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Original Article

Microsurgical free muscle flaps for reconstruction of post-traumatic complex tissue defects of foot

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ABSTRACT

Background: Crush injuries of the foot often result in complex tissue loss with exposed bones and tendons. These three-dimensional defects ideally require flexible well-perfused flaps to fill the space, afford resistance to infections, and to provide supple, durable weight- and pressure-bearing surfaces. Free muscle flaps with split thickness skin graft cover have been found to have several advantages in covering three-dimensional defects with exposed tendons and bones.

Methods: All patients with post-traumatic composite tissue defects of the foot exposing bones and tendons, who presented to a tertiary care center during a 40-month period, were reconstructed with free muscle flaps as the first option. Gracilis muscle flap was used for eight patients and latissimus dorsi muscle for two patients. Decision regarding the choice of muscle was based on the size of the defect. The patients were followed up for 1 year and observed for return to activity, ability to wear footwear, requirement of secondary procedures, and any other complications.

Results: Ten patients presented with composite post-traumatic tissue defects in the foot. All were male, with age ranging from 25 to 76 years. The defects ranged from 25 cm² to 225 cm². Free muscle transfer was successful in nine patients. Even though four required secondary flap contouring, all patients had normal weight-bearing ambulation and returned to their normal activities at 1-year follow-up.

Conclusion: Free muscle flaps merit consideration as primary reconstructive option for post-traumatic composite tissue defects of foot.

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Introduction

Foot injuries are common. The usual modes of injury are road traffic accidents, fall of heavy objects, crushing between

moving objects, and combat-related injuries like mine blasts. They often result in complex tissue loss requiring reconstruction aimed at restoring form and function. The stress and strain of weight bearing, ambulation, activities of daily living, and occupation have to be considered while planning

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reconstructive options for the foot. Adequate bulk, flexibility, and resilience for weight bearing are mandatory for tissues used for reconstruction of these defects. Three-dimensional defects in the foot resulting from composite tissue loss ideally require flexible well-perfused flaps, which fill the defect, afford resistance to infections, provide a smooth gliding surface to tendons, and afford supple, durable weight- and pressure-bearing surfaces. Microsurgical free muscle flaps with split thickness skin graft cover have been found to have several advantages in covering such defects.¹

Decision-making regarding the type of flap to be used is often influenced by institutional practices, facilities, and expertise. Microsurgical free muscle transfer requires higher levels of skills and facilities, and intensive monitoring compared to fasciocutaneous flaps. However, with more surgeons practicing reconstructive microsurgery, the application of this technique is becoming more popular. Skin-grafted muscle flaps are the first choice for post-traumatic defects of the foot and leg at many centers.² Modern protocols for limb salvage surgery in combat injuries have included early flap covers to limit the number and extent of amputations.^{3,4}

We report our experience of using free muscle flaps as the primary option in post-traumatic defects of the foot at a tertiary care center during a 40-month period.

Materials and methods

The study design was prospective interventional (case series). All patients who presented to a tertiary care center during a period of 40 months with post-traumatic complex tissue defects of foot were managed with microsurgical free muscle flaps as the primary option. Complex tissue defects were defined as those found to have loss of skin and subcutaneous tissues along with deeper structures, which resulted in three-dimensional tissue loss exposing tendons or bones.

Wounds were debrided primarily under tourniquet control and loupe magnification to ensure removal of all contamination and devitalized tissue with minimal blood loss. Reconstruction was done in the same sitting in four cases and after 48–72 h in six cases. Decision regarding immediate reconstruction vs deferred coverage was based on the initial contamination, assessed clinically. Deferred cases were managed with antibiotics and gauze dressings and parenteral antibiotics for 2–3 days prior to being taken up for cover, to control the infective load.

The gracilis muscle was used for defects less than 100 cm² and the latissimus dorsi was chosen for defects larger than 100 cm². All cases were operated under epidural analgesia, with the addition of general anesthesia during flap harvest for the two cases managed with latissimus dorsi.

Harvest of gracilis muscle was done through a medial longitudinal thigh incision along a line 5 cm posterior and parallel to the line joining adductor longus tendon and the midpoint of the medial joint line of knee. The muscle was isolated on the major pedicle, which was dissected between the adductor longus and magnus, up to its origin from the descending branch of the medial circumflex femoral vessels. Branches to the adductor magnus were identified and divided

to facilitate this. The donor site was closed primarily in two layers over suction drain.

Harvest of the latissimus dorsi was done under general anesthesia, with the patient turned to lateral decubitus. Incision was just posterior and parallel to the anterior border of the latissimus dorsi. The thoracodorsal vessels were identified in the axilla and muscle harvest completed by dividing the vessels close to its origin from axillary vessels. Donor site was closed primarily with suction drains. Small tube drains were used under the muscle flaps at the recipient site.

Microanastomosis of the flap vessels to recipient vessels was done under 3.2× loupe magnification using interrupted sutures of 8-0 polypropylene. Anterior or posterior tibial vessels were used as recipient vessels depending on the proximity and the lie of the defect. Topical 1% lignocaine soaks were used routinely at the anastomotic site to prevent vasospasm and 3% papaverine was sprayed when spasm persisted.

All cases received 2500 IU of unfractionated heparin intravenously at clamp release. Lignocaine and papaverine were used as local agents at the anastomotic site to augment the flow as required. Split skin grafting of the flap was done at the same sitting for gracilis flap and after 48 h for latissimus dorsi flaps.

Skin grafting of LD flaps was delayed to avoid the risk of graft loss due to ooze from the relatively larger surface area. Delayed grafting was done using freshly taken graft after 48 h. All patients were started on low-dose heparin infusion at 5000 IU over 24 h for 5 days postoperatively. The patients were confined to bed during this period. Monitoring of the flap was done by direct visual observation through a small window in the dressings. First change of dressings was done at 48 h or according to the soakage.

Patients were mobilized out of the bed on a wheelchair on the sixth day, after discontinuation of heparin and removal of epidural catheter. Dressings were discontinued on 15th day and partial weight-bearing ambulation started with a light compression stocking applied to prevent flap edema. All patients were able to wear commercially available soft sandals with loose straps during the initial period of ambulation. The elderly patient who underwent complete “wrap” of the foot with LD flap was prescribed diabetic footwear for comfort and prevention of further graft loss. Patients used walkers and elbow crutches during the initial 2 weeks of ambulation. Gradually, increasing weight bearing was allowed and full weight bearing started at 6 weeks.

Follow-up was done at 3 months, 6 months, and 1 year from surgery. Requirement of secondary procedures was assessed and necessary surgery done between 6 months and 1 year. Final outcome was assessed at 1 year from surgery. The following were considered at outcome analysis: (a) gait, (b) ability to perform activities of daily living, (c) ability to wear footwear comfortably, and (d) performance of occupational tasks.

Results

Ten patients presented with post-traumatic complex tissue defects of the foot. All were male, with age range of 25–76 years. All were crush injuries resulting from road traffic

Table 1 – Patient details, procedure and outcome.

Age/ sex	Foot defect description	Defect area	Flap details	Donor vessels	Harvest time	Warm ischemia time	Secondary procedures	Functional outcome at 1-year follow-up
25/M	Lateral heel pad loss with exposed calcaneum	45 cm ²	Contralateral gracilis Pedicle length 3 cm Artery diameter 1.2 mm 2 venae comitantes 1 and 1.5 mm	Anterior tibial vessels Artery 1.5 mm 2 venae comitantes 1 and 1.5 mm	65 min	125 min	Excision of redundancy Correction of contour	Normal gait Military footwear
32/M	Dorsal soft tissue loss with exposed extensor tendons	42 cm ²	Contralateral gracilis Pedicle length 3.5 cm Artery diameter 1.2 mm 2 venae comitantes 1.5 and 1.5 mm	Anterior tibial vessels Artery 1.2 mm 1 venae comitantes 1.5 mm	60 min	No flow	–	–
33/M	Dorsal soft tissue loss with exposed extensor tendons Loss of 2, 3, 4 toes	90 cm ²	Contralateral gracilis Pedicle length 4 cm Artery diameter 1.7 mm 2 venae comitantes 2 and 2 mm	Anterior tibial vessels Artery 2 mm 2 venae comitantes 1.5 and 1.5 mm	55 min	120 min	Nil	Normal gait Military footwear
36/M	Dorsal soft tissue loss with exposed extensor tendons	70 cm ²	Contralateral gracilis Pedicle length 4 cm Artery diameter 1.5 mm 2 venae comitantes 1.5 and 1.5 mm	Anterior tibial vessels Artery 2 mm 2 venae comitantes 1.5 mm	60 min	105 min	Nil	Normal gait Military footwear
27/M	Dorsal and medial soft tissue loss exposing extensor tendons and medial aspect of calcaneum	120 cm ²	Contralateral latissimus dorsi Pedicle length 5 cm Artery diameter 2 mm 1 venae comitantes 2 mm	Anterior tibial vessels Artery 1.5 mm 2 venae comitantes 1.5 and 1.5 mm	72 min	90 min	Excision of redundancy Correction of contour	Normal gait Open sandals only
28/M	Posterior heel pad loss exposing calcaneum	30 cm ²	Contralateral gracilis Pedicle length 4 cm Artery diameter 1.5 mm 1 venae comitantes 1.5 mm	Posterior tibial vessels Artery 2 mm 2 venae comitantes 1.5 and 2 mm	45 min	90 min	Excision of redundancy	Normal gait Military footwear
34/M	Posterior heelpad loss exposing calcaneum	25 cm ²	Ipsilateral gracilis Pedicle length 3.5 cm Artery diameter 1.7 mm 2 venae comitantes 2 and 1.5 mm	Posterior tibial vessels Artery 2.5 mm 2 Venae comitantes 1.5 and 2 mm	55 min	95 min	Excision of painful callosity	Normal gait Military footwear

Table 1 (Continued)

Age/ sex	Foot defect description	Defect area	Flap details	Donor vessels	Harvest time	Warm ischemia time	Secondary procedures	Functional outcome at 1-year follow-up
55/M	Dorsal and lateral soft tissue loss exposing extensor tendons	80 cm ²	Contralateral gracilis Pedicle length 4 cm Artery diameter 1.6 mm 2 venae comitantes 1.5 and 1.5 mm	Anterior tibial vessels Artery 1.5 mm 2 venae comitantes 1.7 and 1.5 mm	90 min	90 min	Nil	Normal gait Soft shoes
76/M	Near total degloving of foot, extensor tendons and plantar fascia exposed, and loss of heel pad	225 cm ²	Contralateral latissimus dorsi Pedicle length 6 cm Artery diameter 1.5 mm 1 venae comitantes 2 mm	Posterior tibial vessels Artery 2 mm 1 venae comitantes 2 mm	100 min	70 min	Nil	Normal gait Recurrent eczema Habitual indoor barefoot walking
38/M	Dorsal composite tissue loss, loss of 1st and 2nd rays, and extensive loss of tissues in midfoot	85 cm ²	Contralateral gracilis Pedicle length 5 cm Artery diameter 1.5 mm 2 venae comitantes 1.2 and 1.5 mm	Anterior tibial vessels Artery 1.5 mm 2 venae comitantes 1.5 and 1.5 mm	70 min	90 min	Nil	Normal gait Soft shoes

accidents. Eight patients were serving soldiers. The results are summarized in Table 1.

The defects required to be reconstructed ranged from 25 cm² to 225 cm². Three had loss of heel pad causing exposure of calcaneum, and four had tissue loss over the dorsum of the foot exposing extensor tendons. One patient had a large defect exposing both dorsal tendons and the calcaneum medially. One had near total degloving of the foot with loss of soft tissues over the sole as well as the dorsum, and one patient had a severe crush injury with loss of great toe, medial two rays, and composite tissue loss in the midfoot.

Anterior tibial vessels were used for flap anastomosis in seven cases and the posterior tibial in the other three. The length of the gracilis pedicle ranged from 3 to 5 cm. The LD muscle flaps had pedicle lengths of 5 cm and 6 cm. Size of the gracilis pedicle artery ranged from 1.2 mm to 1.7 mm. The latissimus dorsi pedicle arteries were of 1.5 mm and 2.0 mm diameter.

Free muscle flap cover was completed successfully in nine out of the ten patients. Two of the patients who had tissue defects more than 100 cm² were reconstructed with latissimus dorsi flaps. Out of the remaining eight, in one patient aged 32 years, the gracilis flap failed to perfuse due to spasm of the recipient anterior tibial artery, which did not respond to lignocaine or papaverine. Even though the vessels were dissected prior to harvest of the flap and flow confirmed, there was refractory vessel spasm at the time of anastomosis, precluding any flow into the muscle. After two failed attempts at revision anastomosis (warm ischemia time 4 h), the free flap procedure was abandoned and this patient was reconstructed

in the same sitting with a distally based sural artery flap. One patient aged 76 years, who required a near total "wrap" of the foot with free latissimus dorsi flap had profuse ooze from the flap surface necessitating discontinuation of the heparin infusion. He also had patchy loss of the skin grafting over the muscle and required repeat grafting for residual raw areas. None of the other patients had problematic bleeding or loss of skin graft.

All successful cases could be started on partial weight-bearing ambulation at 2 weeks postoperatively, except the 76-year-old patient who was delayed due to the repeat skin grafting for patchy losses. However, he recovered well, and by 6 weeks, all nine patients could ambulate with full weight bearing without support. Compression garment was used for all patients during the initial 4 weeks of ambulation to reduce. At 6 months, four patients complained of flap redundancy and underwent flap reduction and appropriate contouring.

The donor sites healed well without complications. Loss of gracilis muscle did not make any detectable difference to hip adduction. Patients whose latissimus dorsi was harvested had mild loss of power in shoulder abduction. However, this did not affect their routine activities.

At 1-year follow-up, all patients were ambulant without support and with normal gait. All were able to wear routine footwear comfortably. Five of the seven serving soldiers could wear soft boots and take part in almost all unit activities. One patient, the 76-year-old patient with latissimus dorsi flap cover for near total degloving of the foot had repeated episodes of mild eczema, related to habitual barefoot walking inside the house.

Discussion

Foot injuries may occur as part of polytrauma or as isolated injuries. Common modes of injury are motor vehicle accidents, fall of heavy objects and in the armed forces, and combat-related injuries like mine blasts. The overall outcome of trauma depends on capability to ambulate for the purposes of activities of daily living and occupation. The appropriate and timely management of foot injuries thus assumes great significance.

Loss of skin and soft tissue cover of the foot often necessitate complex reconstructive procedures. The tissues used as substitutes need to be capable of withstanding pressure and shear associated with routine weight-bearing ambulation, and occupational and recreational activities. Split skin grafting is the simplest option to provide wound cover, but not suitable for most post-traumatic defects of the foot due to exposure of bones, tendons, or ligaments. Local flaps from tissues in the immediate vicinity are usually inadequate because of the peculiarities of anatomy of the lower one-third of leg and the foot – like bones being subcutaneous, vessels in fascial compartments with limited communications between them, and the concomitant damage to the perforating vessels, which supply the skin.² Regional fasciocutaneous flaps have

been classically described as the mainstay of reconstruction of such post-traumatic complex tissue losses across a wide range of centers.^{5,6} However, with microsurgical facilities and training becoming widely available, free flaps have become the primary choice in specialty centers with adequate expertise and facilities.²

There have been proponents of both free fasciocutaneous free flaps^{7,8,9} and skin-grafted free muscle flaps^{1,10,11} for the weight-bearing area of the foot. Free muscle flaps are an effective method for the reconstruction of deep three-dimensional defects, especially in cases where there is potential for infection.¹⁰ Effective use of free muscle flaps in reconstruction of foot has been well described even for osteomyelitis and diabetic foot.^{12,13}

The present study describes a case series of ten patients of foot trauma resulting in complex tissue defects, which were managed with free muscle flaps as the first choice for reconstruction. Eight patients who had defects smaller than 100 cm² were managed with free gracilis flap and the two larger defects with latissimus dorsi flap. The procedure was successful in nine out of the ten patients. One patient who had a defect on the dorsum of the foot reconstructed with gracilis flap had failure of perfusion on clamp release. This did not respond to warming of the flap, lignocaine soaks, or local papaverine. The anterior tibial vessels chosen as the recipient

Fig. 1 – Near circumferential degloving of foot reconstructed with latissimus dorsi flap. (a) Exposed extensor tendons on dorsum. (b) Exposed plantar aponeurosis. (c) Latissimus dorsi muscle harvested and brought to the recipient foot. (d) Microanastomosis to posterior tibial vessels completed. (e) Viable cover for dorsum. (f) Complete coverage of the sole. (g) and (h) Six months follow-up showing viable near total “wrap” of the foot.

Fig. 2 – Heel pad defect reconstructed with gracilis muscle free flap. (a) Post-traumatic defect exposing calcaneum. (b) Gracilis muscle harvested and posterior tibial vessels dissected. (c) Muscle after anastomosis and inset (d) follow-up at 1 year – full weight bearing on reconstructed heel.

vessels for this case had shown initial pulsatile flow at dissection. An intraoperative Allens test also showed prograde flow in the anterior tibial artery. However, following anastomosis, there was no flow. Reanastomosis was attempted, but there was no sustained flow from the anterior tibial artery. To

avoid risking loss of blood supply to foot by using the posterior tibial artery, and since the defect on the dorsum of the foot was relatively small (42 cm^2), we opted for distally based sural artery flap in the same sitting as an alternative in this case. This patient had an old blunt injury to the anterior aspect of

Fig. 3 – (a) Dorsal defect of foot at presentation. (b) Postdebridement – exposure of extensor tendons. (c) Gracilis muscle flap cover, anastomosis completed, and perfusion advancing into the distal end of the flap. (d) Epimysium opened and muscle fibers spread to achieve adequate coverage. (e) Skin grafting of the flap completed. (f) Well-settled flap at 6-month follow-up.

the leg and possibly the vessels failed to have good flow since they traversed the old injury zone. The risks of inadequate perfusion through vessels in the injury zone have been well documented. Experienced authors have suggested dissecting proximally to avoid the injury zone and using end to side anastomosis in single artery perfused limbs.¹⁴ However, both these options should be considered after sufficient experience has been gained, so that successful revascularization can be completed within safe warm ischemia time. Routine preoperative angiography is not considered to be beneficial in cases where at least one palpable pulse was present in the distal leg.¹⁵

Free flap cover to traumatic defects is applicable to all age groups. Surgical intervention aimed at functional foot salvage should be based on the injury pattern and not only the age of the patient.¹⁶ The elderly have much to gain from being spared the difficulties of adjusting to a life on prosthetics. The largest flap in our series was used for a 76-year-old male with near

total degloving of the foot. The defect size of 225 cm² exposing plantar aponeurosis and dorsal tendons was successfully “wrapped” with latissimus dorsi muscle flap (Fig. 1). Though there was significant ooze from the large surface area of the flap on day 1, it responded well to discontinuation of heparin infusion and administration of fresh frozen plasma. Subsequent patchy loss of the skin graft cover to the muscle flap was successfully covered with another session of skin grafting. Even though he had episodes of mild eczema of the reconstructed foot related to his habitual barefoot walking, the final outcome was very satisfactory – the patient was able to maintain ambulation with near normal gait and independence.

Four patients (all serving soldiers) underwent secondary procedures after 6 months to debulk and contour the flap. One had a large defect of the dorsum and anterior aspect of the ankle extending onto medial aspect of heel exposing calcaneum covered with latissimus dorsi flap. Three of them had

Fig. 4 – Free gracilis flap for composite three-dimensional defect. (a) Presentation at 1 month after injury, necrosis of great toe, and tissues in the forefoot. (b) Debridement resulted in composite tissue loss with a large three-dimensional defect. (c) Free muscle flap with adequate bulk is necessary to fill this defect. (d) Gracilis muscle flap insetted after microanastomosis. (e) Skin grafting of the flap done. (f) Follow-up after 6 months – complete weight bearing on the sensate foot.

relatively smaller heel pad defects exposing the calcaneum, reconstructed with gracilis flaps. After debulking and contouring of the gracilis flaps, the patients with heel pad defects could wear boots, walk with normal gait, and perform near normal functions at 1 year (Fig. 2).

Many authors have reported that reconstruction of defects over the dorsum of foot with free muscle flaps covered with skin grafts have been found to be superior to fasciocutaneous flaps and perforator flaps in overall cosmesis and donor site morbidity.^{17,18,19} In our case series, the gracilis muscle flap was very effective in covering dorsal defects even broader than the muscle itself. By opening the epimysium, it was possible to spread the muscle over the broader defects. The consequent reduction in thickness of the flap was advantageous in achieving a well-contoured flattened cover over the dorsum of the foot (Fig. 3).

Cavitary defects may result due to primary traumatic tissue devascularization or from infection causing necrosis of surrounding tissues. Proper debridement of all devitalized tissue is the key to effective reconstruction. Muscle flaps effectively fill these defects, bringing in rich vascular supply to counteract infection, resulting in optimal salvage. One of our patients presented with failed initial debridement and fixation of open comminuted fractures of the forefoot and midfoot. There was gross infection, which was radically debrided and the resultant defect filled with gracilis muscle flap cover. Salvage of weight-bearing foot with sensate sole was possible (Fig. 4).

Use of gracilis flap as primary option for defects in the foot has been reported with 100% success.²⁰ The flap is especially effective in coverage of moderate-sized defects of the foot. There is hardly any donor site morbidity in the form of loss of function or cosmesis. The procedure can be completed without risks of prolonged general anesthesia, with epidural infusion providing pain relief as well as beneficial vasodilatation in the lower extremities during the immediate postoperative period. Natural atrophy of the denervated muscles makes the flaps supple over a period of time. In case of redundancy, simple procedures can be carried out for debulking and contouring.

All patients in our series were ambulant without support at the end of 1-year follow-up. They could wear footwear according to the demands of their daily living. Five of the seven serving personnel successfully reconstructed with free muscle flaps could wear boots and return to near normal occupational activities.

Conclusion

Trauma to the foot often results in tissue defects requiring flap reconstruction.²¹ Functional outcome of such injuries is improved by astute protocols for debridement and reconstructive procedures.²² Muscle flaps have advantages over fasciocutaneous flaps of bringing in much needed bulk and blood supply to three-dimensional defects. As microsurgical expertise and facilities become widely available, free muscle flaps, especially the gracilis flap, merit consideration as the primary option for reconstruction of post-traumatic complex tissue defects of the foot.

Conflicts of interest

The authors have none to declare.

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