Surgical Technique

Repair of Forefoot Skin and Soft Tissue Defects Using a Lateral Tarsal Flap With a Reverse Dorsalis Pedis Artery Pedicle: A Retrospective Study of 11 Patients

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Abstract

Background Various authors have proposed flaps to reconstruct traumatic forefoot skin and soft tissue defects, especially with exposure of tendon and/or bone although which is best for particular circumstances is unclear.

Description of Technique The indications for the technique were a forefoot defect area of no more than 8-cm × 8-cm and a well-preserved lateral tarsal (LT) donor site. The injured tendons were repaired using tendon grafts. The free dorsalis pedis flap was outlined by centering it on the cutaneous branch of the LT artery and tailoring it to the size of the

wound, allowing 0.5-cm margins in length and width. The flap was rotated around the plantar perforating branch of the dorsalis pedis artery (DPA) to cover the forefoot defect. The lateral dorsalis pedis cutaneous nerve was anastomosed with the recipient plantar nerve stump. The donor site was covered with an inguinal, full-thickness skin graft.

Patients and Methods Traumatic forefoot skin and soft tissue defects with exposure of the tendon and/or bone involving 11 feet in 11 patients (mean age, 32 years) were covered using a LT flap with a reversed DPA pedicle. Three patients with forefoot defects underwent emergency repair within 8 hours of injury, whereas eight patients required delayed repair. All patients were followed up for at least 6 months (mean, 13 months; range, 6–24 months).

Results All flaps survived uneventfully, except for two that had superficial marginal necrosis or severe venous insufficiency. All skin grafts covering the donor sites survived and all wounds healed. None of the patients had restricted standing or walking at followups. The two-point discrimination was 4 mm to 10 mm at 6 months postoperative. The mean hallux-metatarsophalangeal-interphalangeal scale score was 93 points (range, 87–98 points).

Conclusions Our observations suggest the LT flap with a reversed DPA pedicle is a reasonable option for repair of traumatic forefoot skin and soft tissue defects with exposure of tendon and/or bone but a well-preserved LT donor site and is associated with minimal morbidity.

Level of Evidence Level IV, therapeutic study. See Guidelines for Authors for a complete description of levels of evidence.

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Each author certifies that his or her institution approved the human protocol for this investigation, that all investigations were conducted in conformity with ethical principles of research, and that informed consent for participation in the study was obtained.

This study was performed at Union Hospital, Tongji Medical College, Huazhong University of Science and Technology, Wuhan, China.

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Introduction

The forefoot—defined as the portion of the foot distal to the tarsometatarsal joint—is a major weightbearing area when a

person is standing or walking [7]. Severe forefoot skin and soft tissue defects usually are complicated by exposure of and/or injury to tendons, bones, and nerves [17]. Forefoot amputation has an adverse effect on gait, as weightbearing is seriously disturbed [8]. Challenges in reconstructing forefoot defects include adequate skin and soft tissue coverage in the short term and restoration of foot motor and sensory functions in the long term [14]. The reconstruction quality and configuration of the forefoot also may have a long-term affect on shoe-wear, standing, and walking [20].

Multiple approaches are available to repair forefoot skin and soft tissue defects, including skin grafts [26], orthotopic flaps [21], and heterotopic tissue transfer [18]. The use of a full- or split-thickness skin graft can be attempted for repair of simple forefoot defects other than those with a poor underlying granular tissue bed. However, the reconstructed forefoot using skin grafts is prone to postreconstructive ulcer, hyperkeratosis, or hyperalgesia as the forefoot is the primary weightbearing portion [26]. Therefore, a thick skin flap that is able to withstand pressure from standing and walking is required for repair of forefoot skin and soft tissue defects with a condition such as exposure of tendons and bones. The use of a reverse dorsal metatarsal artery flap has been reported for reconstruction of the distal foot, including the great toe [1], however, this technique is at risk for flap failure in covering the forefoot defect as the first dorsal metatarsal artery frequently was injured in these patients [23]. A distally based medial plantar flap with a lateral plantar artery pedicle also has been used to cover the submetatarsal weightbearing zone [15], but its use is restricted owing to its small coverage size and possible damage to the intermetatarsal plantar vascular network [19]. Although a lateral supramalleolar flap can mimic the recipient site [4, 12], this flap has a high risk of necrosis after the transfer and the appearance of scarring after secondary healing frequently leads to patient dissatisfaction. These flaps usually are used to cover small distal forefoot defects [4]. In contrast, cross-leg flap transfers with microsurgical vascular anastomoses can provide coverage of large defects [11], but these flaps require immobilization of the lower limbs and seriously impair patients' quality of life [2]. A free flap, combined with vascular anastomosis, has an overstuffed appearance and impaired sensory return, and requires repeated secondary interventions to restore normal gait [22].

The best flap for repair of forefoot skin and soft tissue defects would provide the wound site with similar color, contour, and thickness. Furthermore, the transfer of such a flap would be less demanding than the other techniques and not require a secondary correction. A lateral tarsal (LT) flap reportedly has good contour, elasticity, and durability similar to the recipient site and thus is a reasonable option for treating traumatic forefoot skin and soft tissue defects or operative wounds [13]. We modified this technique by incorporating a reverse dorsalis pedis artery (DPA) pedicle

instead of the previously reported reversed LT artery pedicle. This modification allowed for more flexible flap rotation for repair of the forefoot skin and soft tissue defects with exposure of tendon and/or bone.

Surgical Technique

The indications for this flap were: (1) the forefoot defect area was no more than 8 cm × 8 cm; (2) the LT donor sited remained well preserved; (3) no local neurocutaneous flaps were available for coverage of the forefoot defect; and (4) preoperative Doppler ultrasonography identified a normal LT artery and DPA. The contraindications were: (1) the patient had a known history of diabetes mellitus or peripheral vasculopathy; (2) the donor site was concomitantly injured; or (3) the LT artery or the DPA showed an abnormal anatomy on Doppler ultrasonography.

One of us (SY) performed all surgeries. Débridement was completed with the patient receiving spinal anesthesia combined with continuous epidural anesthesia. The injured tendons were fixed or repaired using tendon grafts. The LT artery and its perforating branches and the anterior and posterior tibial arteries were orientated and localized using Doppler ultrasonography before flap harvest. The LT flap was outlined centering on the perforating point of the LT artery cutaneous branch, namely, the midpoint between the lateral ankle and the fibular side of the fifth metatarsal head, which was located lateral to the extensor digitorum brevis (EDB) and proximal to the cuboid tubercle (Fig. 1A). The length (4.5–8.5 cm) and width (3.0–7.0 cm) of the flaps had 0.5- to 1.0-cm margins beyond those of the wound. An arch-shaped incision was made along the direction of the DPA to identify the starting point of the LT artery. The EDB was further mobilized to expose the LT artery. The larger-lumen LT artery was used if duplicate LT artery variation was encountered. The LT flap was dissected along the medial margin outward to the lateral margin of the EDB. The EDB subsequently was retracted upward and medially to expose the underlying LT artery and its cutaneous branches using a microscopic hemostat. The musculocutaneous and periosteal branches of the LT artery underlying the EDB were ligated to allow dissection of the LT artery up to its originating point from the DPA (Fig. 1B), with 0.5-cm tissue margins or the underlying periosteum, distally to proximally and vice versa. The EDB could be divided along the muscle fiber to fully expose the underlying musculocutaneous and periosteal branches; the aponeuroses of the third fibular muscle and short fibular muscle were well preserved. The flap was further dissected along the lateral, anterior, and posterior margins successively toward the perforating point of the LT artery cutaneous branch (Fig. 1C). The lateral dorsal pedal cutaneous nerve arising from the sural nerve was located

Fig. 1A–D (A) A schematic outline of the LT flap with a reversed DPA pedicle; (B) dissection of the lateral tarsal artery (LTA) up to its originating point from the DPA; (C) flap mobilization toward the perforating point of the LTA cutaneous branch; and (D) reverse rotation of the flap to cover the forefoot wound are shown. The anatomic landmarks include: 1 = DPA; 2 = LT artery; 3 = cutaneous branch of LT artery; 4 = medial tarsal artery; 5 = deep plantar artery; and 6 = first dorsal metatarsal artery.

between the superficial fascia and the deep fascia anterior to the external malleolus, and harvested through the posterior margin of the flap and for sensory restoration. The incision could be extended proximally to harvest a donor nerve of appropriate length. The LT flap, which contained the deep fascia, LT artery, and its cutaneous branches, was further mobilized from the periosteum at the starting point of the LT artery cutaneous branch. The DPA was dissected from proximally to distally until reaching the proximity to its plantar perforating branch. The proximal end of the DPA was temporarily interrupted using a vascular clip. The DPA was ligated at the point distal to the LT artery starting point if the flap and toes showed good circulation; the medial tarsal artery and the anterior lateral malleolar arteries were well protected in the ligation of the DPA to minimize interruption of the EDB blood supply. The LT flap with a reverse DPA pedicle was created and rotated under the EDB and the extensor digitorum longus to cover the forefoot defect (Fig. 1D). The main trunk of the lateral dorsal pedal cutaneous nerve was anastomosed with the stump of the first or second plantar digital nerve at the recipient site. The donor site was covered with an inguinal full-thickness skin graft and compressed with punctured pressure dressing. The mean operative time was 2 hours (range, 1.5–3 hours).

The injured feet were immobilized using plaster casts for 2 weeks after repair, and the ipsilateral lower limbs were elevated. Patients routinely were given intravenous papaverine, raceanisodamine, dextran, alprostadil, and oral aspirin, within the first postoperative week to minimize the occurrences of vascular crises.

Patients and Methods

We retrospectively reviewed 11 patients who were treated by the described flap for forefoot skin and soft tissue defects

between August 2007 and April 2009 (Table 1). During that time we treated a total of 25 patients with forefoot skin and soft tissues defects. The causes of the injuries were: motor vehicle accidents ($n = 4$), crushing by heavy objects ($n = 6$), and secondary to phalangeal internal fixation ($n = 1$). There were eight males and three females, 12 to 65 years of age (mean, 32 years). The sites of the wounds included the dorsal sides of the first metatarsophalangeal joint ($n = 4$), the toes ($n = 3$), and the distal metatarsal portions ($n = 4$). The wounds ranged in size from 4.0×2.5 cm to 8.0×5.5 cm and were complicated by the loss of forefoot skin and exposure of tendons and/or bones. The skin and soft tissue injuries were evaluated using the modified Oestern-Tscherne classification [16] and determined to be Grade III (open fracture with heavy contamination, extensive soft tissue damage, or associated arterial or neural injuries) or Grade IV (open fracture with incomplete or complete amputation) in all patients. Three patients with less complicated wounds and mild contamination underwent emergency repair within 8 hours of injury, whereas eight patients with massive tissue necrosis and contamination received wound dressing with vacuum-assisted coverage and underwent delayed repair 1 to 2 weeks after the injury. None of these patients had preexisting peripheral vascular disease on history taking, physical examination, or preoperative Doppler ultrasonography. All patients volunteered to provide informed consent in writing before enrollment in this study. Legal representatives were assigned by the patients to give informed consent in an emergency. No patients were lost to followup; all patients were followed up for at least 6 months (mean, 13 months; range, 6–24 months). No patients were recalled specifically for this study; all data were obtained from medical records. The study protocol was approved by the Institutional Review Board at Union Hospital, Tongji Medical College, Huazhong University of Science and Technology.

Table 1. Demographic and clinical data of patients

Patient number	Sex	Age (years)	Site of injury	Etiology of injury	Oestern-Tscherne classification	Repair	AOFAS score after repair
1	Male	32	First metatarso-phalangeal joint	Motor vehicle accident	Grade IV	Delayed	98
2	Female	27	Toes	Motor vehicle accident	Grade IV	Emergency	93
3	Male	48	Distal metatarsal portions	Phalangeal internal fixation	Grade III	Delayed	87
4	Male	42	First metatarso-phalangeal joint	Crushed by heavy object	Grade IV	Delayed	91
5	Male	22	Distal metatarsal portions	Motor vehicle accident	Grade IV	Emergency	94
6	Female	12	Toes	Crushed by heavy object	Grade III	Delayed	92
7	Male	25	First metatarso-phalangeal joint	Crushed by heavy object	Grade III	Delayed	93
8	Male	65	Distal metatarsal portions	Motor vehicle accident	Grade III	Delayed repair	91
9	Female	28	Distal metatarsal portions	Crushed by heavy object	Grade IV	Emergency	96
10	Male	21	Toes	Crushed by heavy object	Grade III	Delayed	91
11	Male	30	First metatarso-phalangeal joint	Crushed by heavy object	Grade IV	Delayed	94

AOFAS = American Orthopaedic Foot and Ankle Society.

These patients were followed every 3 months during the first postoperative year and every 6 months during the second postoperative year, respectively. Two of us (DF and SY) independently evaluated the feet on the basis of physical appearance of the skin flap, standing and walking of the repaired foot, footwear requirements, two-point discrimination of the skin flap, and the hallux-metatarsophalangeal-interphalangeal scale, established by the American Orthopaedic Foot and Ankle Society (AOFAS) [10]. This scale assessed pain components (40 points), functional components (45 points), and alignment components (15 points), for a total of 100 points. The potential complications were assessed using the Clavien-Dindo classification of surgical complications as described by Dindo et al. [5]. They defined complications as any deviation from the normal postoperative course and graded the severity of a complication from Grade I to Grade IV based on the impact on patients and the requirement of therapeutic intervention [5].

Results

All 11 flaps survived the transfer: nine patients had an uneventful postoperative course and the wounds healed by primary intention; two patients experienced postoperative complications (see below) and the wounds healed by secondary intention. The flaps appeared free of any wear or ulcer and similar to the surrounding skin in contour and color at followups. All the skin grafts covering the donor sites survived, and all wounds healed with minimal scarring. No wound infections or dehiscence occurred in any

patient. All patients were satisfied with the reconstruction outcome for the donor site and recipient site.

Patients were observed standing and walking normally by postoperative Days 7 to 10 if the flaps survived completely. The patients reported no discomfort or pain on standing or walking. However, two patients reported intermittent sensory disturbance in the lateral pedal dorsum, which resolved without specific intervention 1 year later. The two-point discrimination of the flap was similar to that of the contralateral site: 4 to 10 mm (mean, 6 mm) 6 months after repair and 3 to 8 mm (mean, 5 mm) 1 year after repair, respectively. Most patients experienced no activity limitation with the reconstructed foot, but some experienced occasional restrictions in recreational activities. Patients were able to wear conventional shoes. The metatarsophalangeal joints and interphalangeal joints showed normal motion or mild restriction; the joints had good stability in all directions. No patients had symptomatic calluses at last followup. The reconstructed forefoot showed good or fair alignment in all patients. Overall, the AOFAS scores for the hallux metatarsophalangeal-interphalangeal scale were 87 to 98 points (mean, 93 points).

Two vascular episodes occurred in two of the three flaps used for emergency repair. One flap showed a superficial marginal necrosis on postoperative Day 3, which was evaluated as a minor (Grade I) arterial insufficiency and was completely controlled by wound dressing. The other flap experienced a vascular crisis 4 hours after the transfer, which required a secondary surgical exploration. A few blood clots that compressed the subcutaneous vascular pedicle were identified on exploration, but the DPA pulse remained palpable; thus, this episode was determined to be severe (Grade III) venous insufficiency. The blood clots were completely

flushed with warm saline, and the incision was closed using relaxation sutures. These two flaps survived well after conservative treatment or surgical intervention, and the wounds healed by secondary intention afterward.

Cases

A 32-year-old man lost his left great toe after his foot was crushed. The soft tissue defect was complicated by the absence of the great toe phalanx (Fig. 2A). After débridement, a 7.0- × 6.5-cm wound located at the first

metatarsophalangeal joint was covered with a 7.5- × 7.0-cm LT flap with a reversed DPA pedicle (Fig. 2B). The flap survived the transfer and showed good perfusion (Fig. 2C). At 3 months, the donor site appeared normal (Fig. 2D).

A 42-year-old man lost his right great toe after a foot-crushing injury. Emergency débridement resulted in a 6.0- × 6.0-cm defect distal to the first metatarsophalangeal joint (Fig. 3A). The wound was covered with a 6.5- × 6.5-cm LT flap with a reversed DPA pedicle (Fig. 3B). The flap was well perfused after the transfer (Fig. 3C), but showed visible skin erosion at the 3-month postoperative visit, which required no specific medical intervention. The

Fig. 2A–D A 32-year-old man lost his left great toe after his foot was crushed. The photographs show (A) the preoperative appearance, (B) outlining of the skin flap, (C) the physical appearance of the recipient, and (D) donor sites 3 month after surgery.

Fig. 3A–D A 42-year-old man lost his right great toe after a foot-crushing injury. The photographs show (A) the preoperative appearance of the foot, (B) outlining of the skin flap (C) the physical appearance after surgery, and (D) the physical appearance 15 months after repair.

reconstructed forefoot had a normal physical appearance 15 months later without compromising the patient's ability to walk or stand (Fig. 3D).

Discussion

Repair of forefoot defects remain a major challenge in surgical practice, especially in terms of reconstructing forefoot appearance and function. Forefoot defects ideally are covered using pedicle flaps, and multiple flap designs have been described. However, previously reported techniques are subject to some limitations [1, 3, 4, 12, 15, 17–20, 25], such as an overstuffed appearance, restricted function, and they are less suitable for treatment of forefoot defects with complicating conditions. We therefore designed a new pedicled fasciocutaneous flap, namely, the LT flap incorporated with a reversed DPA pedicle. Furthermore, we asked whether this technique is clinically feasible, effective, and safe for reconstruction of forefoot skin and soft tissue defects with tendon and/or bone exposure.

We acknowledge three major limitations of this study. First, no control subjects were enrolled to undergo comparable repair using other techniques, but we compared our results against those in the literature. Second, the sample size is relatively small and not every patient underwent similar repair. Three patients were operated on emergently whereas eight had delayed reconstruction. However, the flap harvest and transfer were completed by the same surgical team led by one of the authors, and the followups were performed by two independent surgeons who were blinded to the timing of repairs. Third, the followup duration is relatively short (mean, 13 months) although it is longer than followups in previous reports [9, 25]. However, no late-onset complications were observed in patients followed up for 2 years. Additionally, all patients were seen at a yearly interval to identify any long-term complications.

Our observations show a LT flap with a reversed DPA pedicle is a reliable and effective technique for covering complex forefoot defects for the indications proposed. Flap survival is similar to that for previously reported flaps, such as the medial plantar [19, 20] and dorsal pedal neurocutaneous flaps [9, 25]. Medial plantar flaps reportedly are used to reconstruct the weightbearing forefoot [19, 20], but are less suitable for repair of traumatic injuries attributable to the frequent concomitant damage to the plantar artery in complex cases. Reverse dorsal pedal neurocutaneous flaps are reported to resurface the distal foot or forefoot defects with minimal recipient or donor complications [9, 25]. No major artery is sacrificed in this technique; however, the use of this flap, a local flap, requires a well-preserved donor site in proximity to the recipient site. Additionally, this flap has a restricted rotation range and frequently requires

delayed transfer or secondary revision [9, 25]. Therefore, this flap is less suitable for coverage of forefoot defects with complicating conditions. Otherwise this technique is subject to a high risk of flap failure or other complications [9, 25]. In contrast, the DPA pedicle used in our flap is anatomically constant and well perfused. The lengthened DPA plantar perforating branch, on which the flap is rotated, allows coverage of a distant wound, such as a forefoot defect [3, 9]. Moreover, this branch is less likely to be damaged in a forefoot injury, ensuring a reliable blood supply to the flap. However, it is the primary disadvantage of this technique that the DPA, a major artery nourishing the foot dorsum, is sacrificed to nourish the flap. The microsurgical dissection of the LT artery up to its originating point from the DPA will minimize the blood supply insufficiency of dorsal pedal skin and soft tissue [24].

The hallux metatarsophalangeal-interphalangeal scale is a critical measure for evaluating the repair of a forefoot or distal foot deformity [6]. Our AOFAS data suggest that forefoot function of the injured side is fully restored in all aspects and comparable to that of the contralateral side. The lateral dorsalis pedis cutaneous nerve contained in the LT flap is anastomosed with the stump of the first or second plantar digital nerve to reconstruct the sensation in the recipient site, showing a good two-point discrimination. In contrast to a dorsal pedal neurocutaneous flap, the LT flap has a donor site that is located in the hidden part of the body and bears no weight. Moreover, the donor site for the LT flap is located in a lateral pedal area that is less frequently subject to footwear or friction. As expected, the reconstructed forefoot is durable to footwear and shows no impairment when standing or walking. However, harvest of the lateral dorsal pedal cutaneous nerve for sensory reconstruction compromises skin sensation of the fourth and fifth toes and the lateral margin of the pedal dorsum [24]. A similar sensory disturbance, hyperesthesia or hypesthesia, also is observed in the donor sites for a dorsal pedal neurocutaneous flap owing to damage to the sensory nerve [9, 25]. These unwanted symptoms usually are mild and resolve spontaneously.

Two of our patients experienced vascular complications after emergency repair although both episodes were controlled without any clinically important sequelae. Emergency repair reportedly is associated with a higher risk of flap failure in the treatment of complex foot defects [3]. The primary contributing factor is thought to be the underestimation of vascular injuries in the process of exploration as the primary and secondary injuries may become worse after the repair. Delayed repair is believed to be much safer as the injury can be fully examined and the repair can be well prepared [9]. The major disadvantages associated with delayed repair include difficult dissection of a scarred wound site and increased medical burden. Although the reported complications resolved completely after appropriate management, delayed

repair is recommended for treatment of complex forefoot defects using our technique.

We found the LT flap with a reverse DPA pedicle is a reasonable treatment option for repairing forefoot skin and soft tissue defects. This flap can be used for coverage of small or medium traumatic defects with exposure of tendon and/or bone. The surgical morbidity of donor and recipient sites was low in well-selected cases. This modified technique also provides favorable aesthetic and functional outcomes in the long term. However, this flap may be associated with a risk of vascular crisis, especially in patients undergoing emergency repair. Cautious vascular preconditioning and delayed surgical intervention are likely to minimize the occurrence of pedicle complications.

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