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Chapter 4

Lower Extremity Soft Tissue Reconstruction

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Introduction

Reconstruction of lower extremity injuries aims to restore function, improve quality of life, reduce pain, and allow for patients to return to their daily activities while simultaneously providing a long-lasting, durable repair [1-3]. Reconstructions should be specific to the patient and may be influenced by factors such age, social circumstances, and medical comorbidities.

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As such, a multidisciplinary approach including orthopedics, trauma surgery, medicine, oncology, infectious disease, social work, and rehabilitation therapists, in addition to plastic surgeons, can optimize surgical planning and thereby avail the patient to the best treatment plan [5].

An "orthoplastic" approach consisting of plastic surgery, reconstructive microsurgeons, orthopedic surgeons, and/or trauma teams yield the best outcomes for patients with lower extremity wounds [4,5]. While fracture reduction and stabilization tend to precede reconstruction of soft tissue structures in orthopedic cases, early intervention and reconstruction can maximize potential coverage options by providing input on surgical decisions, such as hardware placement and location of incision sites in subsequent procedures [4]. This collaborative surgical decision-making optimizes surgical outcomes in high-volume centers that value a multidisciplinary approach [5].

Preoperative Evaluation

Preoperative evaluation of the etiology and extent of the wound is essential to determine the appropriate immediate treatment and potential options for reconstruction. Factors including infection, acuity of patient condition, and medical comorbidities may need to be optimized prior to reconstruction. ATLS protocols should be prioritized over reconstructive efforts. However, once the patient is stable, a stepwise evaluation of the limb should take place. Assessment of contamination status, neurologic deficits, distal perfusion, fractures, and soft tissue loss are fundamental in reconstructive planning. Loss of limb is the feared outcome of extremity injuries, and early evaluation is essential for timely intervention.

Types of Cases

The etiology of lower extremity injuries is diverse, encompassing vacular, infectious, traumatic, and iatrogenic injuries, among many others. Medical causes of lower extremity wounds can include but are not limited to vascular insufficiency, infection, cancer resection and/or recurrence, previous hardware placement, etc. Patients who have undergone previous radiation treatment may have extensive irradiated tissue that is inadequate for local reconstruction, and free tissue transfer may be required. Non-healing wounds due to infectious causes may require antibiotic treatment before reconstruction can be considered. Exposed vital structures will also need a more expedited coverage plan.

Of the causes of lower extremity wounds, one of the most frequently seen is due to traumatic injury. High velocity motor vehicle accidents, open tibia-fibula fractures, degloving injuries, gunshot wounds, combat-related wounds are some examples of cases that benefit from reconstruction from a multidisciplinary approach.

Gustilo Classification System

The most widely used classification system in management of lower extremity wounds is the Gustilo classification system. The grading system was initially defined by Gustilo and Anderson in 1976 to grade high-energy open fractures with exposed bone and deep tissue injuries, as injuries sustained from this mechanism are at high risk for infection, wound healing complications, and bony non-union. Gustilo and Anderson retrospectively reviewed infection rates, time to bony union, and outcomes from over 1000 open fractures.

In 1984, the system was modified to include criteria that include wound size and severity [6]. The system is broken down into three types based on increasing size (I, II, and III), with type III wounds being further subdivided based on increased degree of soft tissue damage (IIIA, IIIB, IIIC). The Gustilo classification of open fractures is illustrated in **Table 1**. Gustilo types IIIB and IIIC are the most severe injury classes with damage to the periosteal and vascular structures, respectively, and thus are the predominate types necessitating complex reconstruction.

Table 1: Gustilo classification of open fractures.

Gustilo Classification	***Description***
Type I	Open fracture with soft tissue wound <1 cm
Type II	Open fracture with soft tissue wound 1-10 cm
Type IIIA	Open fracture, >10 cm wound, extensive soft tissue injury, without periosteal stripping
Type IIIB	Open fracture, >10 cm wound, periosteal stripping present
Type IIIC	Open fracture with an associated vascular injury that requires repair for limb survival

Other grading systems exist, such as the Tscherne classification and the Orthopedic Trauma Association-Open Fracture Classification (OTA-OFC), however the Gustilo system remains a useful tool for grading injury severity [1]. The Gustilo classification system ultimately helps to guide treatment, improve communication amongst interdisciplinary teams using a universal language, and aid in the prediction of outcomes in lower extremity reconstruction.

Antibiotic treatment in open fractures: The American Society of Plastic Surgeons (ASPS) recommends starting antibiotics for open fractures as soon as possible, preferably within 3 hours of injury, and should be limited to a 72-hour course. Antibiotic coverage should include a first-generation cephalosporin at minimum, and gram-negative coverage of gentamicin or ceftriaxone should be added in wounds that are highly contaminated and/or wounds that are Gustilo class II A, B, or C.

Pre-Operative Imaging

Pre-operative imaging is crucial not only in the evaluation of fractures, but also in microvascular status of donor sites for potential flap reconstruction. A study by Janhofer et al assessed pre-operative CTA in patients with chronic wounds who were undergoing free-tissue transfer. In 57 patients and 59 free-flaps, 40 patients were found to have vascular abnormalities, 23 of which had stenosis or occlusion and 11 with severe occlusion that they required endovascular or open vascular intervention prior to definitive reconstruction. CTA is an invaluable tool in the evaluation of reconstructive candidacy while similarly allowing for the diagnosis of previously undiagnosed vascular disease [45].

Salvage versus Amputation

"Life before limb" is an axiom that emphasizes the importance of determining candidacy for amputation versus salvage. Initial evaluation consists of ruling out life threatening wounds, shock, and age-related risk. The Mangled Extremity Severity Score (MESS) acts to rank the severity of a lower extremity wound and guide decision making with limb salvage versus amputation. Points are given for increasing soft tissue injury, limb ischemia, shock, and patient age, and limb ischemia scores are doubled for ischemia that has been present for longer than 6 hours (**Table 2**). A score ≤ 6 suggests that the limb can be salvaged, whereas a score >7 is highly predictive of amputation.

Table 2: Mangled Extremity Severity Score (MESS).

Variables	*Score*
Skeletal/soft-tissue injury	
Low energy (stab; simple fracture; pistol gunshot wound)	1
Medium energy (open or multiple fractures, dislocation)	2
High energy (high speed MVA or rifle gunshot wound)	3
Very high energy (high speed trauma + gross contamination)	4
Limb ischemia	
Pulse reduced or absent but perfusion normal	1
Pulseless; paresthesias, diminished capillary refill	2
Cool, paralyzed, insensate, numb	3
Shock	
Systolic blood pressure always >90 mmHg	0
Transiently hypotensive	1
Persistent hypotension	2
Age (years)	
<30	0
30-50	1
>50	2

The decision between limb salvage and amputation must also be determined after considering long-term outcomes [7]. Data have shown that amputations do increase energy expenditure on the patient, especially with more proximal amputations. Above-knee amputations (AKAs) present with as much as a 45-65% increase in energy expenditure and below-knee amputations (BKAs) with a 25% increase. However, these studies have not evolved at the rate that modern-day prosthetics have. Other considerations to be made with limb salvage are the potential for reduced function and quality of life that may occur independently or secondarily to complications, like secondary amputation, osteomyelitis, flap failure, and nonunion [1,2,8,9].

The Lower Extremity Assessment Project (LEAP) initially found superior patient outcomes in amputees. However, after 2 and 7 years there was no difference in Sickness Index Profiles seen between amputation and salvage groups [3,10]. Additionally, while initial costs, surgeries, and complications were found to be increased with limb salvage, long-term costs were cheaper for patients who underwent salvage and reconstruction of Gustilo IIIB and IIIC wounds than for amputees [3,47]. These studies demonstrated no significant difference between salvage and amputation, and lower extremity reconstruction has increased as a result.

For patients who ultimately require amputation, there are still reconstructive options to improve a symptomatic amputation site. Targeted muscle reinnervation and regenerative peripheral nerve interface at the time of amputation or following amputation can reduce incidence of neuroma, phantom limb pain, and maintain muscle bulk at the amputation site [15]. Free tissue transfer of the heel sole to the stump also can make for a more durable amputation site for wear resistance [14,15,46].

Goals and Principles of Lower Extremity Reconstruction

Reconstructive Ladder/Reconstructive Elevator

After the preoperative evaluation is complete and lower extremity reconstruction has been decided, the type of reconstructive approach must then be selected. The "reconstructive ladder" emphasizes using simple closures before resorting to higher level microsurgical closures [8,9]. The order of the reconstructive ladder starts with primary closure and follows the order of healing by secondary intention, skin grafts, local flaps, distant flaps, tissue expansion, and ultimately microvascular free flaps [46]. The "reconstructive elevator" was later described to demonstrate flexibility in choosing the most appropriate means of reconstruction based on an individual patient's needs. Proceeding to a more complex means of reconstruction, such as a free flap, may be the most appropriate option for a patient with a complex traumatic injury as opposed to a split thickness skin graft. In short, the reconstructive elevator emphasizes choosing the best durable solution based on the patient's needs. [1,2,16].

Timing of Reconstruction

Understanding of the timeframe by which inflammation, fibrosis, and scarring occurs is crucial in the success of flap reconstruction. Originally, Godina's "3-day rule" was the standard, with early studies showing less infection and better rates of free flap survival with better outcomes within the first 72 hours [17,18]. However, newer studies show that Godina's 72-hour window can be extended up to 2 weeks, with a consensus that coverage should be established within 7-10 days after injury [19]. This increase in timing has been attributed to utilization of negative pressure wound vac dressings that have subsequently led to accelerated healing and formation of granulation tissue, decreased tissue edema, decreased bacterial loads, and increased tissue perfusion [20].

Wound Preparation

The foundation of wound preparation prior to definitive closure is debridement of all necrotic tissue to help obtain a healthy wound bed that is free of infection. Devitalized and infected tissue can result in multiple reoperations and, if not treated properly, may result in amputation. Cultures can be obtained to assess for degree of contamination and a threshold of 10^5 bacteria/gram of tissue [17,46]. Systemic antibiotics, serial irrigation and debridement is required for any active wound infection prior to moving forward with definitive reconstruction.

Other goals of wound preparation for reconstruction are to restore vascularity, stability, structure, and function. The reconstruction should obliterate any dead space created in debridement while also providing durable coverage of vital structures.

Principles of Soft Tissue Coverage

Soft tissue coverage of lower extremity reconstruction should ideally replace missing tissue with tissue of similar size, depth, consistency, and function [1,4,8]. Flap types consist of musculocutaneous, fasciocutaneous, perforator flaps, chimeric flaps, propellar flaps, and keystone flaps. The Mathes & Nahai classification of muscle flaps is based on types of pedicle vascularity (**Table 3**, **Figure 1**).

Table 3: Mathes & Nahai classification of muscle vascular supply.

Mathes & Nahai Classification	***Description***	***Example***
Type I	One vascular pedicle	Tensor fascia lata
Type II	One dominant pedicle and minor pedicles	Gracilis
Type III	Two dominant pedicles	Gluteus maximus, rectus abdominis
Type IV	Segmental vascular pedicles	Sartorius
Type V	One dominant pedicle and secondary segmental pedicles	Latissimus dorsi

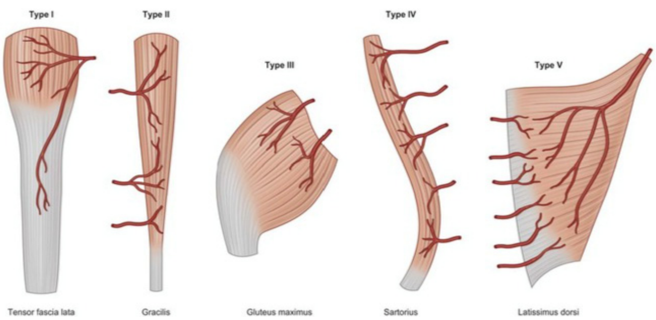

Figure 1: Mathes & Nahai muscle flap types.

Vascularity supplied by myocutaneous flaps was thought to benefit fracture healing and osteomyelitis and in places where extra bulk was needed [2,17]. Since the lower extremity is functionally redundant with compartments of muscles that act in groups, flaps can successfully be harvested without significantly compromising function. While musculocutaneous and fasciocutaneous flaps generally have equivalent outcomes, there has been an increasing shift towards fasciocutaneous flaps as they are less morbid [23,24].

Lower Extremity Reconstruction

Thigh Soft Tissue Reconstruction

The thigh presents multiple options for lower extremity soft tissue reconstruction due to its large size, limited number of compartments, and muscle groups that share similar function and movement. The thigh's vascularity allows for the use of skin grafts (**Figure 2**). Local tissue transfer via V-Y or bipedicled approaches is feasible, and the decision to use ipsilateral or contralateral donor tissue depends on availability. Ipsilateral donor tissue is preferred to limit reconstruction and surgical area to one side and preserve the function of the contralateral leg for ambulation. Larger sized defects or absence of ipsilateral options may require use of contralateral thigh flap.

Figure 2: A 32-year-old man after right femur ORIF after MVA with significant soft tissue loss of his medial thigh. The bulky, healthy musculature of the thigh allowed for successful skin graft take to heal his wound. MVA: Motor vehicle accident; ORIF: Open reduction and internal fixation.

The most commonly used local reconstruction flaps for the thigh include rectus femoris, sartorius, gracilis, vastus lateralis, tensor fascia lata, anterolateral thigh, and biceps femoris. Free tissue transfer is seldom necessary due to the availability of local options.

The sartorius is a Mathes and Nahai type IV flap that can be used for soft tissue coverage as needed and is often employed by vascular surgeons for graft coverage in the group. It has segmental blood supply contributions from the superficial circumflex iliac artery, branches of the superficialis femoris and profunda femoris, and descending geniculate arteries (**Figure 3**). Caution should be taken to preserve the segmental blood supply and avoid vascular complications.

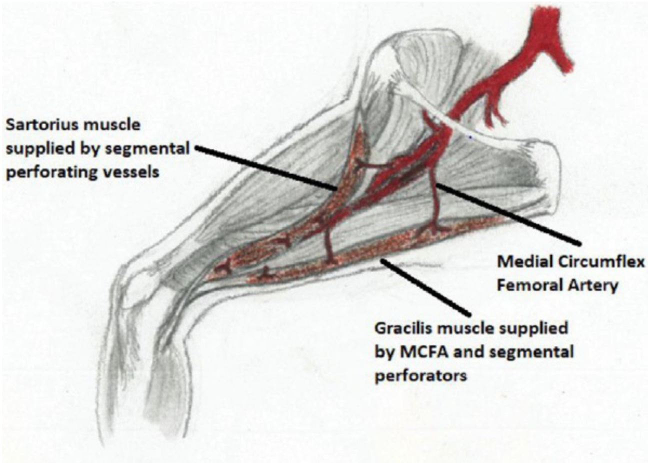

Figure 3: Medial circumflex artery (MCFA) supplying the gracilis and sartorius muscle.

The gracilis is a Mathes and Nahai type II flap that can be used as a myocutaneous or muscle flap. Its main blood supply comes from the ascending branch of the medial circumflex femoral artery, with additional contributions from the superficial femoral artery. This flap can be used as a pedicled or free flap and can maintain motor function via the anterior branch of the obturator nerve if not denervated.

The rectus femoris is a Mathes and Nahai type II flap that can be adapted as a myocutaneous or muscle flap. It has a dominant blood supply from the descending branch of the lateral circumflex femoral artery and minor pedicles from musculocutaneous perforators. The intermediate cutaneous nerve of the thigh can maintain sensation if intact (**Figure 4**).

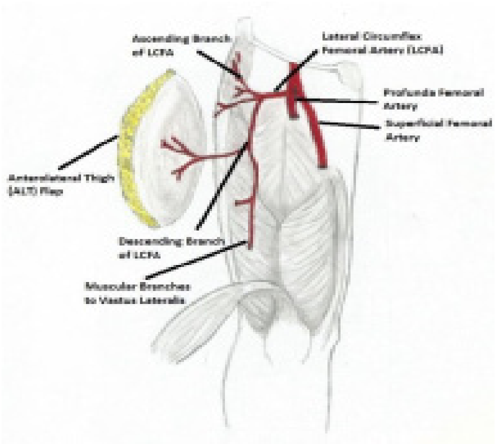

Figure 4: The lateral circumflex femoral artery branches supplying the tensor fascia lata (TFL) muscle, anterolateral thigh (ALT) fasciocutaneous flap, and the vastus lateralis muscle.

The vastus lateralis is a Mathes and Nahai type I musculocutaneous flap that can offer coverage and bulk. Its main blood supply is from the lateral circumflex femoral artery, and the nerve supply runs along the pedicle to provide voluntary control. This flap spans the entire length of the thigh between its origin at the greater trochanter and gluteal tuberosity to the distal insertion at the patella. The tensor fascia lata and anterolateral thigh flaps are chimeric flap options with similar coverage and varying tissue amounts.

The tensor fascia lata is a Mathes and Nahai type I musculocutaneous flap that offers sizable coverage and easy harvesting for soft tissue coverage. It is located superficially to the vastus lateralis and lateral to the sartorius, and its vascular pedicle arises from the proximal-middle thigh from the profunda femoris. Sensation is provided via the lateral femoral cutaneous nerve, and voluntary control is via the descending branch of the superior gluteal nerve. The donor site can be closed primarily, and there is limited donor morbidity.

The anterolateral thigh flap is a fasciocutaneous flap with increasing versatility for coverage. Its blood supply is from the perforating branches of the descending branch of the lateral femoral circumflex that emerges between the rectus femoris and vastus lateralis muscles. Although it lacks the bulk of a muscle flap, it is located near the vastus lateralis and can provide adequate coverage.

A pedicled rectus abdominis muscular or myocutaneous flap is an option for large full-thickness defects in the proximal thigh, groin, or buttocks when local muscle or fasciocutaneous flaps are not feasible. These flaps follow a Mathes and Nahai type III arrangement with dual supply from the deep superior epigastric and deep inferior epigastric arteries. The available skin laxity and tissue in the abdominal region provide ample skin coverage and bulk if needed.

Lower Leg Soft Tissue Reconstruction

Reconstructive options for the lower leg consist of local soft tissue and perforator flaps, which are not always possible depending on the anatomy of the wound. However, some options exist that may reduce the need for a free flap [25].

Upper third: In the upper third of the leg, which is defined by the area immediately surrounding and including the knee the focus is on using local soft tissue options and perforator flaps to reconstruct defects [9,25]. The most commonly used flaps for knee or upper third defects of the lower leg include the gastrocnemius muscle and tibialis anterior muscle flaps. The anterior tibialis muscle is smaller and usually more useful for coverage of defects on the proximal anterior tibia. Other options include propeller flaps from perforators of the 3 major vessels of the lower leg: the peroneal artery, anterior tibial artery, and posterior tibial artery [25]. For the knee, there are also possible perforator flap options from the genicular system. Other options for reconstruction include keystone island perforator flaps.

Middle third: In the middle third of the leg, the soleus muscle is a major workhorse flap for reconstruction [9]. Other options that are limited to smaller defects include the anterior tibialis, flexor digitorum longus, extensor digitorum longus, extensor digitorum hallucis, and longus [29]. Perforator flaps are also viable options for reconstruction with the most robust perforators coming from the posterior tibial artery. Lastly, medial sural artery perforator flaps can be based proximally or distally to provide necessary coverage for defects of the upper and middle lower leg [27,46].

Lower third: In the lower third of the leg, the use of local fasciocutaneous flaps has been shown to be effective and is a great option for tough defects. The distally based or "reverse" sural fasciocutaneous flap is an example of such an option, with the arterial supply coming from the median superficial sural artery that accompanies the sural nerve [9,29]. The pedicle is based on the retrograde flow through perforators from the peroneal artery to the superficial sural.

Foot and Ankle Soft Tissue Reconstruction

The reconstruction of the soft tissues of the foot and ankle poses distinctive difficulties to plastic, orthopedic, and podiatric surgeons [1]. It is crucial to take account the weight-bearing load and compressive forces acting on the foot and ankle when assessing patients for reconstruction. Additionally, an adequately reconstructed foot must withstand the shearing stress caused by bearing weight and conform well to enable comfortable shoe-wearing [30].

General Foot and Ankle Reconstruction

The foot can be classified into seven distinct subunits according to the aesthetic and reconstructive objectives (**Figure 5**). Subunit 1 comprises the dorsal and volar aspects of all toes and requires moderate aesthetic considerations during reconstruction. Reconstruction usually involves free tissue transfer. Subunit 2 refers to the weight-bearing forefoot, which is highly functional and necessitates a durable yet pliable reconstruction. Subunits 3 and 4 include the dorsum of the foot, which is characterized by low function and high aesthetic demand. Here, thin and pliable coverage is necessary. Subunit 5 represents the weight-bearing heel and Achilles region, which has a high functional demand and requires a thicker and more durable kind of coverage. Subunits 6 and 7 correspond to the lateral and medial malleoli, respectively. These regions should be thin but, most importantly, pliable to allow for good ankle movement [31].

Reconstruction of the Plantar Foot

Soft tissue reconstruction of the plantar aspect of the foot can be accomplished through skin grafting or the use of dermal substitutes. Glabrous skin is preferable for skin grafting as it has a reduced risk of hyperkeratotic deposition and contracture as compared to nonglabrous skin [30]. Full-thickness skin grafts harvested from the medial instep or avulsed tissue are also an option [30].

Local and regional flaps can be used for more extensive wounds. Local pedicled and perforator flaps derived from the plantar aspect of the foot are a viable option for reconstruction of the sole of the foot. The medial plantar artery provides a workhorse option for resurfacing adjacent defects through a local perforator flap. The reverse sural flap is a well-studied option for reconstruction of lower one-third wounds of the leg, foot, and ankle [34]. Intrinsic muscle flaps, such as the flexor digitorum brevis flap and the abductor hallucis brevis muscle, are also powerful options for reconstruction. The flexor hallucis brevis muscle can be harvested by itself or in combination with the abductor hallucis brevis for coverage of various foot and heel defects.

Reconstruction of the Dorsal Foot

The utilization of skin grafting and dermal substitutes should be considered in cases of dorsal foot reconstruction when appropriate. In order to achieve the goal of providing a thin, pliable and shear-resistant coverage for dorsal foot reconstruction, thinner coverage options should be considered.

For local flap coverage, the dorsalis pedis artery flap is a feasible option [40]. This flap is versatile for dorsal foot and ankle coverage, being both sensitive and local. The dorsalis pedis artery is a continuation of the anterior tibial artery that terminates in the first dorsal metatarsal artery and the deep plantar artery and has numerous cutaneous branches between the extensor retinaculum and the deep plantar branch [34]. Therefore, the dorsal pedis flap is a viable sensitive fasciocutaneous or myocutaneous flap (including the extensor digitorum brevis muscle) that can be harvested from the dorsum of the foot. Although reconstruction of small defects in the distal portion of the foot can be a challenging task, distally based dorsalis pedis fasciocutaneous flaps have been reported in the literature [41]. As a thin and supple flap that usually fits in its recipient site without bulk, it has also been extensively employed for more proximal defects of the ankle and distal portion of the lower leg.

Another option available is a fasciocutaneous, sensitive flap that can be raised from the dorsum of the foot based distally on the first webspace. The small dimensions of the flap that is supplied by branches of the dorsal and plantar metatarsal arteries and their distal communicating branches. It is a reliable option that is primarily used to resurface defects in the distal foot overlying the metatarsophalangeal joints [42].

Reconstruction of the Medial Side of the Foot

Covering soft tissue defects on the medial side of the foot can be challenging, but local tissue options are available. The medialis pedis flap, based on the medial plantar artery of the hallux or the first plantar metatarsal artery perforator, is a viable option that can be rotated around the medial malleolar area, the Achilles tendon, and can provide coverage for defects in these areas, as well as the posterior aspect of the heel [43,44].

Reconstruction of the Lateral Side of the Foot

Reconstruction of posterior heel and lateral foot defects is challenging due to poor vascularization, osseous bed, and high functional demands. Unfortunately, conservative treatment frequently fails, and options for free flap reconstruction pose unique challenges. The lateral calcaneal flap based on the lateral calcaneal artery provides an important surgical option for hindfoot defects, with the potential to serve as a cutaneous sensitive flap. Along the lateral aspect of the foot, the abductor digiti minimi muscle can serve as a reconstruction for small- to moderate-sized defects with exposed bone, joint, or tendon [37]. This muscle flap receives vascular supply from branches of the lateral plantar artery.

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