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Original Article

Branched crural bypass has no advantage over simple crural bypass in the treatment of peripheral arterial disease

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Abstract: This retrospective study compared mid-term outcome of a simple crural bypass (SCB, n=72) and branched crural bypass (BCB, n=23) constructed with reverse or in situ saphenous grafts or prosthetic grafts in patients with peripheral arterial disease grade III to IV (Fontaine classification) and type D lesions (TASC II classification). Life table analysis showed comparable primary (P=0.83), assisted (P=0.76), and secondary patency rates (P=0.78), limb salvage rates (P=0.64), and survival rates (P=0.81) between BCB and SCB. Comparison between the saphenous vein grafts and prosthetic grafts showed better primary (P=0.0089), assisted (P=0.0013), and secondary patency rates (P=0.0089) where venous grafts were used, but not limb salvage rates (P=0.072). In the SCB group, anastomoses to the anterior tibial artery had worse primary (P=0.023), assisted (P=0.035), and secondary (P=0.042) patency rates, but comparable limb salvage rates (P=0.57). We conclude that BCB provides no advantage but also no additional risk for the patient. When choosing a target crural artery, evidence shows the posterior tibial artery or fibular artery should be preferred to the anterior tibial artery.

Keywords: Peripheral arterial disease, limb ischemia, crural bypass, great saphenous vein, graft patency, polytetrafluorethylene graft

Introduction

Peripheral arterial disease (PAD) is a common condition with increasing prevalence worldwide at all income levels [1]. This trend involves all stages of PAD including critical limb ischemia (CLI) with gangrene and the risk of limb amputation resulting in permanent invalidity [2, 3]. The treatment of severe PAD is guided by a multidisciplinary team based on patient's symptoms, ankle-brachial index, and the extent of the disease shown on imaging studies [4, 5]. For the majority of patients with rest pain, ischemic ulcers, or gangrene, surgical revascularization is necessary to prevent limb amputation [6]. Distal reconstruction with pedal or crural bypass offers good long-term results with limb salvage rates exceeding 70% [7-9]. Several strategies have been proposed to further improve patient outcomes [10, 11].

In the present study, we compared mid-term outcomes of a simple crural bypass (SCB) and branched crural bypass (BCB) in patients with peripheral arterial disease. We hypothesized that BCB would result in improved primary, assisted, and secondary patency rates, and limb salvage rates in the first three years after the reconstruction compared to SCB.

Patients and methods

This retrospective study was performed in accordance with the Declaration of Helsinki and informed consent was waived by the Institutional review board.

Ninety-five patients with peripheral arterial disease stage III to IV (according to Fontaine classification) with chronic total occlusion of the femoral and popliteal artery or popliteal artery and proximal trifurcation vessels (TASC D

Table 1. Patients' characteristics divided according to bypass type

Bypass type	Simple (SCB) (n=72)	Branched (BCB) (n=23)	*p* value
Age (years)	67±10	66±10	0.62
Male	56 (78%)	13 (57%)	0.061
Coronary heart disease[a]	45 (63%)	10 (43%)	0.15
Myocardial infarction[a]	33 (46%)	5 (22%)	0.051
Coronary bypass[a]	21 (29%)	3 (13%)	0.17
Atrial fibrillation[a]	12 (17%)	2 (9%)	0.51
Stroke[a]	22 (31%)	5 (22%)	0.60
Diabetes[a]	36 (50%)	7 (30%)	0.15
Hypertension[a]	65 (90%)	22 (96%)	0.67
Hyperlipidemia[a]	52 (72%)	18 (78%)	0.79
Renal insufficiency[a]	10 (14%)	3 (13%)	1.00
Smoker or ex-smoker[a]	59 (82%)	18 (78%)	0.76
Fontaine			0.91
III	26 (36%)	8 (35%)	
IV	46 (64%)	15 (65%)	
TASC-D	72 (100%)	23 (100%)	1.00

All non-significant (Fischer's exact test, Mann-Whitney U-test, t-test). [a]based on history and previous examinations.

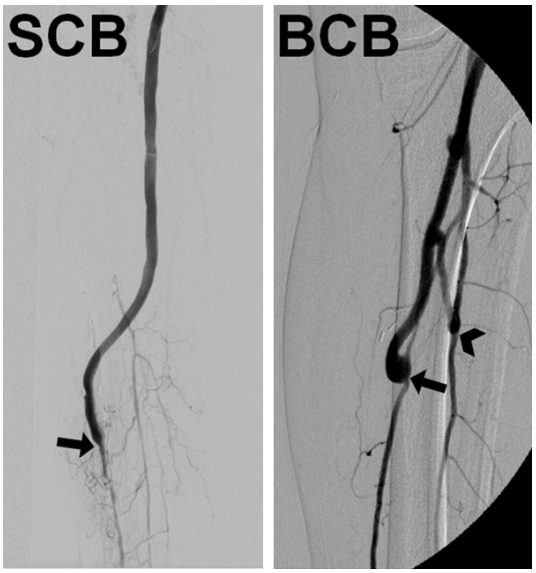

Figure 1. Digital subtraction angiography of a simple crural bypass (SCB) with reverse saphenous graft connected to a. tibialis anterior (arrow) in a 77-year-old patient (left). Branched crural bypass (BCB) in a 62-year-old patient with PTFE graft with distal anastomosis to a. tibialis posterior (arrow) and a side branch connected to a. fibularis (arrowhead, right).

lesions) underwent surgical revascularization between January 2008 and April 2015 with SCB (n=72) or BCB (n=23). Patient characteristics are detailed in **Table 1**.

Imaging

The extent of the disease was preoperatively assessed by digital subtraction angiography (DSA). In patients, who had at least two patent crural arteries as shown on DSA and confirmed during the operation (inspection, palpation), we constructed a branched crural bypass (BCB) whenever possible; the rest underwent a simple crural bypass (SCB).

Venous vasculature of the leg was examined by duplex ultrasound to assess patency and caliber of the veins. Superficial veins with an internal diameter below 3 mm were not used for grafts and patients with insufficient quality, length, and diameter of the great saphenous vein (GSV) received either a reinforced vascular polytetrafluoroethylene (PTFE) graft (Vascu-Graft SOFT [B. Braun Melsungen, Berlin, Germany] or Fusion Vascular Graft [Maquet Holding, Rastatt, Germany]) with a diameter of 6 to 7 mm [12].

Surgical technique

The surgery was performed by three experienced vascular surgeons and there was no significant difference in the proportion of BCBs and SCBs among them. SCBs and BCBs were equally distributed over the duration of the study.

In BCB, the main trunk of the reverse or *in situ* venous bypass, or prosthetic graft was always connected to one of the crural arteries with better quality, assessed by preoperative imaging and intraoperative finding. Additionally, one side branch was connected end-to-side to the main conduit in a reverse fashion (**Figure 1**; **Table 2**). In SCB, only one conduit without a side branch was connected to a crural artery depicted on preoperative angiography (**Figure 1**).

The proximal end of the *in situ* GSV bypass was connected either as end-to-side to the common femoral artery or end-to-end to the superficial femoral artery after endarterectomy. If reverse GSV or prosthetic graft was used, we created an end-to-side anastomosis to the common

Table 2. Proximal anastomosis locations, bypass type, and distal anastomosis locations of simple and branched crural bypasses

Bypass type	Simple (SCB) (n=72)	Branched (BCB) (n=23)	*p* value
Proximal anastomosis			0.77[d]
Common femoral artery	58 (81%)	18 (78%)	
Superficial femoral artery	14 (19%)	5 (22%)	
Bypass type (main conduit)			0.53[d]
In situ great saphenous vein	20 (28%)	7 (30%)	
Reverse great saphenous vein	18 (25%)	8 (35%)	
PTFE	34 (47%)[a]	8 (35%)[b]	
Distal anastomosis			0.058[e]
Anterior tibial artery	36 (50%)	14 (30%)[c]	
Posterior tibial artery	26 (36%)	19 (41%)[c]	
Fibular artery	10 (14%)	13 (28%)[c]	

[a]including vein cuff in 10 patients; [b]including vein cuff in 5 patients; [c]each branched crural bypass (BCB) has two distal anastomoses; [d]Fischer's exact test; [e]χ^2.

Table 3. Perioperative complications (<30 days) in patients with simple (SCB) and branched (BCB) crural bypass

Bypass type	Simple (SCB) (n=72)	Branched (BCB) (n=23)	*p* value
Reoperation for bleeding	1 (1%)	0	1.00
Infection	5 (7%)	1 (4%)	1.00
Wound dehiscence	4 (6%)	0	0.57
Perioperative mortality	0	0	1.00
Graft occlusion	3 (4%)	0	0.55
Acute coronary syndrome	2 (3%)	0	1.00

All non-significant (Fischer's exact test).

femoral, superficial femoral, or popliteal artery (**Table 2**). To improve local hemodynamics, we attempted to form a small angle between the graft and the target artery [13].

Reverse venous grafts were embedded in a subcutaneous tunnel in a location always different from the harvesting site. In the *in situ* bypass, intraluminal valves were cut by a valvulotome (LeMaitre Vascular GmbH, Germany). Branches of the GSV that were visualized by perioperative angiography, were ligated from a small incision [14].

Postoperatively, all patients received anticoagulation therapy with low molecular weight heparin (0.1 ml/10 kg every 12 hours Clexane, Sanofi Winthrop Industrie, France) for at least 5 days, after which they were switched to warfarin (Warfarin Orion, Orion Corporation, Finnland) with target INR of 2.5-3.

Follow-up

Patients were followed-up quarterly in the first postoperative year and later annually by clinical and duplex ultrasound examination [15]. Primary, assisted, and secondary patency rates, along with limb-salvage rates were analyzed.

Statistical analysis

Statistical tests were performed using GraphPad Prism 5 (GraphPad Software, USA) and SPSS 19 (IBM, USA). To test for statistical significance, t-test, Mann-Whitney U test, Fischer's exact test or χ^2 were used as appropriate. Life tables were compared using log rank test. Multivariable analysis was performed by Cox proportional hazard regression model. A *p* value below 0.05 was considered significant.

Results

Operation and perioperative complications

The operation time and hospital stay were 200 (IQR=80) min and 6 (IQR=9) days in BCB group and 152 (IQR=93) min and 6 (IQR=6) days in SCB group (P=0.014 and P=0.92), respectively. The need for reoperation due to wound bleeding, dehiscence or infection was comparable between the groups (**Table 3**).

Graft patency and limb salvage rates between BCB and SCB

Life table analysis (**Figure 2**) showed comparable primary (*P*=0.83), assisted (*P*=0.76), and secondary (*P*=0.78) patency rates between BCB and SCB. The limb salvage (*P*=0.64) and survival rates (*P*=0.81) were comparable as well.

Graft patency and limb salvage rates between saphenous vein and prosthetic grafts

Comparison between the saphenous vein grafts and prosthetic grafts showed better primary (*P*=0.0089), assisted (*P*=0.0013), sec-

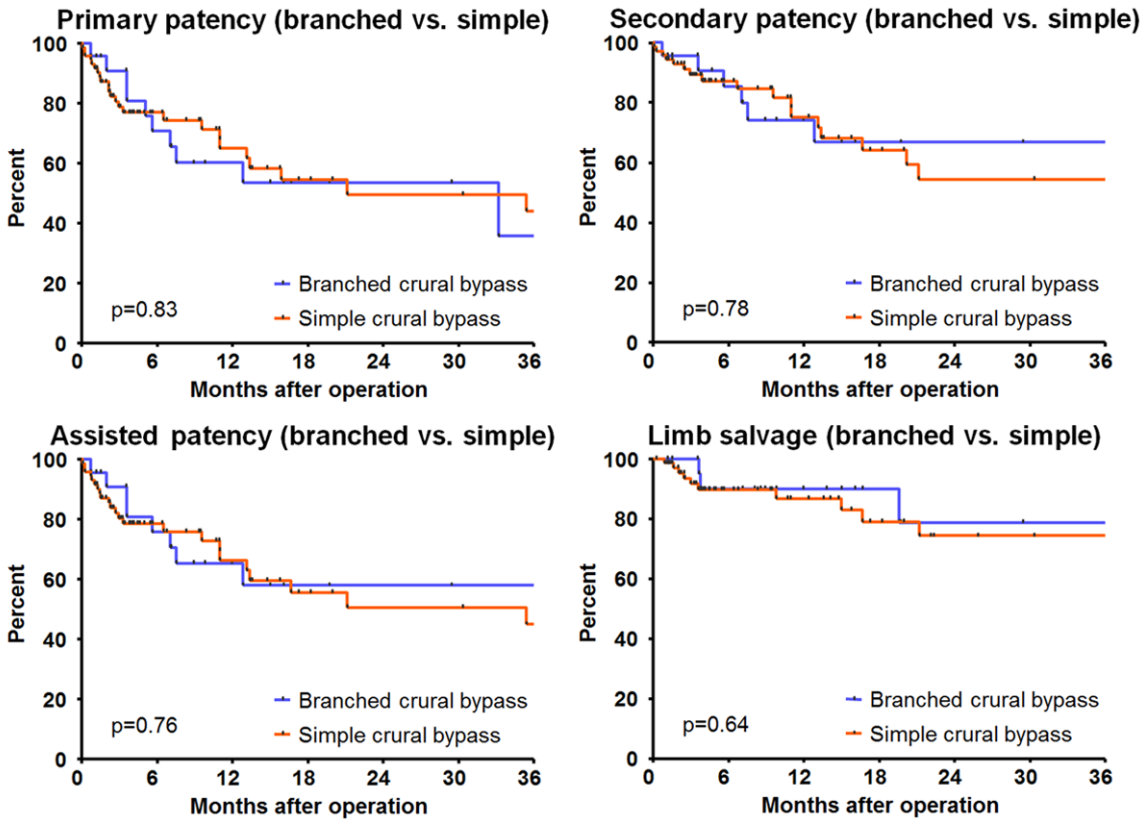

Figure 2. Comparison of primary, assisted, secondary patency rates, and limb salvage rates of the branched and simple crural bypass.

ondary patency rates (*P*=0.0089) where venous grafts were used, but limb salvage rates did not reach statistical significance (*P*=0.072, **Figure 3**).

Graft patency and limb salvage rates according to the target artery

In the SCB group, reconstructions with anastomoses to the anterior tibial artery showed worse primary (*P*=0.023), assisted (*P*=0.035), and secondary (*P*=0.042) patency rates with comparable limb salvage rates (*P*=0.57, **Figure 4**) compared to reconstructions connected to the posterior tibial or fibular artery.

Multivariable Cox regression analysis

The Cox proportional hazard regression model was performed on primary, assisted, secondary patency, and limb salvage rates with the following predictors: patient sex, history of myocardial infarction, conduit type, target artery, and branching of the bypass. Only models for primary (P=0.019) and assisted patency (P=0.0044) were significant (**Table 4**) whereas models for secondary patency (P=0.073) and limb salvage rates (P=0.096) were not significant due to the high percentage of censored observations.

Discussion

The present study showed no advantage of constructing BCB to SCB in terms of mid-term graft patency rates and limb salvage rates.

The idea of constructing a side branch to a bypass has been widely explored in cardiovascular bypass surgery but little is known about this technique in the infragenicular bypass in patients with CLI. The use of BCB has been reported by Van Damme and associates, who used either a bifurcated vein graft in 7 patients or connected an additional side branch in five patients [16]. The rationale behind constructing an additional side branch is based on the assumption that it would: 1) increase the flow

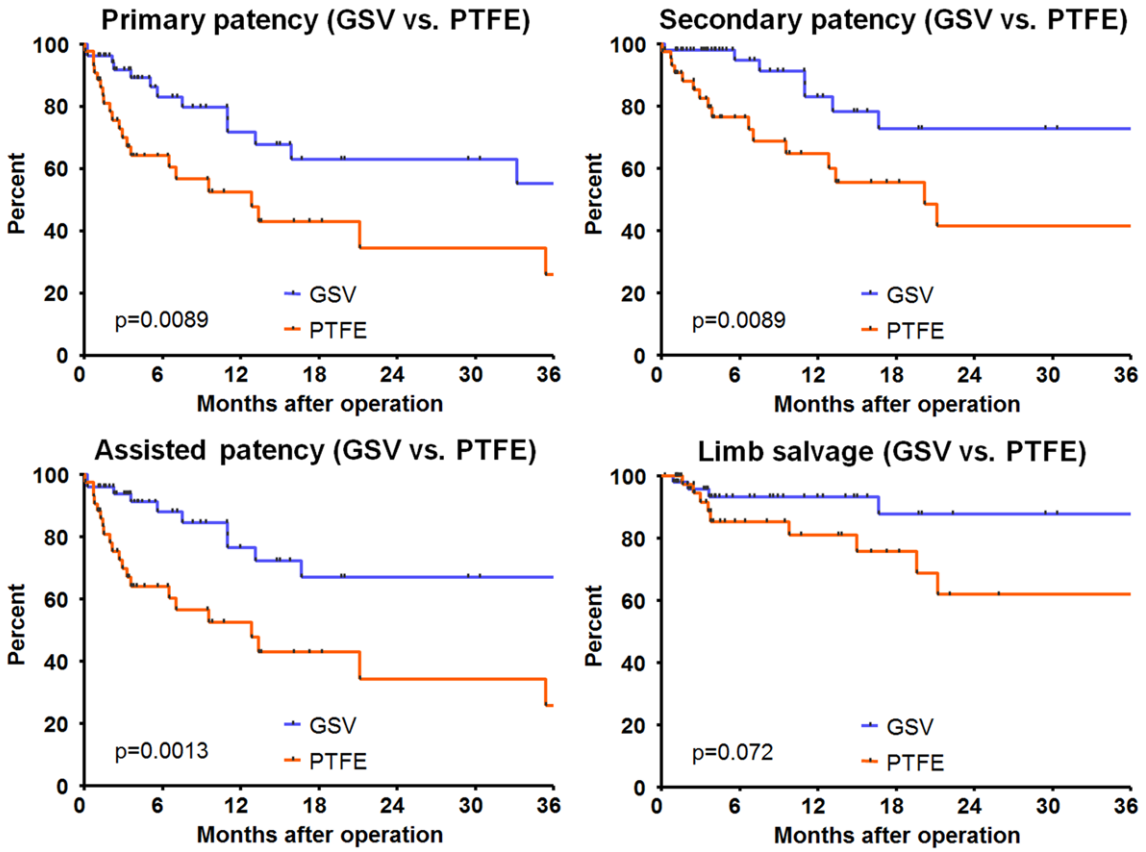

Figure 3. Comparison of primary, assisted, secondary patency rates, and limb salvage rates between venous (GSV = great saphenous vein) and prosthetic (PTFE = polytetrafluoroethylene) grafts.

through the common part of the conduit, 2) increase the outflow bed, and 3) secure a back-up if the distal part of the main conduit became occluded. In this study, however, we were unable to demonstrate improved durability of the reconstruction in BCB. We assume that the net benefit of an additional branch is probably cancelled because the additional anastomosis itself is more vulnerable to the development of intimal hyperplasia or progression of atherosclerosis, as in composite grafts [17]. Perhaps, this effect may be addressed by the use of bifurcated venous grafts (whenever available) or bifurcated prostheses manufactured from new materials [16]. Currently, new grafts made of fish collagen are under preclinical evaluation at our department. Another promising option shown by Rogers and associates in 6 patients was to construct a sequential bypass [18].

In the design and construction of BCB, other factors known to influence the development of intimal hyperplasia, including the ratio of diameters between the bypass and the target artery and the anastomosis angle should be addressed [13, 19-21]. Although constructing a branched bypass is more technically demanding and requires longer operation time, there has been no difference in hospital stay or perioperative complications, indicating the safety of this procedure.

Our results can be well compared with a study by Slim and associates, who used both autologous veins and PTFE grafts and showed a primary patency rate of 62% at one year and amputation free survival of 83% [22]. However, in their study only 10% of patients had PTFE bypass compared to 44% in our study. Because GSV conduit has better patency rates as also shown in this study, it should be preferred to prosthetic grafts whenever available [23, 24]. *In situ* GSV bypass is technically less demanding and faster to perform, but there is a greater risk of formation of arteriovenous fistula and development of leg edema. Reversed GSV

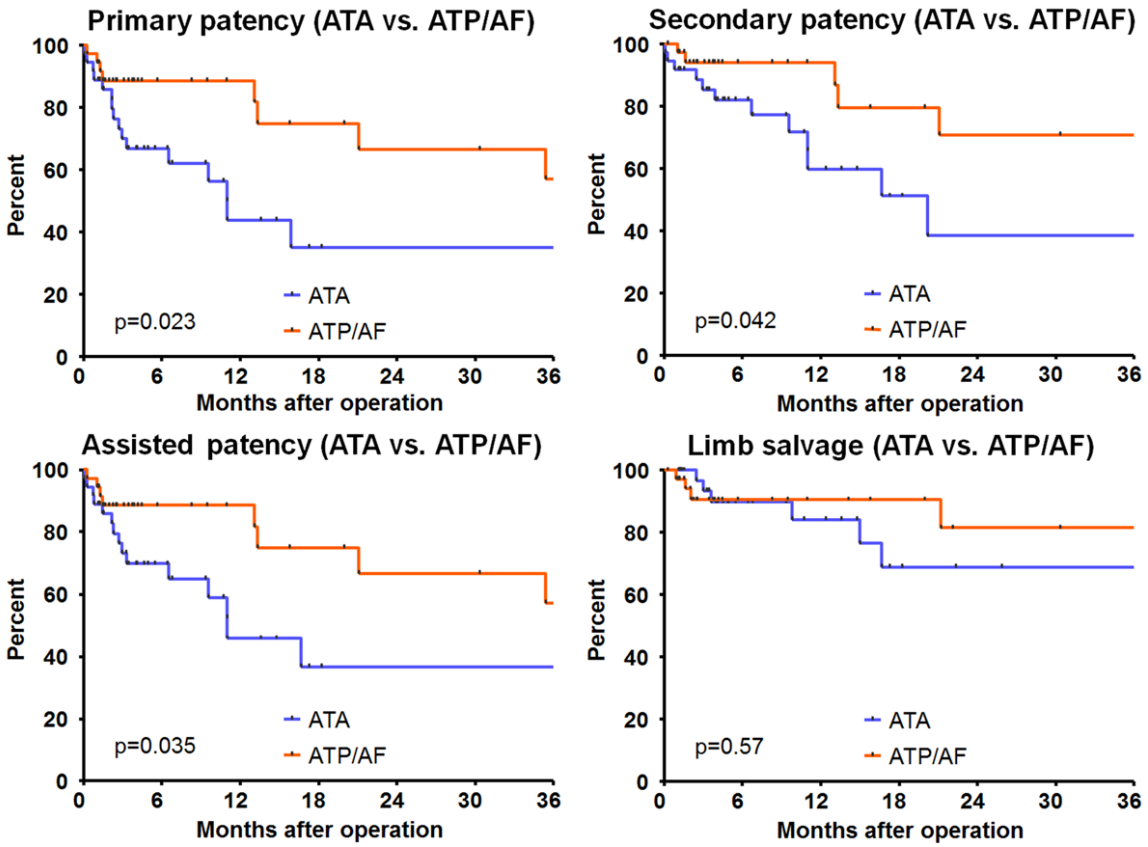

Figure 4. Comparison of primary, assisted, secondary patency rates, and limb salvage rates between grafts connected to anterior tibial artery (ATA) and to the posterior tibial arteries (ATP = posterior tibial artery, AF = fibular artery).

Table 4. Multivariable Cox regression analysis

Variable	Primary patency	Assisted Patency
	Hazard ratio (95% CI)	Hazard ratio 95% CI
Sex (female vs. male)	1.24 (0.57-2.56)	1.06 (0.45-2.30)
Myocardial infarction (no vs. yes)	1.14 (0.52-2.57)	1.14 (0.50-2.68)
Conduit type (PTFE vs. GSV)	2.83 (1.39-6.01)	4.06 (1.84-9.69)
Target artery (ATA vs. ATP/AF)	1.88 (0.91-3.95)	1.53 (0.60-4.14)
Branching (BCB vs. SCB)	1.51 (0.62-3.50)	1.40 (0.53-3.48)

CI: confidence interval; GSV: great saphenous vein; PTFE: polytetrafluoroethylene; ATA: a. tibialis anterior; ATP: a. tibialis posterior; AF: a. fibularis; SCB: simple crural bypass; BCB: branched crural bypass.

grafts should have reportedly similar or better performance compared to *in situ* GSV [25, 26].

The fact that limb salvage rate invariably exceeds that of patency rates indicates that about 10 to 30% patients may benefit from even a temporary revascularization in terms of healing of ischemic ulcers, demarcation of areas of gangrene, and improvement in their symptoms. This effect reduces the net difference in limb preservation between study groups.

To assess the extent and distribution of stenotic lesions in lower limb arteries, we used DSA, which is considered the gold standard. CT angiography of lower limbs may be less adequate due to difficulties in contrast timing and the presence of severe calcifications, which may be overcome to some degree by novel reconstruction techniques and co-registration of scans [27]. In some centers, MR angiography has been adopted instead [28]. SCB can be connected only to a patent crural vessel. However, if there is a choice, the anterior tibial artery should be avoided due to worse patency rates as shown in this study.

The present study has the following limitations. Firstly, the BCB group is small and there were three bypass types used in both groups. Se-

condly, BCB can be constructed only in patients who have more than one patent target artery, constituting a selection bias. However, we did not prove any difference in the preoperative characteristics between the groups.

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Disclosure of conflict of interest

None.

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