The Mangled Foot and Ankle: Soft Tissue Salvage Techniques.

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The Mangled Foot and Ankle
Soft Tissue Salvage Techniques

Geoffrey G. Hallock, MD

KEYWORDS
• Mangled foot and ankle • Soft tissue reconstruction • Free flap • Perforator flap

KEY POINTS
• The mangled foot and ankle may be defined as an injury to multiple organ systems, but a significant loss of soft tissues may be the major determinant as to whether the limb is retrievable.
• Wound preparation if salvage is attempted requires an orderly progression of fracture fixation, revascularization if needed, and then débridement of all nonviable tissues. Any attempt at soft tissue coverage must be delayed until this requisite débridement has been completed.
• Because multiple foot subunits are typically involved in the mangled injury, the resultant large defects may be best covered by a free tissue transfer.
• The decision to salvage the mangled foot and ankle must be a team effort from the beginning and should include the opinion of a reconstructive microsurgeon to decide if it is even possible to restore the missing soft tissues.

Just what qualifies to be called a mangled foot or ankle injury may be a point of conjecture, but usually there is little doubt when seen (Fig. 1). Purists consider this to have to be a multisystem injury where 3 of 4 major organ systems ( integument, vascular, nerve, and bone) have been simultaneously violated.1–3 Others have broadened this appellation to include severe injuries that have occurred to only 2 of these 4 organ systems, but soft tissue loss alone has been extensive, with the latter perhaps so defined if it spans more than a single foot subunit (Fig. 2).2 If a mangled foot or ankle has no soft tissue component, then the need for coverage is not a concern and the remainder of this article becomes irrelevant—but that is rarely the case.

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Fig. 1. (A) Mangled left foot as a result of a motor cycle accident with exposed tendons and extensive soft tissue loss, (B) involving subunits 5 and 6, (C) which required a megaflap for coverage, here designed as an ipsilateral anterolateral thigh (ALT) perforator flap about 2 perforators marked “x” found with an audible Doppler; (D) undersurface of ALT free flap with the 2 vastus lateralis musculocutaneous perforators on microgrid pieces that both joined the extremely long descending branch of the lateral circumflex femoral vessels vascular leash (in microclamp); (E) reasonable appearance and contour of the left foot required no secondary procedures; (F) because such a huge flap was necessary, a skin graft of the thigh donor site was needed to avoid a compartment syndrome.
**Homo sapiens** is somewhat unique in the animal world in that they maintain an erect posture and simultaneously have mobilization capabilities that depend on the foot as a dynamic platform that must withstand constant load-bearing and shearing forces.\(^4\) When confronted with a mangled foot or ankle, the initial treating surgical team must make the correct judgment to decide whether to proceed with an immediate amputation or begin the steps needed not only for salvage of the extremity but also the restoration of an adequate ambulatory function. This is never as simple as it seems, and several injury graded severity scores, such as Mangled Extremity Syndrome Index,\(^1\) Mangled Extremity Severity Score,\(^5\) Predictive Salvage Index,\(^2\) and Limb Salvage Index,\(^2\) have attempted to provide an objective mechanism for making this decision. Prospectively these have usually proved a futile exercise, because although adequate to decide when limb salvage should be undertaken, they are poor predictors of when amputation is more appropriate.\(^2,6-8\) Although this debate is better discussed elsewhere in this entire issue, the easiest solution may not be the best long-term solution for a given individual. What can be more disastrous than Lange’s\(^9\) conundrum—“a protracted course of treatment resulting in a limb with minimal functional capability, or immediate amputation of a limb where reasonable

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**Fig. 2.** Zones of the foot and ankle based on functional and aesthetic subunits (1, toes; 2, plantar forefoot; 3, plantar midfoot; 4, hindfoot; 5, dorsum of foot; 6, ankle joint and vicinity, encompassing medial and lateral malleoli; and 7, posterior hindfoot). *(Modified from Hallock GG. Foot and ankle reconstruction. In: Blondeel PN, Morris SF, Hallock GG, et al, editors. Perforator flaps: anatomy, technique, & clinical applications, vol. 2. 2nd edition. St Louis (MO): Quality Medical Publishing; 2013. p. 1211.)*
functional potential was discarded?" If reasonable function cannot be expected, however, limb amputation should not be viewed as a failure but a respectable and definitive treatment option.10,11

Although most lower extremity injury graded severity scores were predicated on data based on tibial fractures alone,1,2,5 the Lower Extremity Assessment Project (LEAP) also analyzed mangled foot and ankle cases where inclusion criteria was severe open hindfoot or midfoot injury that encompassed the presence of an insensate plantar surface, devascularization, a major degloving injury, or soft tissue injury requiring some form of coverage as well as Gustillo-Anderson grade IIIB open pilon or ankle fractures.8 The LEAP study concluded that the severity of the soft tissue injury had the greatest impact on the decision to attempt limb salvage.8 If true, whether or not a given soft tissue deficit can be restored at all becomes a factor of paramount importance that mandates that the judgment of a reconstructive microsurgeon be appropriately considered as part of an overall team effort that makes any final treatment decisions.

PREOPERATIVE ASSESSMENT

Non–Soft Tissue Issues

Other life-threatening injuries or comorbidities cannot be a concern and must rely on an accurate assessment by the trauma team that has been handling the initial patient presentation. If not contraindicated, soft tissue replacement then requires an orderly progression of interventions. Adequate fracture reduction by an orthopedic or podiatric surgeon must first be completed. Any vascular insufficiency must be rectified not only to sustain foot viability but also to retain the possibility of simpler local foot flaps for smaller wounds and potential vascular recipient sites if a free flap is essential.

Wound Preparation

It is next imperative that all devitalized tissue be removed even if structurally of some importance, because only a pristine wound avoids the risk of a later infection. Three words to remember how to accomplish this task are apropos—débridement, then débridement, and finally more débridement—until only viable tissues remain.10 Many physicians assume that the now ubiquitous negative-pressure wound therapy devices alone suffice to accomplish this objective,12 but there is never any substitute for a surgeon’s touch.

There is no question that negative-pressure wound therapy devices reduce the needed frequency of dressing changes to thereby minimize patient discomfort, lessen the burden on the nursing staff, and prevent wound desiccation that occurs so often if conventional dressings are neglected.13 This modality enhances the formation of granulation tissues and wound contraction by secondary intention that can result in spontaneous healing of a small defect or allow use of only an autogenous skin graft14 or, if still unacceptable to complete closure, perhaps use of a bilaminar acellular dermal regeneration template.15,16 For the sheer magnitude of the mangled foot and ankle defect, however, usually the negative-pressure wound therapy device must be realized as no more than a bridge to the definitive method for restoring skin integrity, and that for many of these wounds is preferably a free flap.4,10

Subunits

If a vascularized tissue transfer is imperative to provide bulk or cover exposed fractures, tendon, or neurovascular structures, as is inevitably the case with the mangled foot and ankle, it is important to review some basic concepts to insure an appropriate
choice. Hidalgo and Shaw\textsuperscript{17} and other investigators\textsuperscript{18} have previously introduced the subunit principle that has divided the foot and ankle into discrete zones according to the specific unique tissue requirements for each (see Fig. 2, Table 1). For example, the highly specialized glabrous skin of the plantar surface of the foot is difficult to replace with a durable yet thin flap.\textsuperscript{19} The dorsum of the foot must also be thin, but because highly visible, a final acceptable aesthetic appearance is of significant importance. This is also true for the ankle, but any impediment of motion is a functional concern. The Duke group has updated this important idea so that any flap selected must meet the functional and aesthetic demands of the given zone, with bulk or contour that does not impede the use of shoe wear and proper ambulation (see Table 1).\textsuperscript{4}

The Duke group also listed their preferences for coverage for each foot and ankle zone,\textsuperscript{4} which has been updated here to include perforator flaps that essentially are fasciocutaneous flaps that do not include muscle (Table 2).\textsuperscript{10} Many flap donor sites that are adequate for a single subunit, as listed in Table 2, may not be able to provide enough surface area for the typical mangled foot and ankle deformity that by definition of the term involves 2 or more subunits simultaneously. For the same reason, local foot flaps\textsuperscript{20,21} and distal-based neurocutaneous flaps\textsuperscript{22} from the more proximal leg that have been championed as an alternative to microsurgical tissue transfers are inadequate. The cross-leg flap, as commonly used in the past century, would perhaps suffice as a desperation option,\textsuperscript{23} but today is otherwise unacceptable in terms of the cost of long-term limb immobilization and need for a staged procedure.\textsuperscript{19}

**Timing**

Although Godina\textsuperscript{24} proselytized that any open lower extremity wound should be closed immediately or soon afterward, this is not usually logistically practical. Many investigators strongly believe that closure in the acute wound phase (ie, within the first week) is preferable, especially if bone, tendon, nerves, and vessels are exposed.\textsuperscript{4} Not all wounds have the same characteristics, however, because more severe injuries may require more time than this before achieving a satisfactory milieu.\textsuperscript{25} The negative-pressure wound therapy device has helped extend this window of opportunity to some degree but should not be considered a panacea without limit.\textsuperscript{13} From a pragmatic standpoint, the sooner the better is a reasonable goal, because the inflammatory response and fibrosis of wound healing migrate from the wound of injury to encompass nearby possible recipient sites—making them more fragile, more difficult to dissect, more susceptible to vasospasm, and invariably the cause of microanastomotic nightmares.

<table>
<thead>
<tr>
<th>Zone</th>
<th>Subunit</th>
<th>Functional</th>
<th>Bulk</th>
<th>Aesthetics</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Toes</td>
<td>None</td>
<td>Thin</td>
<td>Visible</td>
</tr>
<tr>
<td>2</td>
<td>Plantar forefoot</td>
<td>High demand: push-off point</td>
<td>Thin and durable</td>
<td>Minimal visibility</td>
</tr>
<tr>
<td>3</td>
<td>Plantar midfoot</td>
<td>None</td>
<td>Thin</td>
<td>Hidden</td>
</tr>
<tr>
<td>4</td>
<td>Hindfoot</td>
<td>High demand: weight bearing</td>
<td>Bulky and durable</td>
<td>Hidden</td>
</tr>
<tr>
<td>5</td>
<td>Dorsal foot</td>
<td>None</td>
<td>Thin</td>
<td>Highly visible</td>
</tr>
<tr>
<td>6</td>
<td>Ankle</td>
<td>Moderate: to allow motion</td>
<td>Thin and pliable</td>
<td>Some visibility</td>
</tr>
<tr>
<td>7</td>
<td>Posterior hindfoot</td>
<td>None</td>
<td>Thin</td>
<td>Some visibility</td>
</tr>
</tbody>
</table>
As previously suggested, many methods to restore the soft tissue integrity of the foot and ankle are possible proceeding up the reconstructive ladder from secondary contraction, skin graft, and local flap from the foot to distant flap from the leg itself (see **Table 2**). The mangled foot and ankle, however, by definition, is a severe cutaneous injury that involves more than 1 subunit for which the preceding options are inadequate solutions just on the basis of their limited surface area. Instead, a microvascular tissue transfer or free flap taken from another body region has traditionally been the frontline choice. The advantages of free flaps include the potential for soft tissue replacement of unlimited spatial dimensions, thickness or thinness of choice, avoidance of a skin graft, and independence in insetting because they are not constrained by the location of a vascular pedicle. In addition, cutaneous free flaps can be sensate, but this may not be that important because the LEAP data showed that one-half of patients who presented with an insensate foot ultimately regained sensation by 2 years later.

### Donor Site Alternatives

For all practical purposes, there are 2 types of soft tissue flaps. They can be muscle or fasciocutaneous flaps, with each having attributes as well as liabilities. A muscle chosen as a flap must be expendable, readily accessible, and of large size. A major advantage of any muscle is its malleability, which is important for the filling of any deep caverns while retaining the capability for wrapping around the 3-D contours of the foot to reach the multiple subunits that need resurfacing. A skin graft has to be placed on any muscle that may be an aesthetic detriment. Primary closure of the donor site, however, leaves an acceptable linear scar.

Perforator flaps today for many reconstructive surgeons have become the workhorse subtype of fasciocutaneous flaps. They can be constructed of any tissue components found from the deep fascia to the integument. Although the perforator of the deep fascia that supplies the vascular supply to these flaps may have coursed through or required an intramuscular dissection, no muscle need ever be included, so this is always a function preservation procedure. Any perforator anywhere in the body can be chosen with its surrounding cutaneous territory to meet the qualities of the foot

**Table 2**  
**Hierarchy for flap selection by requirements for foot and ankle subunit reconstruction**

<table>
<thead>
<tr>
<th>Zone</th>
<th>Subunit</th>
<th>Muscle</th>
<th>Perforator Flap</th>
<th>Secondary Choices</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Toes</td>
<td>Gracilis</td>
<td>LD &gt; MSAP</td>
<td>Amputation</td>
</tr>
<tr>
<td>2</td>
<td>Plantar forefoot</td>
<td>Gracilis</td>
<td>LD &gt; ALT &gt; MSAP</td>
<td>Intrinsic foot</td>
</tr>
<tr>
<td>3</td>
<td>Plantar midfoot</td>
<td>Gracilis</td>
<td>LD &gt; ALT, MSAP</td>
<td>Intrinsic foot</td>
</tr>
<tr>
<td>4</td>
<td>Hindfoot</td>
<td>LD &gt; gracilis</td>
<td>ALT, MCFAP &gt; CSAP &gt; MSAP</td>
<td>Distal-based sural</td>
</tr>
<tr>
<td>5</td>
<td>Dorsal foot</td>
<td>LD &gt; gracilis</td>
<td>ALT &gt; CSAP, MCFAP &gt; MSAP</td>
<td>Distal-based sural</td>
</tr>
<tr>
<td>6</td>
<td>Ankle</td>
<td>LD, gracilis</td>
<td>ALT, MSAP &gt; CSAP</td>
<td>Distal-based sural, distal leg propeller flaps</td>
</tr>
<tr>
<td>7</td>
<td>Posterior hindfoot</td>
<td>LD, gracilis</td>
<td>ALT, MSAP &gt; CSAP</td>
<td>Distal-based sural, distal leg propeller flaps</td>
</tr>
</tbody>
</table>

**Abbreviations:**  
ALT, anterolateral thigh; CSAP, circumflex scapular artery perforator (scapular or parascapular); LD, latissimus dorsi; MCFAP, medial circumflex femoral artery perforator (groin).  
* Peroneal artery perforator flap.  
* Distal leg perforator based.
and ankle subunits that need replacement.\textsuperscript{30} Perforator flaps are superior for flatter surfaces yet, depending on their thickness, are more difficult to bend around spatial irregularities.

**Donor Site Selection**

Most mangled foot and ankle extensive soft tissue defects are too large to be covered by any expendable muscle other than the latissimus dorsi muscle (Fig. 3).\textsuperscript{31} Harvest of this workhorse muscle requires that a patient be kept in a semilateral position, but this

![Fig. 3](image-url) 

**Fig. 3.** (A) Mangled left foot after a lawnmower injury in a 4-year-old child, after débridement and fracture reduction leaving exposed bone and tendon surrounding a large central cavity, (B) involving subunits 1, 5, and 6; (C) entire width of latissimus dorsi muscle free flap was needed (D) and successfully inset to fill and cover the entire defect before skin grafting; (E) malposition of some toes are seen 1 year later, but contour is excellent and ambulation unimpeded.
should not prevent simultaneous access to all foot subunits. In addition, either the anterior tibial or posterior tibial vessels can readily be exposed to serve as the requisite vascular recipient site. The vascular pedicle is long enough to usually allow reach outside the zone of injury without the need for vein grafts. The muscle is thin enough to replace any foot subunit, although atrophy and further thinning occur with time. Skin replacement requires a skin graft on the muscle, which is aesthetically displeasing.

It is always easier to maneuver within the operative theater when a patient is in a supine position. A perforator flap with characteristics similar to the subunit involved can be chosen specifically just for this reason. Patients cannot be morbidly obese because any donor site must be thin enough so that shoe wear can be worn during ambulation in an unimpeded fashion. As such, the medial sural artery perforator (MSAP) flap can be thin even in obese individuals (Fig. 4). The MSAP flap can encompass almost all the skin of the calf and corresponds to the territory of the medial gastrocnemius muscle, because the latter’s musculocutaneous perforator is its vascular source. This vascular leash has a length and caliber similar to those of the latissimus dorsi muscle. The donor site is nearby the foot and ankle defect so any iatrogenic morbidity is limited to the same lower extremity. No muscle is included. No skin graft is needed so a reasonable aesthetic result is possible. A large flap requires a skin graft to close the donor site, however, and even direct closure leaves a vertical scar that is unacceptable, particularly for women.

Some reconstructive surgeons say that the anterolateral thigh perforator flap is the most ideal soft tissue flap of all (see Fig. 1). Its surface area can exceed even that of the latissimus dorsi muscle. The potential vascular pedicle can be of large caliber and sometimes even too long, if that were possible. Again, the ipsilateral lower extremity can serve as the donor site to limit discomfort to the same leg. Fascia should not usually be included with the flap to maximize adherence to underlying structures during wound healing that minimizes wobbling during ambulation. A bulky flap in an obese patient is unacceptable for proper shoe fitting, so thinning might be needed primarily or as a secondary procedure. No skin graft is needed, but in a hirsute patient there is a contrast with the appearance of the rest of the foot. An exceedingly large flap also requires a donor site skin graft that is conspicuous.

**Intraoperative Concerns**

To reiterate, complete wound débridement must precede flap transfer. A template of the defect should be created to ascertain the dimensions and design of the chosen flap. Confirmation of an adequate vascular recipient site must be established prior to dividing the pedicle of the free flap. Flap harvest is followed by temporary exact insetting over the foot and ankle defect. Microanastomoses are then completed, usually in an end-to-side fashion for the artery to preserve all major leg source vessels to the foot, and end-to-end between flap vein(s) and deep venae comitantes adjacent to

Fig. 4. (A) Forklift crush injury with devascularization of left great toe region; (B) after débridement of all ischemic tissues, exposed proximal phalanx and first metatarsal phalangeal joint were preserved, (C) but with loss of surrounding skin, (D) involving subunits 1, 2, and 5; (E) design on medial ipsilateral calf of MSAP flap about 2 perforators “x” as ascertained with the audible Doppler; (F) subfascial course of central perforator kept with this flap seen emanating from medial head of the gastrocnemius muscle; (G) MSAP flap free on the back table, with microgrid under the perforators and microclamp on the relatively long medial sural vascular pedicle; (H) durable, thin soft tissue coverage of the medial foot; (I) large width of this flap required a donor site skin graft, which demonstrates a nonaesthetic compromise.
the arterial anastomosis, although superficial foot veins may be preferable if a larger caliber is needed. When flow is reestablished, permanent flap insetting is finished.

POSTOPERATIVE EXPECTATIONS

Unfortunately, a liability with free flaps is that the job is not yet done. Postoperative monitoring is essential because 95% of anastomotic catastrophies occur within the first 3 days. Dangling and walking protocols after that depend on the extent of other bodily system involvements. Edema management requires limb elevation for an indeterminate period. When later appropriate, use of shoe wear should be chosen so that constriction at the recipient site is avoided, and pressure on an insensate flap does no harm. The Duke group found that the mean time to unrestricted ambulation after a free flap was greater than 3 months.

Long-term secondary procedures may require flap re-elevation, such as the need for bone grafts. Care must be taken while raising the flap to not compromise its circulation, which is far more facile a task if a perforator flap had been used. Not infrequently, flap contours need readjustment, especially to reduce bulk, which is often avoided by use of a muscle flap, which naturally atrophies. Instability of the flap, especially due to intrinsic mobility or wobble, is most common over the heel and a concern for both muscle and perforator flaps that may need correction.

SUMMARY

The decision to salvage the mangled foot and ankle in lieu of amputation cannot be taken lightly by a team of responsible physicians. A typical reconstructive microsurgery consultant usually insists that any soft tissue defect can be covered. Yet each patient must still be treated as an individual, because no simple protocol has yet been devised that meets the physical, social, psychological, or perhaps today the economic needs of everyone. The ultimate goal after these devastating injuries is to maximize restoration of an individual’s lifestyle with the best possible outcome, and that is the ability to ambulate as independently as possible.

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