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EDITORIAL

Distally based perforator sural flaps for foot and ankle reconstruction

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Abstract

Distally based perforator sural flaps from the posterolateral or posteromedial lower leg aspect are initially a neurofasciocutaneous flap that can be transferred reversely to the foot and ankle region with no need to harvest and sacrifice the deep major artery. These flaps are supplied by a perforating artery issued from the deep peroneal artery or the posterior tibial artery, and the chain-linked adipofascial neurovascular axis around the sural/saphenous nerve. It is a versatile and reliable technique for soft-tissue reconstruction of the heel and ankle region with 180-degrees rotation. In this paper, we present its developing history, vascular basis, surgical techniques including flap design and elevation, flap variations in pedicle and component, surgical indications, and illustrative case reports with different perforating vessels as pivot points for foot and ankle coverage.

Key words: Fasciocutaneous flap; Distally based flap; Foot and ankle; Perforator flap; Neurocutaneous flap; Sural flap; Propeller flap

Core tip: Distally based perforator sural flaps are perfused by a perforating artery issued from the deep peroneal or posterior tibial artery, and the longitudinal chain-linked adipofascial neurovascular axis around the sural/saphenous nerve. It is a versatile and reliable rapid procedure for soft-tissue reconstruction of the heel and ankle region with 180-degrees rotation. This paper presents the developing history, vascular basis, surgical techniques including flap design and elevation, flap variations in pedicle and component, surgical indications, and illustrative case reports with different perforating vessels as pivot points for foot and ankle coverage.

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INTRODUCTION

Reconstruction of the foot and ankle wounds, especially when complicated with deep vital structures such as bone, joint, nerves or tendon are exposed, remains a challenging problem for the treating surgeon. The foot with the features of weight bearing requirement, the lack of intervening muscle between the skeleton and the skin, and the limited movement of the overlying skin, make the soft-tissue coverage even more difficult[1]. In general, there are several methods of surgical procedures, including vascular-pedicled loco-regional transposition and microsurgical free transfer of muscle or myocutaneous flaps, and fascial or fasciocutaneous flaps. Each procedure has its own merits and drawbacks on indications, technical requirement, flap size, range of vascular pedicle, and limitations of patient's local and general conditions[2].

Besides free flaps with microsurgical vascular anastomosis, there are other options using pedicled vascular flaps from the ipsilateral uninjured lower leg with a distal-base, which had been developed and consequently modified in the past two decades[3]. Currently, those reverse-transferred flaps can be categorized into three patterns[4]: (1) The reverse-flow island flaps, such as the reversed anterior tibial artery flap, the posterior tibial artery flap, and the peroneal artery flap; (2) The distally perforator-based flaps, which avoid the sacrifice of the main deep arteries, such as the lateral and medial supra-malleolar flap; and (3) The distally based neuro-veno-fasciocutaneous flaps that are supplied by the chain-linked longitudinal directed vascular plexuses from a wide neuro-veno-adipofascial pedicle. These three loco-regional kinds of flaps can be elevated easily and substituted for microsurgical free flaps for foot and ankle reconstructions in some conditions.

HISTORIC PERSPECTIVE

The concept of fasciocutaneous flaps was first introduced by Ponten *et al*[5] in 1981 for lower leg soft-tissue reconstruction. The first distally based lateral sural fasciocutaneous flap was described by Donski *et al*[6] in 1983 for Achilles tendon coverage. The flap was supplied by a septocutaneous vessel issued from the peroneal artery that located in the postero-lateral septum of the lower leg and about 10cm above the lateral malleolus. In 1986 Amarante *et al*[7] reported a similar medial sural flap supplied by a perforator from the posterior tibial artery that located in the postero-medial septum of the lower leg. In 1988 Masquelet *et al*[8] introduced the lateral supramalleolar flap that perfused by the anterior perforator of the peroneal artery located at 5 cm above the lateral malleolus. In 1992 Masquelet *et al*[9] proposed the concept of neurocutaneous flap, and described the distally based sural neurocutaneous flap for reconstructing the distal third leg, foot and ankle defects. This flap is nourished by the lower-most septocutaneous perforator from the peroneal vessel, usually located 5 cm (4-7 cm) above the lateral malleolus as demonstrated by Hasegawa *et al*[10] in 1994, and the longitudinally disposed chain-linked adipofascial plexuses as well as the neuro-vascular axis around the sensitive sural nerve. In 1996 Chang[11] pointed out that in essence, neurocutaneous flaps in the limbs was a specific example of fasciocutaneous flaps, as it was basically fasciocutaneous in flap component but strengthened in blood supply by longitudinally disposed perineural vascular plexus. These flaps also called neurofasciocutaneous flaps[11]. In 1999 Nakajima *et al*[12] notified the accompanying vessels of the lesser saphenous vein and sural nerve, and proposed the term of veno-fasciocutaneous flap and neurovenofasciocutaneous flap. In 2003 Chang *et al*[13,14] demonstrated in experimental studies that cutaneous large superficial veins in distally-based flaps played a negative role and suggested ligate these big cutaneous veins (great/lesser saphenous vein) to prevent flap ingress. In 2004, Chang *et al*[15] converted the flap pedicle from wide adipofascial to septum perforator, making it easy for 180-degrees rotation. In 2007 Chang *et al*[16] described a new vascular basis of the sural neurocutaneous flap, which is supplied by the lateral retromalleolar perforator of the peroneal artery usually located 1 cm above lateral malleolus. To reduce the postoperative flap congestion, Chang *et al*[17] further modified a technique in 2014 with perforator-plus-adipofascial pedicle for sural propeller flaps.

VASCULAR ANATOMIC CONSIDERATIONS

The fasciocutaneous vascularization of the lower leg is mainly provided by septocutaneous perforators, sometimes supplemented by musculocutaneous perforators and strengthened by the neuro-veno-cutaneous plexuses[18-22].

Vascular anatomic studies have shown that there 2 longitudinal rows of perforators in the distal sural region. The medial row was issued from the posterior tibial artery, located between the tibia and the Achilles tendon. The lateral row was originated from the peroneal artery, located between the fibula and the Achilles tendon. As a general rule, perforators can be found above the medial or lateral malleollar tip approximately at (1) 2 cm (which is termed the retro-malleolar space perforator); (2) 5 cm (which is termed the distal-most septocutaneous perforator); and (3) 10 cm (the middle septocutaneous perforator), respectively (Figure 1). These perforators form a three-dimensional vascular architecture. There are prominent longitudinal axiality of the vasculature in different tissue layers, including fascial, paraneural and perivenous vascular plexuses[23-25].

Anatomic study also showed the possibility to

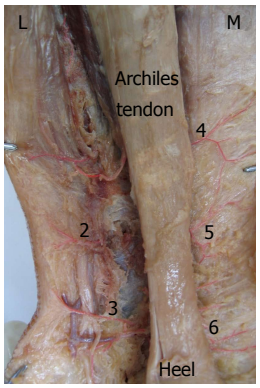

Figure 1 Two rows of perforators are distributed in the posterior lower leg sural region, originating from the peroneal artery (1, 2, and 3) in the posterolateral aspect and the posterior tibial artery (4, 5, and 6) in the posteromedial aspect, respectively. Note the lateral peroneal artery perforators are developed more robust than that of the medial posterior tibial artery.

harvest muscles with the sural flap. The gastrocnemius muscle-tendon junction was located at the mid-point (1/2) of the lower leg. The sural nerve was found passing through the deep fascia from the inter-gastrocnemius muscle groove to the superficially subcutaneous tissue at the junction of upper-middle third (1/3). Therefore, a midline "groove muscle cuff" around the inter gastrocnemius sural nerve "mesentery" would be included to form a fasciomyocutaneous flap to cure osteomyelitis and/or filling dead space[26,27]. There was a 4 cm overlapping length (range 3 to 5 cm) between the lateral gastrocnemius muscle belly and the deep fascia foramen where the sural nerve went from the subfascial to the suprafascial. In its suprafascial route, the sural neurovascular axis gave off at least 1 branch, *i.e.*, the musculo-fascio-cutaneous perforator, reversely to the lateral gastrocnemius muscle, and usually 2 branches, reversely to the medial muscle. The diameter of these perforators was smaller than 0.5 mm (range 0.2 to 0.5 mm)[28]. These findings provide the anatomic basis for harvesting distally based sural neuro-fasciomyocutaneous flap with the distal portion of gastrocnemius muscle. The vascular supply for the attached gastrocnemius muscle fragment beneath the deep fascia, was assumed reversely from the superficial neuroadipofascial vascular axis, which was perfused by the distal perforator of the peroneal artery[28].

Venous drainage in distally based flaps is usually a special concern in hemodynamic physiology because the venous blood of the flap must reversely return to its distal pedicle against venous valves. Venous problems are one of the major reasons for flap complications and failures. Chang *et al*[13,14,29,30] proposed that the lesser saphenous vein in distally based sural flap have no positive role for venous drainage, but conduct the venous blood from the foot to ingress the flap to cause venous overloaded, which is hazardous for flap survival. Large superficial veins should be interrupted and ligated distal to the pivot point of the flap to prevent flap congestion and swelling. Other methods to relieve venous load include venous anastomosis by microsurgical technique and leech therapy.

SURGICAL TECHNIQUE

Flap design

In designing a surgical flap, five key points should be considered: (1) pivot point, the flap is rotated around this point, which is usually the axial vascular perforator issued from the deep main vascular stem; (2) axial line, the flap is designed along this line, which is the direction of vascularization of the flap; (3) flap area, which is the size of the flap according to the defect; (4) dissection plane, which is the surface that the flap was elevated; and (5) rotation arc, which indicates the most distal point that the flap can reach by rotation.

A longitudinal line roughly represents the course of the posterior tibial artery (or peroneal artery) is drawn from the mid-point of popliteal fossa to the mid-point between Achilles tendon and medial malleolus (or lateral malleolus) in the leg. This also represents the course of the posterior branch of the saphenous nerve in the postero-medial aspect, or the superficial sural nerve and the lesser saphenous vein in the postero-lateral aspect of the lower leg, respectively. All distal-based perforator flaps are centered on either of these two lines. The required skin paddle is then outlined reversely on the lower leg, according to location and the size of the tissue defect.

Flap elevation

Under continuous epidural anesthesia or intratracheal intubational general anethesia, the patient was placed in the prone (for heel coverage), supine (for medial ankle coverage), or lateral position (for lateral ankle coverage). A thigh pneumatic tourniquet was used and the leg is exanguinated by elevation and hand compression for 1-2 min. This maneuver allows emptying of most of the blood from the leg but retains enough in the perforating vessels to allowing for easier identification during operative exploration. After debridement of the defect, a sharp long exploratory incision (5-7 cm in length) along its posterior margin (Achilles side), is firstly made, straightly down to the deep fascia from the wound to the distal part of the flap. Temporary anchoring stitches should be used to secure the deep fascia with the skin paddle. Then the flap is elevated forward from the sub-fascial level (the surgical plane) to the septum to search the perforator. After a proper perforator is identified, the flap design is re-evaluated and adjusted, according to the exact location of the perforator. If the perforator showed nice (for example, 1 mm in diameter, at least 2 cm in length, and closer companion of the perforating artery and partner veins, and observed pulsation after pneumatic release), we recommended skeletonize the perforating vessels to achieve free-restrict rotation. If

Figure 2 Distally based fasciocutaneous island flap for lateral malleolus coverage. A: Pressure ulcer over the lateral malleolus in a 60-year-old male patient; B: Harvest of distally based fasciocutaneous island flap from the lateral sural region with a wide adipofascial pedicle; C: Flap inset to the recipient with tension-free; D: Final complete survival.

Table 1 Variations of distally based lateral sural flap

Vascular perforator
Middle septocutaneou perforator, located approximately 10 cm above malleolus
Lowermost septocutaneous perforator, located approximately 5 cm above malleolus
Retromalleolar perforator, located approximately 2 cm above malleolus
Pedicle component
Fasciocutaneous pedicle (full-thickness, peninsular)
Adipofascial pedicle (without overlying skin bridge, island)
Neurofasciocutaneous, neurovenofasciocutaneous
Perforator with septum intact
Perforator-plus-adipofascial
Perforator with septum dissection (perforator skeletonized)
Flap constituent
Fasciocutaneous flap
Neurofasciocutaneous, neurovenofasciocutaneous flap
Adipofascial flap
Fasciomyocutaneous flap (including a fragment of gastrocnemius muscle)

the perforator was not so nice, then a perforator-plus-adipofascial pedicle was preferred. Usually, at least a quarter (1/4) of adipofascial tissue was preserved in intact around the perforator. No further intra-septal dissection of the perforator was performed. Then the flap dissection proceeded from the sub-fascial plane in the proximal-to-distal direction, until the distal perforating vessel is reached. No attempts were made to sparing the superficial cutaneous nerves if they are located in flap dimension. The flap was rotated 180 degrees to reach the recipient foot or heel and inset with tension-free. No venous anastomosis was performed for super-drainage. The sural nerves in the flaps were harvested more proximally to get extra 2 to 3 cm, and coated the proximal cut end of sural nerve to a recipient nerve (saphenous nerve or superficial peroneal nerve) in end-to-side fashion or calcaneal branch from the medial plantar nerve in side-to-side fashion to restore the flap sensation. The donor areas can be covered by split-thickness skin grafts, or directly closed provided its width is less than 5 cm.

For foot and calcaneus coverage, an anterior supportive plaster of Paris or splint was used postoperatively for immobilization for 2 wk. After plaster was removed, the patients started an active and passive physical rehabilitation program to get maximum range of ankle motion.

FLAP VARIATIONS

Many different modifications of the sural flaps have been made based on its vascular pedicle and flap components[31,32]. Table 1 summarizes those different types of flap variations.

SURGICAL INDICATIONS

The distally based sural fasciocutaneous flaps can generally be rotated to cover any soft-tissue defect of

Figure 3 Distally based turnover adipofascial flap for calcaneal wound coverage. A: Preoperative appearance of lateral calcaneal sinus; B: Distally based adipofascial flap harvest from the lateral sural region; C: The flap was turned 180-degrees over to fill the calcaneus cavity; D: Skin graft over the adipofascial flap; E: Appearance of postoperative 3 mo; F: Successful subtarlar joint fusion.

the foot and ankle region, usually small to medium-sized defect (about 10 cm in length). In practice, it usually restricts to the middle of the foot.

Distally based adipofascial flap can be transferred by turn-over mode to provide thin and subtle coverage for exposed tendons and bone on the dorsum of the foot. The adipofascial flap is then covered with skin graft primarily or secondarily.

Distally based fasciomyocutaneous flap can provide a bulk and high metabolic viable muscle component for repairs of the soft tissue defects complicated with osteomyelitis, deep dead space and for plantar heel pad reconstruction, which need thickness.

CASE PRESENTATIONS

Case 1: Fasciocutaneous island flap

A 60-year-old paraplegic male suffered a pressure ulcer over the lateral malleolus of his left leg for 6 mo. After debridement, the wound was measured 4 cm × 3 cm in size with bone exposure. A distally based fasciocutaneous island flap from the lateral sural region was used to solve the problem. The skin paddle measured 5 cm × 4 cm in size, supplied by a 3 cm wide and 4 cm long adipofascial pedicle. The flap was rotated to the defect and inset with tension free. The donor site was closed directly. The flap survived completely, and the wound was cured successfully (Figure 2).

Case 2: Turnover adipofascial flap

A 62-year-old woman suffered calcaneus fracture of her right foot. After open reduction and plate fixation through lateral extended L-shaped incision, the wound became infected. One-year later, she was referred to us with chronic calcaneal osteomyelitis and a skin sinus. The problem was solved in three stages. In the first stage, the implant was removed and complete

Figure 4 Perforator-plus fasciocutaneous flap for medial malleolar coverage. A: Delayed wound infection after open pilon fracture; B: First stage management, debridement and vacuum-sealing-drainage; C: Perforator-plus fasciocutaneous flap harvest from the posteromedial sural region; D: Flap transfer and inset; E: Complete flap survival in two weeks.

debridement was performed, followed with a vacuum-sealing-drainage (VSD) for 1 wk. In the second stage, as the wound was clean, an adipofascial turnover flap was designed on the posterolateral aspect of the lower leg to eradicate the dead space. The flap was based on the lateral retromalleolar perforators, the pivot point was located 2 cm above the lateral malleolus, and the flap measured 13 cm × 5 cm. The flap was turned over 180-degrees to fill the cavity of the calcaneus. In the third stage, the adipofascial flap was covered with split-skin grafts, and the subtalar joint was fused with 2 screws. The patient was followed up 3 mo. The wound was cured successfully, and she was able to walk independently (Figure 3).

Case 3: Perforator-plus fasciocutaneous flap

A 52-year-old man suffered an open pilon fracture of his right leg. After open reduction and internal fixation, the medial wound developed a delayed infection 3 mo later. The wound was first debridement and supplemented with VSD management. One week later, a distally based medial sural fasciocutaneous flap was designed to cover the defect. The flap was pivoted on the septocutaneous perforator located 10 cm above the medial malleolus, with a quarter of adipofascial to protect the perforator. The skin island measured 5 cm × 3 cm with a narrow skin bridge over the adipofascial pedicle. The flap was rotated 180-degrees to reach the recipient site, and inset with tension-free. The donor site was closed directly. Both the flap and donor site healed without complications (Figure 4).

Case 4: Perforator skeletonized propeller fasciocutaneous flap

A 60-year-old female suffered an open pilon fracture of her left leg. After plate fixation, the skin over the plate

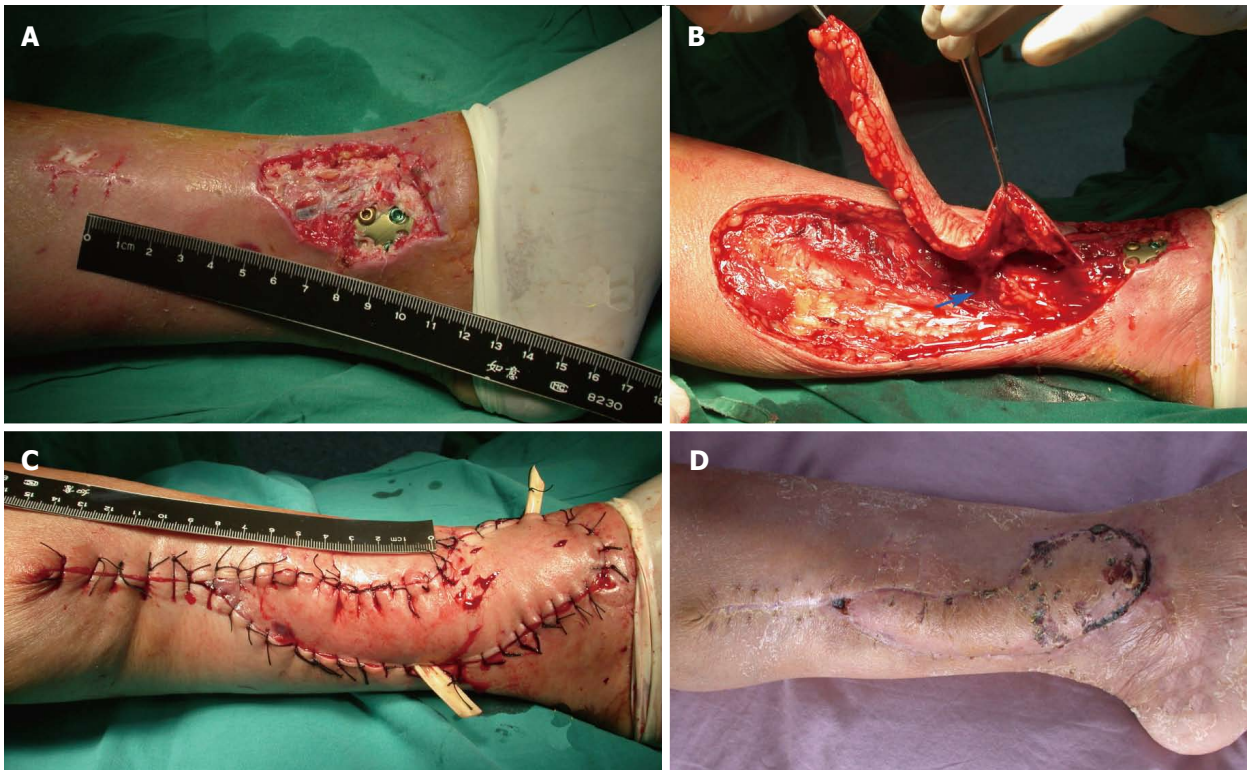

Figure 5 Perforator pedicled propeller flap for pilon wound coverage. A: Plate exposure in a 60-year-old woman with open pilon fracture; B: Posterior tibial artery perforator pedicled fasciocutaneous flap was raised, the perforator was skeletonized; C: The flap was propelled 180-degrees to the recipient site; D: Flap survival, with minor superficial marginal necrosis.

was necrotized, leaving a 5 cm × 4 cm wound with plate exposure. A medial sural island fasciocutaneous flap, nourished by a posterior tibial artery perforator (Φ1.0 mm with 2 partner veins) located 9 cm above the medial malleolus. The flap was designed as propeller flap, with large blade 10 cm × 4 cm, and small blade 4 cm × 2 cm. The flap was rotated 180-degrees to reach the wound. Both the donor and recipient sites were sutured primarily. Postoperatively, the flap showed venous congestion and swelling. This was managed with multiple small incisions over the flap to let blood out. The flap survived completely after two weeks (Figure 5).

DISCUSSION

Coverage of soft-tissue defects of the foot is a challenging procedure in trauma and reconstructive surgery. The options lie in vascular pedicled flaps and microsurgical free flaps.

Since the introduction of fasciocutaneous, neurocutaneous, and perforator flaps in the lower leg, the vascularization of the calf and sural region has been extensively investigated. Anatomic studies have shown that the superficial sural artery from the popliteal, the septocutaneous perforators from posterior tibial artery (medial side) and peroneal artery (lateral side), and myocutaneous perforators from gastrocnemius and soleus, form a three-dimensional vascular architecture with prominent longitudinal orientation in the posterior lower leg[28]. There are 4 to 5 axial communications between this longitudinal neuro-veno-adipofascial plexus and the posterolateral/posteromedial septocutaneous perforators issued from the peroneal artery/posterior tibial artery, respectively. The distal perforators, in particular, can be used effectively for coverage of defects of the heel, malleolus, Achilles tendon, and distal third of the tibia[33].

Island flap pedicled with a single perforator, also called pedicled perforator flap, island perforator flap, local perforator flap, or perforator pedicled propeller flap, has the greatest freedom of rotation, which can reach up to 180 degrees[34]. In recent years, there was a great increasing use of perforator-based propeller flaps in limb reconstruction, especially for the lower leg and foot, with a distal rotation[35,36]. These flaps combine the advantages of pedicled local flaps (good color and texture match), pedicled regional flaps (up to 180 degrees arc of rotation), pedicled distant flap (larger flap size and vascular reliable), and without microsurgical vascular anastomosis. Furthermore, for most small to medium-sized defects (< 10 cm in length), it allows linear closure with direct suture of the donor site.

The distally based sural island flaps is a useful and versatile reconstructive option in patients with soft-tissue defects of the foot. The advantages include: (1) the ability to be transferred from a proximal donor site to

a distal recipient; (2) the avoidance of foot dependence; (3) the one-stage rapid procedure, which requires no microsurgical technique; and (4) it is supplied by a perforating artery and the chain-linked adipofascial vascular plexus, which is no need to harvest and sacrifice the deep major artery.

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