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Vein conduit for end-to-side anastomosis of a calcified vessel in lower extremity free flap reconstruction

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Abstract *Background:* As the microsurgical and interventional revascularization techniques are evolving, traditionally amputated limbs are now challenged to salvage. However, a calcified recipient vessel is a common but challenging problem encountered in lower extremity reconstruction.
Methods: An end-to-side anastomosis of a vein graft (1.5-3.5 cm in length) was performed to the recipient vessel when it was difficult to clamp the recipient vessel near the defect because of the inelastic and hard vessel wall. The vascular clamp was applied to the vein graft, and the flap's pedicle was anastomosed to the vein graft.
Results: A total of 18 free flaps (10 ALT cases, 4 TDAP cases, 2 PAP cases, and 2 SCIP cases) were anastomosed with a bridge vein graft to the heavily calcified recipient vessels (7 ATA cases, 3 PTA cases, 7 DPA cases, and 1 MPA case). Overall flap survival rate was 83.3%. Limb salvage rate was 93.7%, and anastomosis patency rate was 94.4%
Conclusion: Vein conduit in an end-to-side anastomosis of severely calcified recipient vessels shows a reasonable limb salvage rate. It acts as a buffer, which makes microscopic vessel

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manipulation easier. If vessel calcification is the only drawback for a free flap reconstruction, then a vein graft needs to be prepared instead of an amputation. This method may extend the surgical option to more high-risk patients in lower extremity microsurgical reconstruction and increase the limb salvage rate.

Introduction

Microvascular free tissue transfer is no longer regarded as contraindicated and has gained wide acceptance as the preferred method of reconstruction for complex defects of the lower extremity. The supermicrosurgical approach, which utilizes small perforating vessels from the adjacent angiosome territory as a recipient vessel, has furthermore extended the spectrum of the lower extremity reconstruction.[1,2] Nevertheless, proper recipient vessel selection is troublesome when the patient has widespread calcification of leg vessels. It is not always possible to find any reliable pulsating perforating vessel or noncalcified vessel with desirable geometry nearby.[3]

With progress in the percutaneous revascularization method, many patients with atherosclerosis have received multiple procedures before the occurrence of actual ischemic necrosis of extremity.[4] In cases of skin and soft tissue defects, the patent vessels in the patient's leg are usually severely calcified to the entire circumference and length. Mönckeberg's sclerosis refers to calcification of tunica media, and it changes the artery to a hard pipe-like structure.[5]

Regardless of the patient's progress, in repetitively revascularized vessels or Mönckeberg's sclerosis vessels, the blood flow will still be surprisingly strong. Nevertheless, the use of these vessels as a recipient vessel for free flap surgery has many obstacles. First, a hard, stiff recipient artery is incapable of being clamped. Pumping arterial flow may persist even with thigh tourniquet because of concomitant calcification of thigh arteries. Second, handling and suturing of the hard tube-like vessels are difficult, and brittle calcified vessel wall often cracks open, thus making hemostasis impossible. Vessel manipulation or applying vascular clamps might lead to cracking of the vessels toward the interior, causing intraluminal occlusion. Finally, even when the anastomosis is in place, the vulnerability of pedicle kinking, stretching, and disruption is quite high.[5-9]

Clinically, many surgeons usually make an incision more proximally or distally to find the less calcified vessel. However, sometimes, this extended incision is prone to lapse into an additional problematic wound. We have designed a simple and effective method to overcome these problems.

Outcomes of microvascular free tissue transfer for foot and leg defects when recipient vessels and flap vascular pedicles are affected by calcified arteriosclerosis have not been well described. We share our experience in overcoming such situations utilizing the nonclampable calcified vessel as a recipient site for microvascular anastomosis with a vein conduit graft.

Methods

From 2013 to 2017, 16 consecutive patients with defects of lower extremity from our microsurgery department were operated with 18 free flaps according to the following method. The procedure was performed using a thigh pneumatic tourniquet in a supine position. Doppler ultrasonography was used to identify adequate arterial flow of possible recipient artery before the operation. After exposing a favorable recipient artery nearest to the defect, a vein graft was prepared if circumferential calcification was involved throughout the vessel with no branch or another vessel of possible recipient site. During the flap dissection, a vein segment measuring approximately 2–3 cm from the cutaneous vein venae comitantes of the flap pedicle or recipient vessel was prepared as an interpositional vein graft. The adventitia of the calcified recipient artery was stripped at the anticipated end-to-side anastomosis site. Preferentially, the patient was placed in the Trendelenburg position, and further exsanguination of the leg was carried out using the elastic bandages. The thigh pneumatic tourniquet was set to 350 mmHg, and the arteriotomy was performed using curved microvascular scissors. Even with a tourniquet pressure and arterial clamps, a gush of strong arterial blood flow may come out in severely calcified vessels. Subsequently, a direct manual compression with gauze at the arterial opening was then applied. A waiting period of 5–10 min will lead to a surprising reduction in the blood flow to a level that vascular anastomosis becomes possible with suction assistance. A careful end-to-side anastomosis to a previously harvested vein graft was carried out. We commonly used 8/0 Ethilon (BV 130-5, Ethicon, Inc.) sutures for the anastomosis. Needles smaller than 8/0 sutures are prone to fail penetration into the calcified vessels. To avoid intima detachment or inward cracking of calcified plaque, we managed the penetration into the calcified arterial wall from the intraluminal side. Suture bites were usually kept larger than a conventional end-to-side anastomosis to stretch the vein orifice over the hard arterial wall and cover potential leak points. Once the vein conduit was anastomosed, the vascular clamp was applied to the vein. Subsequently, the patient was returned to the horizontal position and tourniquet was deflated. The clamp was released for a moment to check reliable arterial blood flow from the vein conduit. An end-to-end anastomosis was carried out between the bridge vein graft and the flap pedicle artery. The remaining venae comitantes of the flap pedicle were anastomosed to a recipient vein, and the flap inset was performed (Figure 1) (Supplementary video 1).

Postoperatively, aspirin and prostaglandin were routinely administered for a week. If preoperative angioplasty was

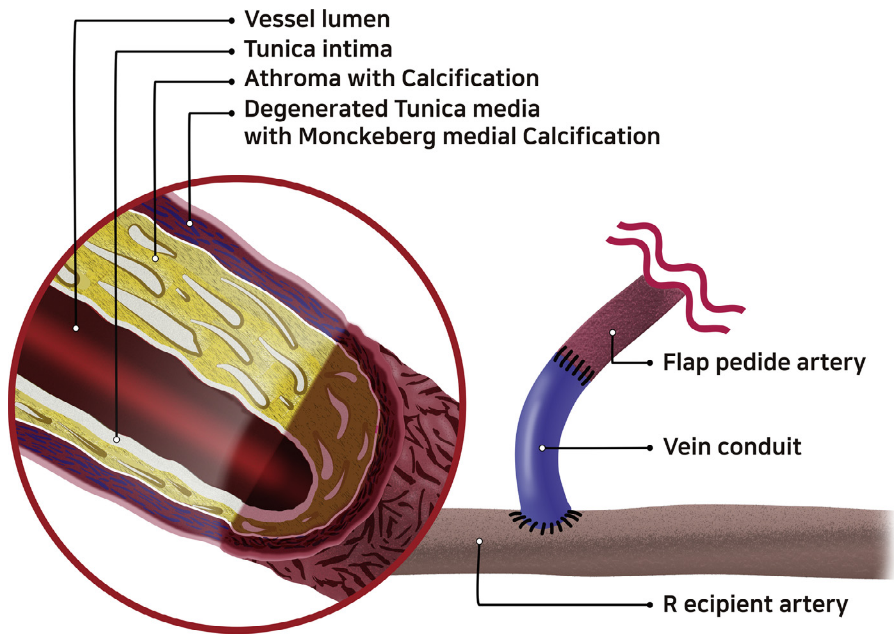

Figure 1 Schematic image of anastomosed vein conduit. The recipient artery and the vein graft are anastomosed in an end-to-side manner, and the flap pedicle is linked to the vein graft in an end-to-end anastomosis. Note that both recipient artery and flap pedicle artery are shown in chalky colors to schematize vessel wall calcifications.

performed, heparin fluid was kept throughout the perioperative period for a week.[10]

Result

The characteristics of the patients are summarized in detail in Table 1. The age of the patients (12 males and 4 females) at the time of surgery ranged from 40 to 83 years (average 65.6 years). All the patients had one or more risk factors for atherosclerosis: old age (over 65 years), obesity (body mass index > 25), hypertension, diabetes mellitus, and arteriosclerosis obliterans. Ten patients had undergone previous angioplasty of lower extremity arteries. Anterolateral thigh (ALT) free flaps were used in 10 cases, thoracodorsal artery perforator (TDAP) flaps in 4 cases, peroneal artery perforator (PAP) flaps in 2 cases, and superficial circumflex iliac artery perforator (SCIP) flaps in 2 cases. The mean length of the vein conduit was 2.27 cm (range: 1.5–3.5 cm).

Overall flap survival rate was 83.3% (15 out of 18 flaps). Two flap failures were experienced: one was due to venous congestion, and the other was due to an arterial occlusion caused by the breakage of calcified flap pedicle proximal to the anastomosis site. At the time of revision surgery of the patient with flap congestion, vein conduit was still patent and was reused as a recipient for a second free flap. The second free flap showed complete survival, and limb salvage was achieved. All the causes of anastomosis failure were analyzed by postnecrosis angiography. Postoperative wound disruption occurred in one flap and later healed by secondary intention. Another one flap had partial margin necrosis, and it was repaired with debridement and simple closure. Ten out of 16 patients needed postoperative transfusion. As we managed to maintain postoperative hemoglobin level at 10 g/dl, all cases were prophylactic transfusions without any symptoms. Anastomosis patency rate was 94.4% (17 out of 18 anastomoses). Necrosis due to anastomosis site problem was seen only in one case. All other flaps exhibited complete survival, and no signs of distal circulation deterioration were observed. Events expected from pedicle kinking or breaking were also not observed. Overall limb salvage rate was 93.7% (15 out of 16 patients). Patient number 3 received skin graft over the forefoot defect after several cycles of negative-pressure wound therapy. Only patient number 12 received below knee amputation due to multiple reocclusion of preoperative angioplasty sites in the proximal vessels at the calf level.

Case reports

Case 1 (patient number 11)

A 70-year-old female patient presented with skin necrosis and accompanying first metatarsophalangeal joint destruction. Percutaneous angiography and ballooning of multiple stenotic lesions of the lower leg and pedal vessel were performed prior to the reconstructive operation. After thorough debridement of the necrotic tissues and osteotomy of infected tarsal bones, ALT flap was harvested. The dorsalis pedis artery was selected as a recipient site, but severe vessel calcification was noted throughout the length of the artery. From near the foot dorsum incision site, 2 cm-sized venae comitantes of the recipient vessel were harvested, and end-to-side anastomosis was performed to the calcified artery as mentioned above. The flap survived completely without any complications (Figure 2).

Table 1 Demographic characteristics of the patient population.

Patient	Operation number	Age	Gender	Underlying disease	Diagnosis	Defect site	Preoperative angioplasty	Recipient artery	Flap donor	Vein length (cm)	Vein source	Results	Flap necrosis	Limb salvage	Anastomosis patency
1	1	59	M	DM, HBP, CKD (no dialysis), ICMP	Necrotizing fasciitis	Lower leg	(−)	ATA	ALT	3	Venae comitantes of ALT flap pedicle	Partial margin necrosis	-	Success	Patent
	2								ALT	2.5	Venae comitantes of ALT flap pedicle		-		Patent
2	3	40	M	DM, HBP, obesity (BMI: 39.1)	Traumatic defect	Ankle dorsal	(−)	DPA	PAP	2	Superficial vein		-	Success	Patent
3	4	77	M	DM, HBP, ESRD(HD)	Diabetic foot	Ankle dorsal	(+)	ATA	ALT	1.5	Venae comitantes of ALT flap pedicle	Flap failure due to venous congestion	O	Success	Uncertain
4	5	83	M	DM, A fib, CAD	Diabetic foot	Heel	(+)	DPA	ALT	1.5	Superficial vein	Postoperative wound disruption	-	Success	Patent
5	6	58	F	DM, HBP, ESRD(HD)	Diabetic foot	Heel	(+)	DPA	TDAP	2.5	Superficial vein		-	Success	Patent
6	7	60	F	DM, HBP, ESRD(HD)	Diabetic foot	Heel	(+)	PTA	ALT	2.5	Venae comitantes of recipient vessel		-	Success	Patent
7	8	70	M	DM, HBP, PSKT	Diabetic foot	Heel	(−)	PTA	TDAP	2	Venae comitantes of recipient vessel		-	Success	Patent
8	9	75	F	DM, CKD	Burn	Ankle	(−)	PTA	PAP	2.5	Venae comitantes of recipient vessel		-	Success	Patent
9	10	67	M	DM, HBP, ESRD(HD)	Diabetic foot	Foot dorsum	(+)	DPA	SCIP	2.5	Superficial vein		-	Success	Patent
10	11	70	M	DM, HBP, ESRD(HD)	Diabetic foot	Foot dorsum	(+)	MPA	SCIP	2	Superficial vein		-	Success	Patent

(*continued on next page*)

Table 1 (*continued*)

Patient	Operation number	Age	Gender	Underlying disease	Diagnosis	Defect site	Preoperative angioplasty	Recipient artery	Flap donor	Vein length (cm)	Vein source	Results	Flap necrosis	Limb salvage	Anastomosis patency
11	12	70	F	DM, HBP, ESRD(HD)	Diabetic foot	Forefoot	(+)	DPA	ALT	2	Superficial vein		-	Success	Patent
12	13	75	M	DM, HBP, ESRD(HD)	Diabetic foot	Forefoot	(+)	ATA	ALT	3.5	Venae comitantes of ALT flap pedicle	Flap failure due to flap pedicle occlusion	O	Failure	Occluded
13	14	64	M	DM, HBP, ESRD(HD)	Diabetic foot	Forefoot	(+)	ATA	TDAP	2.5	Venae comitantes of recipient vessel		-	Success	Patent
14	15	51	M	DM, HBP, ESRD(PD)	Wound infection	Lower leg	(−)	ATA	ALT	3.5	Venae comitantes of ALT flap pedicle		-	Success	Patent
15	16	64	M	Osteosarcoma, prosthesis	Radiation necrosis	Lower leg	(−)	ATA	ALT	2	Venae comitantes of ALT flap pedicle		-	Success	Patent
16	17	67	M	DM, HBP, ESRD(HD)	Diabetic foot	Forefoot	(+)	DPA	ALT	1.5	Venae comitantes of ALT flap pedicle	Flap failure due to flap pedicle thrombosis (distal to anastomosis site)	O	Success	Patent
	18								TDAP	1.5	Superficial vein		-		Patent

Abbreviations: ATA; Anterior tibial artery, DPA; Dorsalis pedis artery, PTA; Posterior tibial artery, ALT; anterolateral thigh, PAP; peroneal artery perforator, TDAP; thoracodorsal artery perforator, SCIP; superficial circumflex iliac artery perforator.

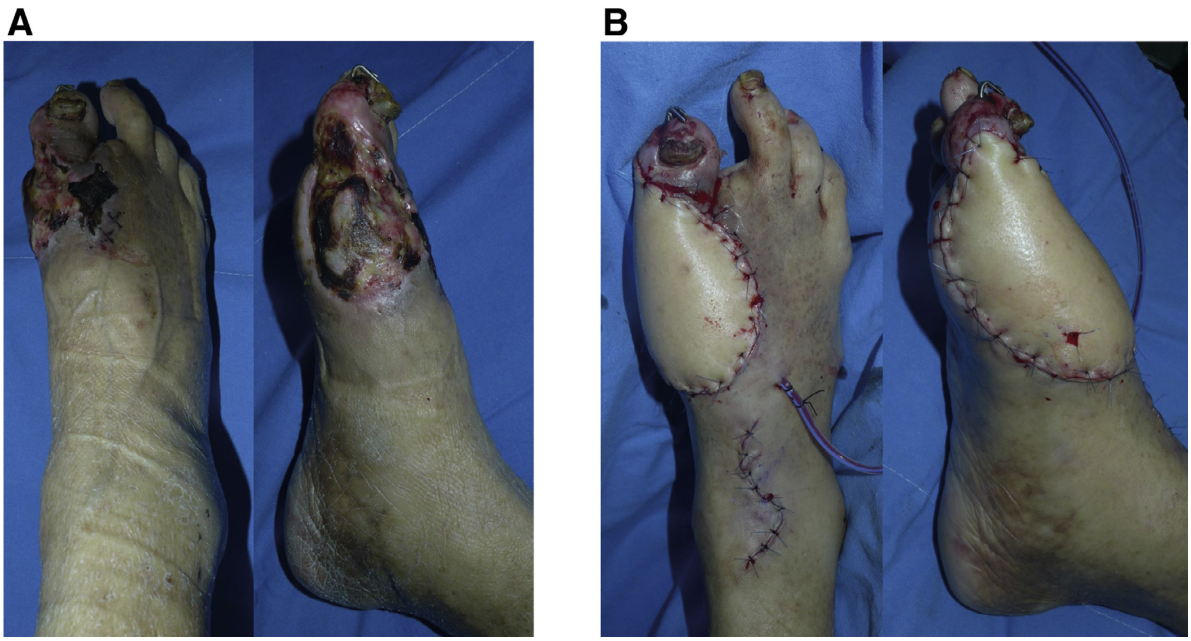

Figure 2 Case 1; (A) Preoperative photo of a 70-year-old female with right metatarsophalangeal joint area skin necrosis. (B) Postoperative photo of the same patient following debridement and anterolateral thigh free flap coverage.

Figure 3 Case 2; Diabetic foot ulcer of a 67-year-old male patient was reconstructed with an anterolateral thigh flap, and complete flap necrosis occurred.

Case 2 (patient number 16)

Complete flap failure occurred in a patient after first reconstruction using an ALT flap (Figure 3). The patient had calcification from the anterior tibial artery to the dorsalis pedis and dorsal metatarsal arteries. The thigh vessels in the patient were also calcified, and the pedicle of the ALT lacked pliability (Figure 4). Therefore, we used one vena comitans as a vein conduit between the recipient artery and the flap pedicle artery. Postoperative angiography revealed pedicle thrombosis distal to the anastomosis site. In addition to the defects of the initial surgery, skin damage to the pedicle extension site was seen. We selected TDAP and LD chimeric flaps and STSG for the simultaneous coverage of lateral forefoot and foot dorsum (Figure 5). At the time of second surgery, after removing the failed ALT flap, vein conduit was still patent with good arterial blood flow. The chimeric flap was anastomosed to the previous vein conduit. The flap survived without any complication, and a flap debulking surgery was performed 6 weeks later (Figure 6).

Figure 4 Preoperative X-ray film shows widespread calcification of pedal vessels.

With readymade shoes, the patient could ambulate without any problem.

Discussion

Microvascular free tissue transfer has demonstrated remarkable consistency as a reconstructive modality, with success rates ranging from 96% to 99%.[2,4,11] Yet, several risk factors have been commonly cited to increase the risk of flap failure, including obesity, age, smoking, previous irradiation, diabetes, and systemic vascular disease. Peripheral arterial disease (up to 50%) is observed in patients with diabetic foot ulcer. Diabetes is the most common cause of chronic kidney disease, which is another independent risk factor for arteriosclerosis and vascular calcification. In patients with diabetes, calcification occurs in both the tunica media and the tunica intima. Atherosclerosis is related to tunica intima calcification, and Mönckeberg's sclerosis is associated with tunica media calcification.[12-16]

Mönckeberg medial calcific sclerosis is characterized by calcific deposits within the media of medium- and small-sized muscular arteries. It does not cause luminal narrowing and shows good blood flow. The calcification is typically diffuse and circumferential along the vessel and is readily visible on plain film. In addition, clinical examination by palpation of the peripheral pulses can often reveal the absence of abnormalities in patients with Mönckeberg sclerosis. Even after the management of intima narrowing with percutaneous vascular interventions, tunica media calcification remains. Therefore, when patients present with gradually developed ischemic changes, blood flow to the extremity is surprisingly well maintained.[14,15,17-19]

However, the temptation to utilize the calcified but patent vessels often leads to flap failure. In general, high lower extremity calcium scores (as determined on CT) are associated with disease severity and poor outcomes, including the risk of amputation and all-cause mortality. In particular, the presence of arteriosclerosis affecting the donor or recipient vessels has been identified to increase the complication rate and the technical difficulty of free flap reconstruction. In the setting of arteriosclerosis, transmural sutures during the microvascular anastomosis are apt to cause separation of the tunica intima from the tunica media, which may elevate the risk of substantial thrombosis and anastomotic failure. Despite the risk management with delicate anastomosis technique, hard and pipe-like calcified vessels are often nonclampable and exhibit fragility.[20]

Figure 5 Free latissimus dorsi muscle-chimeric thoracodorsal artery perforator flap with split-thickness skin graft was used for salvage operation.

Figure 6 Final result after a flap debulking surgery.

To utilize the calcified vessels when it is the only available recipient vessel, a few problems should be managed. First, as mentioned above, vessels with extensive tube-like calcification make it impossible to apply any vascular clamps. Without any spare segment or reliable branches, anastomosis with pumping arterial blood flow is almost impossible. To make the matters worse, calcification takes place not only in the pedal vessels but also throughout the body, resulting in thigh tourniquet failure.[21-23] Second, atherosclerotic vessels may lose their elasticity secondary to vascular calcifications, and arrangement of ideal pedicle geometry may be particularly challenging. If the donor and recipient arteries are concurrently affected, then it is extremely difficult to manipulate these vessels into an ideal position to perform microvascular anastomosis and avoid subsequent kinking and breaking.[6,20,24,25]

Tourniquet failure has a few correctable factors, but majorly, it leads to limb salvage failure. Based on our experience, direct compression of the pumping artery and positioning the patient to Trendelenburg surely reduce the pressure and flow of the open vessel. Local and systemic changes may explain the consequences. Locally, arterial wall contraction may take place even in the calcified vessels. Circular fibers of the arterial wall are difficult to contract, but when an arterial slit is made longitudinally, longitudinal fibers may contract and contribute to adherence of cut ends. Systemically, no direct experiment has proven that head down position causes decrease in arterial pressure, but there exist studies stating that the Trendelenburg position reduces cutaneous flow of lower extremity. Increase in effective circulatory volume and venous return caused by the position change consequently decreases cardiac output to maintain adequate blood pressure. This systemic decline in arterial blood pressure may help the thigh tourniquet to be more effective, thus leading to arterial flow being ceased from the slit of the recipient artery. In addition, as the inelasticity of the calcified lower leg vessels has relatively high resistance, it may exhibit a greater drop in blood flow subsequent to decrease in blood pressure than normal healthy vessels.[26-30]

In lower extremity reconstruction, the advantages of end-to-side anastomosis are well established.[31,32] Preoperative revascularization with percutaneous interventions usually ensures enough blood flow to the very distal parts, but because many patients have essentially one-vessel leg, only end-to-side anastomosis should be used for reconstruction. The anastomosis using T- or Y-shaped vessel grafts also can be used in damaged or difficult anastomosis with reconstitution of distal run-off.[33,34] Intended advantage of this graft is that as the T or Y joint is a natural one, it may be less susceptible to kinking and thrombosis. However, good vessel match is required with three points of the anastomosis. In the similar sense, if end-to-side anastomosis is technically feasible, ETS anastomosis of a vein graft would show the same merits. Compared to the T or Y grafts, a straight vein graft could be harvested easily near the defects or through the flap donor sites or even from the venae comitantes of the flap pedicle.[35-38] Our method needs one additional anastomosis from the usual. However, we think that two comfortable anastomoses are better than one demanding anastomosis. Additionally, questions related to the reliability of vein graft may arise. However, it is now widely accepted that vein graft does not influence the results of anastomosis patency.[31,32,38-40] The vein conduit acts as a buffer, allowing the operator to handle more comfortably, lessens the possibility of vessel fracture during manipulation, and makes checking the both sides of the anastomosis possible. Postoperatively, a concern about pedicle breaking arises when the patient starts to walk and anastomosis site is located near ankle or other joints. But, the vein graft may act as a reservoir of pliability under such circumstances, and we have not experienced any signs of pedicle breakage of kinking postoperatively. Nevertheless, the vein graft should not be too long (just long enough to put a vessel clamp), and cautious vein positioning is required at the time of operation with a range of motion tests to assess the possibilities of any traction or kinking.

Preferably, one should search for a noncalcified vessel segment more proximally and do less anastomosis as possible. However, our method is preferred for patients with most advanced vessel calcification. In treating diabetic foot ulcers in such patients, many surgeons encounter sequential spread of skin necrosis after nearby tissue manipulation. Expanding or making a new incision to find a noncalcified region is rather a dangerous choice in such cases. As our method does not need more proximal or distal incision, a possibility of creating a new and intractable wound can be avoided. Using a Bulldog clamp may also be another option to cease the arterial flow when the nonclampable calcified vessel is encountered, although the risk of vessel fracture during clamping and consequential risk of thrombosis is very high.

During the end-to-side anastomosis, we managed to grab the vein first and then pass the needle from the lumen to the outside to avoid intima detachment. Penetration points were made relatively far from the arteriotomy slit to stretch the end of the vein graft to cover the slit completely.[41-44] To perform an anastomosis while blood oozes out, perforated vessel background was put over a cottonoid gauze, and continuous suction of the gauze was performed. Such a step was adequate to make the operation field bloodless.

The risk factors for the failure of the operation are similar to those of PTA reocclusion, which include multiple vessel involvement of peripheral arterial disease, involvement of higher peroneal or pedal or plantar arteries, patients on dialysis, and a history of ischemic heart disease.[45] Two-thirds of our patient group received preoperative angioplasty, and flap necrosis occurred only in the PTA group with those risk factors.

One more clue to avoid delayed flap failure is to use a skin graft over a pedicle when the recipient vessel and the flap pedicle are both sclerotic and hard due to calcification. If some external force over the pedicle is applied postoperatively or even after the patient starts ambulation, inward fracture of the calcified vessels may occur, causing occlusion. We have experienced this incident in patient number 12. In suspected cases, especially if the anastomosis site is near the ankle joint, we made an additional extension incision to release any possible skin tension over the pedicle and cover it with skin graft. Most of the time, the skin graft is harvested from dog-ear deformity of the flap donor site so that no additional wound should be needed.

Our overall flap survival rate was relatively low compared with that of recent lower extremity microvascular reconstruction reports. However, it is encouraging that this method has been applied to groups of patients who were considered as an improper case for free flap surgery. We hope that as more refinements take place, microvascular reconstruction may become a universal method for lower extremity reconstruction regardless of the condition of the vessel.

Conclusion

Vein conduit at end-to-side anastomosis between calcified recipient vessel and free flap pedicle can be a novel option for lower extremity reconstruction, especially in diabetic foot reconstruction. When an artery calcification is widespread and involves the thigh, a pneumatic tourniquet is prone to be a failure. A direct manual compression performed in the Trendelenburg position has been an effective ancillary method. These refinements may be a breakthrough in the most difficult microvascular reconstruction of diabetic foot with severely calcified arteries, thus increasing potential surgical candidates and limb salvage rate.

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Conflict of interest

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Supplementary materials

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References

1. Suh HS, Oh TS, Lee HS, Lee SH, Cho YP, Park JR, et al. A New Approach for Reconstruction of Diabetic Foot Wounds Using the Angiosome and Supermicrosurgery Concept. *Plast Reconstr Surg* 2016;**138**(4) 702e–709e.
2. Kang MJ, Chung CH, Chang YJ, Kim KH. Reconstruction of the lower extremity using free flaps. *Arch Plast Surg* 2013;**40**(5):575–83.
3. Aragon-Sanchez J, Lazaro-Martinez JL. Factors associated with calcification in the pedal arteries in patients with diabetes and neuropathy admitted for foot disease and its clinical significance. *Int J Low Extrem Wounds* 2013;**12**(4):252–5.
4. Jang YJ, Park MC, Hong YS, Won JH, Lim SH, Park DH, et al. Successful lower extremity salvage with free flap after endovascular angioplasty in peripheral arterial occlusive disease. *J Plast Reconstr Aesthet Surg* 2014;**67**(8):1136–43.
5. Castling B, Bhatia S, Ahsan F. Monckeberg's arteriosclerosis: vascular calcification complicating microvascular surgery. *Int J Oral Maxillofac Surg* 2015;**44**(1):34–6.

6. Ohtsuka H, Kamiishi H, Saito H, Ito M, Shioya N. Successful free flap transfers with diseased recipient vessels. *British journal of plastic surgery* 1976;**29**(1):5–7.
7. Esclamado RM, Carroll WR. The pathogenesis of vascular thrombosis and its impact in microvascular surgery. *Head Neck* 1999;**21**(4):355–62.
8. Lee MK, Blackwell KE, Kim B, Nabili V. Feasibility of microvascular head and neck reconstruction in the setting of calcified arteriosclerosis of the vascular pedicle. *JAMA Facial Plast Surg* 2013;**15**(2):135–40.
9. Lee YK, Park KY, Koo YT, Baek RM, Heo CY, Eun SC, et al. Analysis of multiple risk factors affecting the result of free flap transfer for necrotising soft tissue defects of the lower extremities in patients with type 2 diabetes mellitus. *J Plast Reconstr Aesthet Surg* 2014;**67**(5):624–8.
10. Kim JY, Choi HG, Uhm KI, Kim SH, Kim CK, In Jo D, et al. Salvage of a free flap using postoperative percutaneous angioplasty in patients with diabetic foot ulcers. *Arch Plast Surg* 2014;**41**(6):788–90.
11. Huang CC, Chang CH, Hsu H, Mark Chiu CH, Lin CM, Lee JT, et al. Endovascular revascularization and free tissue transfer for lower limb salvage. *J Plast Reconstr Aesthet Surg* 2014;**67**(10):1407–14.
12. El-Abbadi M, Giachelli CM. Mechanisms of vascular calcification. *Adv Chronic Kidney Dis* 2007;**14**(1):54–66.
13. McCullough PA, Agrawal V, Danielewicz E, Abela GS. Accelerated atherosclerotic calcification and Monckeberg's sclerosis: a continuum of advanced vascular pathology in chronic kidney disease. *Clin J Am Soc Nephrol* 2008;**3**(6):1585–98.
14. Wu M, Rementer C, Giachelli CM. Vascular calcification: an update on mechanisms and challenges in treatment. *Calcif Tissue Int* 2013;**93**(4):365–73.
15. Forsythe RO, Brownrigg J, Hinchliffe RJ. Peripheral arterial disease and revascularization of the diabetic foot. *Diabetes Obes Metab* 2015;**17**(5):435–44.
16. Lee KM, Kim WH, Lee JH, Choi MS. Risk factors of treatment failure in diabetic foot ulcer patients. *Arch Plast Surg* 2013;**40**(2):123–8.
17. Lichtenfels E, Frankini AD, Becker AS, Pires VC. Monckeberg's arteriosclerosis as a cause of lower limb critical ischemia: case report. *J Vasc Bras* 2007;**6**(1):97–100.
18. Forsythe RO, Hinchliffe RJ. Assessment of foot perfusion in patients with a diabetic foot ulcer. *Diabetes Metab Res Rev* 2016;**32**(Suppl 1):232–8.
19. Mills JL. Lower limb ischaemia in patients with diabetic foot ulcers and gangrene: recognition, anatomic patterns and revascularization strategies. *Diabetes Metab Res Rev* 2016;**32**(Suppl 1):239–45.
20. Chen HC, Coskunfirat OK, Ozkan O, Mardini S, Cigna E, Salgado CJ, et al. Guidelines for the optimization of microsurgery in atherosclerotic patients. *Microsurgery* 2006;**26**(5):356–62.
21. Jeyaseelan S, Stevenson TM, Pfitzner J. Tourniquet failure and arterial calcification. Case report and theoretical dangers. *Anaesthesia* 1981;**36**(1):48–50.
22. Bunker TD, Ratliff AH. Uncontrollable bleeding under tourniquet. *Br Med J (Clin Res Ed)* 1984;**288**(6434):1905.
23. Barr L, Iyer US, Sardesai A, Chitnavis J. Tourniquet failure during total knee replacement due to arterial calcification: case report and review of the literature. *J Perioper Pract* 2010;**20**(2):55–8.
24. Shestak KC, Fitz DG, Newton ED, Swartz WM. Expanding the horizons in treatment of severe peripheral vascular disease using microsurgical techniques. *Plast Reconstr Surg* 1990;**85**(3):406–11.
25. Cho HE, Roh SG, Lee NH, Yang KM. Breakthrough Technique for Free Tissue Transfer of Poorly Vascularized Lower Extremity: Arteriovenous Loop Revisited. *Arch Plast Surg* 2015;**42**(5):652–5.
26. Aratow M, Hargens AR, Meyer JU, Arnaud SB. Postural responses of head and foot cutaneous microvascular flow and their sensitivity to bed rest. *Aviation, space, and environmental medicine* 1991;**62**(3):246–51.
27. Breit GA, Watenpaugh DE, Ballard RE, Hargens AR. Acute cutaneous microvascular flow responses to whole-body tilting in humans. *Microvascular research* 1993;**46**(3):351–8.
28. Parry T, Hirsch N, Fauvel N. Comparison of direct blood pressure measurement at the radial and dorsalis pedis arteries during surgery in the horizontal and reverse Trendelenburg positions. *Anaesthesia* 1995;**50**(6):553–5.
29. Chang DS, Breit GA, Styf JR, Hargens AR. Cutaneous microvascular flow in the foot during simulated variable gravities. *The American journal of physiology* 1996;**271**(4 Pt 2):R961–6.
30. Koscheyev VS, Leon GR, Coca A, List N. Enhancing circulation to lower limbs during head-down tilt by warming upper body and thighs. *Aviation, space, and environmental medicine* 2004;**75**(7):596–602.
31. Tsai YT, Lin TS. The suitability of end-to-side microvascular anastomosis in free flap transfer for limb reconstruction. *Ann Plast Surg* 2012;**68**(2):171–4.
32. Mao H, Xu G. A retrospective study of end-to-side venous anastomosis for free flap in extremity reconstruction. *Int J Surg* 2015;**17**:72–8.
33. Lister GD, Arnez ZM. Arterial T and Y grafts. *Plast Reconstr Surg* 1991;**88**(2):319–22.
34. Tsao CK, Chen HC, Chen HT, Coskunfirat OK. Using a Y-shaped vein graft with drain-out branches to provide additional arterial sources for free flap reconstruction in injured lower extremities. *Chang Gung medical journal* 2003;**26**(11):813–21.
35. Germann G, Steinau HU. The clinical reliability of vein grafts in free-flap transfer. *J Reconstr Microsurg* 1996;**12**(1):11–17.
36. Classen DA. The indications and reliability of vein graft use in free flap transfer. *The Canadian journal of plastic surgery = Journal canadien de chirurgie plastique* 2004;**12**(1):27–9.
37. Stewart D, Liau J, Vasconez H. Flap pedicle vena comitant as a vein graft donor source. *Microsurgery* 2009;**29**(2):115–18.
38. Cheng HT, Lin FY, Chang SC. Evidence-based analysis of vein graft interposition in head and neck free flap reconstruction. *Plast Reconstr Surg* 2012;**129**(5) 853e-4e.
39. Piazza C, Taglietti V, Paderno A, Nicolai P. End-to-end versus end-to-side venous microanastomoses in head and neck reconstruction. *Eur Arch Otorhinolaryngol* 2014;**271**(1):157–62.
40. Jandali Z, Bafiq N, Loh CY, Athanassopoulos T. An improvised arterial end-to-side anastomosis from flap to arterialised vein graft in the diabetic foot. *Int Wound J* 2016;**13**(1):146–7.
41. Verhelle NA, Heymans O. How to deal with difficult microsurgical end-to-side anastomoses. *Microsurgery* 2005;**25**(3):203–8.
42. Tan BK, Wong CH, Chew W, Hong SW. Use of the slit arteriotomy for end-to-side arterial anastomosis in free-tissue transfers to the extremities. *J Plast Reconstr Aesthet Surg* 2009;**62**(11):1519–23.
43. Cho EH, Garcia RM, Blau J, Levinson H, Erdmann D, Levin LS, et al. Microvascular Anastomoses Using End-to-End versus End-to-Side Technique in Lower Extremity Free Tissue Transfer. *J Reconstr Microsurg* 2016;**32**(2):114–20.
44. Miyamoto S, Okazaki M, Takushima A, Shiraishi T, Omori M, Harii K. Versatility of a posterior-wall-first anastomotic technique using a short-thread double-needle microsuture for atherosclerotic arterial anastomosis. *Microsurgery* 2008;**28**(7):505–8.
45. Meloni M, et al. Recurrence of critical limb ischemia after endovascular intervention in patients with diabetic foot ulcers. *Adv Wound Care (New Rochelle)* 2018;**7**(6):171–6.