Early results from an angiosome-directed open surgical technique for venous arterialization in patients with critical lower limb ischemia

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Background: Patients with critical lower limb ischemia without patent pedal arteries cannot be treated by the conventional arterial reconstruction. Venous arterialization has been suggested to improve limb salvage in this subgroup of patients but has not gained wide acceptance. We report our early experience after implementing deep and superficial venous arterialization of the lower limb.

Materials and methods: Ten patients with critical ischemia and without crural or pedal arteries available for conventional bypass surgery or angioplasty were treated with distal venous arterialization. Inflow was from the most distal unobstructed segment. Run-off was the dorsal pedal venous arch ($n=5$), the dorsal pedal venous arch and a concomitant vein of the posterior tibial artery ($n=3$), or the dorsal pedal venous arch and a concomitant vein of the common plantar artery ($n=2$) depending on the location of the ischemic lesion. Venous valves were destroyed using antegrade valvulotomes, guide wires, knob needles, or retrograde valvulotomes via an extra incision.

Results: Seven of the operated limbs were amputated after 23 (1–256) days (median [range]). The main reasons for amputation were lack of healing of either the original wound, of incisional wounds on the foot, or persisting pain at rest. In three cases, the bypass was open at the time of amputation. Two patients experienced complete wound healing after 231 and 342 days, respectively. By the end of follow-up, the last patient was ambulating with slow wound healing but without pain 309 days after surgery.

Conclusion: Venous arterialization may be used as a treatment of otherwise unsalvageable limbs. The success rate is, however, limited. Technical optimization of the technique is warranted.

Keywords: *critical limb ischemia; venous arterialization; revascularization; amputation prevention; wound healing*

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Amputations due to critical lower limb ischemia are a major cause of disability and loss of quality of life, especially in the developed countries. Due to an aging population and an increase in the prevalence of diabetes, the condition can be expected to gain increased significance in the future (1). A subgroup of patients that is especially difficult to treat is the patients with critical limb ischemia without the option for arterial reconstruction as a result of extensive peripheral arterial occlusive disease with patent aorto-iliac segment.

Theoretically, venous arterialization may relieve ischemia by improving tissue nutrition, increasing flow in existing collaterals, and stimulating angiogenesis. Initial

experiences with venous arterialization were disappointing (2–4). The authors of more recent series have, however, been more successful after refinement of the technique by: (a) placing the anastomosis as distally as possible (5); (b) destruction of the distal valves; and (c) angiographic control of the extent of the revascularization. In the later studies, distal anastomosis has been placed either at the level of the dorsal venous arch or at a concomitant vein of the posterior tibial artery (5–8).

Recently, Alexandriescu et al. added the concept of angiosome-directed revascularization, originally introduced by Taylor and Attinger (9–11) to a partly endovascular technique for venous arterialization. This technique did

not, however, comply with the principle of placing the anastomosis as distally as possible.

Based on this, we applied a technique of open surgical, angiosome-directed venous arterialization to test whether limb salvage could be achieved in patients with critical limb ischemia and without graftable crural or pedal arteries.

Materials and methods

Patients

In the period from October 2011 to April 2013, 614 patients with critical limb ischemia were operated on with distal revascularization at the Department of Vascular Surgery in Kolding Hospital, Denmark. A total of 354 received open surgical treatment and 260 were treated endovascularly. In 10 patients, no crural or pedal arteries were available for conventional bypass surgery. These patients were offered and accepted distal venous arterialization.

The group included eight males and two females, with a median age of 70 years. Eight had gangrene or painful ischemic ulceration of the foot, while two had ischemic rest pain. Half of the patients had earlier suffered above-ankle amputation of the contralateral leg. Nine patients had previously undergone failed attempts of vascular reconstruction of the affected limb. Comorbidity and risk factors included diabetes ($n=8$), renal insufficiency ($n=3$), hypertension ($n=7$), current or previous smokers ($n=7$).

Preoperative imaging

Magnetic resonance angiography or digital subtraction angiography was applied to assess the arterial system and ultrasound examination was used for mapping of the venous system.

Surgical technique

The operations were performed under regional anesthesia ($n=2$) or general anesthesia ($n=8$). Prophylactic antibiotics and perioperative heparin administration were applied. The *in situ* technique was applied using a LeMaitre valvulotome (Le Maitre Vascular, Burlington, MA) to perform retrograde destruction of valves to the level of the ankle. Inflow was from the most distal unobstructed segment. This was the common femoral artery ($n=6$), the superficial femoral artery ($n=1$), or the distal popliteal artery ($n=3$). Run-off was the dorsal pedal venous arch ($n=5$), the dorsal pedal venous arch and concomitant vein of the posterior tibial artery ($n=3$), or the dorsal pedal venous arch and a concomitant vein of the common plantar artery ($n=2$), depending on the location of the ischemic lesion according to the angiosomes theory. An example of arterialization of both the dorsal pedal arch and a concomitant vein of the posterior tibial artery in a patient with gangrene of the medial calcaneal area and an ischemic wound at the base of the hallux is shown in Fig. 1. In three cases, the venous

A

B

C

Fig. 1. Example of angiosome-directed, combined deep and superficial venous arterialization in a patient with an ischemic wound at the toe and gangrene of the medial heel. (A) The great saphenous vein *in situ*, proximally anastomosed to the common femoral artery. It can be noted from the color of the vein that arterial blood fills the vein proximal to the vascular clamps (arrows). (B) At this stage, a posterior branch of the great saphenous vein has been transposed to a posterior tibial vein, allowing arterialization of the superficial venous arch toward the first toe and of the deep veins toward the heel. (C) Same foot after closure of the incision. The ischemic lesions can be seen. The color of the skin suggests successful revascularization.

arterialization was an extension of an existing *in situ* bypass with insufficient arterial run-off. In eight cases, only venous material was used (greater saphenous vein or small saphenous vein), while in two cases also 6 mm ringed, heparin-coated ePTFE (Propaten, W. L. Gore and Associates, Flagstaff, AZ), was interposed. In the pedal arch and deep pedal veins, valves were destroyed under radiologic guidance. It was possible to destroy the valves of the pedal arch retrogradely using a Le Maitre valvulotome via an extra incision. The distal-most pedal veins that contained valves in need of destruction to obtain antegrade flow were the interosseous veins at the base of each toe. In some cases, these veins were large enough for a Mills antegrade valvulotome to be used for the veins of the first toe. In other cases, and when we needed flow to other toes, smaller instruments were used, including knob needles, intravascular sheaths, or guide wires. In one patient, supplemental valve destruction was performed endovascularly using a 0.035 guidewire, a 5 F sheath, and a Van Schie catheter (COOK Medical, Bloomington, IN) for valve destruction, and embolization of backflow was performed using Trufill microcoils (Cordis, Johnson & Johnson, Warren, NJ) (Fig. 2). Access was gained through the graft via a puncture approximately 15 cm above the ankle. In eight cases, perioperative measurements of graft flow were performed using Transit Time technique (Medistim, Oslo, Norway).

Follow-up was performed until: all wounds on the foot were healed with continuous epithelialization; the operated limb was amputated above the ankle; the patient died; or the end of follow-up was reached on 25 August 2013, whichever occurred first. In the cases when the patients were discharged before an endpoint was reached, follow-up was performed in an outpatient clinic.

Results

Characteristics and outcomes of each patient are given in Table 1. Seven of the operated limbs were amputated above the ankle after 23 (1–256) days (median, range).

The main reasons for amputation were lack of healing of either the original wound, of incisional wounds on the foot, or persisting pain at rest. In three cases, the bypass was open at the time of amputation. In spite of this, two patients showed signs of sepsis and needed urgent amputation. One patient subsequently died in a pattern of respiratory failure after amputation. One patient with a patent graft chose amputation after 256 days although the wound was in a picture of slow healing.

Three patients had avoided amputation at the end of follow-up. Two patients had complete wound healing after 231 and 342 days, respectively. The original wound of the last patient, originating from amputation of the hallux, healed within 6 weeks, but before the healing of the incisions was complete, the patient had a plantar abscess that needed a surgical incision. This incision showed slow healing and at the end of follow-up – 309 days after surgery – the patient was in need of home-based wound care, but was ambulating.

In one of the patients who experienced wound healing, the distal portion of the arterialized venous arch was thrombosed at the time when healing was complete. However, the proximal part of the bypass was open with run-off in a mid-crural fistula. The two other patients had open grafts.

Discussion

In our first experience with venous arterialization, amputation was avoided in 3 out of 10 patients. In a recent systematic review and meta-analysis, the results of a total of 228 patients were analyzed (12). This analysis showed 71% limb salvage at 1-year follow-up, with the best results found in Chinese and Russian populations and better results in patients with Buerger's disease than in patients with obstructive atherosclerosis (6, 8). The largest material from a Western population was reported by Lengua, who operated on 59 patients over a period of 26 years (5). He achieved 1-year foot preservation in 60% of the patients. Although the present results of 30% limb

Fig. 2. (A) Digital subtraction angiogram showing antegrade filling of the pedal veins obstructed by a competent valve (arrow). (B) After the valve has been destroyed by means of a cutting balloon, distal filling has improved, but backflow is still prominent through an ascending vein (arrow). (C) After placement of coils in the ascending vein (arrows), backflow is partially obstructed. Antegrade flow reaches the hallux.

Table 1. Patient characteristics and outcomes

Patient No.	Age (years)	Gender	Wound location	Inflow artery	Target veins	Conduit	Clinical outcome	Length of follow-up	Flow in graft
1	58	F	Ischemic wound dorsal part of hallux + gangrene medial calcaneus	Common femoral artery	Dorsal venous arch, superficial interosseous veins of the first toe, and posterior tibial vein	Heparin-bonded ePTFE and great saphenous vein	Crural amputation after 13 days	13 days	80 ml/min
2	65	M	Ischemic wound dorsal part of hallux + gangrene of second toe	Infragenicular popliteal artery	Dorsal venous arch and superficial interosseous veins of the first and second toe, and posterior tibial vein	Great saphenous vein	Crural amputation after 256 days (with open bypass)	256 days	55 ml/min
3	74	M	Non-healing amputation wound at fourth and fifth toe	Superficial femoral artery	Dorsal venous arch, superficial interosseous veins of fourth and fifth toe, and common plantar vein	Great saphenous vein	Wound healing at 342 days	342 days	90 ml/min
4	90	M	Ischemic wound first toe and and gangrene fifth toe	Common femoral artery	Dorsal venous arch, superficial interosseous veins of first and fifth toe	Great saphenous vein	Crural amputation after 10 days	10 days	200 ml/min
5	77	M	Ischemic wounds at first, third, fourth, and fifth toe	Common femoral artery	Dorsal venous arch and superficial interosseous veins of the third, fourth, and fifth toe and common plantar vein	Great saphenous vein and lesser saphenous vein	Wound healing after fore-foot amputation at 231 days	231 days	–
6	69	F	Rest pain	Common femoral artery	Dorsal venous arch, superficial interosseous veins of first toe, and posterior tibial vein	Heparin-bonded ePTFE and great saphenous vein	Crural amputation after 1 day	1 day	–
7	82	M	Ischemic wounds at first and second toe	Common femoral artery	Dorsal venous arch, superficial interosseous veins of first and second toe	Great saphenous vein and lesser saphenous vein	Initial wound healed. New wound present	309 days	210 ml/min
8	71	M	Ischemic wounds at second and fourth toe	Infragenicular popliteal artery	Dorsal venous arch, superficial interosseous veins of second and fourth toe	Great saphenous vein	Crural amputation after 118 days	118 days	150 ml/min
9	67	M	Ischemic wounds at first and second toe	Common femoral artery	Dorsal venous arch, superficial interosseous veins of first and second toe	Great saphenous vein	Crural amputation after 35 days	35 days	130 ml/min
10	44	M	Rest pain	Infragenicular popliteal artery	Dorsal venous arch, superficial interosseous veins of first toe	Great saphenous vein	Crural amputation after 18 days	18 days	130 ml/min

salvage do seem disappointing compared to the few earlier published series, it must be suspected that a significant 'publication bias' may be present, causing mainly good results to be published and disappointing results not to be reported. Taking this into account, our results may be average rather than poor. Also, since this is our initial experience, an effect of a learning curve may be suspected.

Patient selection is of course a major concern when comparing outcome. As opposed to some other investigators who used 'no crural arteries' as inclusion criterium (12), we used arterial run-off for all patients where these were available, including plantar and dorsal pedal arteries, either as seen on preoperative angiograms or found by surgical exploration. We also performed a high number of endovascular reconstructions including crural and pedal arteries. Intensive, conservative wound treatment was applied. In this environment, venous arterialization was only used as *ultimum refugium* in cases with very extensive distal calcifications, or when arterial bypasses had already been attempted but had failed. The results should, therefore, not be compared to the results of arterial bypass or PTA, but rather with treatments like vasodilator antiplatelet prostacyclin, which has shown only a modest superiority over placebo in preventing amputation (13), or lumbar sympathectomy, which may relieve symptoms but does not convincingly improve limb salvage (14).

Potential improvement of the operative technique should be considered. Similar to other authors, we found poor healing of incisional wounds on the foot to be of importance for poor limb salvage. This experience seems to favor using a more proximally located distal anastomosis combined with endovascular valve destruction and closure of arteriovenous fistula in a manner more similar to the technique originally described by Alexandriescu (11). For this initial group of patients, evaluation was only based on clinical assessment. In retrospect, it would have been helpful to perform pre- and post-operative measurement of toe pressures and skin perfusion pressures, and we intend to do so in future cases.

We found the healing rate after venous arterialization to be slower than usually seen after arterial bypass surgery. In one case, where healing was evident, the patient lost patience and opted for amputation. It is important, when consenting the patients for this type of surgery, to inform them thoroughly about a long expected recovery and venous arterialization should be reserved for patients who are willing to go through a long healing process which includes outpatient wound care and an uncertain final outcome. It is also important that surgeons and caretakers are aware of the slower healing rate with venous compared to arterial revascularization. This may prevent amputations in cases where slow healing causes disillusion.

For the included patients, the only alternative treatment would be to have an amputation sooner. Patients with peripheral arterial disease who undergo major limb amputation have a very poor prognosis, with almost 50% mortality within 1 year (15). Patients who have had one leg amputated may be able to stay in their home, but after losing their second leg almost inevitably need to stay in nursing homes, causing loss of quality of life and large societal costs (16). Hence, we find extensive attempts of limb salvage in this group of patients to be justified, given the patient is willing to undergo the treatment.

In conclusion, we found venous arterialization of the lower limb to be a possible alternative to primary amputation in cases where no other revascularizing options are present. The operative technique may be improved by increasing the use of endovascular techniques of valve destruction and closure of fistula, and patient selection may be improved by thorough pre-consent information about expected prolonged wound healing.

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