Using a Y-Shaped Vein Graft with Drain-out Branches to Provide Additional Arterial Sources for Free Flap Reconstruction in Injured Lower Extremities

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Background: Reconstruction of the distal lower extremity with poor arterial circulation is a challenge for reconstructive surgeons, especially when a microsurgical free tissue transfer is necessary. One may face the problem of having no suitable recipient artery to be used except the main one. To overcome this difficult situation, utilization of a Y-shaped vein graft (YVG) was developed.

Methods: We report on 3 successful reconstructions of the lower extremities with free flaps using YVG to supply the arterial inflow and in which the distal circulation of the lower extremity was preserved at the same time. The therapeutic goals, design, surgical technique, and outcomes are clarified. The indications, advantages, and disadvantages are also discussed.

Results: All 3 patients achieved successful reconstruction of the affected limbs with uneventful surgery. Special microsurgical skills are unnecessary in this method. It can provide an additional arterial source, which is useful and reliable for revascularizing various kinds of free tissue. Utmost care must be taken to examine the direction of flow during harvesting since only the drain-out branches can serve as an ideal YVG.

Conclusion: We concluded that Y-shaped vein grafting is a good alternative technique to achieve free flap reconstruction of a distal lower extremity with simultaneous preservation of the distal circulation in selected difficult cases.

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Key words: **Y-shaped vein graft, free flaps, revascularization, limb preservation.**

Y-shaped vein grafts (YVGs) specifically selected from the venous system of the foot dorsum have been used to bridge arterial defects in multiple digit replantations.[3,4] It is thought to be a reliable and simple method to provide adequate arterial inflow to both adjacent digits simultaneously. We expanded its use to achieve microsurgical reconstruction of a lower extremity in selected cases. The YVG can serve as an interposition graft and revascularize not only the limb but also a free flap at the same time. In this article, we share our successful experience with 3 cases, and we reached the conclusion that Y-shaped vein grafting can resolve the lack of a suitable recipient artery. It is also a good alternative method for end-to-side arterial anastomosis.

METHODS

In 3 patients, microsurgical free tissue transfer was the lifeboat procedure to preserve their compro-

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mised lower extremities following injury. During the operation, some vascular problems in the recipient sites were found, which made the free flap reconstruction nearly impossible. To overcome these difficult situations, utilization of YVG was developed and applied to the affected limbs. The procedures of the Y-shaped vein grafting began with adequate design and harvest of a YVG. And then transection or segmental resection of the only available artery in the recipient site was performed, which may result in devascularization of the distal part of the leg and foot. Finally we used the main stem of the YVG to bridge the created arterial gap, with the branch stem of the YVG serving as an additional arterial source. Microsurgical free tissue transfer could thus be easily performed. Different kinds of free tissue including 2 muscle flaps and 1 fasciocutaneous flap were successfully transferred with this method. The therapeutic goals, design, surgical technique, and outcomes are clarified. The indications, advantages, and disadvantages are also discussed.

RESULTS

The results are summarized in detail in Table 1. Different free flaps were utilized, and the perfusion of each was successfully reestablished from the branch stem of the YVG. All 3 transferred flaps completely survived, and the circulation of the distal limb was preserved uneventfully. All the YVGs were harvested from the contralateral dorsal foot after carefully noting the flow direction. The YVG donor wounds were closed primarily. The average length of the main stems of the YVGs used to bridge the arterial gap was 2.5 cm. The average length of branch stems was 2.7 cm. In our experience, special microsurgical skills are unnecessary with this method. Although the extra end-to-end micro-anastomoses were somewhat tedious, they could easily be performed in a good operative field. We learned from the 3 cases that the design and harvest of the YVG are very important. Utmost care must be taken to examine the direction of flow during harvesting since only the drain-out branches can serve as ideal YVGs.

CASE REPORTS

Case 1

A 57-year-old man sustained a crushing injury to his right ankle in a motorcycle accident, which resulted in an 8×7-cm skin defect over the medial malleolar area with partial tendon and bone exposure. A free latissimus dorsi (LD) muscle flap from the left back was designed to cover the defect. Originally, we planned to use the posterior tibial artery (PTA) as the recipient artery for end-to-side anastomosis. However, a damaged PTA was noted during exploration. It was thus transected for examination, and a thrombus was found inside the injured lumen. The injured segment was removed and a 3-cm arterial gap was created. In order to preserve the distal circulation of the PTA, a YVG was obtained from the left dorsal foot after carefully noting the flow direction. It was used to bridge the arterial gap and simultaneously provide branched flow to the transferred LD flap (Fig. 1). The main stem was about 3 cm in length, and the branch stem was 2 cm. All 3 end-to-end anastomoses were completed smoothly. The recipient vein was a nearby superficial vein. The warm ischemic time of the LD flap was 120 min. The LD flap was pink, and perfusion was good after completing the entire microsurgical procedures. The donor sites over the left back and

Table 1. Results

Patient	Age(y/o)	Gender	YVG donor site	YVG length (cm)		Free flap	Results	F/U period
				Main-stem	Branch-stem			(months)
1	57	M	Left dorsal foot	3	2	LD	Flap Survival with wound healing	26
2	51	M	Left dorsal foot	2	3	SF	Flap Survival with wound healing	16
3	62	M	Right dorsal foot	2.5	3	VL	Flap Survival with wound healing	7

Abbreviations: YVG: Y-shaped vein graft; LD: latissimus dorsi muscle flap; SF: scapular fasciocutaneous flap; VL: vastus lateralis muscle flap.

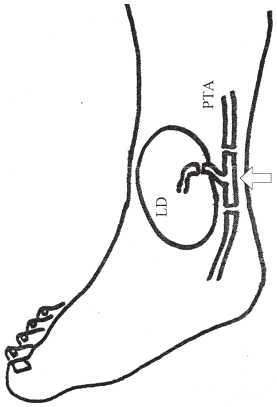

Fig. 1 Y-shaped vein graft (arrow) bridges the arterial gap and provides an additional arterial source to supply the free flap. (LD: latissimus dorsi muscle flap; PTA: posterior tibial artery)

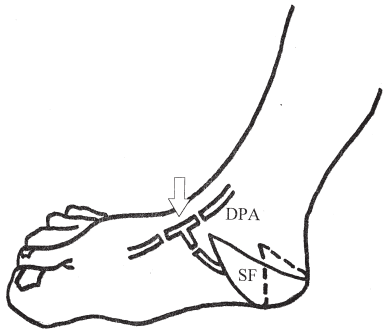

Fig. 2 Designs of free flap and Y-shaped vein graft (arrow). (SF: scapular fasciocutaneous flap; DPA: dorsalis pedis artery)

dorsal foot were primarily closed. The total operative time was 5 h and 10 min.

The postoperative course was uneventful. The transferred flap completely survived, and the donor wounds completely healed in 10 days. A secondary procedure of skin grafting to cover the residual skin defect was performed 13 days later. The skin graft took well. He recovered and began walking 2 weeks after skin grafting. The functional and aesthetic results were both acceptable.

Case 2

The right ankle of a 51-year-old man had been mangled in a motor vehicle accident 2 years previous. After a series of reconstructive surgeries including a free LD muscle flap for ankle defect coverage, the patient regained function of his extremity at discharge. He soon went back to his work without a hitch. Unfortunately, a chronic ulcer developed on his right heel due to decreased sensitivity 1 year later. Debridement, a sequestrectomy, removal of a bony prominence, and local flap reconstruction had all been tried to attain ulcer healing but in vain. To definitively solve this chronic problem, extensive removal of the ulcer pocket and a free scapular fasciocutaneous flap transfer were planned. During the operation, the defect was measured after adequate debridement and then a 15×6 cm scapular flap was harvested from the right back. At first, we had planned to use the PTA as the recipient artery, which had been severed at the original trauma and used to revascularize the previous LD flap. However, it was found to be too small with calcified change and was surrounded by fibrotic tissue even in the middle calf area. The plan was changed because the PTA was unsuitable. The residual dorsalis pedis artery (DPA) was thus considered to provide the arterial inflow to the transferred flap by end-to-side anastomosis. On exploration, the DPA was also so small that it was unsuitable for an end-to-side anastomosis. Consequently, a YVG instead of end-to-side anastomosis was used to provide 2 constant arterial flows simultaneously (Fig. 2). After transecting the DPA and preparing the cut ends, the arterial gap was 1.5 cm. The YVG was harvested from the left dorsal foot after carefully noting the flow direction. It was used to bridge the arterial gap and simultaneously provide a branched flow to the transferred scapular flap. The main stem used was 2 cm in length, and the branch stem was 3 cm. All 3 end-to-end anastomoses were achieved smoothly. The recipient vein was a nearby superficial vein. The warm ischemic time of the scapular flap was only 60 min, because we did not remove the scapular flap until the Y-shaped vein graft had reestablished the continuity of the DPA. The scapular flap and distal foot were pink, and perfusion was good after completing the entire microsurgical procedures. The donor sites over the right back and left dorsal foot were directly closed. The total operative time was 13 hours and 30 min.

The postoperative course was uneventful. The transferred flap completely survived, and all wounds healed with no problems. Because of the bulky flap,

he received a defatting procedure to reduce the flap volume and revision of the heel shape 35 days later. The patient recovered enough to walk after another 2 weeks.

Case 3

A 62-year-old man had suffered from left leg osteomyelitis for 6 months. His trauma history was a crushing injury to the left leg and foot in a traffic accident 16 years previous. In addition, the patient had a history of diabetes mellitus for more than 10 years without regular control. Two reconstructive microsurgeries had been tried to functionally reconstruct the affected limb. A gracilis muscle flap was first transferred to the left sole for adequate coverage of the exposed bone immediately after the trauma. At that time, the recipient artery was the DPA. A secondary microsurgical reconstruction was performed 5 years later. A left vastus lateralis (VL) myocutaneous flap was transferred to treat the repeated ulceration of the left foot sole due to decreased sensitivity. The VL flap was revascularized using the anterior tibial artery (ATA) to a more-proximal part of the previous pedicle of the gracilis flap. Although atherosclerotic change in the ATA was noted during the microvascular anastomosis, successful reconstruction was achieved uneventfully. The patient had no problem in the past 10 years until 6 months previous when repeated cellulitis and chronic osteomyelitis developed in his left middle lower leg. It was thought to have some relation with his diabetic history. Medical control by antibiotics had been administered for a long period but in vain. Surgical debridement and free tissue coverage were thus employed. After adequate debridement and a sequestrectomy, the defect was measured and no bone defect was observed. Then, a right VL muscle flap based on the descending branch of the lateral circumflex femoral artery was selected. At first, we planned to use the ATA as the recipient artery. However, it was not available because of severe stenosis and atherosclerosis. We thus explored the PTA and found it was only available at a higher level near the trifurcation of the tibioperoneal trunk. Also atherosclerotic change was noted on the vessel wall. The lumen was only 1 mm in diameter; however the thickness of the vessel wall was about 1.6 mm. The poor circulatory condition with arterial atherosclerosis was anticipated preoperatively because diffuse soft tissue calcification and bony hyperostosis were noted on the radiograph of the involved leg. However, it was still beyond our expectation. We considered that it would be very hard to perform an end-to-side anastomosis to the explored PTA. Therefore, we used Y-shaped vein grafting to displace the end-to-side method for preserving the distal circulation and simultaneously providing arterial inflow to perfuse the transferred muscle flap (Fig. 3). After transecting the PTA and preparing the cut ends, the arterial gap was 2.5 cm. The main stem used to bridge the arterial gap was 3 cm in length, and the branch stem was 3 cm. End-to-end anastomosis was relatively easy, and the arterial inflows to both the distal leg and the flap were reestablished smoothly. The recipient vein was a concomitant vein of the PTA. After completing the entire microsurgical procedures, the transferred muscle flap and distal leg were confirmed to be pink and well perfused. The warm ischemic time of the VL flap was 70 min, and the total operative time was 14 hours and 38 min. The donor sites over the right thigh and right dorsal foot were closed primarily.

The postoperative course was uneventful. The donor wounds completely healed in 10 days, and the VL muscle flap completely survived. A secondary procedure of skin grafting to cover the residual skin defect was performed 33 days later. The skin graft took well, and the osteomyelitis was finally cured.

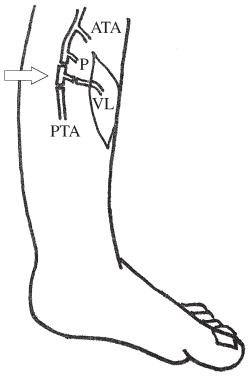

Fig. 3 Designs of free flap and Y-shaped vein graft (arrow). (VL: vastus lateralis muscle flap; ATA: anterior tibial artery; P: peroneal artery; PTA: posterior tibial artery)

DISCUSSION

Various methods have been utilized to overcome

the difficulty of the lack of an available recipient artery in lower limb reconstruction, including (1) utilization of previously injured vessels with or without vein grafts, (2) end-to-side arterial anastomosis, (3) a flow-through flap technique, (4) Y-shaped arterial anastomosis, and (5) a cross-leg flap.[5-12] However, most of these are either technically difficult or practically limited as described below.

The utilization of previously injured vessels is the most popular method to restore the circulation of a free flap. It is an economical method without jeopardizing the distal circulation. However, it is not easy to judge the reliability of these injured arteries, and the area that is suitable for microvascular anastomosis is usually too far away from the defect.[5,13] A long vein graft or temporary arteriovenous loop is necessary which may increase the risk of vascular complications.[14]

In general, direct end-to-side arterial anastomosis to the remaining major artery is the simplest way to solve the problem of the lack of a recipient artery. A long pedicle is not necessary in free flap transfer, and the surgeon can save much time since extensive exploration is not required to search for an available recipient vessel. We also revascularize free flaps in this method, but it is not always available. The need for special skills, especially in small-sized or atherosclerotic vessels, limits its application. It is difficult and unsuitable to perform end-to-side anastomosis on an artery with a small-sized lumen or with atherosclerotic change. Inadequate anastomosis may result in arterial thrombosis that affects not only the free flap but also the distal leg. In addition, end-to-side anastomosis to the vein graft that bridges the arterial gap of a severely mangled lower leg is not a good choice for free flap revascularization. It may increase the risk of graft thrombosis, since the anastomotic technique is complex and difficult because of the thin and fragile wall of the vein graft. We can simply use the YVG to avoid such a complicated procedure.

Free flaps can provide simultaneous revascularization and coverage, such as the latissimus dorsi flap, radial forearm flap, anterolateral thigh flap, etc. Utilization of the free flap pedicle to bridge the arterial gap has been widely discussed in the literature.[5-8] The thoracodorsal artery has a branch supplying the serratus anterior muscle. This branch can be used to reestablish the continuity of 1 of the major arteries in the distal leg, which constitutes the so-called interpositional anastomosis or flow-through technique. The same principle can be applied with the radial artery and descending branch of the lateral circumflex femoral artery. They can serve as a conduit to restore the circulation of the distal leg and/or another free flap. These designs are thought to be useful methods for difficult reconstructions of the lower extremities. However, they are practically limited and are indicated only in a few certain situations because of the restricted direction of the pedicle and flap axis, which limits the freedom in flap insetting. In addition, the distal end or the branch of the pedicle used for reestablishing the distal circulation is usually too small in comparison to the major arteries of the lower leg. If a prominent size discrepancy exists, a vein graft should be used instead of this method.

A Y-shaped microvascular anastomosis is an end-to-end anastomosis between 3 ends: 2 small ones on 1 side and a larger vessel on the opposite site. The blood flow can go through the anastomosis in both directions. It is a useful method to restore the arterial inflow of the distal leg and to simultaneously revascularize the transferred free flap.[9,10] However, it is a quite-difficult technique and is not recommended except for someone who is familiar with it.

A cross-leg flap, either pedicled or free, offers the possibility of limb salvage which is otherwise nonreconstructable.[11,12] It allows well-vascularized tissue supplied by the contralateral leg to cover the defect of the involved limb. However, prolonged cross-leg fixation results in many unwanted complications such as joint stiffness, pressure sores, and deep vein thrombosis. Furthermore, almost all patients feel very uncomfortable during the period of cross-leg fixation. Thus, this method is not suggested until all other options have failed to achieve reconstruction. It can be a lifeboat for limb salvage when no suitable recipient vessel exists in the neighboring regions of the defect.

Y-shaped vein grafting is another option to create an additional recipient artery for free flap revascularization and maintain an adequate blood supply to the distal part of the limb at the same time. It means using an interpositional vein graft to bridge a separated artery and simultaneously including a branch within the vein graft to provide another source of blood flow. Of course, the branched flow

must be confirmed to pass without any obstruction in the drain-out direction. Utmost care must be taken to design the YVG since most of the branches joining the main trunk of the superficial venous system are drain-in forms (Fig. 4A, B). Such trifurcation cannot fit our requirement because the venous valves inside the branch will interrupt the arterial flow due to an incorrect flow direction (Fig. 4C). On the contrary, a drain-out trifurcation is the ideal YVG to provide an additional arterial source for supplying a transferred flap (Fig. 4D).

The design and harvest of the YVG are very important, but not difficult. After the lower extremity is placed in a dependent position for a while, the venous branches and communications with the saphenous system are outlined. The possible trifurcations are marked out and then a skin incision is made along the main trunk distribution. Harvesting a YVG is similar to dissecting a traditional vein graft except for the inclusion of all branches and leaving them as long as possible. Before taking the vein graft off, a practical method is applied to screen which branches allow the blood to flow out. Branches which may serve as a YVG are cleared by filling the lumen with a heparinized solution from the distal end to engorge the entire harvested segment (Fig. 5). After gently filling it up, a well-engorged branch means that either it is a drain-out from trifurcation or there is no valve inside.

Utilization of a YVG to provide an additional recipient arterial source has many advantages. (1) It is a simple operative technique which is the same as the standard interpositional vein grafting. End-to-end vascular anastomosis is the only requirement of this microsurgical technique. Thus one can achieve these difficult reconstructions without special microsurgical skills. (2) A graft is easily accessible; a YVG can be found easily in the lower leg and dorsal foot.[3,4] The superficial venous system in the dorsal hand is also available. Its harvest is just like harvesting an interposition vein graft except that the branches should be left as long as possible. (3) There is freedom in the flap inset; the additional recipient artery provided by the YVG is always in the reconstructive area. This makes design of the flap easier, since a longer pedicle is not necessary and there is no axial limitation. Any kind of free tissue is available as long as it can be harvested smoothly and fits the requirement of reconstruction. The 2 outflow stems of the YVG can be harvested in different lengths to fit the various conditions in practical use. (4) There

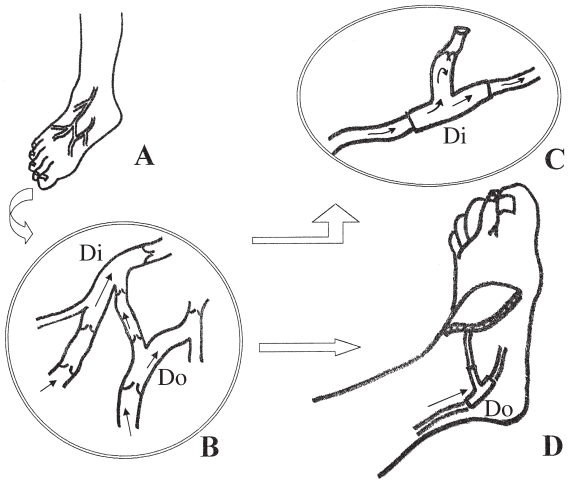

Fig. 4 (A) Superficial venous netowrk of dorsal foot. (B) Illustration of venous valves and the direction of blood flow (arrows). Di: drain-in form trifurcation, Do: drain-out form trifurcation; (C) Drain-in form trifurcation is not suitable to serve as the Y-shaped vein fraft. Venous valves inside the branch may interrupt the blood flow; (D) Drain-out form trifurcation can be an ideal Y-shaped vein graft to maintain the circulation of distal foot and supply a transferred flap simultaneously.

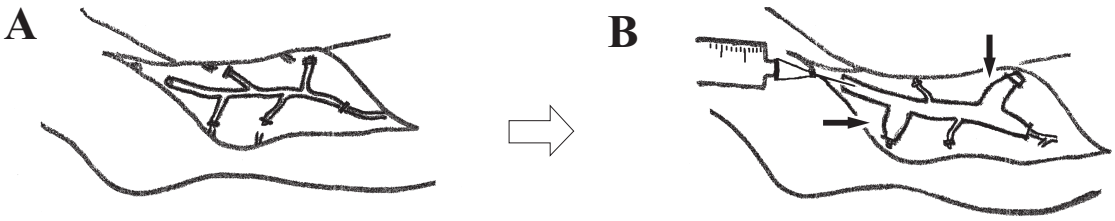

Fig. 5 (A) Harvesting the vein graft with leaving all branches as long as possible; (B) Filling the lumen with the heparinized solution from the distal end to engorge the whole harvested segment, only the dilated branches (arrow heads) could serve as ideal Y-shaped vein grafts.

is improved distal circulation. Simultaneously, the YVG bridges the continuity of the artery to restore the blood inflow to the distal ischemic part after traumatic injury. The distal blood supply is sufficient and reliable in spite of a branched flow created at the same time. This not only provides an adequate recipient artery for free flap transfer, but also acts like a bypass graft to displace the constricted segment and improve the distal circulation. Lorenzetti et al. revealed that after creating a branched flow from a previous pedal bypass graft to a free muscle flap, the remaining blood flow to the distal part of the bypass graft increases, rather than decreases with time.[15] Shestak et al. demonstrated that a successful free muscle transfer to an ischemic leg could improve the entire distal circulation.[16] In fact, any kind of flap can function as a "nutrient flap" when it is long enough to bridge the zone of injury. Therefore, it is not an absolute but a good indication to perform microsurgical reconstruction with Y-shaped vein grafting in an ischemic leg.

However there are several disadvantages of Y-shaped vein grafting as follows. (1) A vein graft should be placed in an antidromic position, since there are valves in even small tributaries. These valves will not influence arterial flow if they are put in the correct direction. The branches of the vein graft are usually the drain-in form, and the valves may resist blood flowing out. As illustrated in Fig. 4, only the drain-out form branches can serve as an adequate YVG to provide 2 constant arterial flows. Thus one has to pay much attention to the selection of vein grafts for the branching configuration; otherwise, a dysfunctional YVG may result. (2) The vein graft is usually put inside the injured zone, and an anastomosis is performed nearby. A poor vascular bed and an infected wound may cause some risk of graft thrombosis. (3) The integrity of the utilized artery is disrupted. The blood supply to the distal part can be compromised because of vascular complications after microsurgery.[15] This may lead to cyanotic or even gangrenous changes of the distal leg. Although the incidence is low, the risk of an ischemic leg and the possibility of amputation above the reconstructed level must be well explained to the patient and family. (4) An increase in the number of anastomoses is time consuming and tedious.

With appropriate flap planning and a good surgical technique, the need for interposition vein grafting should be quite infrequent and hopefully avoided because it is associated with a high complication rate.[17] However, when necessary, the vein graft remains the gold standard. One should use the vein graft with special care to provide a high degree of reliability by avoiding size mismatches and long vein grafts.[18] In our experience, 1 to 3 cm in each limb of the YVG is the most practical length. Being too short will increase the difficulty of the micro-anastomosis. Being too long can be redundant and unnecessary.

Since adequate planning to avoid a vein graft as far as is possible is 1 of the general principles of selecting a recipient artery,[19,20] Y-shaped vein grafting is suggested to serve as a back-up procedure instead of the first line choice. We did not originally plan to utilize the YVG for the cases described in this article. Efforts were made to look for a less-important artery as the recipient but in vain. When the only major artery is decided upon, end-to-side anastomosis is our first choice because we are familiar with it. However, because of the damaged appearance, small caliber, and atherosclerotic change, we ultimately modified our plans. A small-caliber recipient artery, especially when it is smaller than the pedicle artery, is a relative contraindication for performing end-to-side arterial anastomosis. It may increase the risk of anastomotic site thrombosis. In this situation, utilization of a YVG becomes the best choice. In our experience, end-to-end anastomosis to an artery with severe atherosclerotic change is relatively easy and safe in comparison with the end-to-side method. In addition, we found that the PTA is usually placed in tension when lengthening the Achilles tendon and releasing the contracture deformity of the ankle. Y-shaped vein grafting is also superior to the end-to-side arterial anastomosis in this condition because the former may elongate the PTA and provide a tension-free microvascular anastomosis.

In conclusion, Y-shaped vein grafting can be applied to 2 kinds of selected patients. (1) The first are cases with compromised distal circulation of a lower extremity and simultaneous necessity of free tissue transfer for reconstruction. Compromised circulation means 1 or 2 major arteries of the lower leg have been severed or obstructed. Sacrifice of any residual major artery has the potential risk of damaging the distal circulation. In general, an end-to-side

arterial anastomosis can be the first choice in this situation. However, if the selected artery is small in size or atherosclerotic change of the vessel wall is present, end-to-side arterial anastomosis becomes relatively difficult and has a higher potential risk of vascular complications. Therefore, Y-shaped vein grafting serves as the best choice at that time. (2) Second are traumatic patients in whom revascularization of the distal ischemic part of the lower leg and simultaneous free flap reconstruction are essential. The YVG not only can serve as an interposition conduit to bridge the arterial gap but also can provide an additional recipient artery for a microsurgical free flap to facilitate revascularization at the same time. Furthermore, Y-shaped vein grafting can be a backup procedure in an urgent situation of re-exploration in which reestablishment of circulation should be maintained as soon as possible to rescue both the transferred flap and distal leg.

Conclusions

Y-shaped vein grafting restores both arterial inflow of a distal part of a limb and simultaneously revascularizes the transferred free tissue. It is a reliable and useful procedure when performed carefully.

We conclude that utilization of a YVG to provide an additional recipient artery is a good alternative choice for end-to-side arterial anastomosis to achieve successful reconstruction of a lower extremity in selected cases.

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利用分流式Y形脈移植提供游離皮瓣之動脈血流以完成困難的下肢重建

曹中侃 陳宏基 陳煥棠 O. Koray Coskunfirat

背 景： 要重建血液循環不良的遠端肢體對外科醫師而言，是一項困難的挑戰；尤其是需要做顯微游離組織移植時。我們會遭遇到的一種情形是，除了一條供應遠端循環的主要動脈之外，沒有其他合適的接受區動脈可資運用。爲了克服這種困難，而在不影響遠端的血液循環之下完成游離皮瓣之移植，我們嘗試運用Y形靜脈移植來解決問題。

方 法： 我們報告了三位使用Y形靜脈移植而成功的達成下肢重建的病例。Y形靜脈移植提供游離皮瓣動脈血流的同時，也保留了下肢遠端的循環。文中詳細論述了治療目的、手術方式、設計以及結果。並且針對適應症以及優缺點加以討論。

結 果： 三位病例均成功的達成下肢重建的目的。運用Y形靜脈移植並不需要特殊的顯微手術技巧。所提供的接受區動脈是既可靠又實用，可符合各種顯微移植組織的重建需要。由於只有分流型的靜脈分支才能達到將動脈分流的目的，所以在取下Y形靜脈移植前，必需仔細確認血流的方向。

結 論： 我們的結論是在一些血管問題特殊的情形下，要達成以自由游離皮瓣重建遠端下肢的目的，使用Y形靜脈移植是一個很好的解決方法。

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關鍵字： Y形靜脈移植，游離皮瓣，血流重建，肢體重建。

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