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A Free Bypass Flap for Chronic Limb-threatening Ischemia

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Background: Recently, significant inframalleolar disease seems to increase in chronic limb-threatening ischemia (CLTI) patients, making identifying sufficient outflow vessels in the foot challenging. In these difficult situations, free tissue transfer is a valuable tool to provide a low-resistance vascular bed to the affected part. However, there remains concern that free tissue transfer may impede adequate perfusion of the higher resistance diseased vascular bed.

Methods: To improve perfusion of the affected area directly, the authors have developed a concept of a free bypass flap, adding bypass surgery to free tissue transfer. After anastomosis with the recipient vessels in a conventional manner for free tissue transfer, bypass surgery to the foot is performed by anastomosis of the branch of the flap pedicle with the diseased artery to the foot. A retrospective chart review of nine CLTI patients was performed to analyze the outcomes of free bypass flap transfer between 2018 and 2023.

Results: The flap success rate was 100% (n = 9). Postoperative angiography or echo confirmed the patency of all but one bypass vessel (n = 8). There were six fatalities, however, due to causes other than foot lesions, with an average observation period of 16 months. The limb salvage rate was 89% (n = 8).

Conclusions: A free bypass flap enhances the overall blood circulation to the foot. Due to its high patency rate of bypass vessels, it is a valuable method for preserving the limbs of highly comorbid patients with CLTI. *(Plast Reconstr Surg Glob Open 2024; 12:e5875; doi: 10.1097/GOX.0000000000005875; Published online 10 June 2024.)*

Chronic limb-threatening ischemia (CLTI) is associated with mortality, amputation, and impaired quality of life. Successful revascularization in CLTI, particularly in patients with tissue loss, nearly always requires restoration of pulsatile in-line flow to the foot.[1] Bypass surgery requires adequate inflow and outflow. For the diagnosis of CLTI, an established peripheral artery disease in association with ischemic rest pain or tissue loss is required. The prevalence of peripheral artery disease has been increasing in recent years, probably due to the growing prevalence of diabetes mellitus associated with the aging population.[2] Consequently, significant inframalleolar disease appears to increase in CLTI patients,[1,3,4] making identifying sufficient outflow vessels in the foot challenging. In these difficult situations, especially in renal failure or diabetes, free tissue transfer is a valuable tool to provide a low-resistance vascular bed to the affected part. However, there remains concern about the microvascular steal phenomenon.[5,6] Free tissue transfer may impede adequate perfusion of the higher resistance diseased vascular bed. To improve perfusion of the affected area directly and mitigate the steal phenomenon, the authors have developed a concept of a free bypass flap, adding bypass surgery to free tissue transfer.

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PATIENTS AND METHODS

We performed a retrospective chart review of nine CLTI patients treated with bypass flap from January 2018 to April 2023. The senior surgeon conducted all operations. Postoperatively, we checked the patency of the bypass blood flow under echography or angiography.

Disclosure statements are at the end of this article, following the correspondence information.

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Primary outcomes were complications, flap survival, bypass patency, limb salvage, and ambulatory status.

Surgical Technique

Schematic diagrams of the free bypass flap are outlined in Figure 1. In cases where necrosis of the heel occurs due to the diseased posterior tibial artery, consideration is given to transferring a free flap with the anterior tibial artery as the recipient. In this scenario, a bypass flap involves anastomosing an arterial branch in the flap to the posterior tibial artery to improve blood flow toward the heel and the plantar. Thus, a free bypass flap supplements the blood flow to poorly perfused vessels from the artery branch in the free flap. The flap of choice is generally the subscapular system flap, represented by the latissimus dorsi flap because the subscapular artery divides into several branches that can provide many options for distal anastomosis in bypass surgery. The anterolateral thigh flap sacrifices useful collateral circulation in the ischemic lower limbs, and we routinely do not choose it for CLTI patients. Although the subscapular system flap is raised in the lateral decubitus position, there is no need for position changing, and a two-team approach is possible when transplanting it to the foot. The reason is that the foot has a considerable range of motion when combining the hip, knee, and ankle joints. The preoperative evaluation includes a thorough vascular assessment to identify a recipient artery and an appropriate target vessel for bypass surgery. Angiography was performed to determine the availability of the donor and delineate blood flow to the foot. In addition, preoperative arterial waveform analysis using color Doppler ultrasonography is essential to determine the bypass target artery. Arterial waveforms were classified into four types from D-1 to D-4 using blood flow waveform classification reported by Hirai et al.[7]: D1: normal triphasic pattern; D-2: spectral broadening with a distinct peak but no reversal of flow; D-3: decreased peak systolic flow velocity and no distinct peak; D-4: diffusely attenuated flow with no distinct peak (Fig. 2). (**See figure, Supplemental Digital Content 1,** which displays a preoperative image of arterial waveform analysis of the posterior tibial artery using color Doppler ultrasonography in case 1. The waveform is classified as Hirai's classification type D-4. **http://links.lww.com/PRSGO/D261**.) Among these four waveform types, the bypass targets are D-3 and D-4. If the waveform is D-1 or D-2, it indicates sufficient blood flow, and the artery is not a bypass target but a candidate for the recipient artery. If the waveform is D-3 or D-4, it indicates proximal stenosis or occlusion of the dominant artery to the point where this waveform is observed, and the target artery is patent with insufficient collateral flow, performing bypass surgery would be beneficial. The least diseased recipient artery and an optimal outflow artery to the affected part are selected. Parallel evaluations were also performed on the pedicle's required length, optimal course, and a suitable branch for bypass surgery. General anesthesia is usually favored for free bypass flap. First, debridement of the affected part is performed, followed by incisions for vascular exposure primarily at the ankle level of approximately 5-10 cm along both the recipient artery and the bypass target artery. A subcutaneous tunnel is then created among the incisions and the affected part. In many cases, the incision along the target artery relates to the debridement incision. After the flap harvest, the flap is positioned to the affected part. The pedicle is passed through a subcutaneous tunnel, followed by anastomoses in an end-to-side manner to the recipient artery using the slit arteriotomy,[8] with the addition of only minor circular cuts at both ends of the slit, which inevitably form acute angles, and in an end-to-end or end-to-side to the recipient's vein according to the size of the vein. Then, an anastomosis of the branch of the pedicle to the target artery is performed to revascularize the diseased vascular bed. Adding a bypass anastomosis typically is not a complicated procedure and does not significantly extend the surgery time, as the anastomosis area is located near the affected part.

Takeaways

Question: Is a branch of the pedicle in a free flap suitable for a conduit to bypass the diseased artery in the foot of chronic limb-threatening ischemia patient?

Findings: A high patency rate of arteries through bypass surgery was achieved by utilizing a branch of the pedicle in a free flap as a conduit.

Meaning: Due to the high patency rate, bypass surgery using a branch of a free flap pedicle is a valuable method for preserving the limb of highly comorbid patients with chronic limb-threatening ischemia.

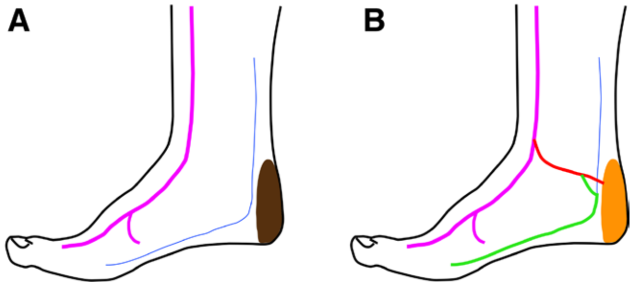

Fig. 1. Schematic diagrams of the "free bypass flap" (purple, recipient artery; blue, diseased artery; dark brown, the affected area; red, pedicle of the free flap; orange, skin paddle of the free flap; green, the arterial branch of the pedicle to the diseased artery and the increased blood flow). A free bypass flap supplements the blood flow to poorly perfused vessels from the artery branch in the free flap. A, In cases where necrosis of the heel occurs due to the diseased posterior tibial artery, consideration is given to transferring a free flap with the anterior tibial artery as the recipient. B, In this scenario, a bypass flap involves anastomosing an arterial branch in the flap to the posterior tibial artery to improve blood flow toward the heel and the plantar.

Indications and Contraindications

The indication for a free bypass flap is CLTI with significant tissue loss (WIfI[9] wound grade 2 to 3) in the weight-bearing area. This is applicable when there is no progress

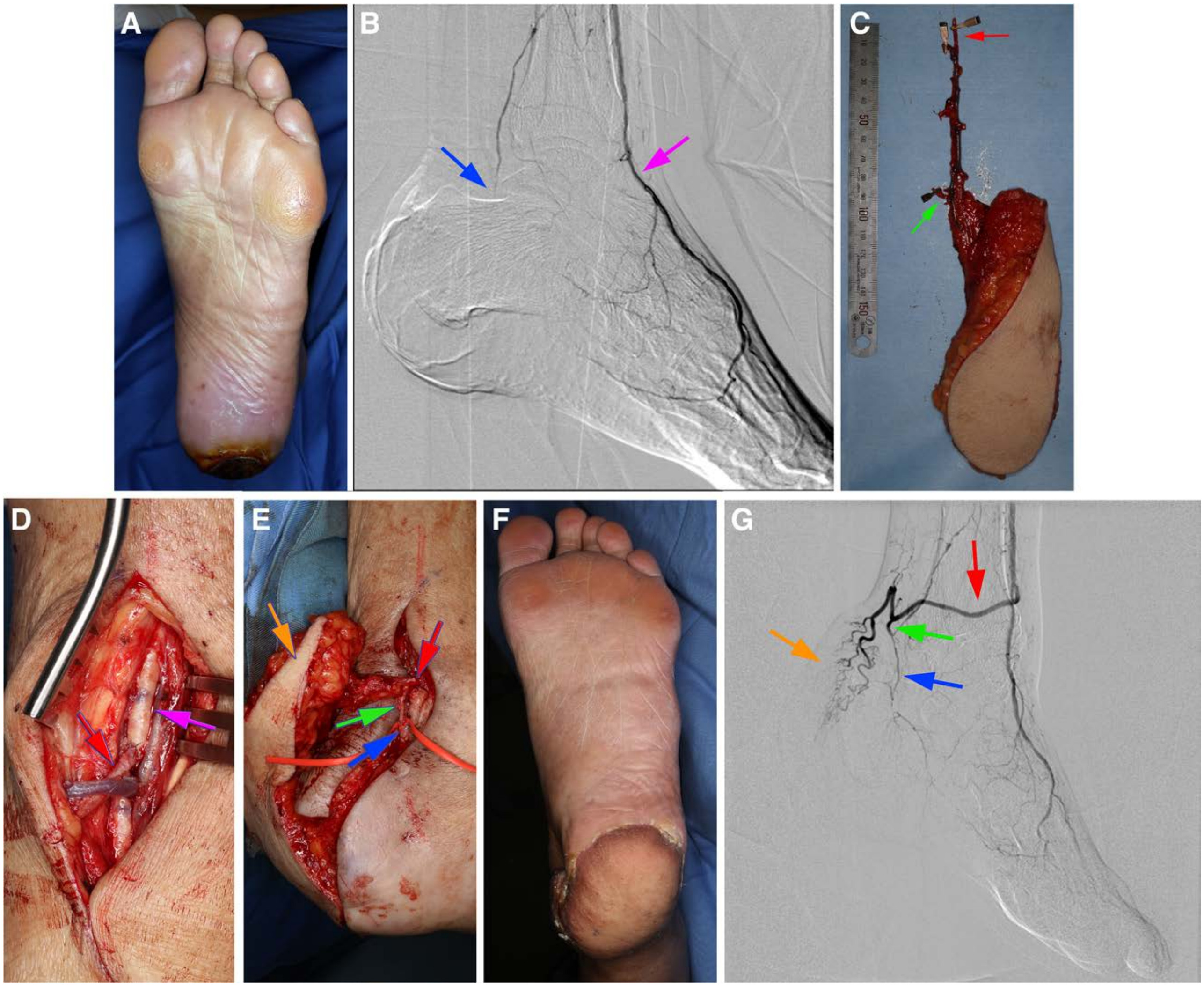

Fig. 2. Case 1: A 74-year-old man with left heel gangrene. A, A plantar view of the left foot, preoperatively. B, A preoperative angiographic image, planning to use the anterior tibial artery (purple arrow) as the recipient and the transverse branch of the flap's pedicle as a bypass conduit to the posterior tibial artery (blue arrow). Note the paucity of vessels in the heel. C, A latissimus dorsi flap and its pedicle intraoperatively. The proximal portion of the thoracodorsal artery (red arrow) for anastomosis to the anterior tibial artery. The transverse branch (green arrow) of the thoracodorsal artery for a bypass to the posterior tibial artery. D, The anastomoses between the thoracodorsal vessels (red arrow) between the recipient anterior tibial (purple arrow) vessels on the dorsum. E, The anastomosis of the bypass artery, the transverse branch (green arrow) of the pedicle (red arrow) to the posterior tibial artery (blue arrow) on the heel. The orange arrow shows the skin paddle. F, A plantar view of the heel, 3 months postoperatively. G, A medial view of the foot under angiography, three months postoperatively, shows a patent in-line flow from the transverse branch (green arrow) of the thoracodorsal artery (red arrow) to the bypassed posterior tibial artery (blue arrow). The orange arrow shows the vessels of the skin paddle.

in healing or deterioration of symptoms, even after treatment of significant inflow disease to restore in-line flow to the foot, but which fails in indirect revascularization to the affected part. A free bypass flap is not applicable if there is no patent flow to the affected area. If sufficient flow to the affected area is confirmed, bypass surgery is unnecessary. The method is relatively contraindicated for patients with limited mobility and significant medical risks.

Postoperative Management

Alprostadil, a prostaglandin E1 preparation, is administered once daily at 10 μg for one week postoperatively. Limb elevation should be maintained for 2 weeks, followed by the initiation of graduated weight-bearing 4 weeks postoperatively. The priority remains to maintain ambulatory function over wound healing, but the stages of recovery are flexibly adjusted backward depending on the healing progress.

RESULTS

Table 1 summarizes patient characteristics, wound locations, the details of the surgery, and clinical outcomes. The flap success rate was 100% (n = 9). The limb salvage rate was 89% (n = 8). All patients with salvaged

Table 1. Summary of Patients: "Free Bypass Flap"

Patient	Age	Sex	Medical History	Preoperative Revascularization	Wound Locations	Flap Types	Flap Size (cm × cm)	Length of Pedicles (cm)	Recipient Arteries	Branches for Bypass Surgery	Target Arteries	Flap Success	Patency of Bypass Arteries	Postoperative Complications	Limb Salvage/ Healing Time (Mo)	Ambulation	Follow-up (Mo)
1	74	M	DM HD post-CABG	EVT for SFA&ATA	Heel	LDMC	14× 4	9	ATA	Transverse br.	PTA	Yes	Yes	Partial skin graft failure dehiscence	Yes/3	Yes	18: died due to spondylitis
2	34	F	DM (juvenile) HD PTCA	PopA-ATA Bypass	Heel	LDMC	22× 6	9	Bypass graft	Serratus br.	PTA	Yes	Yes	dehiscence	Yes/3	Yes	42: died due to airway obstruction
3	66	M	DM gastric cancer	CFA-PTA Bypass	Forefoot	LDMC	18× 8	8	PTA	Serratus br.	DPA	Yes	Yes	dehiscence	Yes/2	Yes	3: transferred to another hospital
4	72	F	DM HD CABG AVR	PopA-ATA bypass	Dorsum Forefoot	LDMC	14× 7	8	ATA	Serratus br.	DPA	Yes	Yes	Partial skin graft failure dehiscence	Yes/2	Yes	12: died due to congestive heart failure
5	71	M	DM HD OMI pemphigoid	None	Heel	LDMC	16× 6	8	PTA	Scapular a.	Plantar	Yes	Yes	Dehiscence	Yes/3	Yes	6: died due to multi-organ failure
6	72	M	DM HD PTCA	PopA-DPA bypass	Plantar	LDMC	19× 7	8	Bypass graft	Serratus br.	PTA	Yes	Yes	Dehiscence	Yes/7	Yes	9: died due to aspiration pneumonia
7	70	M	DM HD	CFA-ATA bypass	Heel	LDMC	18× 8	10	ATA	Serratus br.	PTA	Yes	Yes	dehiscence	Yes/2	Yes	32
8	72	M	DM ESRD dementia	None	Forefoot	Scapular	10× 7	8	ATA	Thoracodorsal a.	PTA	Yes	Yes	dehiscence	Yes/7	Yes	19: died due to sepsis
9	52	M	DM HD	None	Dorsum forefoot	LDMC	19× 10	10	PTA	Serratus br.	DPA	Yes	NR	dehiscence	No/-	No	5: required below-knee amputation

ATA, anterior tibial artery; AVR, post aortic valve replacement; CABG, postcoronary artery bypass graft; CFA, common femoral artery; DM, diabetes mellitus; DPA, dorsalis pedis artery; ESRD, end-stage renal disease; EVT, endovascular therapy; HD, end-stage renal disease on hemodialysis; LDMC, latissimus dorsi musculocutaneous flap; NR, data not reported; OMI, old myocardial ischemia; PopA, popliteal artery; PTA, posterior tibial artery; br., branch; a., artery; PTCA, post percutaneous transluminal coronary angioplasty; SFA, superficial femoral artery.

limbs were ambulating except in the terminal phase. The average age was 64.8 years, and all patients had diabetes. There were eight cases of end-stage renal disease, indicating that the patients had progressive peripheral artery atherosclerosis. Bypass from the anterior tibial artery to the posterior tibial artery was conducted in five cases; from the posterior tibial artery to anterior tibial artery in two cases; from the anterior tibial to its distal end in one case; and from the posterior tibial to its distal end in one case. In all patients, we observed wound dehiscence on the side of the diseased vessel and suppuration due to attempting minimal debridement to preserve ambulatory function. Still, they healed conservatively to a level not affecting daily life, except in one case, as one patient required eventual below-knee amputation five months postoperatively. Postoperative angiography or echo confirmed the patency of all but one bypass vessel. There were six fatalities, however, due to causes other than foot lesions, with an average observation period of 16 months.

CASE REPORTS

Case 1: Patient 1

Patient 1 (Table 1) was a 74-year-old man with left heel gangrene (Fig. 2) (**See figure, Supplemental Digital Content 1, http://links.lww.com/PRSGO/D261**.) [**See figure, Supplemental Digital Content 2**, which displays an anterior view of the left foot, intraoperatively in case 1. The purple waveform represents the incision line on the anterior tibial artery (red line). The dashed line represents the course of the pedicle. **http://links.lww.com/PRSGO/D262**.] [**See figure, Supplemental Digital Content 3**, which displays a posteromedial view of the left foot, intraoperatively in case 1. The purple waveform represents the incision line on the posterior tibial artery (red line). **http://links.lww.com/PRSGO/D263**.]. The patient was on maintenance dialysis due to diabetic chronic kidney disease and had a history of coronary artery bypass grafting for old myocardial infarction and prior distal bypass surgery for the right lower leg for CLTI. The patient had undergone endovascular therapy for stenosis of the superficial femoral artery and the anterior tibial artery. However, the posterior tibial and peroneal arteries remained occluded at their trunks. We transferred the free latissimus dorsi muscle flap to the left heel, with the anterior tibial artery and vein as recipient vessels, passing the pedicle through the medial side of the ankle joint. Simultaneously, we performed a bypass surgery, anastomosing the transverse branch of the thoracodorsal artery to the posterior tibial artery to restore blood flow to the affected heel. Due to the thickness of the subcutaneous fat, there is a risk of compressing the pedicle if closed directly. Therefore, mesh grafting was performed after partially de-epithelializing the flap near the anastomosis site. The wound has healed, and the patient was ambulating at three months postoperatively. Postoperative angiography shows a patent in-line flow from the thoracodorsal artery to the posterior tibial artery (Fig. 2). [**See Video 1 (online),** which demonstrates postoperative angiography of the left foot in case 1. A patent in-line flow is delineated from the transverse branch (green arrow) of the thoracodorsal artery (red arrow) to the bypassed posterior tibial artery (blue arrow). The orange arrow shows the vessels of the skin paddle.]

Case 2: Patient 8

Patient 8 (Table 1) was a 72-year-old man with left second and third toe gangrene (Fig. 3). (**See figure, Supplemental Digital Content 4,** which displays a preoperative image of arterial waveform analysis of the posterior tibial artery in case 8. The waveform is classified as type D-3. **http://links.lww.com/PRSGO/D264**.) (**See figure, Supplemental Digital Content 5**, which displays a preoperative image of arterial waveform analysis of the anterior tibial artery for comparison in case 8. The waveform is classified as type D-1. **http://links.lww.com/PRSGO/D265**.) The patient had stage 5 chronic kidney disease due to diabetes. We performed debridement but observed the spread of infection in the midfoot, leading to osteomyelitis of the metatarsal bones. Then we performed Lisfranc amputation, but the plantar aspect of the resultant distal end experienced delayed healing. Preoperative MR angiography showed that only the anterior tibial artery was patent, whereas the peroneal and posterior tibial arteries were occluded. In addition to covering the affected distal end of the foot with a skin paddle, due to the estimated need for sufficient vascular length for the bypass surgery to the posterior tibial artery, we performed a transfer of a free scapular flap including a long segment of vessels from the subscapular artery to the thoracodorsal artery, with the anterior tibial artery and vein as recipient vessels, and thoracodorsal artery as a bypass graft to the posterior tibial artery to improve blood flow to the affected plantar. The wound has healed, and the patient was ambulating a year postoperatively. Postoperative angiography shows a patent flow from the anterior tibial artery into the subscapular and posterior tibial artery through the thoracodorsal artery, improving the plantar vascular bed (Fig. 3). [**See Video 2 (online), which** demonstrates postoperative angiography of the left foot in case 2. A patent flow is shown from the anterior tibial artery (purple arrow) into the subscapular artery, the circumflex scapular artery (red arrow) to the skin paddle (orange arrow), and the bypassed posterior tibial artery (blue arrow) through the thoracodorsal artery (green arrow).] Maintenance dialysis was initiated in the patient seven months postoperatively. The patient ultimately succumbed to sepsis 19 months postoperatively after refusing surgery for contralateral foot gangrene.

DISCUSSION

We demonstrate the effectiveness of a free bypass flap in saving the limbs of patients with CLTI. Oh et al demonstrated that free tissue transfer significantly improves the five-year survival rate compared with patients undergoing amputation.[10] Furthermore, free tissue transfer with bypass anastomosis supplies needed blood flow to

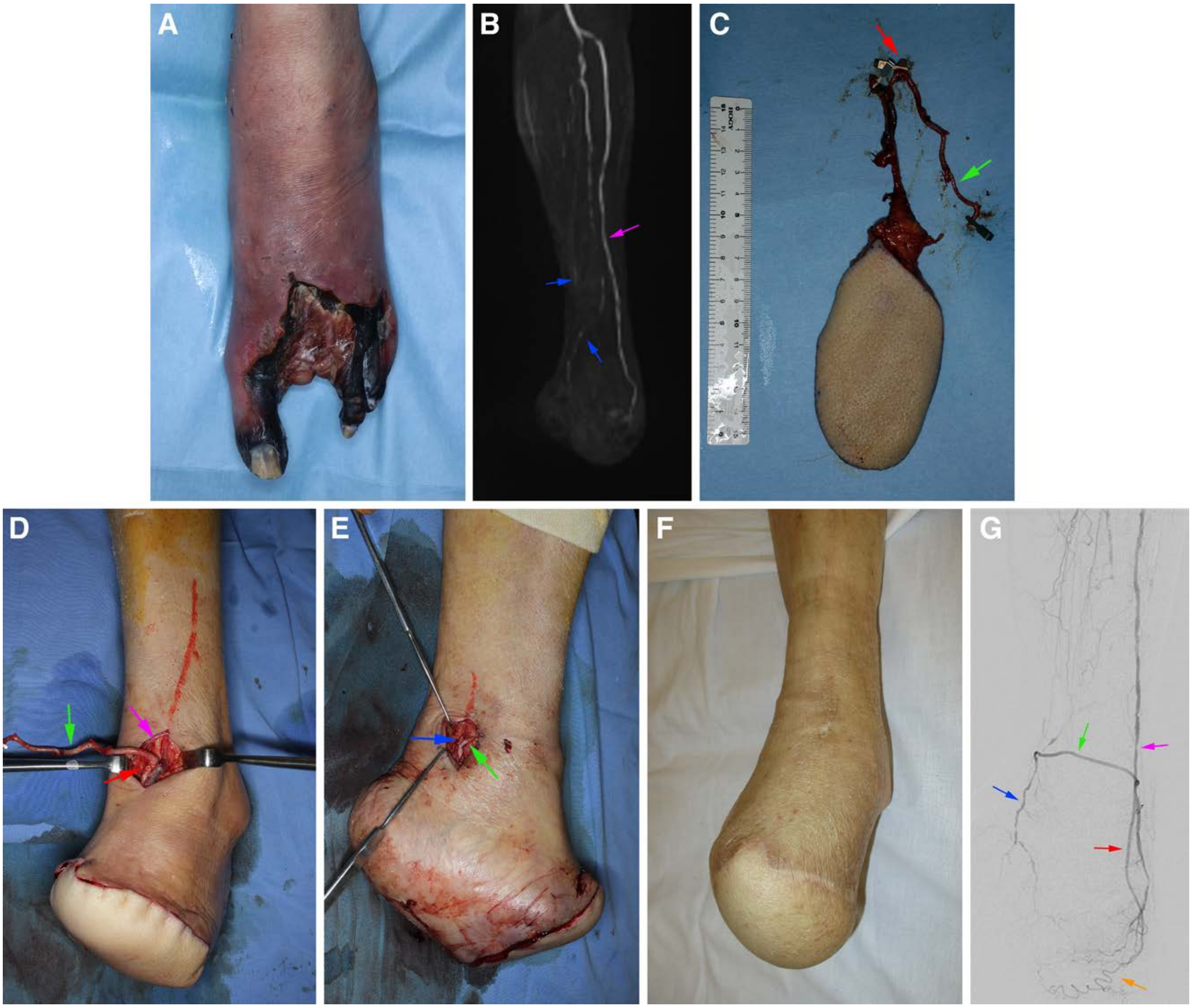

Fig. 3. Case 8: A 72-year-old man with left second and third toe gangrene. A, An anterior view of the left foot before Lisfranc amputation. B, An MR angiographic image, preoperatively. The anterior tibial artery (purple arrow) was patent, whereas the peroneal and posterior tibial arteries were occluded (blue arrows). C, A scapular flap and its pedicle intraoperatively. Red arrow, the proximal portion of the subscapular artery for anastomosis to the anterior tibial artery; green arrow, the thoracodorsal artery for bypassing the posterior tibial artery. D, An intraoperative image of the anterior foot shows the arrangement of a scapular flap and pedicle. Purple arrow, the anterior tibial artery as the recipient artery; red arrow, the subscapular artery and circumflex scapular artery to the scapular flap; green arrow, the thoracodorsal artery as a bypass conduit to be anastomosed to the posterior tibial artery. E, The anastomosis between the bypass conduit and the diseased artery on the heel. Green arrow, the thoracodorsal artery; blue arrow, the posterior tibial artery. F, An anterior view of the foot, a year postoperatively. G, An anterior view of the foot under angiography, six months postoperatively, shows a patent flow from the anterior tibial artery (purple arrow) into the subscapular artery, the circumflex scapular artery (red arrow) to the skin paddle (orange arrow), and the bypassed posterior tibial artery (blue arrow) through the thoracodorsal artery (green arrow).

an area of localized ischemia in these patients. The high success rate (89%) in treating recalcitrant foot ulcers in challenging comorbid populations, such as enduring diabetes and renal failure, can be attributed to added bypass anastomosis to improve the blood flow to the affected site. The affected part is perfused by insufficient collateral flow. Free tissue transfer has negative aspects for wound healing in the sense that it impedes collateral flow to the affected part due to the microvascular steal phenomenon. Additional bypass flow to the affected part can mitigate this negative impact. Adding bypass surgery provides an immediate positive impact on wound healing compared with the time it takes for a free tissue transfer alone to revascularize the affected part through the bridging of vessels. Neville et al already reported that direct revascularization of the angiosome specific to the anatomy of the wound is beneficial for wound healing and limb salvage.[11]

According to fluid mechanics calculations, additional bypass surgery to the free flap makes the inflow volume of the pedicle higher than with each surgery, leading to increased blood flow to the foot (Fig. 4). Although the settings may vary slightly, Lorenzetti et al reported that a free muscle flap

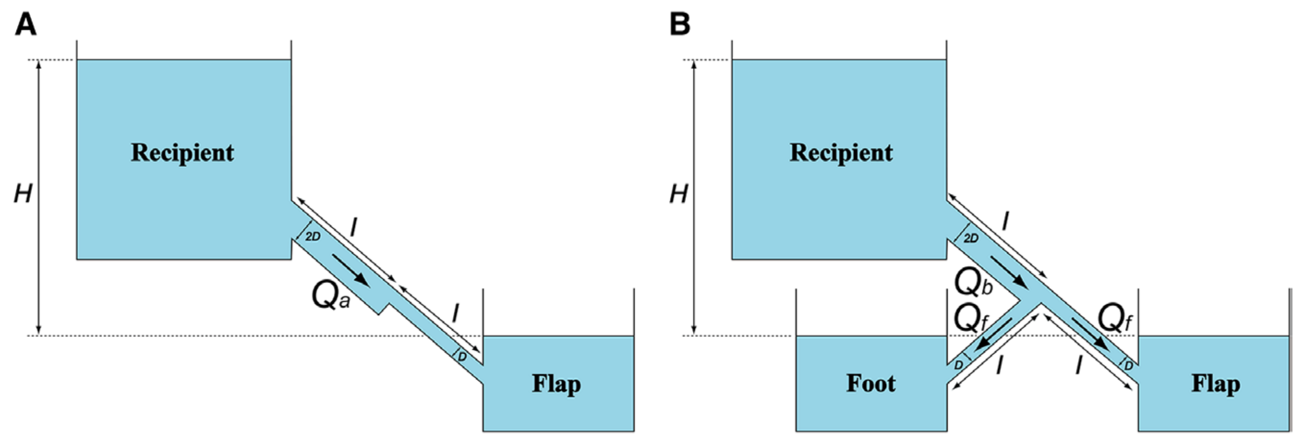

Fig. 4. Water tank model of the vessel flow. H = the total head loss, Q_a = volume flow rate of the pedicle vessel in case (a), Q_b = volume flow rate of the pedicle vessel in case (b), Q_f = volume flow rate of the vessel to the flap and the bypass vessel in case (b), f = Darcy friction factor of the vessel pipe, D = vessel diameter, l = length of blood vessels within an arbitrarily defined section, g = the gravitational acceleration. The diameter of the proximal half of the blood vessel is assumed to be twice the diameter of the distal half. A, The recipient artery and the pedicled flap without bypass anastomosis. B, The recipient artery and the pedicled flap with bypass anastomosis. To explain the increase in volume flow rate of a free bypass flap in case (b) compared with a free flap in case (a), consider the water tank model, designing a free flap to a branching conduit system. A high-level reservoir represents the recipient artery, and pipes and two water tanks at the lower level represent the vascular flow to the free flap tissue and the bypass flow to the affected foot site. In cases where the conduit system is generally long, losses due to shape, such as the entrance effects, are negligible compared with friction factors; hence, only friction losses in pipes are considered. The lengths of the pipes before and after branching are assumed to be equal and denoted as "l." The friction factor of the vessel is assumed to be constant across all sections. The total head loss to the flap and the foot is considered the same and represented as "H." The Bernoulli equation in case (a) and (b) can be calculated as follows, respectively:

$$H = \frac{8fl}{\pi^2 g(2D)^5} Q_a^2 + \frac{8fl}{\pi^2 g D^5} Q_a^2 = \frac{33fl}{4\pi^2 g D^5} Q_a^2, \quad (1)$$

$$H = \frac{8fl}{\pi^2 g(2D)^5} Q_b^2 + \frac{8fl}{\pi^2 g D^5} Q_f^2. \quad (2)$$

Substituting $Q_f = \frac{Q_b}{2}$ into (2), we obtain

$$H = \frac{fl}{4\pi^2 g D^5} Q_b^2 + \frac{8fl}{\pi^2 g D^5} \left(\frac{Q_b}{2}\right)^2 = \frac{9fl}{4\pi^2 g D^5} Q_b^2. \quad (3)$$

Then,

$$\frac{33fl}{4\pi^2 g D^5} Q_a^2 = \frac{9fl}{4\pi^2 g D^5} Q_b^2$$

$$\Rightarrow Q_b = \frac{\sqrt{33}}{3} Q_a \approx 1.91 Q_a. \quad (4)$$

connected to an infrapopliteal bypass decreases the outflow resistance and increases bypass graft flow.[12] Their research demonstrated that increasing the number of branches will increase the blood flow to the pedicle following fluid dynamics principles. The increased blood flow to the pedicle also reduces the potential for vascular occlusion.

In cases where direct vascular reconstruction is challenging due to severely diseased inframalleolar arteries, it is often expected that functioning blood vessels with even minimal flow are present. In this method, these vessels can be used as bypass outflow targets, as the bypass conduit is the vascularized short-length artery in the flap, allowing for sufficient patency to be anticipated. Short lengths of the conduit are proven reliable and are often preferred.[13–15] Suppose you define the length of the bypass conduit as the distance from the vascularized recipient vessel to the outflow vessel. In that case, the conduit length becomes zero in a free bypass flap. In general, autogenous conduits used for vascular bypass are veins. More effectively than venous grafts, arterial grafts treat limb-threatening ischemia in patients with end-stage renal disease and inframalleolar arterial insufficiency.[16] The free bypass flap decreases the recipient artery flow along the pathway down to the foot. However, its decrease is minimal, unless the recipient artery is highly diseased. Due to bypass surgery to a patent artery, the total vascular resistance in the foot decreases. Therefore, a free bypass flap enhances the overall blood circulation to the foot. The following is the equivalent of the argument that traffic efficiency would increase if a two-lane highway were expanded to three lanes. Because the rate of microvascular complications decreases as resistance within the flap decreases,[17] adding bypass surgery also improves the patency rate of the pedicle. Thus, by adding bypass surgery with a vascularized artery, a free bypass flap enhances the flap's function as a nutrient flap and improves the patency rate of its pedicle.

The relationship between a flowthrough flap and a free bypass flap is somewhat complicated. "Flowthrough" means anastomosing the distal end of the vascular pedicle of a free flap to a distal vessel, but if that distal vessel is a diseased artery, it becomes a free bypass flap. The subscapular system flap has multiple branches and offers flexibility in placement. The distal end of the pedicle is merely one of the many choices for a vascular stump for bypass surgery. However, it is often difficult to select the distal end of the pedicle as it tends to run in the direction of the skin paddle too far away from the target artery.

Our study is retrospective and describes a small number of patients. Therefore, our results can only be preliminary evidence of our technique's effectiveness. Our calculations were based on simplifying assumptions that the flow is steady even though the heartbeat creates a pulsatile flow, and blood acts as a Newtonian fluid, defined as fluids for which the shear stress is linearly proportional to the shear strain rate.[18] However, it is unlikely that these assumptions would significantly impact the fundamental conclusion that overall blood flow to the foot increases with the addition of bypass surgery to the free tissue transfer. In all patients, we observed minor wound dehiscence on the side of the diseased vessel, but it healed conservatively except in one case. One reason for dehiscence might be to minimize debridement as much as possible to preserve the affected limb's function fully. Severe arterial atherosclerotic disease presents a significant challenge in treating patients with a limited prognosis.[19–21] Still, it is considered crucial to preserve their ambulatory function until the end of life.

CONCLUSIONS

A free bypass flap enhances the overall blood circulation to the foot. Due to its high patency rate of bypass vessels, it is a valuable method for preserving the limbs of patients with CLTI, even when inframalleolar arteries are severely diseased.

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DISCLOSURE

The authors have no financial interest to declare in relation to the content of this article.

REFERENCES

1. Conte MS, Bradbury AW, Kolh P, et al; GVG Writing Group. Global vascular guidelines on the management of chronic limb-threatening ischemia. *J Vasc Surg.* 2019;69:3S–125S.e40.
2. Berchiolli R, Bertagna G, Adami D, et al. Chronic limb-threatening ischemia and the need for revascularization. *J Clin Med.* 2023;12:2682.
3. Kawarada O, Fujihara M, Higashimori A, et al. Predictors of adverse clinical outcomes after successful infrapopliteal intervention. *Catheter Cardiovasc Interv.* 2012;80:861–871.
4. Haine A, Haynes AG, Limacher A, et al. Patency of the arterial pedal-plantar arch in patients with chronic kidney disease or diabetes mellitus. *Ther Adv Cardiovasc Dis.* 2018;12:145–153.
5. Sonntag BV, Murphy RXJ, Chernofsky MA, et al. Microvascular steal phenomenon in lower extremity reconstruction. *Ann Plast Surg.* 1995;34:336–9; discussion 339.
6. Tosenovsky P, Zalesak B, Janousek L, et al. Microvascular steal syndrome in the pedal bypass and free muscle transfer? *Eur J Vasc Endovasc Surg.* 2003;26:562–564.
7. Hirai T, Ohishi H, Kichikawa K, et al. Ultrasonographic screening for arterial occlusive disease in the pelvis and lower extremities. *Radiat Med.* 1998;16:411–416.
8. Black C, Fan KL, Defazio MV, et al. Limb salvage rates and functional outcomes using a longitudinal slit arteriotomy end-to-side anastomosis for limb-threatening defects in a high-risk patient population. *Plast Reconstr Surg.* 2020;145:1302–1312.
9. Mills JLS, Conte MS, Armstrong DG, et al; Society for Vascular Surgery Lower Extremity Guidelines Committee. The society for vascular surgery lower extremity threatened limb classification system: risk stratification based on wound, ischemia, and foot infection (WIfI). *J Vasc Surg.* 2014;59:220–234.
10. Oh TS, Lee HS, Hong JP. Diabetic foot reconstruction using free flaps increases 5-year-survival rate. *J Plast Reconstr Aesthet Surg.* 2013;66:243–250.
11. Neville RF, Attinger CE, Bulan EJ, et al. Revascularization of a specific angiosome for limb salvage: does the target artery matter? *Ann Vasc Surg.* 2009;23:367–373.
12. Lorenzetti F, Tukiainen E, Alback A, et al. Blood flow in a pedal bypass combined with a free muscle flap. *Eur J Vasc Endovasc Surg.* 2001;22:161–164.
13. Veith FJ, Gupta SK, Samson RH, et al. Superficial femoral and popliteal arteries as inflow sites for distal bypasses. *Surgery.* 1981;90:980–990.
14. Ballotta E, Renon L, De Rossi A, et al. Prospective randomized study on reversed saphenous vein infrapopliteal bypass to treat limb-threatening ischemia: common femoral artery versus superficial femoral or popliteal and tibial arteries as inflow. *J Vasc Surg.* 2004;40:732–740.
15. Tran K, Ho VT, Itoga NK, et al. Comparison of mid-term graft patency in common femoral versus superficial femoral artery inflow for infra-geniculate bypass in the vascular quality initiative. *Vascular.* 2020;28:722–730.
16. Treiman GS, Lawrence PF, Rockwell WB. Autogenous arterial bypass grafts: durable patency and limb salvage in patients with inframalleolar occlusive disease and end-stage renal disease. *J Vasc Surg.* 2000;32:13–22.
17. Sasmor MT, Reus WF, Straker DJ, et al. Vascular resistance considerations in free-tissue transfer. *J Reconstr Microsurg.* 1992;8:195–200.
18. Çengel YA, Cimbala JM. *Fluid Mechanics: Fundamentals and Applications.* New York, N.Y.: McGraw-Hill Science Engineering; 2013.
19. Dossa CD, Shepard AD, Amos AM, et al. Results of lower extremity amputations in patients with end-stage renal disease. *J Vasc Surg.* 1994;20:14–19.
20. O'Hare AM, Feinglass J, Sidawy AN, et al. Impact of renal insufficiency on short-term morbidity and mortality after lower extremity revascularization: data from the department of veterans affairs' national surgical quality improvement program. *J Am Soc Nephrol.* 2003;14:1287–1295.
21. O'Hare AM, Feinglass J, Reiber GE, et al. Postoperative mortality after nontraumatic lower extremity amputation in patients with renal insufficiency. *J Am Soc Nephrol.* 2004;15:427–434.