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Foot Wounds and the Reconstructive Ladder

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Background: Foot soft tissue coverage represents a challenge to reconstructive surgeons due to a lack of donor sites for this specialized skin. This glabrous tethered thick skin is designed to withstand weight bearing stress and is hard to replace. The limited arch of rotation of foot local flaps contributes to further difficulties. In this study, we share our experience in foot soft tissue loss coverage using techniques tailored to each wound presentation.
Methods: This case series presents eight patients with wounds of the plantar and dorsal surfaces of the foot, heel, and ankle. Closure techniques were selected and planned based on wound presentation and comorbidity status.
Results: Patients' mean age at surgery was 61 years. Etiologies of wounds include trauma, frostbite, diabetic ulceration, malignancy, pressure ulcer with osteomyelitis, and necrotizing infection. Coverage techniques included split and full-thickness skin graft, medial plantar arch pinch graft, cultured epithelial autograft, Hyalomatrix wound device, EpiFix tissue matrix, pedicle flap, and free rectus flap. Complete soft tissue coverage was achieved in each case within reasonable postoperative periods, and ambulation was preserved and/or restored.
Conclusions: Foot soft tissue reconstruction is challenging and should be planned carefully due to the required specialized skin replacement. Primary closure should be considered first and attempted if possible. Technique escalation in accordance with the reconstructive ladder should be undertaken based on wound etiology, presentation, amount and nature of tissue loss, available resources, and surgeon experience. *(Plast Reconstr Surg Glob Open 2021;9:e3989; doi: 10.1097/GOX.0000000000003989; Published online 27 December 2021.)*

INTRODUCTION

Soft tissue reconstruction on the foot is a unique surgical challenge for several reasons. The function of the plantar foot as the surface of weight bearing and ambulation means that the skin requires a distinctive composition capable of withstanding the pressure and force associated with bipedal movement. The skin of the plantar surface of the foot is a thick, glabrous skin and is largely free of melanocytes, and contains a substantially thickened stratum corneum. Additionally, it contains cytokeratin 9 (CK9), a cytokeratin species found exclusively in the suprabasal layers of the plantar foot and palm of the hand.[1] The dermis and epidermis of the plantar foot are also firmly tethered to the underlying plantar fascia via fibrous connective tissue, another adaptation to the trauma associated with ambulation.[2]

The unique composition and microanatomy of the plantar surface of the foot, combined with limited donor-site availability, makes it difficult to adhere to the fundamental reconstructive tenet of "replacing like by like."[1,3] Skin of this composition is exclusive to the sole of the foot and the palmar surface of the hand, and the challenge is further compounded by the limited arch of rotation of local plantar flaps. Thus, restoration of the plantar foot's full functionality following trauma, including withstanding weight and compression during ambulation, is an elusive goal. Defects of the heel and ankle present a substantial challenge to surgeons as well. In addition to being of a unique, intricate form, these structures are the crux of ambulation and movement and, thus, play an integral functional role.[4]

Foot injury can present as a result of direct trauma, surgical excision of malignancies and growths, infection, ischemia, diabetic ulcers, burns, and more.[5] There are numerous treatment modalities and strategies for soft tissue reconstruction depending on the nature and extent of foot trauma. In this case series, we present techniques for foot soft tissue coverage, including tissue replacement

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products, cultured epithelial autografts, split and full-thickness grafts, and pedicle and free flaps.

CASE 1

Here, we present a case of a 65-year-old man with diabetes with a nonhealing, 6-week-old right foot ulcer. This ulcer spanned roughly one-third of the dorsum of the foot and contained exposed tendons. EpiCord was applied following debridement in the OR. Figure 1A shows EpiCord covering the wound 2 weeks after surgery. One week later, the tendons were partially covered. Two applications of EpiFix were performed in the next month in the outpatient clinic (Fig. 1B). Complete healing was achieved in 8 weeks (Fig. 1C). A satisfactory aesthetic outcome was achieved, and the patient was fully ambulatory following wound closure.

Takeaways

Question: What approaches can plastic surgeons take when presented with complex wounds of the foot?

Findings: By tailoring reconstructive techniques to each of eight unique foot wound presentations, we were able to provide complete coverage and preserve ambulatory capability using various modalities, including tissue replacement products, cultured epithelial autografts, split and full-thickness grafts, and pedicle and free flaps

Meaning: Despite the unique challenges associated with reconstruction of the plantar foot, heel, and ankle, plastic surgeons have a multitude of treatment modalities at their disposal to achieve a durable, lasting, and aesthetically pleasing result.

CASE 2

In this case, we present a 67-year-old man with diabetes mellitus type II with peripheral neuropathy S/P surgical debridement of a necrotizing soft tissue infection. He was referred to plastic surgery for skin grafting and amputation of the left fourth toe. He had partially exposed necrotic extensor tendons shown in Supplemental Digital Content 1. (See **figure, Supplemental Digital Content 1**, which shows the wound bed preparation for skin grafting with hyaluronic acid-based matrix. A, Partially exposed necrotic extensor tendons of left foot. B, Two weeks later, all wounds were covered with granulation tissue and were ready to receive skin grafts. C, Wounds 10 days after receiving split-thickness skin grafts. D, Healed wounds, including the fourth toe at 4 weeks post grafting and 9 weeks from presentation. **http://links.lww.com/PRSGO/B926**.) The medial left ankle and leg wounds were partially covered with slough. The patient was taken to the OR and underwent debridement of necrotic tissue, which included part of the extensor tendons followed by application of a hyaluronic-acid-based 3D matrix covered with a silicone layer. Five days postoperatively, the patient developed a *Pseudomonas* infection treated with oral ciprofloxacin and twice-a-day dressing changes using wet to moist one-fourth strength Dakin's solution and gauze after removing the silicone sheets. Two weeks later, another application of hyaluronic acid matrix was done at the wound center over the partially exposed tendon of the fourth toe. Two weeks later, all wounds were ready to receive skin grafts (Supplemental Digital Content 1B). Supplemental Digital Content 1C shows the wound 10 days after split-thickness skin grafting. All wounds were healed, including the fourth toe, at 4 weeks post grafting and 9 weeks from presentation (Supplemental Digital Content 1D).

CASE 3

Simman et al presented a case of a 30-year-old man presenting with severe bilateral frostbite of the feet requiring necrotic tissue debridement to the level of the plantar fascia (Fig. 2A). The authors cultured palmar keratinocytes taken from a biopsy of the hypothenar area, and applied a palmar keratinocyte autograft to cover the patient's right sole (Fig. 2B), while they used a split-thickness graft from the thigh for the patient's left sole and the remaining open area of the right forefoot.[1] Each sole was fully covered, and the patient was fully and freely ambulatory

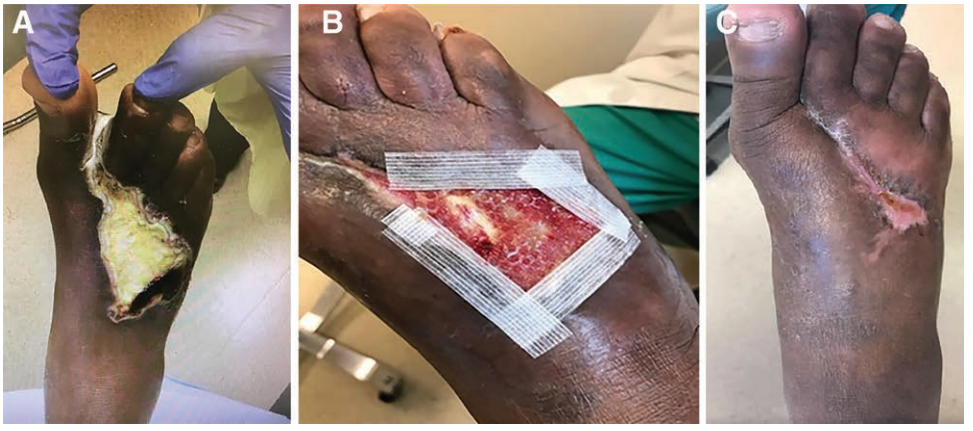

Fig. 1. Treatment of a diabetic foot ulcer with EpiCord and EpiFix. A, EpiCord 2 weeks after application over exposed tendons of the right foot. B, EpiFix is being applied. C, Healed wound 8 weeks after presentation.

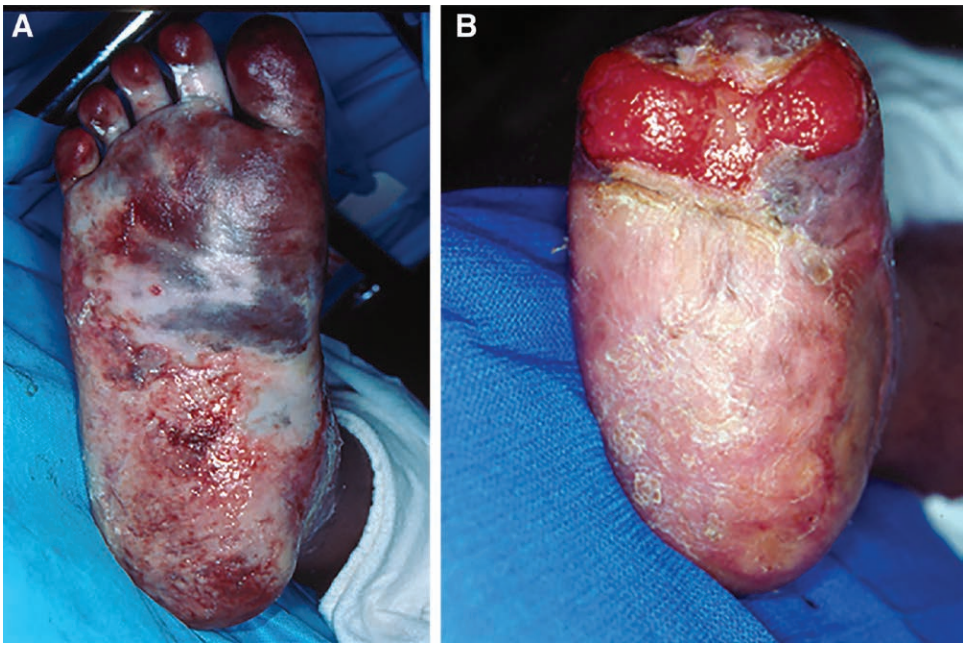

Fig. 2. Cultured epithelial autografts for treatment of severe frostbite. Replacing like by like. A, Plantar right foot frostbite. B, Healing plantar foot wound with autologous keratinocytes.

with orthotic shoes 5 months later. Biopsies from each sole were taken for histological and immunohistochemical analysis after each graft was completely healed. The cultured graft displayed histochemical features consistent with the thick, glabrous skin of the palmar and plantar surfaces, including a thickened stratum corneum, absence of melanocytes and the presence of cytokeratin 9. The split-thickness thigh graft did not show these characteristics. Both grafts healed in the same amount of time, and both were durable and capable of bearing weight and withstanding the forces of ambulation.

CASE 4

In a previous case report by Simman, a 45-year-old male patient presented with a traumatic wound of the right lateral heel.[5] For this wound, primary closure was not possible, and healing by secondary intention would have involved excessive time, pain, and potential scarring. Split-thickness pinch grafts were taken from the MPA of the foot ipsilateral to the wound (to localize any potential morbidity to one foot and retain full integrity on the contralateral side).[5] The medial arch bears little to no weight relative to other areas of the sole, making it an optimal donor site for a graft.[6] The wound was covered with 12 pinch grafts. Figure 3A shows the pinch grafts 1 week postapplication. The donor site healed in 10 days, and full wound coverage was achieved in 14 days when the grafts reached confluence. Figure 3B shows the healed wound 1 month later. Both recipient and donor sites received Xeroform gauze and Kerlex roll for coverage. The patient showed pain-free ambulation, with little reservations regarding weight placed on the operative sole. The grafts also displayed features consistent with the surrounding native skin at 14-weeks follow up, matching it with respect

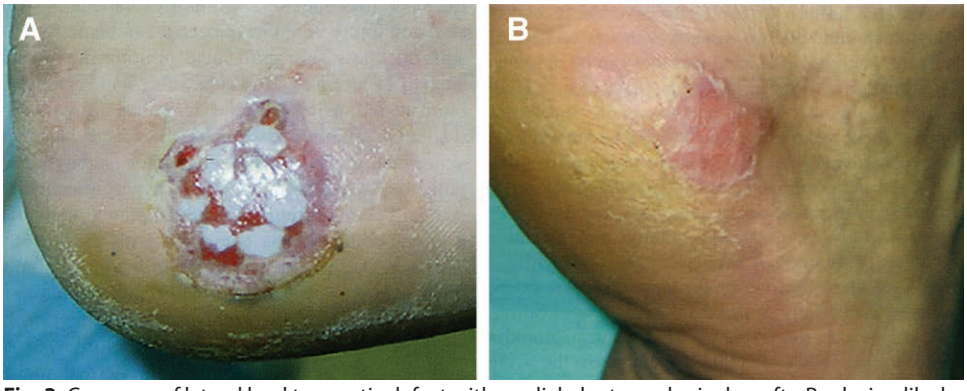

Fig. 3. Coverage of lateral heel traumatic defect with medial plantar arch pinch grafts. Replacing like by like. A, One week post application of pinch grafts to right lateral heel traumatic wound taken from the MPA. B, Healed wound at 4 weeks.

Fig. 4. Lisfranc amputation and subsequent flap reconstruction following gangrene and chronic osteomyelitis. A, Nonhealing right foot wound with chronic osteomyelitis, deformity, and pain. B, Healed right foot medial plantar flap.

to pigmentation and texture, and were free of scarring, contracture, and complications of any nature. Patient survey indicated strong aesthetic results and high patient satisfaction. Additionally, pain completely disappeared within 3 weeks after surgery and sensation returned to the graft area within 6 months.[5]

CASE 5

Here, we present a relatively unusual scenario of classical Kaposi sarcoma (KS) developing in an older woman in the absence of HIV or other immunocompromised status. This case involves a 91-year-old woman with recurrent bleeding lesions on the right plantar forefoot and great toe. (See figure, **Supplemental Digital Content 2**, which shows the full-thickness skin graft to cover plantar forefoot excision site. A, Bleeding KS at the right plantar forefoot and great toe. B, S/P excision and full-thickness skin graft 6 weeks later. **http://links.lww.com/PRSGO/B927**.) Biopsy of the lesions showed KS. She also tested positive for HHV 8. She underwent excision of the lesions, and defects were subsequently closed with a full-thickness skin graft. The graft healed 6 weeks later (Supplemental Digital Content 2B). In a case of classic KS such as this, in which the cutaneous lesions are localized and benign, local treatment was most effective.[7] Surgical excision was performed in this case, which provided an aesthetically satisfactory result and allowed the patient to retain ambulatory capability.

CASE 6

This case involves a 56-year-old man S/P Whipple procedure for pancreatic cyst removal. He was placed on heparin postoperatively and developed HIT (heparin induced thrombocytopenia) syndrome. He was placed on IV Argatoban and stabilized. He was then sent to the wound clinic with dry gangrenes shown here and was subsequently cleared by vascular surgery. Then he underwent left transmetatarsal amputation and right foot fifth and fourth ray amputations. After a few months, his right foot wounds were not healing (Fig. 4A). Due to residual chronic osteomyelitis in his metatarsal bones, chronic pain, and forefoot deformity shown here, he was offered below knee amputation or Lisfranc amputation. He chose the latter, and his wound was closed with an MPA myocutaneous rotational flap. He healed 6 weeks later and was ambulating with orthotic shoes (Fig. 4B).

CASE 7

Here we present a 67-year-old man with diabetes with a history of CABG who presented with right forefoot gangrene. Vascular status was assessed and found to be satisfactory. He was admitted and placed on IV antibiotics and underwent excision of the necrotic area, which included soft tissue and the distal first metatarsal head with osteomyelitis (Fig. 5A). PICC line was placed for the administration of IV vancomycin to treat his staphylococcus infection. Daily dressing changes were done using wet and moist N/S and gauze. Two weeks later, he was taken back to the OR and his wound was debrided, the proximal part of the defect was closed with undermined skin flaps over a drain and the fillet of right great toe pedicle flap was used to close the distal part of the defect (Fig. 5B). The wound healed a month later and the patient was able to ambulate (Fig. 5C).

CASE 8

Here, we present a 65-year-old man with a history of spinal chordoma, producing bilateral neuropathy of the lower extremities that led to pain, weakness, and numbness. He was admitted to the hospital with a left heel stage IV pressure ulcer with necrosis and osteomyelitis of the calcaneus (Fig. 6A, B). He received IV antibiotics via PICC line and underwent excisional debridement, which included a partial calcanectomy. Dressing changes using calcium alginate silver were started with complete offloading of the heel.

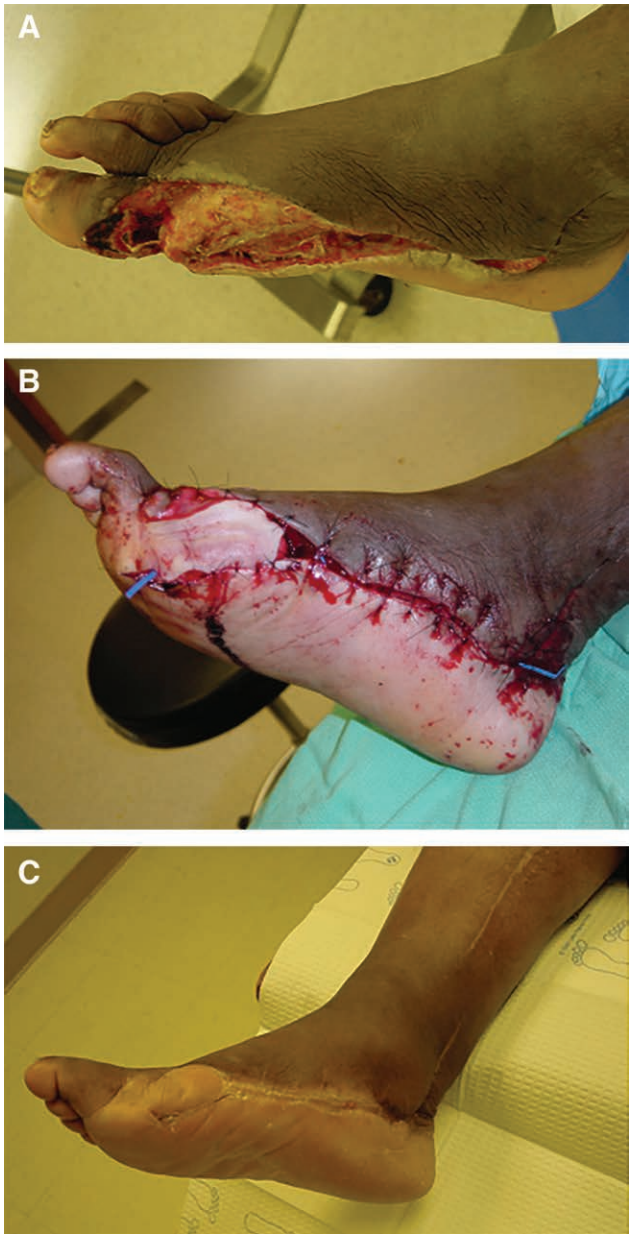

Fig. 5. "Spare parts": coverage of distal foot surgical defect achieved with fillet of toe flap. A, S/P surgical excision of necrotic soft tissue and the distal first metatarsal head. B, S/P second OR visit for wound debridement, the proximal part of the defect was closed with undermined skin flaps over a drain, and the fillet of right great toe pedicle flap was used to close the distal part of the defect. C, Healed wound 6 weeks later.

Several weeks later, he was taken back to the OR and underwent right rectus muscle free flap and split-thickness skin graft over the muscle. The flap healed 3 weeks later. He subsequently received physical therapy and was then able to ambulate with a walker and braces a few weeks later.

DISCUSSION

Placental Matrix Replacement in Diabetic Foot Ulcers (EpiCord, EpiFix)

The EpiFix allograft is a placenta-derived tissue matrix obtained from dehydrated human amnion/chorion membrane that is rich in growth factors, cytokines, and metalloproteinase inhibitors, which are conducive to cell proliferation and wound coverage.[6] EpiFix has also demonstrated competency in the recruitment of human mesenchymal, adipose-derived, and hematopoietic stem cells in vitro, and has been shown to upregulate both their migration and activity.[8] By stimulating endogenous wound healing pathways, EpiFix has a role as an adjunct to the standard of wound care and a tool for expedited coverage of chronic, nonhealing wounds. Randomized, multicenter clinical trials have concluded that allografts such as EpiFix are superiorly effective in providing timely, complete closure of chronic diabetic and venous ulcers of the lower extremity compared with conventional methods.[9–11] The lifetime risk of foot ulceration for diabetic patients is estimated to be about 15%. Roughly 60%–80% of diabetic foot ulcers will heal via standard approaches, with the remainder progressing to chronicity, putting many patients at risk for amputation.[12] Dehydrated human amnion/chorion membrane tissue matrices have potential value as a reinforcement when the standard of care fails, thus presenting an opportunity to improve outcomes for diabetic patients.

Hyaluronic Acid-based Matrix Replacement (Hyaff) over Exposed Tendons

Skin grafts placed over complex wounds containing exposed musculoskeletal structures in the absence of a perfused, granulating wound bed can result in contracture, deformity, and graft failure.[13–15] Additionally, factors such as age and comorbidity can preclude a patient from being a suitable candidate for free flap microsurgery, which is often used in these wounds.[13,15] Esterified hyaluronic acid matrix technology provides an alternative avenue for closure of complex lower extremity wounds in patients for whom flap coverage is contraindicated. Hyaluronic acid is a glycosaminoglycan that is found throughout the body as a principle component of extracellular matrix and joint capsules, a cell signaling molecule with receptors on almost all human cells, and a mediator in inflammation, immune response, and tissue repair.[16] It has been posited that its roles in wound repair include cell migration and infiltration, inflammatory attenuation, and stimulation of angiogenesis, in addition to its role as a key constituent of extracellular matrix.[17,18] Hyalomatrix is an esterified hyaluronic acid matrix product consisting of esterified hyaluronic acid, called Hyaff, and an outer silicone sheet.[19] This matrix, when placed on a tissue bed with exposed tendons that is devoid of granulation tissue, helps generate a richly vascularized scaffolding for grafting and ultimately wound closure.[15]

Grafting Techniques

Coverage of large, full-thickness injuries to the sole of the foot can be achieved via cultured epithelial autograft techniques. This technique can provide large epithelial sheets from relatively small tissue samples, and is a useful alternative in cases where there is limited donor-site availability, defects are large, there are several traumas present,

Fig. 6. Free rectus muscle flap coverage of left heel defect after stage 4 pressure ulcer debridement and partial calcaniectomy of osteomyelitis. A, Left heel stage IV pressure ulcer with necrosis and osteomyelitis of the calcaneus. B, Healed rectus abdominis free muscle flap with split-thickness skin graft to left heel after debridement and partial calcaniectomy, final result.

or when the patient is not a suitable candidate for long, invasive surgery.[1,20]

MPA pinch grafts are effective in resurfacing wounds of the heel, toes, thumb, and palm of the hand. However, this technique is limited in its application. The donor site itself is limited, as the medial arch cannot yield enough soft tissue to provide full coverage of large defects.[5] Additionally, for defects on the plantar surface of the foot containing exposed vessels, tendons, or bone, flap coverage is necessary.[21] Still, there remains a place for split-thickness grafts such as the MPA pinch graft in the foot reconstructive ladder.

Right MPA Flap after Lisfranc Amputation

The MPA flap is derived from the MPA of the foot, receiving vascular supply from the medial plantar artery and innervation from cutaneous branches of the medial plantar nerve.[22] Current literature describes the MPA flap and the reverse sural artery flap as the two most prominent modalities for hindfoot reconstruction.[23] The MPA flap provides the glabrous skin of the plantar foot that is crucial in weight bearing and ambulation. Additionally, the MPA flap remains sensate and provides protective sensation to the covered area in the majority of reconstructions.[23–25] Finally, the MPA flap is associated with lower rates of complication and avoids latent venous congestion and edema that often occurs in patients years after receiving a sural artery-based reconstruction.[24,25] In the first systematic review of MPA-based reconstruction, Opoku-Agyeman et al found a 98.2% flap survival rate, 9.4% flap complication rate, 5.2% donor-site complication rate, and retention of protective sensation in 99% of MPA flap reconstructions.[23] Thus, several features of the MPA flap confer distinct advantages to this approach.

Fillet of Toe Flap

Fillet flaps are a product of the "spare parts" concept, in which limbs or digits that cannot be salvaged are repurposed as a source of material for the repair of large defects.[26] In this case, amputation of the patient's hallux was necessary due to extensive forefoot necrosis and surgical debridement of the distal first metatarsal head and surrounding soft tissue. However, his vascular supply was good, and his digit was repurposed into a well perfused, ideally suited source of soft tissue for reconstruction of his forefoot defect. Fillet flaps such as the one used herein are a strong choice for coverage of forefoot defects because they provide comparable tissue, have limited donor-site morbidity, and avoid many of the complexities associated with a forefoot reconstruction of this nature.[27]

Free Flap Coverage of Foot Defects

Treatment of extensive calcaneal osteomyelitis with soft tissue involvement and skin ulceration continues to challenge reconstructive surgeons. Systematic review of the various therapeutic strategies that exist for this have struggled to identify specific bone treatment, soft tissue coverage, and wound healing modalities that lead to superior results relative to others.[28] Although below the knee amputation is often considered the definitive treatment, partial and total calcanectomy have been identified as viable, potentially limb-sparing alternatives. Furthermore, partial calcanectomy has been associated with lower rates of postoperative complications and secondary amputation compared with total calcenectomy.[29,30] Following extensive debridement and partial calcanectomy, a free flap is often necessary to completely permeate the vacated space with well-vascularized tissue.[28] Given that calcaneal osteomyelitis combined with heel ulceration is often a multifactorial disease process that is hindered by comorbidity, significant prognostic variation exists in these cases. More investigation is necessary and future efforts should aim to develop a more standardized, empirically backed algorithm for management.

CONCLUSIONS

Foot soft tissue reconstruction can be a puzzling task for reconstructive surgeons. Defects in this area can be

complicated by comorbidity, vascular insufficiency, neuropathy, and superimposed infection. Furthermore, this area is anatomically and histologically unique due to the presence of specialized glabrous skin, a thickened stratum corneum, thickened fascial layers and unique molecular composition, including lack of pigmentation and presence of CK9. We have highlighted eight cases of foot soft-tissue defects resulting from trauma, surgical excision of malignancy, diabetic ulceration, vascular deficiency, frostbite and more, and have detailed various reconstructive modalities for their correction. Although cases are heterogenous in presentation, and outcome and case series are limited in their application, we understand the limitations and do not intend to generalize our results. Rather, we intend to document unique situations and demonstrate the therapeutic modalities that experienced reconstructive surgeons are armed with that can be effective in treating the broad range of defects observed in the foot.

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