Cardiovasc Intervent Radiol (2021) 44:1309–1322
https://doi.org/10.1007/s00270-021-02891-5

CIRSE Standards of Practice on Below-the-Knee Revascularisation

Stavros Spiliopoulos[1] · Costantino Del Giudice[2] · Marco Manzi[3] · Lazaros Reppas[1] · Thomas Rodt[4] · Raman Uberoi[5]

Received: 17 November 2020 / Accepted: 1 June 2021 / Published online: 25 June 2021

Abstract The CIRSE Standards of Practice Committee established a writing group that was tasked with producing up-to-date recommendations for performing below-the-knee revascularisation, taking into account data on novel techniques, devices, and long-term outcomes that have emerged over the last decade. CIRSE Standards of Practice documents are not clinical practice guidelines or systematic reviews of the literature. This document is not intended to impose a standard of clinical patient care but recommends a reasonable approach to and best practices for performing below-the-knee revascularisation.

Keywords Endovascular treatment · Below-the-knee · Pedal arch · Cronic limb-threatening ischemia · Balloon angioplasty · Drug-eluting sents · Drug-coated balloons

Abbreviations

ABI	Ankle-brachial index
BTK	Below the knee
CLTI	Chronic limb-threatening ischemia
CTA	Computed tomography angiography
DES	Drug-eluting stent
DOAC	Direct oral anticoagulation
DSA	Digital subtraction Angiography
DUS	Duplex ultrasound
DAPT	Dual antiplatelet therapy
DCB	Drug-coated balloon
FD-OCT	Frequency-domain optical coherence tomography
HTPR	High on-treatment platelet reactivity
IVUS	Intravascular ultrasound
PAD	Peripheral arterial disease
SAPT	Single anti-platelet therapy
TBI	Toe-brachial index
$TcPO_2$	Transcutaneous oxygen pressure
WiFi	Wound, ischemia and foot infection

✉ Stavros Spiliopoulos
stavspiliop@med.uoa.gr

[1] Interventional Radiology Unit, 2nd Department of Radiology, National and Kapodistrian University of Athens, "Attikon" University General Hospital, Athens, Greece

[2] Department of Radiology, Institut Mutualiste Montsouris, Paris, France

[3] Policlinico Abano Terme, Padova, Italy

[4] Dept. of Diagnostic and Interventional Radiology, Lüneburg Hospital, Lüneburg, Germany

[5] John Radcliffe Hospital, Oxford University Hospitals, Oxford, UK

Introduction

The CIRSE Standards of Practice Committee established a writing group that was tasked with producing up-to-date recommendations for performing below-the-knee revascularisation, taking into account data on novel techniques, devices, and long-term outcomes that have emerged over the last decade. CIRSE Standards of Practice documents are not clinical practice guidelines or systematic reviews of the literature. This document is not intended to impose a standard of clinical patient care, but recommend a

reasonable approach to and best practices for performing below-the-knee revascularisation.

Methods

The writing group, which was established by the CIRSE Standards of Practice Committee, consisted of six clinicians with internationally recognised expertise in below-the-knee interventions. The writing group reviewed the existing literature on below-the-knee interventions, performing a pragmatic evidence search using PubMed to search for relevant publications in the English language from 2004 to 2020.

Background

The infra-popliteal steno-occlusive arterial disease of the tibial vessels and pedal arch predominantly affects patients with diabetes and those receiving dialysis and has been widely recognised as a major factor contributing to limb loss [1–3]. It is important to recognise that in chronic limb-threatening ischemia (CLTI) patients, there is often multilevel disease and significant proximal disease that should also be treated before dealing with the below-knee vessels. This usually requires complex techniques to achieve vessel BTK and pedal arch revascularisation. The absence of adequate foot perfusion is related to a greater risk of amputation and an increased mortality rate, thus underscoring the potential benefits of revascularisation procedures. Percutaneous endovascular angioplasty or stenting, or open surgical distal venous by-pass are currently recognised revascularisation treatment options, providing satisfactory technical and clinical outcomes [4–6]. The continuous technological advances of endovascular devices, as well as increasing clinical experience supported by evidence, now justify an "endovascular first" approach in most patients suffering from chronic limb-threatening ischemia (CLTI) and infrapopliteal arterial disease [7].

Key recommendations on BTK revascularisation are given in Table 1.

Indications, Contraindications, and Patient Selection

Optimal management requires individualised decision-making by a multidisciplinary team with specific endovascular skills and experience to obtain the best results for patients [5–9]. In patients with pedal arch disease, patients without a vein suitable for distal bypass surgery and patients at high surgical risk due to advanced age or various comorbidities, endovascular treatment is often the only feasible way of revascularisation. Treatment choice based only on the TransAtlantic InterSociety Consensus (TASC) morphological classification of infrapopliteal disease is not recommended.

Indications for BTK revascularisation [6–8]:

- Rest pain (Fontaine stage 3, Rutherford category 4) or non-healing ulcer/gangrene (Fontaine stage 4, Rutherford categories 5–6)
- Non-healing ischaemic ulcer following amputation attributable to arterial occlusive disease
- Salvage of failing surgical bypass

Notably, diabetic patients may progress rapidly from even long-distance claudication to CLTI by minor foot injuries [10]. In everyday clinical practice, radiologically documented infrapopliteal disease correlated to non-healing tissue loss/gangrene and toe pressure < 50 mmHg/transcutaneous oxygen pressure ($TcPO_2$) ≤ 30 mmHg, constitutes the commonest indication for endovascular revascularisation. For subjects with diabetic foot and PAD, rapid revascularisation should be considered to promote rapid wound healing and avoid limb-threatening superinfection.

Absolute contraindications [6]:

Table 1 Summary of key recommendations

Recommendation
The treatment plan for infrapopliteal arterial disease should be case-sensitive and decided in the ambit of a multidisciplinary team meeting
Endovascular treatment options should include advanced revascularisation techniques including trans-pedal access, plantar-loop, transcollateral techniques, pedal arch reconstruction, and venous arterialisation for "no-option" patients
Optimally, BTK procedures for wound healing, should aim in providing the maximal foot perfusion possible via wound-directed revascularisation, > 1 vessel treatment, and pedal arch improvement
POBA remains the treatment of choice for long BTL lesions and pedal arch disease
DES provides superior outcomes in short-to-medium-length lesions. More data are required to establish the role of devices such as drug-coated balloons, atherectomy, and bioabsorbable scaffolds, for BTK revascularisation
Real-time foot perfusion assessment, quantification of endovascular treatment result, endovascular imaging (FD-OCT/IVUS), and personalised pharmacotherapy using point of care tests could optimise clinical outcomes and merit further investigation

- haemodynamically unstable patients (not stabilised by anaesthesiology)
- uncorrectable coagulopathy

Relative contraindications:

- known life-threatening allergy to contrast media allergy (CO_2 or Gadolinium may be used)
- impaired renal function (EGFR: 30 ml/min/1.73 m^2) (maybe possible with CO_2 and or pre-hydration measures)
- inability to cooperate and/or lay flat during and after the procedure (maybe possible under GA)
- contra-indication to antiplatelet or heparin treatment
- pregnancy
- acute limb ischemia (prior thrombolysis and/or thrombectomy indicated)
- no identified patent foot vessels

In cases of life-threatening infected gangrene, revascularisation can be performed to limit the extent of amputation and enable post-amputation wound healing [11].

Relative contraindications and the proposed solution to proceed with safety to endovascular treatment are shown in Table 2.

Patient Preparation

Standard Patient Pre-Procedural Work-up

- Complete medical history, thorough peripheral vascular examination (presence of pulses, foot inspection), ankle-brachial index (ABI) or toe-brachial index (TBI; for diabetic and dialysis patients), and review of relevant imaging studies (Duplex, plain foot X-rays, CTA or MRA). Patients with CTLI should undergo a pre-procedural cardiological examination including basal ECG and optimally echocardiography, due to the high prevalence of cardiological co-morbid conditions (ischaemic coronary disease, left ventricle dysfunction, heart valve disease, etc.). Thorough wound assessment and categorisation of tissue loss according to the wound, ischemia, and foot infection (WiFi) classification is recommended [12].
- Full blood count, renal function (eGFR), glucose, electrolytes, and coagulation profile (PT, aPTT, INR).
- Warfarin should be discontinued for 3 days and heparin may be given as bridging therapy according to local hospital policy.
- According to the 2019 SIR recommendations, peripheral arterial interventions using arterial sheaths up to 6Fr have been categorised as low bleeding risk procedures and could be performed in cases with INR 2.0–3.0 and platelets $>$ 20.000 /mcL. [13]. However, this is consensus-based, with a very low level of evidence. It is suggested that BTK revascularisation should be attempted if the platelet count is $>$ 50.000/mcL and INR $<$ 1.5, and endovascular treatment in patients with increased bleeding risk (INR 2.0–3.0; platelets $>$ 20.000 /mcL) is only justified in selected cases of limb-threatening CLTI and only if attempts to optimise the coagulation status are not expected to succeed.
- In cases of compromised renal function [eGFR $<$ 45 ml/min/1.73m^2 before intra-arterial contrast media (CM) administration with first pass renal exposure (undiluted CM), and eGFR $<$ 30 ml/min/1.73m^2 before intravenous injection or intra-arterial injection with second pass renal exposure (diluted CM)]) the renal team should be consulted, to reduce the risk of contrast-induced nephropathy (CIN). Generally, for patients at risk (eGFR $<$ $<$ 30 ml/min/1.73m^2) intravenous saline 0.9% 1 ml/kg/hr for 3–4 h before and 4–6 h after CM administration or intravenous sodium bicarbonate protocols as an alternative, are recommended according to the ESUR guidelines Individualized preventive hydration is recommended in patients with severe congestive heart failure (NYHA grade 3–4) or patients with eGFR $<$ 15 ml/min/1.73 m^2. To avoid lactic acidosis, patients with (a) with eGFR $<$ 30 ml/min/1.73 m^2 should discontinue metformin from the time of CM administration, and restart metformin if eGFR has not changed significantly within 48 h. [14]. Carbon dioxide

Table 2 Overcoming relative contraindications for endovascular treatment

Life-threatening allergy to contrast media	Pre-procedural administration of cortisone therapy (per os at least 48 h before the procedure)
Impaired renal function	Liaise with the renal team: hydration and consider CO_2 as contrast media
Unable to cooperate or lay flat	General anaesthesia. Closure device for haemostasis to limit post-procedural access-site bleeding complications
Life-threatening infected gangrene, or osteomyelitis or gangrene extending above the Chopart joint	Revascularisation can be performed to enable post-amputation wound-healing and/or limit the extent of amputation. Pre-procedural antibiotic therapy is absolutely necessary

(CO_2) could also be used as contrast media to avoid CIN in cases in patients with eGFR < 40 ml/min/1.73 m^2 [15, 16].

- Data on pre-procedural antiplatelet therapy are missing and preloading with antiplatelet agents is not generally instituted. However, most patients are already receiving antiplatelet therapy, as recommended for symptomatic PAD, which should not be discontinued before endovascular treatment. [6, 17–19].
- Antibiotic therapy should be continued in cases of infected wound/ulcer /gangrene.
- In case of wet gangrene, pre-procedural debridement could reduce the risk of septic shock post-revascularisation.
- Antihypertensive drugs should be continued as normal the day of the procedure to preserve BPS < 160 mmHg and reduce bleeding risk.
- The patient should be fasted and clear of fluids for at least 6 h. For patients with insulin-dependent diabetes mellitus, the dose of insulin should be adjusted accordingly. The bladder should be empty before entering the angiography suite, and a catheter should be considered only for specific cases. Peripheral 18-gauge i.v. access must be obtained.

Selected, low-risk, patients could be treated as day cases. However, closure devices or low-profile 4Fr sheath compatible devices should be considered. Patients with infected wounds may require hospitalisation to enable in-hospital intravenous antibiotic therapy, wound care/surgical debridement, and microbiological cultures [20, 21].

Pre-Procedural Imaging

Non-invasive pre-procedural imaging, in particular, CT angiography (CTA) or time-resolved, contrast-enhanced MR-angiography (CE-MRA) is recommended, especially for the assessment of the aortic, iliac, and femoropopliteal inflow [22]. High-frequency Duplex ultrasound (HF-DUS) could also be used and can be very useful to detect distal-foot, target vessels, as well as to establish the accessibility of the common femoral artery and pedal arteries for antegrade and retrograde access, respectively. Severe calcification of the crural vessels is a significant drawback of CTA and in many cases CTA is not diagnostic due to significant blooming artefact, while small-calibre crural vessels are best imaged using CE-MRA, even in subjects with diabetes. However, CE-MRA is time-consuming, and not always readily available. In pre-dialysis patients and those with compromised renal function (stage 3 or 4 chronic kidney disease) preoperative HF-DU is recommended and further preprocedural imaging should be reserved in non-diagnostic cases and could include CE-MRA using gadobenate dimeglumine or gadopentetate dimeglumine, non-enhanced MRA, or CO_2 angiography [6].

In cases where no distal run-off pedal vessels are recognized in pre-procedural imaging, selective DSA with the catheter at the distal popliteal artery is recommended to evaluate the presence of a distal target vessel. The choice should be case-sensitive depending on the patient's renal function and clinical condition, the specific advantages and disadvantages for each case, as well as the local availability and expertise. In any case, selective diagnostic DSA with the catheter at the level of the distal popliteal artery should be performed to provide information regarding the optimal treatment plan at the beginning of the procedure.

Endovascular Devices

The following are the types of endovascular devices currently available for infrapopliteal use; however, the specific choices will depend on the site, disease, and operator preferences [23].

- Plain balloon catheters—commonly 1.5–5 mm of various lengths/ tapered balloon catheters
- High-pressure balloon catheters
- Balloon-expandable and self-expanding metal stents
- Drug-eluting stents—usually 2.5–4.0 mm in diameter (sirolimus-, siroloimus-analogs and paclitaxel-eluting stents)
- Drug-coated balloon catheters (paclitaxel-coated balloons)
- Bioabsorbable drug-eluting stents
- Percutaneous endovascular atherectomy devices
- Drug-infusion devices
- Lithotripsy
- Microwires—including hydrophilic—0.014/0.018-inch as well as 0.035-inch guidewires
- Below-knee micro-catheters

Procedural Details and Endovascular Techniques

Most of the procedures can be performed using local anaesthesia at the puncture site and mild i.v. conscious sedation. Ultrasound-guided lidocaine (1–2%) injection within the subcutaneous tissue and up to the level of the adventitia is recommended to reduce the level of pain, while US-guided access should be performed to minimise the number of puncture attempts, time to access, and access-site complication rates [24]. Intravenous sedation (a combination of midazolam and fentanyl) is suggested to reduce the pain in patients with rest pain and/or painful wounds until blood flow has been restored. General

anaesthesia (GA) should be reserved for patients unable to cooperate, lay flat, remain immobile, or those unwilling to undergo the procedure without GA. The presence of the anaesthesiology team is also recommended for critically ill patients with severe cardiovascular comorbidities [25]. Dialysis patients should undergo infrapopliteal revascularisation only when the electrolyte balance is normal (usually after dialysis).

Access

Several approaches and catheter skills are used for challenging below-knee cases. A first option is an antegrade approach using standard common femoral artery access, as it is safe, and provides adequate pushability and torquability of the catheters and guidewires, as well as the required length for advanced around the arch revascularisations. Other advantages of the antegrade technique include the limited use of iodine contrast media and radiation protection. A 21G micropuncture set can be used, however, in cases of obese or scarred groins, standard 18G needles and 0.035' stiff guidewire systems are recommended as they provide more stability.

Another option for obese patients with large hostile abdomen covering the access site is the direct superficial femoral artery (SFA) puncture access; however, the use of a closure device for haemostasis is advised, as manual compression of the SFA distal to the femoral head could be ineffective, especially for 6Fr access [26]. Unfractionated heparin (usually 3000–5000 IU or a weight-adjusted dosage), either i.v. or intra-arterially through the sheath, is necessary to maintain an activated clotting time of around 200–250 s. Standard 10-cm arterial sheaths are usually used but longer sheaths or guiding catheters can be used for support in hard atherosclerotic lesions.

Revascularisation

Revascularisation should be initially focused on establishing a straight line of blood flow to the distal foot. Pedal arch angioplasty using 2–2.5 mm diameter balloon catheters should be attempted to improve foot perfusion, while pedal arch recanalisation is a significant advantage of endovascular versus open revascularisation. Pedal arch revascularisation has been identified as an independent predictor of improved wound healing [27]. According to the Global Vascular Guidelines on the Management of Chronic Limb-Threatening Ischemia, integrated, limb-based anatomic staging systems (such as the GLASS) could be considered for treatment decision-making [28].

Simple stenoses should be treated using an antegrade approach with standard straight or angled 0.014'' or 0.018'' BTK guidewires. Selective catheterisation of the BTK vessel can be obtained using standard curved angiographic 4Fr catheters. Generally, to obtain the maximum acute luminal gain and prevent vessel perforation, the proximal tibial arteries should be dilated up to 3.5 mm, middle-segment arteries up to 3.0 mm, and distal-segment arteries close to the ankle—the dorsalis pedis included—up to 2.5 mm. An increase by 0.5 mm for the tibioperoneal trunk and a reduction of 0.5 mm for the whole peroneal artery is recommended. Optimal vessel sizing, as well as accurate evaluation of angioplasty outcomes as to proceed with bail-out stenting, can be performed using adjunct extravascular US-guidance (EVUS) or endovascular imaging such as intravascular ultrasound (IVUS), and frequency-domain optical coherence tomography (FD-OCT) [29]. However, this is not widely utilised.

For chronic total occlusions (CTOs), the preferable recanalisation technique is intraluminal instead of subintimal tracking as, although spontaneous true-lumen re-entry is possible when subintimal tracking in the small tibial arteries is performed, it frequently fails. The use of dedicated 0.014'' or 0.018'' CTO guidewires with higher tip stiffness with load in grams $\geq$ 3, and enhanced penetration due to specially designed tips should be considered for severe calcific lesions in order to attempt an intraluminal recanalisation. However, due to the length of and chronicity of CTOs in BTK arteries, very frequently the lesion cannot be crossed intraluminally and the subintimal tracking technique is the most common strategy of revascularisation. Although data comparing various infrapopliteal lesion-crossing techniques and devices are missing, a recommended dedicated strategy to increase the success rate and reduce complication in BTK CTOs is as follows: The CTO segment could be divided into three distinct parts: the proximal cap, the CTO's body, and the distal cap. Crossing of the proximal cap is possible with 0.014 or 0.018 inches polymer jacketed wires, while high penetration force wires should be reserved to calcified caps. The navigation of the CTOP body could be performed with polymer jacketed low penetration wires using the knuckle-wire technique (an "umbrella-handle shaped" bend of the wire tip to distribute force over a larger surface area and break through the subendothelial layer into the true lumen). Crossing the distal cap is the most important aspect of the procedure and the re-entry in the true lumen has to be done at the point of vessel reconstitution to avoid the extension of vessel dissection in the healthy, non-occluded segment. Although it is frequent to re-enter with a polymer jacketed wire using the knuckle-wire technique, in some cases a step-up strategy to a high penetration tip wire is necessary. A re-entry device may also be considered. In selected cases, when every other antegrade option has failed, a 0.035' half stiff guidewire can be used for the subintimal technique also in BTK CTOs. In case of failure, a

retrograde strategy should be attempted. Dedicated guidewires may be of great value in challenging cases (0.014, 0.018, nitinol or hydrophilic tipped, weighted-tipped chronic total occlusion CTO wires, active guidewires, with or without supporting/crossing microcatheters). For tortuous distal anterior and posterior tibial artery lesions, manual flexion or extension of the foot could facilitate lesion crossing. In the case of very fibrotic and/or calcified lesions, low profile crossing and support catheters are very useful, while ultra-low-profile balloons are advised for optimal vessel dilatation. In cases of focal flow-limiting dissections, the use of drug-eluting stents is recommended [30, 31].

Attempt to revascularise more than one vessel is justified but should be case-specific and based on a risk/benefit approach. Overall, the theory of angiosome-directed or wound-directed revascularisation supports the reduction of time to wound healing, which is important for limb salvage in patients with diabetes [32–34].

According to the operators' experience, the most accessible lesion/vessel (based on angiographic anatomic complexity) should be revascularised first while multivessel revascularisation is preferable to angiosome-guided revascularisation of a single vessel, to maximise foot perfusion, enhance wound healing and preserve adequate blood supply in cases of vessel restenosis/re-occlusion [35]. In experienced hands, 2- vessel recanalisation downwards to the forefoot is the best treatment option.

Bifurcation Angioplasty and Stenting

Steno-occlusive lesions at the level of BTK bifurcations (anterior tibial- tibioperoneal artery and posterior tibial-peroneal artery bifurcations) are frequent [36]. Endovascular angioplasty and stenting techniques for bifurcation lesions are focused on preserving the patency of both vessels and include: (i) kissing balloons using two wires and simultaneous balloon dilation (ii) stenting of the main vessel followed by guidewire retrieval and catheterisation of the second vessel through the deployed stent and strut crush at the level of the bifurcation with a balloon (single stent technique), (iii) T-shape double-stent using two guidewires and stenting across the main vessel and at the ostium of the second vessel, and (iv) culotte double-stent technique with two guidewires and parallel stenting across the bifurcation. According to two retrospective case series, single stent technique may yield to superior patency outcomes, but the evidence is sparse." (Fig. 1) [36, 37] The use of absorbable dedicated BTK stents is also an option in bifurcation lesions as currently available results, although limited, are optimistic. [38–40]

Advanced Revascularisation Techniques

Pedal Access

An alternative option, to be attempted only in case of antegrade failure, is the retrograde pedal puncture of the distal anterior or posterior tibial arteries, or their proximal segments to facilitate retrograde lesion crossing with or without the SAFARI technique (e.g. retrograde guidewire re-introduced within the CFA sheath and revascularisation performed via an antegrade approach (SAFARI) or direct angioplasty or stenting via retrograde pedal access) [33]. Pedal access and retrograde lesion crossing, in general, is more likely required in cases of calcified flush occlusions.

In more extreme cases, puncture of the digital/metatarsal arteries or other small collateral vessels may also be considered [34, 35]. Micropuncture systems are suggested as the first approach to reduce the risk of vessel dissection, while dedicated pedal access sets with 4 Fr, 0.018' compatible, low-profile sheaths should be employed for pedal access cases [33]. Pedal access can be achieved under ultrasonographic or fluoroscopic guidance (Fig. 1). The vast majority of 0.014/0.018 inch balloon catheters and stents used in BTK vessels are compatible with 4Fr sheaths, while balloons could be advanced from the retrograde approach without using a sheath ("sheathless technique"). Haemostasis can be finally achieved by low-pressure balloon angioplasty across the access site. The latter is also useful in cases of severe spasm not resolving by local administration of nitro-glycerine. Manual compression can also be used for haemostasis when the puncture has been performed at the level of the ankle/foot.

Plantar-Loop Technique

Another option is to navigate a guidewire across the pedal-plantar loop and perform retrograde recanalisation, e.g. descend the anterior tibial across the pedal arch and cross retrogradely the plantar and posterior tibial arteries, or vice versa (Fig. 2). In general, 0.014′/300 mm BTK guidewires are recommended and 0.018′ strong-support guidewires should be avoided if possible as they could get caught around the arch. Guidewires with soft polymer tip are very useful for plantar arch navigation. The use of dedicated 0.014″ microcatheter systems or 0.014″ balloons is particularly helpful for pedal-plantar loop cases to support guidewire manipulation around the arch and allows for selective contrast injection as necessary [41, 42]. The suggested angulations to navigate around the pedal arch are the lateral oblique (the base of the fifth metatarsal bone should project externally from the base of the foot) and the anteroposterior (visualisation of the first proximal metatarsal inter-space) angiographic projections [9].

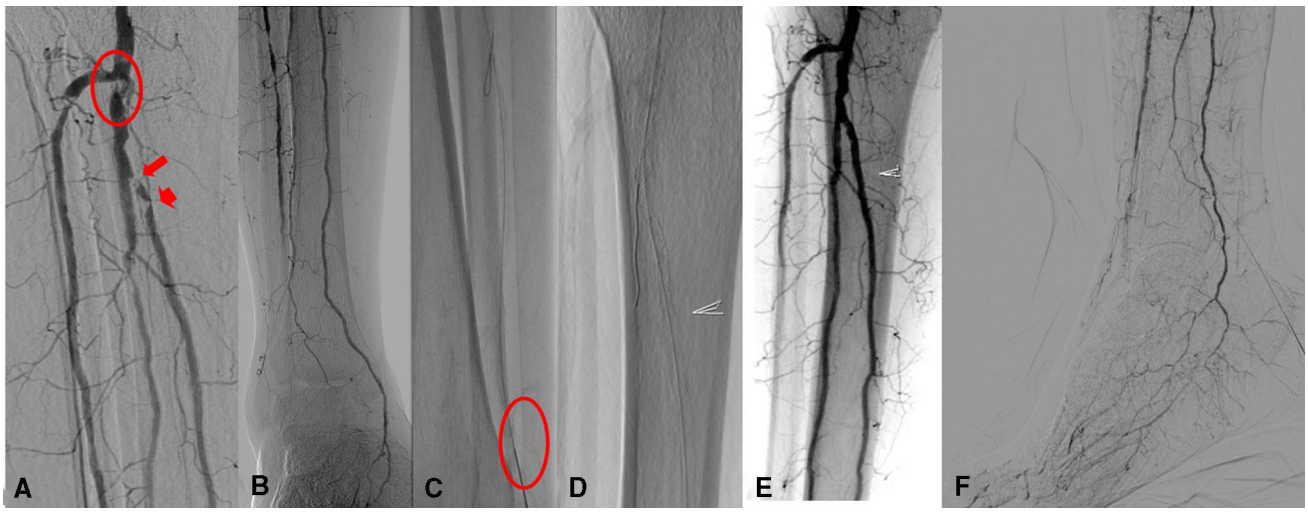


Fig. 1 Pedal access and bifurcation stenting. **A** Antegrade CFA access and selective DSA demonstrating severe stenosis of the tibioperoneal artery, calcified occlusion of the origin (arrow), and severe stenosis (arrowhead) of the posterior tibial artery. The anterior tibial artery is occluded. **B** Posterior tibial and peroneal arteries are patent to the distal foot. The pedal arch is mainly formed by the posterior tibial artery. **C** After failure to cross the occlusion, US-guided access of the distal posterior tibial artery was obtained (circle) and the lesion was crossed intraluminally with a straight 0.014' guidewire. **D** The crush stent technique was performed. Everolimus-eluting stents were deployed from the 5Fr pedal access and stent struts were crushed using a balloon from the antegrade CFA access. **D** and **E** Final angiography demonstrating an excellent immediate angiographic result and patent two-vessel distal run-off to the distal foot

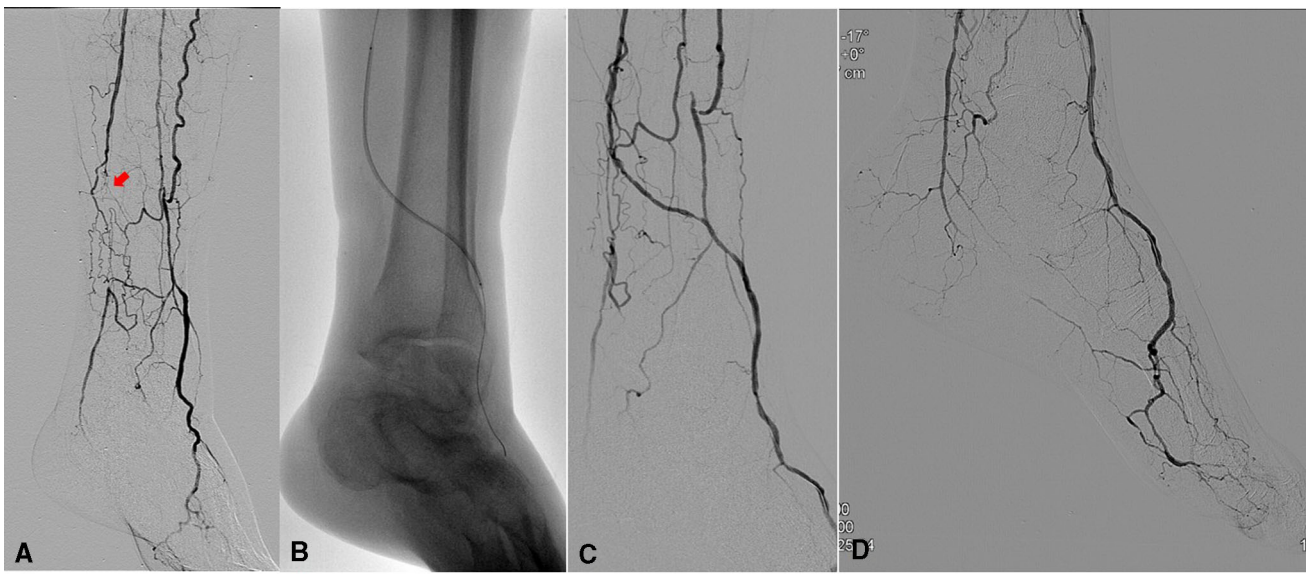
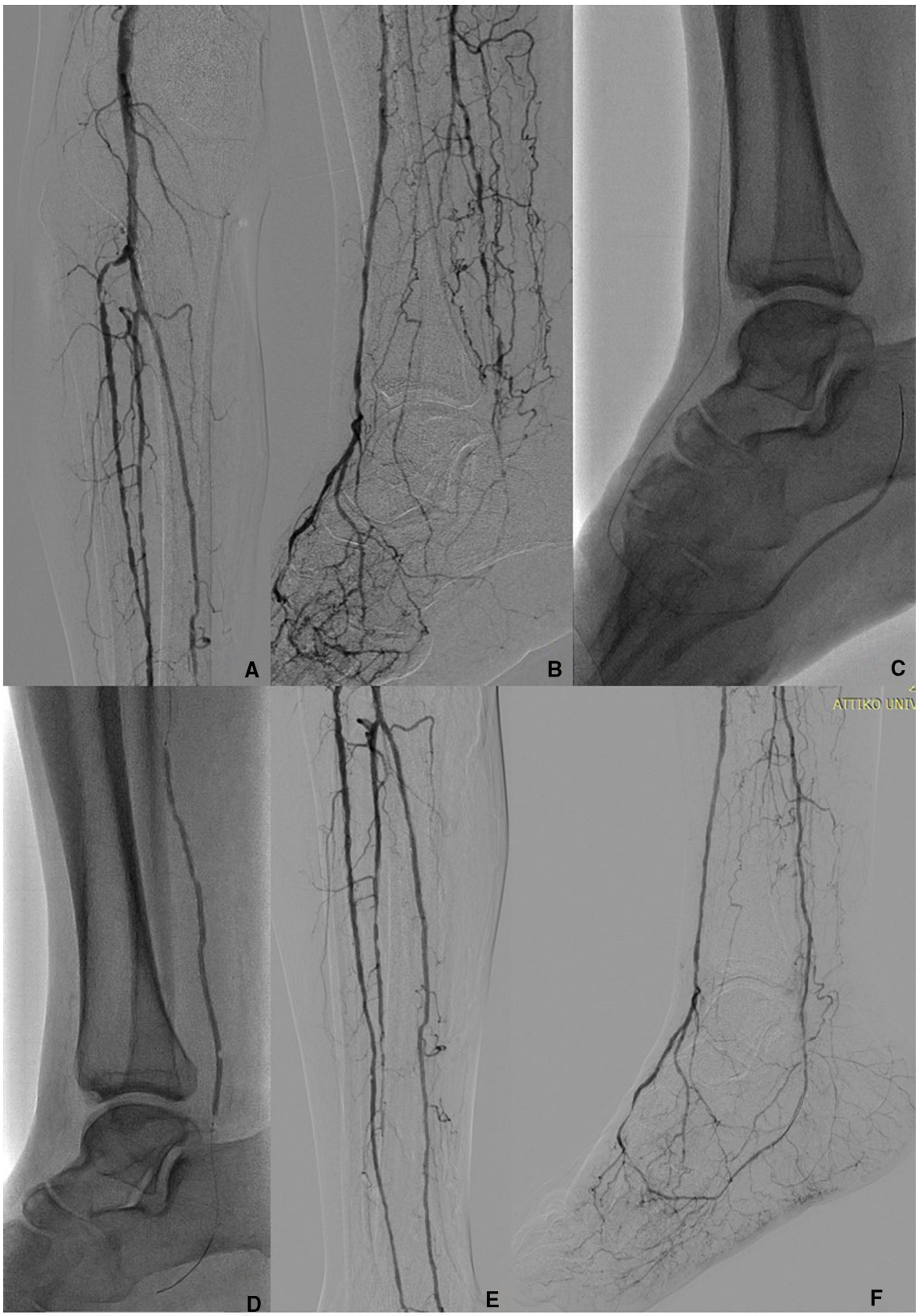


Fig. 2 Transcollateral approach. **A** DSA demonstrating occlusion of the distal anterior tibial artery. After failed antegrade lesion crossing a 0.014' angled guidewire was navigated through a collateral vessel (arrow) to the distal anterior tibial artery. **B** Balloon angioplasty was performed using a 2 mm and subsequently a 2.5 mm balloon catheter and **C** and **D** the final angiographic result demonstrated an uninterrupted line of blood flow from the posterior tibial to the anterior tibial artery supplying the distal foot

Transcollateral Approach

The transcollateral route to achieve foot perfusion can also be considered in cases in which direct foot perfusion via one of the three main BTK arteries fails. Selective catheterisation is imperative in order to choose an adequate collateral vessel. Transcollateral angioplasty usually establishes an indirect communication between the anterior tibial artery (ATA) and the posterior tibial artery (PTA) (Fig. 3) or the peroneal artery and the ATA or PTA. In general, 2–2.5 mm diameter balloons are required for the dilation of the target collateral artery.


A
B
C
D
E
F
ATTIKO UNIV

◀**Fig. 3** Pedal arch angioplasty and around the arch revascularisation. **A**, **B** DSA demonstrating diffuse three vessels infrapopliteal disease, posterior tibial artery distal occlusion, and pedal arch disease. Pedal arch angioplasty **C** with a 2.5-mm balloon catheter and around the arch recanalisation of the distal posterior tibial artery occlusion. **D** The remaining posterior tibial artery lesions were recanalised using the antegrade CFA access. **E** and **F** Final DSA demonstrating two-vessel run-off and pedal arch reconstruction

Deep Vein Arterialisation (DVA)

For no-option patients, without target outflow pedal vessels available for endovascular or open surgical revascularisation, percutaneous endovascular DVA has been recently proposed as a last resort to avoid major amputation. This technique aims to arterialise a deep vein of the limb that will serve as an outflow vessel and provide blood supply to the distal foot, by creating an arteriovenous fistula from an infrapopliteal artery [43]. Percutaneous DVA can be performed using either a commercially available dedicated device, re-entry devices or alternatively using a technique of percutaneous puncture through a snare positioned within the target deep vein and a balloon catheter placed within the adjacent artery as described by Ysa A, et al. [44].

Another alternative technique involves the inflation a balloon within the deep vein and puncture of the balloon from the artery using an outback re-entry device. Small calibre covered stents are required for such procedures. Nevertheless, clinical experience and published data about DVA remain limited [45].

Of note, severe cardiac failure (EF $< 35\%$) is a contraindication for this technique [44].

Intraprocedural Foot Perfusion Assessment

Real-time quantification of foot perfusion during endovascular treatment is feasible using 2D-perfusion angiography or fluorescence angiography. Although these modalities can provide a sequentially quantifiable angioplasty outcome, their value in intraprocedural decision-making requires further investigation [46, 47].

Medication and Post-procedural Care

- *Bed rest* as for standard care. Vascular closure devices are recommended to increase safety and accelerate patient ambulation. Distal foot and pedal puncture sites are adequately controlled with manual compression, or external low-pressure cuff compression, or using endovascular tamponade with a standard angioplasty balloon inflated across the puncture site for 2–3 min. However, the above recommendations are not based on high-quality evidence.
- *Post-procedural surveillance* access site and vital signs monitoring. In cases of painful access-site haematoma the presence of a pseudoaneurysm should be excluded. A pseudoaneurysm should be treated with US-guided compression or thrombin injection, stent-graft placement or less frequent with open surgery. If no adverse event is noted, switching early from intravenous to oral hydration and a light diet is advisable after 4–5 h, especially in diabetic patients.
- *Medical therapy* If patients are not receiving Coumadin or DOAC, dual antiplatelet therapy is advised, with clopidogrel 75 mg and acetylsalicylic acid 75 mg or 100 mg once daily, for 6 months, followed by lifelong monotherapy with clopidogrel, as this scheme has been correlated with reduced major amputations following percutaneous revascularisation [48]. However, the duration of treatment should be individualised. High on-treatment platelet reactivity (HTPR) during clopidogrel treatment has been reported in 50% of patients with critical limb ischemia (CLI) [49]. Moreover, 12% of PAD patients demonstrate dual resistance to both clopidogrel and aspirin [42]. Personalised antiplatelet therapy and alternative antiplatelet therapy could be considered in cases of complex BTK disease demonstrating high on-treatment platelet reactivity (HTPR), although more data to support such therapeutic schemes are awaited. Ticagrelor 90 mg twice daily could be considered as an alternative antiplatelet agent, as it has been reported to successfully overcome HTPR, although evidence supporting its use in CLTI patients remains limited [50, 51]. Dual antithrombotic therapy using rivaroxaban 2.5 mg twice daily and aspirin 100 mg once daily may also be considered in selected CLI patients with low bleeding risk and concomitant coronary disease. This may be considered as the results of the VOYAGER PAD multicentre double-blind trial, demonstrated a significant benefit compared to aspirin monotherapy in reducing major adverse events (acute limb ischemia, major amputation for vascular causes, myocardial infarction, ischemic stroke, or death from cardiovascular causes) in PAD patients who had undergone revascularisation. Nevertheless, significantly more major bleeding events occurred in the group receiving dual antithrombotic therapy. [52] As a high level of evidence for antithrombotic therapy following BTK revascularisation remain limited, a personalized approach, considering all the above-mentioned options, is recommended. All patients with symptomatic PAD should be on statins despite normal cholesterol plasma levels, pharmacotherapy for hypertension and diabetes, and should restrain from smoking [53].

Post-Treatment and Follow-up Care

Patients with tissue loss should receive wound care in specialised centres with an available multidisciplinary foot care team (including vascular surgeons, podiatrists, and diabetologists). Once wound healing has been obtained, light daily exercise should be encouraged to assist cardiovascular rehabilitation. Strict follow-up is recommended following complex BTK and pedal procedures. Early DUS is advisable before discharge, in order to obtain baseline post-procedural imaging or detect a clinically silent re-occlusion, which should immediately prompt further treatment. Pre-scheduled clinical visits at 1-, 3-, 6- and 12-month post-procedure are recommended and should include wound inspection, peripheral pulses, clinical history, and ABI, transcutaneous oxygen pressure ($TcPO_2$) values (tissue perfusion surveillance), if available, and DUS. Toe-brachial index (TBI) is advised for a subject with diabetes to avoid false-negative results in incompressible calcified vessels. In case of positive DUS findings, correlated with clinical deterioration or relapse, the patient should be referred for DSA with a view to re-intervention. Adherence to pharmacotherapy should be monitored during clinical visits to ensure patient compliance.

Various modalities can be used for the non-invasive surveillance of foot perfusion [39].

- *ABI and TBI* Both are highly recommended for surveillance. TBI is a more accurate haemodynamic assessment of foot arterial supply than ABI, which is compromised by incompressible vessels noted in diabetic and/or dialysis patients.
- *$TcPO_2$ and Skin Perfusion Pressure (SPP)* Both provide quantification of regional skin blood flow and can be used for surveillance as they have been correlated with the prediction of amputation and wound healing. Various novel non-invasive modalities such as subcutaneously injected O_2 micro-sensors, laser Doppler imaging, and microwave radiometry are currently under investigation. However, more data are awaited in order to prove their value in foot perfusion assessment and be incorporated in CLI surveillance protocols.

Outcomes

Plain Balloon Angioplasty (POBA)

POBA remains the first treatment choice for long infrapopliteal lesions. Studies conducted the previous decade, reported an immediate technical success rate between 80 and 100% and up to 80% limb salvage rate at two years [6]. Moreover, in a 2008 meta-analysis infrapopliteal angioplasty resulted in similar limb salvage (PTA 86.0 ± 2.7% vs. 88.5 ± 2.2% bypass) but significantly lower 1-year patency rates compared to popliteal-to-distal vein bypass (58.1 ± 4.6% vs. 81.5 ± 2.0%). On the other hand, 30-day mortality (5.2% vs. 2.7%) was significantly higher for infrainguinal bypass [= 54]. Similarly, in a large propensity score analysis published in 2006 (1023 patients), similar 5-year results for limb salvage (75.3% vs. 76.0%) and amputation-free survival (37.7% vs. 37.3%), were reported, while in a subgroup analysis of the BASIL randomised trial, patients with infrapopliteal disease (with or without femoropopliteal disease), demonstrated similar amputation-free and overall survival, following vein bypass surgery and endovascular treatment [54, 55]. More recent comparative studies further indicate that endovascular treatment obtains a similar limb salvage rate with open bypass and results from multicentre RCTs are awaited [56].

As expected, slightly lower technical success and limb salvage rates are reported for advanced BTK procedures. Technical success of pedal arch angioplasty ranges between approximately 60 and 96% [49, 57]. Additionally, pedal arch revascularisation has been identified as an independent factor for improved wound healing (HR: 1.564; 95%CI:1.068–2.290) [58]. The reported limb salvage outcomes of pedal arch angioplasty at 2-year follow-up is approximately 82% [59]. In a recent meta-analysis investigating the efficacy of additional below the ankle angioplasty, a pooled proportion of limb salvage of 92% at 1 year has been reported [60].

Drug-Eluting Stents (DES) and Drug-Coated Balloons (DCB)

Several multicentre, randomised controlled trials (RCT) designed to investigate the use of DES for infrapopliteal artery disease, have provided level as evidence to support the use DES for short-to-medium-length lesions [31]. According to meta-analytical data, DES deployment in short–to–medium-length infrapopliteal lesions was superior in terms of patency, target lesion revascularisation, Rutherford improvement and wound healing at 1-year follow-up, compared to bare metal stenting or plain balloon angioplasty. Nevertheless, superior patency was not sustained at 3 years [59]. Long-term outcomes remain scarce.

The results of the use of paclitaxel-coated balloons in BTK disease remain contradictory. Two initial multicentre RCTs failed to establish a significant benefit compared to plain balloon angioplasty [18]. In a 2016 network meta-analysis of 16 RTCs (1.805 patients) comparing DES, paclitaxel-coated balloons (PCBs), and POBA, PCBs reduced TLR rates compared with bare-metal stents and

plain balloons but the quality of evidence (QOE) was low to moderate [31]. In a 2020 meta-analysis of 8 RCTs (1.420 patients) investigating PCBs, a significantly lower TLR was noted following PCB treatment (11.8% crude risk of TLR versus 25.6% in control; p = o. o4). However, amputation-free survival was significantly lower for PCB (13.7% crude risk of death or limb loss vs. 9.4% in plain balloon angioplasty; $p = 0.008$). Nonetheless, individual endpoints of death or major amputation did not breach statistical significance when analysed separately [60]. Recently, the 12-month data from the Lutonix BTK multicentre RCT were made publicly available, further disputing any advantage provided by PCB technology in infrapopliteal lesions [61]. On 17th February, 2021, the FDA issued a negative decision regarding the approval of the Lutonix PCB catheter for use in BTK disease. Moreover, 9-month results of the IN.PACT BTK multi-centre randomized study failed to demonstrate superiority in the pre-defined primary endpoint of late lumen loss (0.89 ± 0.77 mm for PCB vs. 1.31 ± 0.72 mm for PTA) or target lesion reintervention rates (8.7% in both groups) compared to POBA. [62] On the other hand, the ACOART BTK single-centre RCT and the ACOART II BTK multicentre RCT demonstrated superior primary patency and significantly less reintervention in favour of the specific PCB balloon catheter. [63, 64] As available RCTs are contradictive and safety issues have been raised, the use of PCBs in BTK disease remains controversial and further multicentre RCTs are required to support their use in every-day clinical practice.

On the other hand, high QOE indicated that infrapopliteal DES significantly reduced restenosis and TLR compared with bare-metal stents and plain balloons at 1-year follow-up, but only for short-length lesions which constitute the vast minority of BTK cases and do not match the need of long CTO which are the typical CLI scenario. Moreover, only DES significantly reduced limb amputations compared with all other treatments with moderate to a high quality of evidence and significantly improved wound healing compared with bare-metal stents and plain balloons with high QoE. Finally, plain balloons achieved less TLR compared to bare metal stents with high-quality evidence [27]. According to recent data (five studies with 155 patients), the use of dedicated absorbable DES could be another option in selected cases, to improve clinical outcomes without using permanent metallic scaffolds. However, prospective comparative data are missing, and the level of evidence remains low, to recommend these devices as standard clinical practice. [39]

Other Endovascular Treatment Modalities

There is still limited evidence for the use of infrapopliteal low-profile atherectomy devices (mostly rotational ones), and although positive initial results have been noted in prospective registries, concerns about safety and efficacy have been also raised [55]. In a more recent large retrospective study comparing infrapopliteal angioplasty (n = 183) versus atherectomy (n = 159), similar clinical and patency outcomes were achieved, but with significantly more complications for atherectomy (4% vs. 0.5%; $p = 0.03$) [65]. Notably, atherectomy is not recommended following subintimal crossing, which is frequently required in calcified BTK CTOs. Other, more recent elution technologies include bioabsorbable stents, bioabsorbable DES, and infusion catheters locally delivering therapeutic agents directly to the vessel wall require significantly more data in order to be considered as treatment options in everyday clinical practice [66, 67]. Finally, deep venous arterialisation has also yielded promising initial results, in patients that would be otherwise treated conservatively with an extremely poor prognosis. Del Giudice et al. have reported 100% technical success and 60% complete wound healing at 1-year follow-up [68]. Similarly, Kum et al., in a small series of seven patients reported 71% complete wound healing at 1 year [69].

Complications

The rate of complications occurring during or shortly after infrapopliteal endovascular procedures ranges between 2 and 10% and access-site-related complications (vessel occlusion, puncture site hematomas, false aneurysms, and access site or retroperitoneal bleeding) are the most frequent. However, major complications requiring further treatment are usually observed in 3–4% of the cases, but this rate is largely dependent on the definition used [6, 70]. For pedal access, complications include bleeding, pseudoaneurysm formation, severe spasm, and vessel occlusion that may lead to limb loss. Other complications include flow-limiting dissection/occlusion that can be treated with a DES or prolonged (3 min or longer) balloon inflation. Spasm can be treated using nitro-glycerine from the sheath or locally from a catheter (using a Y valve as to not remove the guidewire), although caution is needed in patients with low systolic blood pressure due to the systemic effect of nitro-glycerine. Thromboembolic events during infrapopliteal angioplasty are rare ($< 1\%$) and can be treated with percutaneous aspiration thrombectomy (PAT) using a 5-6Fr catheter or larger [71]. Concomitant catheter-directed local thrombolysis with urokinase or recombinant tissue plasminogen activator (rt-PA) is advised to treat distal pedal small emboli and enhance outflow, while mechanical

thrombectomy and thrombus "caging" using stents have also been reported to be effective [72]. Vessel perforation occurs due to accidental guide wire misplacement or distal migration and is usually self-contained. If bleeding persists, low-pressure balloon inflation of the inflow or even external manual compression usually achieves haemostasis. Trans-catheter coil embolisation is rarely required.

Funding This study was not supported by any funding.

Declarations

Conflict of Interest M. Manzi is a consultant for Abbott, Angiodroid, BDBard, Biotronik, Boston Scientific, Cook Medical and Terumo. All other authors declare they have no conflict of interest.

Ethical Approval For this type of study, informed consent is not required.

References

1. Hinchliffe RJ, Brownrigg JR, Andros G, et al. Effectiveness of revascularization of the ulcerated foot in patients with diabetes and peripheral artery disease: a systematic review. Diabetes Metab Res Rev. 2016;32(Suppl 1):136–44.
2. Young MJ, McCardle JE, Randall LE, et al. Improved survival of diabetic foot ulcer patients 1995–2008: possible impact of aggressive cardiovascular risk management. Diabetes Care. 2008;31:2143–7.
3. International Best Practice Guidelines: Wound Management in Diabetic Foot Ulcers. Wounds International 2013; Available from: www. woundsinternational.com (2013).
4. Chi YW, Jaff MR. Optimal risk factor modification and medical management of the patient with peripheral arterial disease. Catheter Cardiovasc Interv. 2008;71(4):475–89.
5. Faglia E, Dalla Paola L, Clerici G, et al. Peripheral angioplasty as the first-choice revascularization procedure in diabetic patients with critical limb ischemia: prospective study of 993 consecutive patients hospitalized and followed between 1999 and 2003. Eur J Vasc Endovasc Surg. 2005;29(6):620–7.
6. van Overhagen H, Spiliopoulos S, Tsetis D. Below-the-knee interventions. Cardiovasc Interv Radiol. 2013;36(2):302–11.
7. Caitlin W Hicks, Joseph K Canner, Ying W Lum, James H Black 3rd, Christopher J Abularrage (2019) Long-term outcomes of an endovascular-first approach for diabetic patients with predominantly tibial disease treated in a multidisciplinary setting. Ann Vasc Surg 60:315–326.e2.
8. Gray BH, Diaz-Sandoval LJ, Dieter RS, Jaff MR, White CJ. Peripheral vascular disease committee for the society for cardiovascular angiography and interventions. SCAI Expert Consensus Statement Infrapopliteal Arter Interv Appropr Use. 2014;84(4):539–45.
9. 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.
10. Bus SA, Lavery LA, Monteiro-Soares M et al 2020 International Working Group on the Diabetic Foot. Guidelines on the prevention of foot ulcers in persons with diabetes (IWGDF 2019 update). Diabetes Metab Res Rev 36(Suppl 1):e3269.
11. Katsanos K, Tepe G, Tsetis D, Fanelli F. Standards of practice for superficial femoral and popliteal artery angioplasty and stenting. Cardiovasc Intervent Radiol. 2014;37(3):592–603. https://doi.org/10.1007/s00270-014-0876-3.
12. Joseph L Mills Sr, Michael S Conte, David G Armstrong et al (2014) The society for vascular surgery lower extremity threatened limb classification system: risk stratification based on wound, ischemia, and foot infection (WIfI). J Vasc Surg 59(1):220–34.e1–2.
13. Patel IJ, Rahim S, Davidson JC, et al. Society of Interventional Radiology Consensus Guidelines for the periprocedural management of thrombotic and bleeding risk in patients undergoing percutaneous image-guided interventions—part II: recommendations: endorsed by the Canadian Association for Interventional Radiology and the Cardiovascular and Interventional Radiological Society of Europe. J Vasc Interv Radiol. 2019;30(8):1168-1184.e1.
14. van der Molen AJ, Reimer P, Dekkers IA, et al. Post-contrast acute kidney injury. Part 2: risk stratification, role of hydration and other prophylactic measures, patients taking metformin and chronic dialysis patients: recommendations for updated ESUR Contrast Medium Safety Committee guidelines. Eur Radiol. 2018;28:2856–69.
15. Stegemann E, Tegtmeier C, Bimpong-Buta NY, et al. Carbon-dioxide-aided angiography decreases contrast volume and preserves kidney function in peripheral vascular interventions. Angiology. 2016;67(9):875–81.
16. Vergadis C, Festas G, Spathi E, Pappas P, Spiliopoulos S. Methods for reducing contrast use and avoiding acute kidney injury during endovascular procedures. Curr Pharm Des. 2019;25(44):4648–55.
17. Frank U, Nikol S, Belch J, et al. ESVM guideline on peripheral arterial disease. Vasa. 2019;48(Suppl 102):1–79.
18. Savcic M, Hauert J, Bachmann F et al (1999) Clopidogrel loading dose regimens: kinetic profile of pharmacodynamic response in healthy subjects. Semin Thromb Hemost 25(2 Suppl):15–19
19. Gurbel PA, Cummings CC, Bell CR, Alford AB, Meister AF, Serebruany VL. Plavix reduction Of new thrombus occurrence (PRONTO) trial. Onset and extent of platelet inhibition by clopidogrel loading in patients undergoing elective coronary stenting: the plavix reduction of new thrombus occurrence (PRONTO) trial. Am Heart J. 2003;145(2):239-247.
20. Spiliopoulos S, Karnabatidis D, Katsanos K, et al. Day-case treatment of peripheral arterial disease: results from a multicenter european study. Cardiovasc Interv Radiol. 2016;39(12):1684–91.
21. Akopian G, Katz SG. Peripheral angioplasty with same-day discharge in patients with intermittent claudication. J Vasc Surg. 2006;44(1):115–8.
22. Norgren L, Hiatt WR, Dormandy JA, et al. Inter-society consensus for the management of peripheral arterial disease (TASC II). Eur J Vasc Endovasc Surg. 2007;33(Suppl 1):S1-75.
23. Shishehbor MH, Jaff MR. Percutaneous therapies for peripheral artery disease. Circulation. 2016;134(24):2008–27.
24. Spiliopoulos S, Katsanos K, Diamantopoulos A, Karnabatidis D, Siablis D. Does ultrasound-guided lidocaine injection improve local anaesthesia before femoral artery catheterization? Clin Radiol. 2011;66(5):449–55.
25. Bailey SR, Beckman JA, Dao TD, et al. ACC/AHA/SCAI/SIR/SVM 2018 appropriate use criteria for peripheral artery intervention: a report of the american college of cardiology appropriate use criteria task force, American heart association, society for cardiovascular angiography and interventions, society of interventional radiology, and society for vascular medicine. J Am Coll Cardiol. 2019;73(2):214–37.
26. Spiliopoulos S, Kitrou P, Christeas N, Karnabatidis D. Starclose SE® hemostasis after 6F direct antegrade superficial femoral artery access distal to the femoral head for peripheral

endovascular procedures in obese patients. Diagn Interv Radiol. 2016;22(6):542–7.
27. Jung HW, Ko YG, Hong SJ, et al. Editor's choice -impact of endovascular pedal artery revascularisation on wound healing in patients with critical limb ischaemia. Eur J Vasc Endovasc Surg. 2019;58(6):854–63.
28. Conte MS, Bradbury AW, Kolh P, et al. Global vascular guidelines on the management of chronic limb-threatening ischemia. J Vasc Surg. 2019;69(6):3S–125Se4.
29. Shammas NW, Shammas WJ, Jones-Miller S, et al. Optimal vessel sizing and understanding dissections in infrapopliteal interventions: data from the iDissection below the knee study. Endovasc Ther. 2020. https://doi.org/10.1177/1526602820924815.
30. Liu X, Zheng G, Wen S. Drug-eluting stents versus control therapy in the infrapopliteal disease: a meta-analysis of eight randomized controlled trials and two cohort studies. Int J Surg. 2017;44:166–75.
31. Katsanos K, Kitrou P, Spiliopoulos S, Diamantopoulos A, Karnabatidis D. Comparative effectiveness of plain balloon angioplasty, bare metal stents, drug-coated balloons, and drug-eluting stents for the treatment of infrapopliteal artery disease: systematic review and Bayesian Network meta-analysis of randomized controlled trials. J Endovasc Ther. 2016;23(6):851–63.
32. Tsubakimoto Y, Nakama T, Kamoi D, Andoh H, Urasawa KJ. Outcomes of pedal artery angioplasty are independent of the severity of inframalleolar disease: a subanalysis of the multicenter RENDEZVOUS registry. Endovasc Ther. 2020;27(2):186–93.
33. Palena LM, Garcia LF, Brigato C, et al. Angiosomes: how do they affect my treatment? Tech Vasc Interv Radiol. 2014;17(3):155–69.
34. Alexandrescu VA, Brochier S, Limgba A et al (2019) Healing of diabetic neuroischemic foot wounds with vs without wound-targeted revascularization: preliminary observations from an 8-year prospective dual-center registry. J Endovasc Ther https://doi.org/10.1177/1526602819885131. [Epub ahead of print]
35. Peregrin JH, Koznar B, Kovác J, et al. PTA of infrapopliteal arteries: long-term clinical follow-up and analysis of factors influencing clinical outcome. Cardiovasc Interv Radiol. 2010;33(4):720–5.
36. Spiliopoulos S, Fragkos G, Katsanos K, Diamantopoulos A, Karnabatidis D, Siablis D. Long-term outcomes following primary drug-eluting stenting of infrapopliteal bifurcations. J Endovasc Ther. 2012;19(6):788–96.
37. Werner M, Scheinert S, Bausback Y, et al. Bifurcation stenting after failed angioplasty of infrapopliteal arteries in critical limb ischemia: techniques and short-term follow-up. Catheter Cardiovasc Interv. 2013;82(4):E522–8.
38. Gandini R, Uccioli L, Spinelli A, et al. Alternative techniques for treatment of complex below-the knee arterial occlusions in diabetic patients with critical limb ischemia. Cardiovasc Interv Radiol. 2013;36(1):75–83.
39. Ipema J, Kum S, Huizing E, Schreve MA, Varcoe RL, Hazenberg CE, de Vries JP, Ünlü Ç. A systematic review and meta-analysis of bioresorbable vascular scaffolds for below-the-knee arterial disease. Int Angiol. 2021;40(1):42–51.
40. Huizing E, Kum S, Ipema J et al (2021) Mid-term outcomes of an everolimus-eluting bioresorbable vascular scaffold in patients with below-the-knee arterial disease: a pooled analysis of individual patient data. Vasc Med https://doi.org/10.1177/1358863X20977907. Epub ahead of print. PMID: 33507844.
41. Palena LM, Brocco E, Manzi M. The clinical utility of below-the-ankle angioplasty using "transmetatarsal artery access" in complex cases of CLI. Catheter Cardiovasc Interv. 2014;83(1):123–9.
42. Manzi M, Palena LM. Treating calf and pedal vessel disease: the extremes of intervention. Semin Interv Radiol. 2014;31(4):313–9.
43. Del Giudice C, Van Den Heuvel D, et al. Percutaneous deep venous arterialization for severe critical limb ischemia in patients with no option of revascularization: early experience from two European centers. Cardiovasc Interv Radiol. 2018;41(10):1474–80.
44. Ysa A, Lobato M, Mikelarena E, et al. Homemade device to facilitate percutaneous venous arterialization in patients with no-option critical limb ischemia. J Endovasc Ther. 2019;26(2):213–8.
45. Mustapha JA, Saab FA, Clair D, Schneider P. Interim results of the PROMISE I trial to investigate the lim flow system of percutaneous deep vein arterialization for the treatment of critical limb dschemia. J Invasive Cardiol. 2019;31(3):57–63.
46. Kevin Rogers R, Montero-Baker Miguel, Biswas Minakshi, Morrison Justin, Braun Jonathan. Assessment of foot perfusion: overview of modalities, review of evidence, and identification of evidence gaps. Vasc Med. 2020. https://doi.org/10.1177/1358863X20909433.
47. Reekers JA, Koelemay MJ, Marquering HA, van Bavel ET. Functional imaging of the foot with perfusion angiography in critical limb ischemia. Cardiovasc Interv Radiol. 2016;39(2):183–9.
48. Katsanos K, Spiliopoulos S, Saha P, et al. Comparative efficacy and safety of different antiplatelet agents for prevention of major cardiovascular events and leg amputations in patients with peripheral arterial disease: a systematic review and network meta-analysis. PLoS One. 2015;10(8):e0135692.
49. Jung HW, Ko YG, Hong SJ, et al. Editor's choice –impact of endovascular pedal artery revascularisation on wound healing in patients with critical limb ischaemia. Eur J Vasc Endovasc Surg. 2019;58(6):854–63.
50. Lemesle G, Schurtz G, Bauters C, Hamon M. High on-treatment platelet reactivity with ticagrelor versus prasugrel: a systematic review and meta-analysis. J Thromb Haemost. 2015;13(6):931–42.
51. Spiliopoulos S, Katsanos K, Pastromas G, Diamantopoulos A, Kitrou P, Siablis D, Karnabatidis D. Initial experience with ticagrelor in patients with critical limb ischemia and high on-clopidogrel platelet reactivity undergoing complex peripheral endovascular procedures. Cardiovasc Interv Radiol. 2014;37(6):1450–7.
52. Bonaca MP, Bauersachs RM, Anand SS, et al. Rivaroxaban in peripheral artery disease after revascularization. N Engl J Med. 2020;382(21):1994–2004.
53. Gerhard-Herman MD, Gornik HL, Barrett C, et al. (2016) AHA/ACC guideline on the management of patients with lower extremity peripheral artery disease: executive summary. J Am Coll Cardiol. 2017;69(11):1465–508.
54. Albers M, Romiti M, Brochado-Neto FC, et al. Metaanalysis of popliteal to distal vein bypass grafts for critical ischemia. J Vasc Surg. 2006;43:498–503.
55. Popplewell MA, Davies HOB, Narayanswami J, et al. A comparison of outcomes in patients with infrapopliteal disease randomised to vein bypass or plain balloon angioplasty in the bypass vs. angioplasty in severe ischaemia of the leg (BASIL) trial. Eur J Vasc Endovasc Surg. 2017;54(2):195–201.
56. Patel SD, Biasi L, Paraskevopoulos I, et al. Comparison of angioplasty and bypass surgery for critical limb ischaemia in patients with infrapopliteal peripheral artery disease. Br J Surg. 2016;103(13):1815–22.
57. Nakama T, Watanabe N, Haraguchi T, et al. Clinical outcomes of pedal artery angioplasty for patients with ischemic wounds: results from the multicenter RENDEZVOUS registry. JACC Cardiovasc Interv. 2017;10:79–90.

58. Meyer A, Schinz K, Lang W, Schmid A, Regus S, Rother U. Outcomes and influence of the pedal arch in below-the-knee angioplasty in patients with end-stage renal disease and critical limb ischemia. Ann Vasc Surg. 2016;35:121–9.
59. Varcoe RL, Paravastu SC, Thomas SD, Bennett MH. The use of drug-eluting stents in infrapopliteal arteries: an updated systematic review and meta-analysis of randomized trials. Int Angiol. 2019;38(2):121–35.
60. Katsanos K, Spiliopoulos S, Kitrou P, Krokidis M, Paraskevopoulos I, Karnabatidis D. Risk of death and amputation with use of paclitaxel-coated balloons in the infrapopliteal arteries for treatment of critical limb ischemia: a systematic review and meta-analysis of randomized controlled trials. J Vasc Interv Radiol. 2020;31(2):202–12.
61. Lutonix DCB Versus Standard Balloon Angioplasty for Treatment of Below-The-Knee (BTK) Arteries. ClinicalTrials.gov. Available online https://clinicaltrials.gov/ct2/show/NCT01870401. Accessed 29 Jan 2020.
62. Safety and Effectiveness of Drug-Coated Balloon Angioplasty versus Plain Balloon Angioplasty in the Infrapopliteal Arteries: IN.PACT BTK Randomized Study 9-Month Primary Outcomes. Presented by Micari A, TCT 2020.
63. Liistro F, Angioli P, Ventoruzzo G, et al. Randomized controlled trial of acotec drug-eluting balloon versus plain balloon for below-the-knee angioplasty. JACC Cardiovasc Interv. 2020;13(19):2277–86.
64. Jia X, Zhuang B, Wang F, et al (2020) Drug-coated balloon angioplasty compared With uncoated balloons in the treatment of infrapopliteal artery lesions (AcoArt II-BTK). J Endovasc Ther https://doi.org/10.1177/1526602820969681. Epub ahead of print. PMID: 33118432.
65. Shammas NW. Current role of stherectomy for treatment of femoropopliteal and infrapopliteal disease. Interv Cardiol Clin. 2017;6(2):235–49.
66. Zia S, Juneja A, Sara Shams S, et al. Contemporary outcomes of infrapopliteal atherectomy with angioplasty versus balloon angioplasty alone for critical limb ischemia. J Vasc Surg. 2020;71(6):2056–64.
67. Bunch F, Walker C, Kassab E, Carr J. A universal drug delivery catheter for the treatment of infrapopliteal arterial disease: results from the multi-center first-in-human study. Catheter Cardiovasc Interv. 2018;91:296–301.
68. Del Giudice C, Van Den Heuvel D, et al. Percutaneous deep venous arterialization for severe critical limb ischemia in patients with no option of revascularization: early experience from two European centers. Cardiovasc Intervent Radiol. 2018;41(10):1474–80.
69. Kum S, Tan YK, Schreve MA, Ferraresi R, et al. Midterm outcomes from a pilot study of percutaneous deep vein arterialization for the treatment of no-option critical limb ischemia. J Endovasc Ther. 2017;24(5):619–26.
70. Filippiadis DK, Binkert C, Pellerin O, Hoffmann RT, Krajina A, Pereira PL. Cirse quality assurance document and standards for classification of complications: the cirse classification system. Cardiovasc Interv Radiol. 2017;40(8):1141–6.
71. Gandini R, Merolla S, Chegai F, et al. Foot embolization during limb salvage procedures in critical limb ischemia patients successfully managed with mechanical thromboaspiration: a technical note. J Endovasc Ther. 2015;22(4):558–63.
72. Spiliopoulos S, Katsanos K, Fragkos G, Karnabatidis D, Siablis D. Treatment of infrainguinal thromboembolic complications during peripheral endovascular procedures with AngioJet rheolytic thrombectomy, intraoperative thrombolysis, and selective stenting. J Vasc Surg. 2012;56(5):1308–16.