, Stone J, Tracci MC, Matsumoto AH, Angle JF. Retrograde pedal access technique for revascularization of infrainguinal arterial occlusive disease. J Vasc Interv Radiol. 2015;26(1):29–38.
21. Gandini R, Uccioli L, Spinelli A, Del Giudice C, Da Ros V, Volpi T, et al. Alternative techniques for treatment of complex below-the knee arterial occlusions in diabetic patients with critical limb ischemia. Cardiovasc Intervent Radiol. 2013;36(1):75–83.
22. Manzi M, Cester G, Palena LM, Alek J, Candeo A, Ferraresi R. Vascular imaging of the foot: the first step toward endovascular recanalization. Radiographics. 2011;31(6):1623–36.
23. Graziani L, Silvestro A, Bertone V, Manara E, Andreini R. Sigala A,et al. Vascular involvement in diabetic subjects with ischemic foot ulcer: a new morphologic categorization of disease severity. Eur J Vasc Endovasc Surg. 2007;33:453–60.
24. Faglia E, Mantero M, Caminiti M, Caravaggi C, De Giglio R, Pritelli C, et al. Extensive use of peripheral angioplasty, particularly infrapopliteal, in the treatment of ischaemic diabetic foot ulcers: clinical results of a multicentric study of 221 consecutive diabetic subjects. J Intern Med. 2002;252:225–32.
25. Peregrin JH, Koznar B, Kovac J, Lastovicková J, Novotný J, Vedlich D, et al. PTA of infrapopliteal arteries: long-term clinical follow-up and analysis of factors influencing clinical outcome. Cardiovasc Intervent Radiol. 2010;33:720–5.
26. Rashid H, Slim H, Zayed H, Huang DY Wilkins CJ, Evans DR, et al. The impact of arterial pedal arch quality and angiosome revascularization on foot tissue loss healing and infrapopliteal bypass outcome. J Vasc Surg. 2013;57(5):1219–26.
27. Nakama T, Watanabe N, Kimura T, Ogata K, Nishino S, Furugen M, et al. Clinical implications of additional pedal artery angioplasty in critical limb ischemia patients with infrapopliteal and pedal artery disease. J Endovasc Ther. 2016;23(1):83–91.
28. Manzi M, Palena LM, Brocco E. Is digital arteries recanalization useful to preserve the foot functionality and avoid toes amputation, after pedal recanalization? Clinical results. J Cardiovasc Surg (Torino). 2012;53(1):61–8.
29. Das T, McNamara T, Gray B, et al. Cryoplasty therapy for limb salvage in patients with critical limb ischemia. J Endovasc Ther. 2007;14:753–62.

30. Zeller T, Rastan A, Schwarzwälder U, Ulrich F, Burgelin K, Amantea P, et al. Midterm results after atherectomy-assisted angioplasty of below- knee arteries with use of the Silverhawk device. J Vasc Interv Radiol. 2004;15:1391–7.
31. Laird JR, Zeller T, Gray BH, Scheinert D, Vranic M, Reiser C, et al. Limb salvage following laser-assisted angioplasty for critical limb ischemia: results of the LACI multicenter trial. J Endovasc Ther. 2006;13:1–11.
32. Ansel GM, Sample NS, Botti CF III, Jr, Tracy AJ, Silver MJ, Marshall BJ, et al. Cutting balloon angioplasty of the popliteal and infrapopliteal vessels for symptomatic limb ischemia. Catheter Cardiovasc Interv. 2004;61:1–4
33. White CJ. Brave new world: value-based purchasing for peripheral vascular stents is coming to a hospital near you. Circulation. 2013;127:2475–6.
34. Peripheral arterial disease: diagnosis and management NICE guidelines [CG147].
35. Liistro F, Porto I, Angiolil P, Grottil S, Ricci L, Ducci K, et al. Drug eluting balloon for below the knee angioplasty evaluation: the DEBATE BTK study. JACC Cardiovasc Interv. 2013;6(12):1295–302.
36. Zeller T, Baumgartner I, Scheinert D, Brodmann M, Bosiers M, Micari A, et al. Drug-eluting balloon versus standard balloon angioplasty for infrapopliteal arterial revascularization in critical limb ischemia: 12-month results from the IN.PACT DEEP randomized trial. J Am Coll Cardiol. 2014;64:1568–76.
37. Laird JR, Armstrong EJ. Drug-coated balloons for infrapopliteal disease: digging deep to understand the impact of a negative trial. J Am Coll Cardiol. 2014;64:1577–9.
38. Zeller T, Beschorner U, Pilger E, Bosiers M, Deloose K, Peeters P, et al. Paclitaxel-coated balloon in infrapopliteal arteries: 12-month results from the BIOLUX P-II randomized trial. JACC Cardiovasc Interv. 2015;8:1614–22.
39. Steiner S, Schmidt A, Bausback Y, Braunlich S, Ulrich M, Banning-Eichenseer U, et al. Single-center experience with lutonix drug-coated balloons in infrapopliteal arteries. J Endovasc Ther. 2016;23(3):417–23.
40. Gongora CA, Shibuya M, Wessler JD, McGregor J, Tellez A, Cheng Y, et al. Impact of paclitaxel dose on tissue pharmacokinetics and vascular healing: a comparative drug-coated balloon study in the familial hyper-cholesterolemic swine model of superficial femoral in-stent restenosis. JACC Cardiovasc Interv. 2015;8:1115–23.
41. Scheinert D, Katsanos K, Zeller T, Koppensteiner R, Commeau P, Bosiers M, et al. A prospective randomized multicenter comparison of balloon angioplasty and infrapopliteal stenting with the sirolimus-eluting stent in patients with ischemic peripheral arterial disease: 1-year results from the ACHILLES trial. J Am Coll Cardiol. 2012;60:2290–5.
42. Rastan A, Brechtel K, Krankenberg H, Zahorsky R, Tepe G, Noory E, et al. Sirolimus-eluting stents for treatment of infrapopliteal arteries reduce clinical event rate compared to bare-metal stents: long-term results from a randomized trial. J Am Coll Cardiol. 2012;60: 587–91.
43. Bosiers M, Scheinert D, Peeters P, Torsello G, Zeller T, Deloose K, et al. Randomized comparison of everolimus-eluting versus bare-metal stents in patients with critical limb ischemia and infrapopliteal arterial occlusive disease. J Vasc Surg. 2012;55:390–8.
44. Martens JM, Knippenberg B, Vos JA, de Vries JP, Hansen BE, van Overhagen H, et al. Update on PADI trial: percutaneous transluminal angioplasty and drug-eluting stents for infrapopliteal lesions in critical limb ischemia. J Vasc Surg. 2009;50:687–9.
45. Siablis D, Kitrou PM, Spiliopoulos S, Katsanos K, Karnabatidis D, et al. Paclitaxel-coated balloon angioplasty versus drug-eluting stenting for the treatment of infrapopliteal long-segment arterial occlusive disease: the IDEAS randomized controlled trial. JACC Cardiovasc Interv. 2014;7:1048–56.
46. Spiliopoulos S, Theodosiadou V, Katsanos K, Kitrou P, Kagadis GC, Siablis D, et al. Long-term clinical outcomes of infrapopliteal drug-eluting stent placement for critical limb ischemia in diabetic patients. J Vasc Interv Radiol. 2015;26(10):1423–30.
47. Caradu C, Brizzi V, Auque H, Midy D, Ducasse E. Sense and nonsense of bare metal stents below the knee. J Cardiovasc Surg (Torino). 2016;57(5):653–66.

48. Zafar AM, Dhangana R, Murphy TP, Goodwin SC, Duszak R Jr, Ray CE Jr, et al. Lower-extremity endovascular interventions for Medicare beneficiaries: comparative effectiveness as a function of provider specialty. J Vasc Interven Radiol. 2012;23(1):3–9. e1–14
49. Manzi M, Palena LM, Cester G. Revascularization of tibial and foot arteries: below the knee angioplasty for limb salvage, angioplasty, various techniques and challenges in treatment of congenital and acquired vascular stenoses. In: Angioplasty, Various Techniques and Challenges in Treatment of Congenital and Acquired Vascular Stenoses Ed. Thomas Forbes, 2012, Chapter 10, 209–236.
50. Kawarada O. Contemporary crossing techniques for infrapopliteal chronic total occlusions. J Endovasc Ther. 2014;21:266–80.
51. Reekers JA, Bolia A. Percutaneous intentional extraluminal (subintimal) recanalization: how to do it yourself. Eur J Radiol. 1998;28:192–8.
52. Gandini R, Uccioli L, Spinelli A, Del Giudice C, Da Ros V, Volpi T, et al. Alternative techniques for treatment of complex below- the knee arterial occlusions in diabetic patients with critical limb ischemia. Cardiovasc Intervent Radiol. 2013;36(1):75–83.
53. Spinosa DJ, Harthun NL, Bissonette EA, Cage D, Leung DA, Angle JF, et al. Subintimal arterial flossing with antegrade—retrograde intervention (SAFARI) for subintimal recanalization to treat chronic critical limb ischemia. J Vasc Interv Radiol. 2005;16:37–44.
54. Gandini R, Pipitone V, Stefanini M, Maresca L, Spinelli A, Colangelo V, et al. The “Safari” technique to perform difficult subintimal infragenicular vessels. Cardiovasc Intervent Radiol. 2007;30:469–73.
55. Lupattelli T, Clerissi J, Losa S. Regarding the “SAFARI” technique: a word of caution. Cardiovasc Intervent Radiol. 2009;32:197–8.
56. Kim S, Choi D, Shin S, Shin DH, Kim JS, Kim BK, et al. Dorsal-plantar loop technique using chronic total occlusion devices via anterior tibial artery. Yonsei Med J. 2013;54(2):534–7.
57. Manzi M, Palena LM. Treating calf and pedal vessel disease: the extremes of intervention. Semin Interv Radiol. 2014;31(4):313–9.
58. Palena LM, Manzi M. Extreme below-the-knee interventions: retrograde transmetatarsal or transplantar arch access for foot salvage in challenging cases of critical limb ischemia. J Endovasc Ther. 2012;19:805–11.
59. Palena LM, Brocco E, Manzi M. The clinical utility of below- the-ankle angioplasty using “transmetatarsal artery access” in complex cases of CLI,1. Catheter Cardiovasc Interv. 2014;83(1):123–9.
60. Slim H, Tiwari A, Ahmed A, Ritter JC, Zayed H, Rashid H. Distal versus ultradistal bypass grafts: amputation-free survival and patency rates in patients with critical leg ischaemia. Eur J Vasc Endovasc Surg. 2011;42(1):83–8.
61. Slim H, Huang D, Rashid H. A novel approach using angioplasty for recanalization of a chronically occluded bypass vein graft for limb salvage. Vasc Endovascular Surg. 2010;44(5):377–80.
62. Katsanos K, Spiliopoulos S, Kitrou P, Krokidis M, Karnabatidis D. Risk of death following application of Paclitaxel-Coated balloons and stents in the femoropopliteal artery of the leg: A systematic review and meta-analysis of randomized controlled trials. J Am Heart Assoc. 2018;7(24):e011245.