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Utilizing the Subunit Concept to Achieve Better Outcomes in Lower Limb Reconstruction: A Clinical Experience in an Asian Population

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Background: The goals of reconstruction have progressed from filling a defect to enhancing function and aesthetic appearance. We aimed to achieve better aesthetic and functional outcomes in terms of shoe fitting and mobility. This is accomplished via a classification of the subunits and aesthetic considerations of the lower limb.
Methods: Between April 2017 and December 2021, 66 cases of lower extremity free fasciocutaneous flap reconstruction cases were included in this retrospective study. Data parameters include age, sex, comorbidities, etiology of lower limb wounds, choice of free flap reconstruction, recipient arterial vessels, complications of flap reconstruction, and need for secondary debulking procedures. Physiotherapy records were also examined to determine the time to independent ambulation.
Results: In total, 66 subjects were identified. The mean age was 48.6. An estimated 74.2% (n = 49) were men, 50% (n = 33) had diabetes, and 16.6% (n = 11) had peripheral vascular disease. Of the total wounds, 65.1% (n = 43) were caused by infection, whereas the remaining 34.9% (n = 23) were due to trauma. Of the cases, 72.7% (n = 48) had free anterolateral thigh flap reconstruction, 25.8% (n = 17) were reconstructed with superficial circumflex iliac artery perforator flaps, and 1.5% (n = 1) was reconstructed with medial sural artery perforator flaps. Cases that required secondary debulking procedures comprised 7.6% (n = 5).
Conclusions: Free fasciocutaneous flaps are useful in lower extremity reconstruction. Based on the subunit principle and aesthetic considerations for lower limb reconstruction, it can aid in optimizing functional rehabilitation and decreasing secondary procedures. *(Plast Reconstr Surg Glob Open 2024; 12:e5752; doi: 10.1097/GOX.0000000000005752; Published online 19 April 2024.)*

INTRODUCTION

Lower limb extremity defects can vary from trauma, to infection, to postoncological resection. Many factors, including edema, scarring, major vessel injury, and peripheral vascular disease, pose potential difficulties in lower limb reconstruction.[1] Ponten introduced fasciocutaneous flaps for the coverage of lower limb defects.[2] Saint Cyr et al[3] expanded on the perforasome theory, and this aided surgeons in customizing flap thickness to adhere to contours of wound defects. In view of the complex anatomical variations and considerations for the reconstruction of the lower limb, categorizing the various areas of the lower limb into subunits is useful in achieving good aesthetic outcomes and functional rehabilitation.

METHODS

This retrospective study included 66 cases that underwent free fasciocutaneous reconstruction of lower extremity defects from April 2017 to December 2021 in Changi General Hospital, Singapore. Demographic parameters include age, gender, presence of diabetes, hypertension, chronic kidney disease, ischemic heart disease, and peripheral vascular disease. Various fasciocutaneous flaps were performed based on the required flap size, pedicle length, flap thickness, and recipient vessels. Perioperative complications (within 30 days of surgery) were recorded. Secondary flap debulking procedures were noted, if required. The time to independent ambulation was

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noted based on physiotherapy records. Subgroup analysis was performed to compare time to ambulation in fracture fixation and nonfracture fixation groups. Statistical analyses were done using Mann–Whitney *U* test. Statistical analyses were conducted using the Statistical Package for Social Science software, version 24. A statistical significance was defined as *P* less than 0.05. This retrospective observational study was approved by the institution's ethical review boards (CIRB Ref: 2020/2541), and written informed consent was waived because only anonymized data were used. From our clinical experience, a subunit classification of the lower limb was devised, each with a distinct set of anatomical, functional, and aesthetic considerations.

RESULTS

In total, 66 patients underwent free fasciocutaneous flap coverage to lower limb defects in the study period. The mean age was 48.6 (range, 17–83). Of the patients, 74.2% (n = 49) were male, 50% (n = 33) had diabetes, and 16.6% (n = 11) had peripheral vascular disease. Of the total patients, 10.6% (n = 7) had ischemic heart disease and 12.1% (n = 8) had chronic kidney disease. Among the total wounds, 65.1% (n = 43) were caused by infection, whereas the remaining 34.9% (n = 23) were due to trauma. Of the total wounds, 0.03% (n = 2) were located on the knee, 27.2% (n = 18) were located on the leg, and 69.6% (n = 46) were located in the foot and ankle region (Tables 1–3).

We proposed a classification of subunits of the lower limb (Fig. 1). In our case series, there were wound defects involving more than one subunit: 12.9% (n = 15) were categorized under zone 1, 19.8% (n = 23) in zone 2, 16.3% (n = 19) in zone 3, 19% (n = 22) in zone 4, 12.2% (n = 14) in zone 5, 12.9% (n = 15) in zone 6, 4.3% (n = 5) in zone 7, and 2.6% (n = 3) in zone 8. Free anterolateral thigh (ALT) flap was the major choice of flap reconstruction (72.7%, n = 48), whereas the remaining were composed of superficial circumflex iliac artery perforator (SCIP) flap (25.8%, n = 17) and medial sural artery perforator flap (1.5%, n = 1).

Nine percent (n = 6) developed partial flap failure, whereas 3% (n = 2) developed total failure. Of the patients, 12.1% (n = 8) underwent expedient re-exploration, which involved a takedown and revision of the failed anastomoses. Of the cases of partial flap failures, two cases developed venous thrombosis, and partial flap necrosis developed despite re-exploration. The remaining flap failures were secondary to flap infection. These cases had comorbidities of hypertension, hyperlipidemia, and peripheral arterial disease.

Patients with infective etiologies ambulated independently earlier at an average postoperative day of 17.6 days (range 7–48 days, n = 43). Patients with traumatic wounds took longer to ambulate at an average postoperative day of 43.4 days (range 7–109 days). Further stratification of traumatic wound reconstruction with and without bony fixation showed different results. Patients with bony fixation took an average of 97.8 days (range 91–109 days, n = 9) after the reconstruction operation to ambulate, whereas patients without bony fixation took an average of 16.6 days (range 7–45 days, n = 14). Five patients underwent secondary debulking procedures.

Table 1. Patient Characteristics

Age	Mean	48.6
	Minimum–maximum	17–83
Diabetes	Yes	33 (50%)
	No	33 (50%)
Ischemic heart disease	Yes	7 (10.7%)
	No	59 (89.3%)
Chronic kidney disease	Yes	8 (12.1%)
	No	58 (87.9%)
Peripheral vascular disease of lower limb	Yes	11 (16.7%)
	No	55 (83.3%)

Table 2. Wound Characteristics, Reconstructive Choices, and Outcomes

Wound etiology	Trauma	23 (34.9%)
	Infection	43 (65.1%)
Subunit of lower limb involved by wound defect	1 (antero-medial leg)	15 (12.9%)
	2 (lateral leg, posterior calf)	23 (19.8%)
	3 (distal calf, plantar foot)	19 (16.3%)
	4 (dorsum of foot)	22 (19.0%)
	5 (medial ankle)	14 (12.2%)
	6 (lateral ankle)	15 (12.9%)
	7 (posterior knee)	5 (4.3%)
	8 (anterior knee)	3 (2.6%)

Takeaways

Question: This article aims to maximize aesthetics and function in lower limb reconstruction, using the subunit concept and important principles of orthoplastic reconstruction. Aesthetics and function are two aspects of lower limb reconstruction that should work in concert with each other.

Findings: This retrospective case series consists of 66 free fasciocutaneous flap reconstruction cases. The subunit concept was used together with overarching principles of orthoplastic reconstruction to maximize both form and function at the same time while minimizing donor site morbidity and reducing the number of operations.

Meaning: Utilizing the subunit concept and its guiding orthoplastic principles give a reconstructive surgeon a systematic approach that produces an outcome that maximizes both aesthetics and function.

DISCUSSION

Fasciocutaneous flaps have achieved comparable rates of limb salvage and functional recovery with muscle flaps.[4–6] The main advantages of fasciocutaneous flaps include superior skin color and consistency, easier flap monitoring, easier access for the elevation of the flap for secondary procedures, and better donor site morbidity.[7,8] A recent study by Yamamoto et al demonstrated that certain fasciocutaneous

Table 3. Subunit Zones and Considerations

Zone	Area of Lower Limb	Thickness of Native Skin	Structures Not Amenable to Skin Grafting	Functional Demand	Aesthetic Considerations	Recipient Vessels
1	Anterior-medial leg	Thin	Tibia, extensor tendons of foot	Low	Low	ATA, **PTA**
2	Lateral leg to posterior calf	Moderate	Minimal	Low	Low	**ATA**, PTA
3	Heel to plantar aspect of foot	Thin over heel, thick over sole	Calcaneum, Achilles tendon	High	Moderate	**PTA**, LCA
4	Dorsum of foot to anterior ankle	Thin	Small bones of foot, extensor tendons of foot	Moderate	High	ATA, **DP**
5	Medial ankle	Thin	Medial malleolus	Moderate	Moderate	ATA, **PTA**
6	Lateral ankle	Thin	Lateral malleolus	Moderate	Moderate	ATA, **LCA**
7	Posterior knee	Moderate	Popliteal vessels	Moderate	Low	**MGA**
8	Anterior knee	Moderate	Patella, knee ligaments, knee joint	Moderate	Moderate	**MGA**

Bold letters indicate preferred recipient vessels.

flaps can aid in lymphatic drainage when taking into account the lymphatic axiality in the skin paddle.[9] Seyidova et al concluded that patients undergoing fasciocutaneous flap reconstructions reported better satisfaction.[10]

The aesthetic outcome of lower limb reconstruction has emerging importance. Adherence to the leg contour is crucial for functional rehabilitation (ie, shoe-wearing). The ALT flap is a workhorse fasciocutaneous flap for lower limb reconstruction. Its versatility is demonstrated by the ability to incorporate multiple skin paddles. This allows for complex in-setting of the flap with different skin and subcutaneous tissue thickness to accommodate differing demands when reconstructing multiple subunits. The ALT flap can be bulky in the proximal thigh, which poses a challenge for resurfacing the foot and ankle region. A systemic review by Bulla et al showed that the SCIP flap is emerging in popularity due to the ability to harvest a thin flap. The authors feel that the "one size (flap) fits all" concept should be abandoned and avoid using an ALT flap for every lower limb reconstruction.[11] Hong et al[12] described the SCIP flap to have significant advantages of being a thin flap. The superficial fascial plane for perforator flap elevation is valuable in resurfacing shallow defects.[13,14] Although the ALT flap can be raised along the superficial fascial plane as well, it is usually still thicker than the SCIP flap because most of the subcutaneous fat in the thigh resides in the superficial fat plane. The SCIP flap is limited by size when compared with the ALT flap. Raising a chimeric SCIP flap is an option, but the authors feel that it requires a steeper learning curve to master. Flap thickness can also be determined by the various planes of elevation, as described by Kwon et al.[15] The SCIP flap also has the tendency to be more hyperpigmented than other fasciocutaneous flaps such as the ALT flap and the medial sural artery perforator flap. We prefer utilizing the SCIP flap for the foot and ankle region because the color mismatch to the native skin can be concealed by shoe wear. Scar placement also affects the aesthetic appearance of lower limb reconstruction. This is, however, usually restricted by the site of the defect and, therefore, highly variable. The adherence to the contour of the leg contributes more to the aesthetic appearance of the lower limb.

Hollenback et al described the use of a subunit principle for the foot and ankle soft tissue reconstruction. He looked into the various functional demands of the region and aesthetic considerations and recommended various flap coverage choices.[16] In our current study, a novel subunit classification for the lower limb was devised to characterize the defects. This is based on the thickness of soft tissue, the presence of critical structures that are not amenable to skin grafting, and functional and aesthetic considerations (Table 3).

In zone 1, the region encompasses the anterior-medial aspect of the leg. The skin thickness over this region is considerably thin. Injury to this subunit usually exposes the tibia, and therefore, flap coverage is often required for reconstruction. The proximal one-third of the leg had been traditionally reconstructed via locoregional muscle flaps such as the gastrocnemius or soleus muscle, but skin grafting is required for coverage of the muscle flap, which leads to additional donor site morbidity. However, it still remains a good option for isolated proximal zone 1 defects. An ALT flap can be a viable option for coverage as well. Orientating the proximal part of the flap in the proximal part of zone 1 helps "camouflage" the bulky part of the flap with the bulge of the medial calf. An important point to note is that as we go more proximal in zone 1, the recipient vessels tend to get deeper, making anastomosis difficult. In this scenario, either a vein graft or anastomosing to perforating branches may be required.

Zone 2 encompasses the posterior-lateral aspect of the leg. In zone 2, the soft tissue is relatively thick, which makes thicker flaps like the ALT flap suitable. However, zone 2 is also relatively devoid of critical structures, and hence, skin grafting is usually the prime choice of reconstruction. Skin grafting gives a good contour with relatively low donor site morbidity. Small tendinous structures can be managed with acellular dermal matrices to generate a robust layer of granulation tissue before skin grafting is attempted.

Zone 3 encompasses the heel to the plantar aspect of the foot. Contour considerations are much higher in this region due to the thin skin and presence of critical structures such as the Achilles tendon and calcaneum. The functional demand is also high due to the close proximity of the foot and ankle joints, for which there is expected stretch of the flap during weight-bearing. The SCIP and ALT flap can be equally used, depending on the defect size. An ALT flap is useful for larger

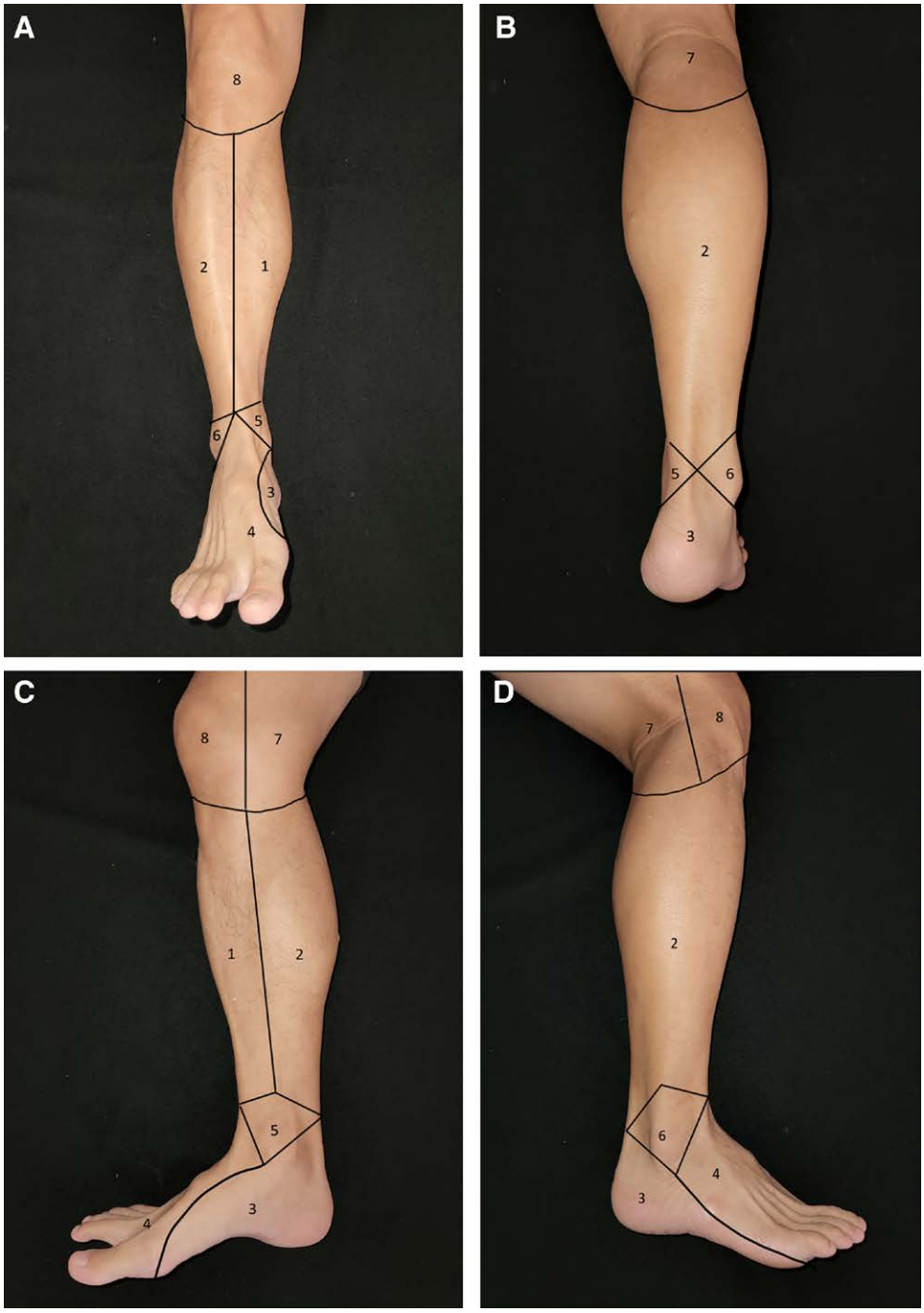

Fig. 1. Subunits of the lower limb. A, Anterior view. B, Posterior view. C, Medial view. D, Lateral view.

defects and for plantar foot reconstruction due to its thickness and ability to withstand shear forces during weight-bearing.[17]

Zone 4 is designated over the anterior ankle to foot dorsum. The soft tissue is the thinnest in this region. Wound defects in this location have a high likelihood of exposed extensor tendons and bones. SCIP flaps or suprafascial distal thigh ALT flaps in a thin individual are good options for providing suitable contour. This is crucial to avoid excessive bulk in the foot.

Zones 5 and 6 are designated over the medial and lateral ankles, respectively. The bony malleoli are at risk of exposure in this zone due to the thin nature of the skin. The malleolar region is an acceptable area to camouflage the bulk of the flap due to the convex contour. The naked eye is accustomed to viewing a natural bulge of the ankle, and therefore, it is aesthetically acceptable to have a bulge from the flap over this region. The posterior tibial artery and lateral calcaneal artery is usually the recipient vessel of choice over zone 5 (medial ankle) and zone 6 (lateral

ankle), respectively. Adhering to the contour of the ankle and foot region is crucial in these zones to allow the patient to don shoes with high cuts at the ankles like boots.

Zones 7 and 8 encompass the posterior and anterior knee regions, respectively. The skin is thicker when compared with the distal leg. Defects can also potentially be deep with exposed vessels in the posterior aspect (ie, popliteal neurovascular structures). A flap of decent bulk such as the ALT flap is a good consideration. Once again, as zone 8 has the patella bony protrusion, a thicker flap is able to be used to give a "normal" appearance. Zone 7 is crucial for flap coverage when compared with skin grafting to avoid potential flexion contracture over the knee joint. Zone 8 has a potential for exposure of the knee capsule, ligaments, and joint, which warrants flap coverage because these structures are not amenable to skin grafting. The recipient vessel of choice for zone 7 and 8 is the medial geniculate artery due to its close proximity.

There are several guiding principles that aid in the reconstruction of the proposed lower limb subunits:

- Simplify large complex wounds using the subunits and prioritize critical defects,
- Prioritize thinner flap tissue distally to give an aesthetic tapering contour to the leg,
- Avoid excessive bulk in the foot to accommodate footwear, and
- Minimize incisions on weight-bearing areas.

We will use several case examples to highlight the rationale behind these principles.

In case example 1 (Fig. 2), this patient sustained a Gustilo-Anderson grade IIIC open tibia fracture with arterial compromise, which required a popliteal bypass graft. The resultant wound defects were over zone 2 (and, to a lesser extent, proximal zone 1) and zone 7. Zone 7 required flap coverage due to the exposed popliteal bypass graft, whereas zone 2 did not have any critical defects. Applying the subunit principle, ALT flap coverage was prioritized over this zone, and primary skin grafting was performed over zone 2. Multiple flap coverage was, therefore, unnecessary.

Case example 2 (Fig. 3) illustrates the usefulness of a suprafascial ALT flap for reconstruction of the distal anterior shin and proximal dorsal ankle defect. The thicker proximal part of the flap is sited proximally over the distal leg, whiler the thinner distal part of the flap (thin arrow) is prioritized over the foot dorsum so as to accommodate footwear. The use of differential flap thickness within a flap gives the illusion of different subunits without splitting into separate skin paddles. The patient was able to develop a good range of motion over the ankle. This highlights the importance of orientating the thinner part of the flap distally.

Case example 3 (Fig. 4) illustrates the usefulness of splitting the ALT flap into two flaps based on one perforator each to achieve a better aesthetic contour to the ankle region. By adherence to the primary anatomical contour of the ankle region, the patient can don normal shoes postreconstruction. Thicker soft tissue is inset over the medial malleolus because it gives the illusion of a natural bony prominence. Splitting the flap avoids a bulky dog ear in the flap as well. This case illustrates the guiding principle of prioritizing a thinner flap tissue distally to give an aesthetic tapering contour to the distal leg. This patient did not require any debulking surgery and could don her old shoes and ambulate within 2 weeks.

In case example 4 (Fig. 5), the patient sustained a severe crush injury to his right foot, resulting in a forefoot

Fig. 2. Case example 1. Case of Gustilo-Anderson IIIC open fracture of tibia with resultant defect of zone 2 and zone 7. Zone 7 required flap coverage with ALT flap due to exposed popliteal bypass graft, whereas zone 2 had exposed muscle and fascia which was amenable to skin grafting. A, Zone 2 (black arrow) with no critical structures exposed and zone 7 with ALT flap coverage. B, Wound defect post reconstruction with zone 2 (black arrow) with skin graft coverage and zone 7 (yellow arrow) with ALT flap coverage.

Fig. 3. Case example 2. The patient had a wound defect over distal zone 1 and proximal zone 4 and underwent free ALT flap coverage, with prioritization of thinner flap tissue over the ankle and foot dorsum. A, Medial view of ALT flap coverage with highlighting of thinner tissue over the anterior ankle (black arrow). B, Anterior-oblique view of ALT flap coverage.

Fig. 4. Case example 3. Woman with severe burn wound infection that required debridement with resultant defects over zones 4 and 5. A free ALT flap reconstruction was performed. A, Medial view of ALT flap, which is split into two flaps with a separate perforator each (black arrows). B, Anterior view of ALT flap. C, Lateral view of ALT flap.

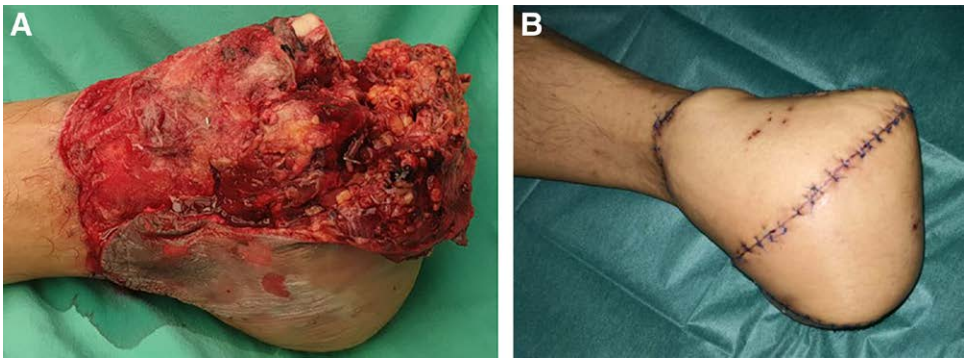

Fig. 5. Case example 4. Zones 3 and 4 defect post debridement from traumatic crush injury to the foot with alt flap reconstruction. A, Lateral view of foot defect. B, Post ALT flap reconstruction, split into two flaps based on two perforators, with the placement of the suture line away from the plantar weight-bearing surface.

wound defect involving zones 3 and 4. This case illustrates the principle of minimizing incisions and suture lines on weight-bearing or pressure areas. This aids in minimizing the risk of flap dehiscence or recurrence of wounds over the suture lines. The patient is able to don a prosthesis with minimal risk of pressure-induced wounds over the suture lines. He is back to playing tennis three times per week 6 months after his surgery.

In case example 5 (Fig. 6), the patient is a young military serviceman who sustained a great toe crush injury with loss of tissue over the toe pulp and exposed distal phalanx. The great toe is of great importance to allow proper shoe wear and ambulation. We used advanced super-microsurgical techniques to raise an ultrathin SCIP flap,[15] which provided excellent contours that blend into the great toe. The patient was able to don shoes without issues. He went back to physical training 2 months after the reconstruction.

There are a few limitations of the study, including relatively small patient numbers, retrospective study design, and lack of controls for comparison of functional outcomes. The limitation of the small patient number is secondary to the exclusion of lower limb wounds that were reconstructed with pedicled flaps, skin grafts, or healing via secondary intention, for which our focus of the article is to describe our experience in the use of free fasciocutaneous flaps for aesthetic reconstruction of the lower limb based on our proposed subunit concept. Only fasciocutaneous flaps were included in the study because we believe that the flaps provide superior aesthetic results without loss of muscle function. In our practice, the utility of muscle flaps has decreased due to better versatility in fasciocutaneous flaps.

We noticed that there was a decrease in cases during the coronavirus disease 2019 pandemic period, from 2020 to 2021, which may have contributed to the limited number of patients. We acknowledge that sensation is also crucial for functional flap reconstruction, particularly in zone 3 (heel weight-bearing area). Rinkinen et al[18] commented that neurotized free flaps seem to have an overall decreased rate of ulceration, improved sensory discrimination, and quicker return to ambulation/activities of daily living in comparison with nonneurotized free flaps. However, there are no significant differences between neurotized and nonneurotized flaps in free ALT and free medial plantar artery fasciocutaneous flaps in terms of durability and functionality (ambulation and return to activities of daily living). Many studies choose to exclude patients with existing peripheral neuropathy, so the benefit of neurotization in these groups of patients is not so well examined yet. In our case series, we have not yet adopted the neurotization of the sole in free flaps. Pedicled medial plantar flaps have been performed in cases that are suitable but are not included in our study. However, this was often not amenable due to large defects

Fig. 6. Case example 5. Case of crush injury to great toe with distal zone 4 defect with ultrathin SCIP flap reconstruction. A, Superior view of great toe defect. B, Ultrathin SCIP flap raised with single artery and vein. C, Superior view of SCIP flap inset over wound defect. D, Medial view of ultrathin SCIP flap inset into the defect E, Postoperative image of patient's ability to don footwear.

requiring larger flap coverage. Our next goal is to look into incorporating neurotizing of the free flaps to restore sensation, which is crucial in heel weight-bearing areas to determine its functional benefits.

CONCLUSIONS

Free fasciocutaneous flaps are useful in lower extremity reconstruction. Based on the proposed algorithm for lower limb reconstruction and abiding by the guiding principles of lower limb reconstruction, it can aid in optimizing aesthetic outcomes and functional rehabilitation and decreasing secondary procedures.

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DISCLOSURE

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

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