Chapter 6
Forefoot Operations

Paul J. Kim

Introduction

The foot is at particularly high risk for injury due to its remote anatomical location and functional requirements. Specifically, wounds can occur for a variety of reasons including acute or repetitive trauma (including burns) or as a direct consequence of a disease such as diabetes mellitus or autoimmune processes (e.g., rheumatoid arthritis) or as a consequence of a treatment for another condition (e.g., radiation, elective or nonelective surgery). Further, repetitive minor trauma can lead to the development and chronicity of a wound due to the forces encountered between the shoe and the foot or the foot and the ground. The forefoot is often the first location where wounds manifest in cases of systemic diseases. This is because of its remote location as well as the decreased soft tissue density covering the bony architecture in this area. The term "wound" and "ulcer" is often used interchangeably. However, more precisely a "wound" should be reserved to describe a soft tissue defect that is more acute, while an "ulcer" denotes a degree of chronicity.

Coverage or closure of a wound is not the only goal of surgical correction in the forefoot. Biomechanical abnormalities are often the underlying reason for development and chronicity of ulcers in the forefoot especially in the environment of underlying systemic diseases [1]. Wound prevention, targeted procedure selection, long-term durability at the wound site, and avoidance of transfer ulcers are all equally important. The surgical treatment of burns, radiation injury, and tumor

Electronic Supplementary Material: The online version of this chapter (https://doi.org/10.1007/978-3-319-66990-8_6) contains supplementary material, which is available to authorized users.

P.J. Kim, DPM, MS (✉)
Georgetown University School of Medicine, Washington, DC 20007, USA

Division of Wound Healing and Hyperbaric Medicine, Department of Plastic Surgery, MedStar Georgetown University Hospital, Bles 1st Floor, 3800 Reservoir Road NW, Washington, DC 20007, USA
e-mail: paul.j.kim@gunet.georgetown.edu

D.P. Orgill (ed.), *Interventional Treatment of Wounds*,
https://doi.org/10.1007/978-3-319-66990-8_6

resection will not be discussed in detail in this chapter. Each of these conditions has their own unique challenges and is out of the scope of this chapter. The focus of this chapter is on biomechanical forefoot surgery related to the chronic or nonhealing wound.

Successful outcome of biomechanical surgery cannot be determined in the operating room but can only be determined when the patient returns to weight bearing and ambulation. This is because the surgical correction addresses the *dynamic* processes during weight bearing and ambulation, while the immediate post-correction examination of the foot in the operating room is a *static* assessment. Maintaining or improving function is the primary goal of surgical correction [2]. This involves selecting the most appropriate procedure and identifying the most appropriate patient. Most wounds will heal with good conservative wound care including the use of dressings, topical ointments, and offloading/immobilization. However, for chronic wounds, surgical correction may be preferred or required to expedite healing and/or address the underlying biomechanical fault.

The fundamentals of patient care apply to forefoot operations including a thorough medical and wound history, a physical examine with a focus on the lower extremity, and an understanding of the patient's expectations for recovery (Table 6.1). The medical history will provide important information as to the healing capacity of the patient including any confounding conditions such as metabolic disorders, diabetes mellitus, renal disease, and cardiac disease. These preexisting conditions will influence procedure selection by limiting the kind of procedure selected based on the patient's capacity to heal and the course of their underlying diseases. A wound is often associated with these underlying conditions, and it should be thought of as one of the manifestations of the underlying disease. For example, a patient with diabetes mellitus may also have peripheral neuropathy and peripheral vascular disease. In this environment, an acute wound can progress to a chronic nonhealing ulcer. Underlying medical problems are important determinants in surgical selection which will be discussed in greater detail in the following paragraphs.

The patient's expectations should also be carefully considered. The patient is typically concerned about esthetic and functional outcomes of surgery. The surgeon should focus the discussion on achieving realistic functional goals. It is important to manage these expectations by having a frank discussion with the patient that biomechanical surgical correction of the forefoot is necessary to heal the ulcer or to prevent one from occurring. The patient may not understand the relationship between the ulcer and the planned biomechanical surgical procedure or understand the nuances of the deformity and the probability of ulcer occurrence. Thus, more time should be spent describing the pathological processes rather than the technical aspects of the surgical technique. Postoperative recovery time including the time needed for nonweight bearing and limited weight bearing should be clearly described. The likelihood of postoperative complications including infection and dehiscence, which occur at higher rates in the compromised population, should also be discussed [3]. Further, the fact that the long-term outcomes of biomechanical surgery are not always predictable and that additional surgeries may be required

Table 6.1 Critical preoperative planning

	Considerations	Comments
Medical history	Comorbidities and medications can contribute to the development and/or chronicity of a wound	Regardless of the treatment rendered, the wound may not heal if the underlying systemic disease is not addressed. An example of this is a patient with an autoimmune disease such as rheumatoid arthritis. In this case both the disease itself as well as medications used for its treatment may inhibit or delay postoperative healing. Communication with a rheumatologist to align good disease management with the surgical plan is critical
Wound history	Important questions need to be answered including why did the wound start, when did it start, what treatments have already been employed? Includes wound trajectory (through wound size and quality documentation) to determine whether healing can occur without surgical intervention	The lack of wound healing progress should trigger a deeper examination. Perhaps there is an infection or biofilm. Is there adequate perfusion to the wound site? Are biomechanics the key contributor? Is there a combination of factors that need to be addressed? Most often a combination of factors lead to wound chronicity
Physical examination	A thorough vascular, neurological, dermatological, and musculoskeletal exam with a focus on identifying biomechanical abnormalities is required The apex of the deformity must be identified and addressed	This examination should be performed with each visit and at the time of surgery. These aspects may change over time, especially with changes in underlying medical conditions and medications
Patient's goals and expectations	A quick surgical recovery and return to daily activities Maintain or improve the appearance of their foot. Maintain or improve their quality of life	A frank discussion is needed regarding what the surgery involves and the recovery time needed including periods of nonweight bearing and partial weight bearing The patient may have unrealistic expectations for the outcomes of surgery. Function should be the focus of the discussion with a clear description of the appearance of the foot after healing has occurred Despite good surgical planning and strict adherence to the treatment course, the outcome is not always predictable The patient should understand that there may be a need for accommodative devices including custom-molded inserts, braces, and shoes after healing has occurred

(continued)

Table 6.1 (continued)

	Considerations	Comments
Surgeon's goals and expectations	The goal of surgical intervention is to maintain or improve function	Surgical intervention may not a be a one-time event. A staged approach may be necessary and revision surgery may be required in the future Complications can occur, especially with patients with underlying comorbidities. These should be expected and addressed promptly

should be carefully explained to the patient. This is because surgical procedures are inexact in correcting the underlying biomechanical fault, and the physiology and the functional demands of the patient change over time. The patient may require life-long use of a modified shoe, custom-molded insert, ankle-foot orthoses, brace and the use of assistive devices (cane, crutches, walker, wheelchair). The management of the patient's expectations is as important as the surgical procedure itself.

Anatomy and Biomechanics

A critical piece of a focused lower extremity physical examination includes the assessment for perfusion. The ulcer may be the result of compromised perfusion due to an underlying disease process or loss of local vasculature. Hence, understanding the etiology is important. Further, the degree of perfusion may dictate the surgical procedure selected and the ultimate outcome. The foot is fed by three large arteries: anterior tibial (AT), posterior tibial (PT), and peroneal. All three arteries feed different angiosomes of the forefoot. An angiosome is a block of tissue fed by a named source artery [4]. The AT artery becomes the dorsalis pedis (DP) artery as it crosses the ankle and have multiple distal branches and feeds the dorsal aspect of the forefoot. The PT artery has two main branches, medial and lateral, which feeds the plantar forefoot. The DP and PT have arterial to arterial connections in the forefoot that is primarily located at the proximal interspaces of the metatarsals. This redundant blood supply in the forefoot is an important anatomical consideration if one of the main arteries are compromised. The peroneal artery feeds the lateral aspect of the forefoot.

The palpation of the main arteries is the critical first level of assessment for perfusion. These arteries should be further assessed utilizing an audible handheld Doppler. Peripheral arterial disease can progress from a triphasic to biphasic to monophasic and finally to no signal. More advanced noninvasive modalities including ankle-brachial index/toe-brachial index, transcutaneous oximetry, skin perfusion pressures, and noninvasive angiography should be considered if there is any suspicion of compromise [5]. Contrast angiography may be necessary to determine the degree of vascular compromise, for the purposes of intervention, or for surgical planning for open bypass. It is important when contrast angiography is utilized that the forefoot is also imaged in multiple planes. Ultimately, perfusion must be adequate enough to heal soft tissue and/or bone. Thus, identifying the level of perfusion as well as maximizing perfusion to the affected area is critically important in surgical planning of the forefoot.

The musculoskeletal anatomy of the foot is directly related to function (Table 6.2). The forefoot is defined as the anatomical structures distal to the metatarsal cuneiform joint (Lisfranc's joint). The toes consist of small long bones with articulations. The hallux has one interphalangeal joint, while toes 2–5 typically have 2 interphalangeal joints. The toes articulate with its corresponding metatarsals 1–5. Although sesamoids can occur anywhere in the foot, the tibial and fibular sesamoids under the first metatarsal head are consistently present and are responsible for changing the axis to enhance the mechanical advantage of flexor hallucis longus. The 1st metatarsal articulates with the medial cuneiform, the 2nd metatarsal with the middle cuneiform, the 3rd metatarsal with the lateral cuneiform, and the 4th and 5th metatarsal with the cuboid. Extrinsic (those that originate from the lower leg) and intrinsic (those that originate within the foot) muscles attach through tendons to the distal foot. The opposing muscles of flexors/extensors, invertors/evertors, and adductors/abductors work in concert to align the foot dynamically during ambulation for efficient shock absorption and propulsion. The skeletal architecture is bound by capsules and ligaments to provide structural rigidity while allowing a small degree of flexibility. Each joint has a unique articular configuration with an axis of rotation. Veins and lymphatics are also important in the foot with the importance of the arterial network discussed above.

The soft tissue envelope of the foot is specially designed to be durable. The skin on the dorsal aspect of the foot is different than the plantar aspect of the foot. The glabrous junction delineates the plantar and dorsal skin. The plantar skin consists of a thicker dermis with a more robust subcutaneous layer which envelops the foot in a moccasin distribution allowing for protection anteriorly/posteriorly and medially/laterally to a small degree. The epidermis and dermis of the plantar foot resist penetration, while the subcutaneous layer disperses shock [6].

The foot can be segmentally divided into sagittal plane columns which function as discrete collective units. The medial column includes the hallux, 1st metatarsal, and cuneiform, the central column consists of metatarsals 2 and 3 and their corresponding middle and lateral cuneiforms, and the lateral column includes the metatarsals 4 and 5 and the cuboid. This columnar division is both anatomical and functional. The medial and lateral columns are considered to have a greater degree of motion in the sagittal and frontal plane than the central column which has relatively less available excursion. This distinction becomes important for surgical procedure selection which will be further discussed in the following paragraphs. The anatomical relationship of the columns can be seen globally in the foot type. Pes planus refers (colloquially described as "flatfeet") to a foot type with a depressed or collapsed medial column, to a lesser degree the lateral column, which can be rigid or nonrigid and may have a valgus (everted) frontal plane rotation. The pes cavus foot type (colloquially described as "high-arched feet") refers to when the medial column, to a lesser degree the lateral column, is elevated which is generally rigid

Table 6.2 Musculoskeletal anatomy and function

	Anatomy	Function
Phalanges (digits)	Long bones with two interphalangeal joints with the exception of the hallux which has one interphalangeal joint Contains both intrinsic and extrinsic muscle tendon insertions	Primarily a sagittal plane range of motion The digits are important for balance and as well serving as a lever arm during propulsion The hallux is a critical digit for forefoot function
Metatarsals	Long bones that articulate with the digits distally and the cuneiforms or cuboid proximally The tibial and fibular sesamoid is located under the first metatarsal head. Other accessory bones can be present in other locations throughout the foot The intrinsic muscle tendon insertions are located about the metatarsal heads around the metatarsal phalangeal joint complexes. Direct extrinsic muscle tendon insertions to the 1st and 5th metatarsal bases	Primarily a sagittal plane range of motion with the 1st and 5th metatarsal with a smaller degree of frontal plane range of motion Significant forces are imparted through the metatarsals during the weight-bearing portion of the gait cycle This includes during the midstance phase of gait and especially during propulsion Pressure is isolated across the metatarsal heads (and to a lesser degree the digits) with heal lift The parabola of the metatarsals provides even pressure distribution
Cuneiforms	Three wedge-shaped bones that articulate with its corresponding metatarsals. Medial cuneiform with the 1st metatarsal, the middle cuneiform with the 2nd metatarsal, and the lateral cuneiform with the 3rd metatarsal Multiple ligamentous attachments exist across the Lisfranc's joint as well as direct tendon insertions from the anterior and posterior tibial muscles	The relative range of motion of the cuneiforms are limited Provides stability of the forefoot on the midfoot especially during propulsion Maintains the integrity of the medial column
Cuboid	A cube-shaped bone that articulates with the 4th and 5th metatarsals Has no direct tendon insertions; however, the peroneus longus traverses in a groove on the plantar aspect	Similar in function to the cuneiforms with less range of motion Maintains the integrity of the lateral column
Medial column	Includes the hallux, 1st metatarsal and medial cuneiform	Functional units that work collectively for maintenance of the medial arch during weight bearing, shock absorption during midstance, and stability during propulsion Has the greatest degree of axis of rotation as compared with the other columns

(continued)

Table 6.2 (continued)

	Anatomy	Function
Central column	Includes the 2nd and 3rd toes, 2nd and 3rd metatarsals, and middle and lateral cuneiforms	Functional units that work collectively for maintenance of stability with weight bearing Has the most limited degree of axis of rotation as compared with the other columns
Lateral ray column	Includes the 4th and 5th toes, 4th and 5th metatarsals, and the cuboid	Functional units that work collectively for maintenance of the lateral arch during weight bearing, shock absorption during midstance, and stability during propulsion Has the 2nd greatest degree of axis of rotation as compared with the other columns

and may have a varus (inverted) frontal plane rotation. Further segmentation of the columns is called rays which include the digit with its adjoining metatarsals. Beyond the sagittal plane columns, the foot can be further segmented into frontal plane segments: forefoot, midfoot, and hindfoot. For the purposes of this chapter, the forefoot has already been defined. However, it is important to recognize that the forefoot, midfoot, and hindfoot are functionally interdependent. Thus, the forefoot should not be viewed in insolation; the foot should be examined globally with the knowledge that the surgical correction will affect all segments of the foot.

The anatomy of the forefoot reflects the biomechanical requirements for efficient ambulation. This includes the ability to stand and balance in a stationary position and propel the body forward during ambulation. The foot is best described as both a flexible adaptor and a rigid lever which reflect the demands during the gait cycle. There are two phases of the gait cycle, swing and stance. The swing phase involves advancing one of the lower extremities forward through the air with each step, while the contralateral limb is in a fixed, stationary position. The extensor muscles below the knee contract to clear the forefoot from the ground by dorsiflexing the toes at the metatarsophalangeal joint and the foot at the ankle joint. The stance phase of the gait cycle begins with heel strike during which the heel impacts the ground. Midstance occurs when the entirety of the foot is in contact with the ground, and during this period the foot functions as shock absorber. Heel lift ends the stance phase of gait and begins the propulsive phase with active plantarflexion of the toes at the metatarsophalangeal joint and the contraction of the extrinsic and intrinsic plantarflexory muscles against the ground. The foot functions as a rigid lever for propulsion. During this period, the pressure is distributed focally across the balls of the foot (across the metatarsal heads) and to a lesser degree the toes with the heel off the surface of the ground. The body is propelled forward, and the gait cycle repeats itself. The physical examination should include evaluation of the lower extremity and any associated pathologies while standing and walking (Table 6.3).

Table 6.3 Deformity and examination

Deformity	Description	Examination	Wound location
Pes planus	Collapse of the medial arch	Can be either rigid or nonrigid with range of motion of the medial column Can affect the relative position and range of motion of the bones in the forefoot causing other structural conditions included in this table	In the rigid condition under the medial column and lateral columns Other wound locations related to the other pathologies list in this table
Pes cavus	Raised medial arch	Generally rigid with limited range of motion at the midfoot Can affect the relative position and range of motion of the bones in the forefoot causing other structural conditions included in this table	Can cause increase pressure across the plantar aspect of the metatarsal heads causing wound development and/or chronicity in these locations Wounds can occur on the dorsal aspect of the midfoot as well due to rubbing in shoes
Hammer toes	Flexion contracture of the digit at interphalangeal joint(s)	Manual range of motion should be conducted to assess the degree of reducibility at the interphalangeal joints Can cause retrograde buckling at the metatarsophalangeal joint	Digital ulcers at the distal tip is a common location Dorsal interphalangeal joint ulcers can occur from rubbing in shoes Sub-metatarsal head ulcers can occur due to the retrograde buckling
Hallux abducto valgus (bunion)	Abduction of the hallux and medial deviation of the 1st metatarsal	1st metatarsal phalangeal joint deviation or subluxation causes limitation of range of motion at this joint Limited to no reducibility of the medial deviation and dorsal excursion of the 1st metatarsal	Medial aspect of the 1st metatarsal head Plantar medial aspect of the hallux interphalangeal joint Sub-2nd metatarsal head due to pressure transference
Tailor's bunion	Lateral deviation of the 5th metatarsal typically associated with a abductovarus rotated 5th digit	The dorsolateral eminence is obvious and is easily palpable due to the relatively thin soft tissue coverage in this area	Lateral aspect of the 5th metatarsal head Lateral aspect of the 5th toe if the digit is rotated Sub-4th metatarsal head due to pressure transference

(continued)

Table 6.3 (continued)

Deformity	Description	Examination	Wound location
Hallux rigidus	Degenerative process of the 1st metatarsal phalangeal joint	Limitation or absence of dorsiflexion with crepitus with range of motion Palpable dorsal or dorsomedial bone spurs	Sub-1st metatarsal head Plantar aspect of the hallux interphalangeal joint
Parabola asymmetry	Irregular length of digits, metatarsals or rays/columns	The physical examination may not reveal this condition. Plain film radiographs are typically needed to evaluate for relative bone or segment length differences	Distal toes Sub-metatarsal heads A short segment can cause adjacent segment wounds A long segment typically causes wounds directly along this segment

Forces are experienced by the foot with weight bearing and ambulation. In the case of wound caused by an acute trauma in an otherwise healthy patient, it may not be as important to consider the forces experienced in the foot. In the compromised patient, repetitive minor trauma may lead to the development and chronicity of ulcers. Thus, deleterious forces must be analyzed and addressed. These forces are experienced between the foot and the shoe or the foot and the ground. This is classically seen in the diabetic patient with peripheral neuropathy. In the insensate foot, the normal mechanism of protecting or offloading the traumatized area in response to noxious stimuli is limited or absent. Therefore, repetitive trauma to the skin goes unrecognized by the patient. This is especially dangerous in the environment of ischemia in the compromised host [7].

Prolonged, excessive, or repetitive forces can cause skin breakdown. There are two important types of forces encountered in the foot. The sagittal plane and shear force. The sagittal plane force is a downward force of the foot to the surface of the shoe or ground. These sagittal plane forces in the foot are referred to as peak plantar pressures which can be measured with an off-the-shelf device [8]. A focal callous is often the precursor to ulceration [9]. The callous is part of the reparative process of the skin and is formed in response to repetitive sagittal plan forces. Shear forces are experienced in the transverse and/or frontal plane between the underlying bone and the skin envelop and/or the skin and the surface of the shoe or ground. This is a force experienced in a side-to-side, front-to-back, or rotational direction [10]. Their forces are more difficult to measure, and there is no commercially available platform for its detection. The classic physical sign of a shear force is the formation of a blister where the epidermis is separated from the dermis. A broad callous can also signify abnormal shear forces. Sagittal and shear forces manifest in a characteristic ulcer shape. The sagittal plane-induced ulcer is typically symmetrical and circular in shape (e.g., 2 × 2cm). Shear force ulcers are typically asymmetrical and oval in shape (e.g., 2 × 3cm). The forefoot experiences these forces when weight bearing and during ambulation. Once the predominant deforming force is identified, the most appropriate surgical procedure can be selected to address it.

Operative Preparation

The success or failure of an operation is less dependent on the technical aspects of the procedure itself but more on the perioperative preparation. The perioperative preparation has several aspects including appropriate patient selection, the physical examination of the deformity, relevant laboratory and imaging, and intraoperative considerations. All of these variables should be carefully considered prior to performing the procedure.

The patient's expectations are important, but it is also the responsibility of the surgeon to identify potential challenges to a successful outcome. In other words, procedure selection should be based on what is the best fit for the patient. This includes the rehabilitation capacity of the patient and adherence to the postoperative plan. Rehabilitation potential is based on factors including age, body mass index (BMI), muscle strength, comorbidities, home environment, and socioeconomic factors. Some patients have a decreased capacity to heal or on medications that delay healing (e.g., long-term steroid use, or other disease modifying medications). The patient may also have a high BMI which may cause difficulties in offloading.

Medical optimization includes nutrition optimization, blood glucose control, short-term reversal of anticoagulation, and stabilization of chronic disease processes (e.g., cardiac function). Thus, coordination with the patient's primary care provider is important beyond that of obtaining a medical clearance for surgery. All operations have inherent risk due to anesthesia even though most forefoot surgeries are not lengthy and can be conducted with monitored anesthesia care with local anesthetic blocks. Further, if the underlying etiology of the wound is a consequence of an underlying medical condition, and this condition is not addressed, the surgical procedure will fail. For example, if a rheumatoid patient has a digital ulcer and is not medically managed, the incision will not heal, or the procedure may succeed in the short term but may not be a durable correction. Friend and family support dynamics and their willingness to assist the patient in recovery are also important. A less appreciated but perhaps a significant factor includes the patient's socioeconomic status. For example, the patient's insurance coverage and access/transport for the follow-up clinic visits and to physical therapy may impact the surgical outcome.

Beyond the vascular assessment discussed in the previous section, the reducibility of the deformity will dictate procedure selection [11]. The reducibility of the deformity is related to the anatomical and biomechanical aspects discussed above. The concept of reducibility (flexibility) is dependent on whether the deformity can be realigned (reduced) into a biomechanical neutral (rectus) position that decreases the deforming force(s). A nonreducible deformity is one that is rigid and cannot be manually manipulated into a rectus position. There is a spectrum of reducibility so

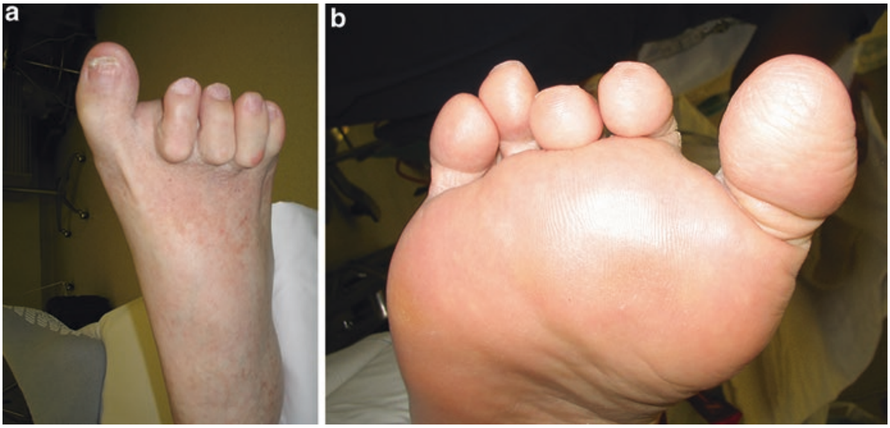

Fig. 6.1 (**a**) A dorsal view of the forefoot. There is deviation of the hallux and contractures of the toes. Note the erythema over the dorsal aspect of the proximal interphalangeal joint of the 4th toe due to rubbing in the shoe. (**b**) A plantar view of the same patient. Note the retrograde buckling at the metatarsophalangeal joint caused by the digital contractures causing an increased pressure across the balls of the foot

it is not absolutely in one state or another. The physical examination includes the assessment of the range of motion of the joints of the foot which will assist in determining the reducibility of the deformity (Fig. 6.1). For example, if a patient has a medial deviation of the first metatarsal (e.g., hallux abducto valgus deformity) and it cannot be laterally displaced with manual manipulation, then this deformity is considered fixed or rigid.

The general approach for procedure selection based on the concept of reducibility is the that a reducible deformity can be addressed using soft tissue correction, whereas a nonreducible deformity requires osseous correction (Fig. 6.2). The exception is when there is gross joint instability wherein an osseous correction is indicated. A deformity may require a combination of soft tissue and osseous correction because the deformity may contain both reducible and nonreducible components. However, a nonreducible deformity can rarely be surgically corrected with a soft tissue correction alone. Further, the apex of the reducibility or nonreducibility should be identified and should be the target of the correction. There may be multiple apices of the deformity which requires a sequential reduction of the deformity at each of these locations. The physical examination should include viewing the unshod patient while standing and walking which may accentuate the deformity. In other words, the deformity may be uncovered under these conditions. For example, on the examination table, the medial arch may be high, but with weight bearing, the medial arch may collapse which would indicate a reducible deformity. This is important to procedure selection.

Imaging is also helpful for surgical planning to determine the degree of reducibility, anatomical relationships around the deformity, and detect the presence of infection or other pathological processes. Plain film radiographs should be taken as

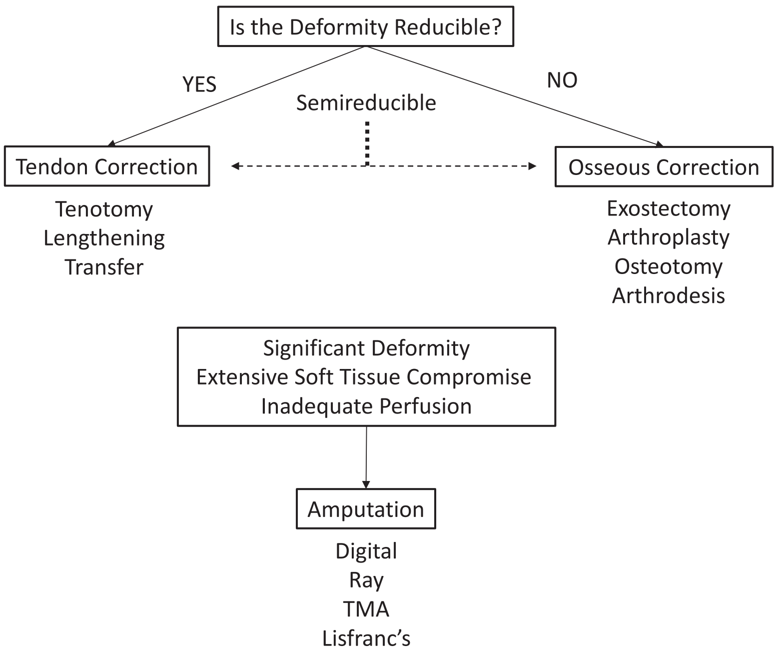

Fig. 6.2 A simple algorithm for procedure selection in the forefoot based on a biomechanical exam focused on the reducibility of a deformity

the initial imaging modality with advanced imaging as necessary. The plain films should be preferably weight bearing, three views (anterior-posterior, oblique, lateral), which includes the entirety of the foot. Other plain films include three views of the ankle and coned-down forefoot views as necessary. Anatomical variations can be readily identified including differences in metatarsal length and joint morphology. Pathological processes identified by the plain films including joint degeneration and infection which will also guide the surgical plan. Of note, joint degeneration is often related to a nonreducible deformity which again will assist in understanding the deformity and in the most appropriate procedure selection.

There are unique intraoperative considerations due to the anatomical location of the forefoot. Local anesthetic blocks are very effective in the foot for intraoperative and postoperative pain control and will speed postoperative recovery [12]. An ankle block involves anesthetizing the posterior tibial, anterior tibial, and peroneal nerves as they cross the ankle. In the case of the forefoot, a more distal block may be all that is required. For example, an isolated digital block may be all that is needed thereby limiting the region of anesthesia. It is important to coordinate the sedation that is provided by the anesthesiologist with the administration of the local anesthetic. The choice of local anesthetics includes Lidocaine and Marcaine. The author recommends the use of 0.5% Marcaine plain due to its tolerability and longer duration of activity although there is delay in onset of activity for 10–15 min. The use of epinephrine is not needed for hemostasis in forefoot surgeries and can be a complicating factor for the vascularly compromised patient. Preoperative and postoperative antibiotics in the compromised host should be conducted routinely; the presence of wound in the non-compromised host is in itself an indication for antibiotics especially if internal fixation is used. An ankle tourniquet set at 250 mmHg for no greater than 1.5–2 contiguous hours is safe and useful for efficiency but is not absolutely necessary [13]. For the vascularly compromised patient, the use of a tourniquet can compromise the ability to visualize the degree of local perfusion. Further, depending on the kind of anesthesia used, the patient may not be able to tolerate inflation of an ankle tourniquet. In the case where an ankle tourniquet is used, it may be necessary to communicate with the anesthesiologist that a deeper level of sedation is needed. It is recommended that the tourniquet be deflated prior to incision closure to obtain hemostasis to prevent hematoma formation. Other specialized equipment for forefoot surgery includes mini or small bone fragment fixation trays and sagittal saw with smaller blades (101 or smaller). Pulsatile or nonpulsatile irrigation prior to closure utilizing antibiotic or surfactant impregnated or unimpregnated solution prior to closing the soft tissue is recommended. Closed suction drains may be helpful to be prevent hematomas and seromas particularly after partial foot amputations. Drains are not typically necessary for any other types of forefoot procedures. Deep venous thrombosis prophylaxis should also be considered due to potentially prolonged immobilization after forefoot surgery.

Surgical Procedures

General surgical principles apply to forefoot surgery. This includes gentle tissue handling and meticulous dissection. Wound bed preparation is especially important in the presence of a chronic ulcer. This includes infection/biofilm eradication, maximization of perfusion, and local edema control. Excisional debridement of the wound should be conducted to remove nonviable and senescent tissue [14]. In the presence of active infection, a staged surgical approach through initial decompression, serial debridements, followed by the definitive procedure is recommended. This is especially important if the surgical plan includes the use of internal fixation because any remaining infection can proliferate in the presence of internal hardware. It is reasonable to make an incision through the wound in order to perform surgical procedures in the forefoot. If it is not clear whether or not the wound is free of infection/biofilm, a separate incision should be made at a different location. Ideally the wound is excised in its entirety allowing for removal of nonviable tissue, infection/biofilm, and for direct access to the surgical site.

Fixation of bone can include internal and external constructs. The general principles of bone fixation apply including maintaining as much of the periosteum as possible, adequate preparation of opposing bone surfaces, and stabilization. The use of internal fixation utilizing wires, screws, and plates are used in the forefoot. External fixation utilizing a mini-rail that spans the bone segments with pins that percutaneously penetrate the skin is sometimes necessary if internal fixation is not desired.

The goal of biomechanical surgery is to reduce the deformity to a neutral position where forces are more evenly distributed. In this way, the wound heals, remains healed in the long term, and prevents the development of new wounds in other locations. Often a combination of procedures that include soft tissue, tendon, osseous, and amputations are performed in concert to address the wound and the underlying deformity. A detailed technical description of each of the procedures is out of the scope of this chapter. The focus of the remaining sections will be on the important principles and rationale for the more commonly performed procedures.

Soft Tissue Plastic reconstructive principles apply to the forefoot including primary closure and the use of grafts. Healing through secondary intention after operative excisional debridement is possible with or without the use of an adjunctive negative pressure wound therapy device. Primary closure or coverage of the wound is often the preferred method. Primary closure should be conducted under little to no tension across the incision line. Local tissue advancement flaps including bilobed, V to Y, and transpositional techniques can be used to close wounds by utilizing the surrounding tissue.

Grafts can be autologous, allografts, or animal-derived tissue which can be used to terminal epithelialization. Autologous grafts should be the considered as the first option in most cases. The split-thickness skin graft (STSG) can be harvested from the thigh, calf, or medial arch. STSG should be pie crusted to allow for evacuation of fluid to prevent a hematoma or seroma. Fenestration utilizing a mesher is usually not necessary for the forefoot because the wounds are generally smaller so there is not a need for STSG expansion to increase its surface area. STSG can be applied to the plantar surface of the forefoot, but dressings and offloading devices should be used to attempt to eliminate shearing of the graft from the surface of the recipient site. A STSG can be applied to deeper wounds with exposed muscle and tendon. However, with contraction of the muscle, the STSG may shear off. Typically, a dermis is necessary to cover deeper exposed tissue prior to the application of a STSG. A choice of human cadaver allograft or animal-derived tissue containing a collagen matrix can be used to build a neodermis. If either are utilized, the application of the STSG should be conducted after the production of a vascularized neodermis which typically takes between 3 and 4 weeks. Other bioengineered alternative tissues are available for surgical use [15]. This includes a variety of processed tissues (e.g., intestinal submucosa, pericardium, tendon, cartilage) harvested from mammals and fish. Further, human fetal foreskin, amniotic tissue, amniotic/placental tissue, and cultured cells containing growth factors and mesenchymal stem cells have been described [16]. Their clinical effectiveness has not been fully elucidated and have been used almost exclusively in the clinic setting. Free tissue transfers are also a viable option in the forefoot for larger defect coverage and will be discussed in another chapter.

Tendon Procedures Tendon surgery is broadly categorized into tenotomies, lengthenings, and transfers (Table 6.4). Certainly, soft tissue deformity includes ligament

Table 6.4 Tendon procedures

Indication example	Procedure	Comment
Digital contractures	Tenotomies	Complete transection of the tendon through percutaneous or open technique
Digital contracture with retrograde buckling at the metatarsophalangeal joint contracture	Tendon lengthening	Typically, the tendon is lengthened by hemisectioning at two locations, one distal and one proximal, along the tendon substance in opposite directions with a midline incision connecting the medial and lateral incision. This creates the Z configuration
Hallux contracture with associated retrograde buckling and plantarflexion of the 1st metatarsal head	Tendon transfer (e.g., Jones tenosuspension)	The extensor hallucis longus is detached at its insertion and rerouted through the neck of the 1st metatarsal and anastomosed onto itself. This tendon essentially functions as a sling by elevating the distal aspect of the 1st metatarsal

and capsular contractures caused by its adaptation to its deformed position. These can be addressed through incisions through the capsule and/or ligaments thereby releasing the contractures during the surgical procedure. As discussed in the previous section, the effectiveness of tendon procedures is predicated on a reducible deformity. A contracted joint can be caused by a biomechanical imbalance of the opposing muscle groups. Thus, diminishing the deforming force through tendon surgery can reduce this imbalance [17]. The physical exam of the forefoot can reveal a taut or bowstrung tendon which is more obvious for the extensor tendons versus the flexor tendons due to the relative thin soft tissue coverage dorsally. The outcome of these procedures cannot be readily predicted on the operating room table. There is a misconception that an increase in the range of motion on the operating room table signifies success. However, since these procedures address the dynamic imbalance, the ultimate outcome is observed during weight bearing during ambulation. A healed wound without recurrence or relocation is the definitive indicator that the procedure was correctly chosen.

A tenotomy is a procedure that completely transects the tendon. This technique is used frequently and effectively for reducible flexion contraction deformities of the toes (e.g., claw toes, hammer toes) [18]. These deformities result in digital tip ulcers and/or ulcers on the dorsal aspect of the interphalangeal joints. Traditionally, a small blade is introduced into the plantar IPJ crease percutaneously or through a small open incision, and the flexor digitorum longus and brevis are transected.

Tendon lengthening typically involves hemisectioning the tendon in a more controlled fashion. This procedure can be performed percutaneously or open. The typical incision into the tendon is conducted in a frontal or sagittal plane Z orientation (Fig. 6.3, Video 6.1). The tendon can be anastomosed side-to-side or end-to-end in the new elongated position. A commonly conducted example of this type of

Fig. 6.3 An intraoperative photograph of a tibialis anterior tendon lengthening open sagittal plane Z lengthening. The proximal and distal incisions have already been conducted. The photograph depicts the midline central incision being conducted. This procedure was performed for a patient with plantar 5th metatarsal head ulcer caused by a reducible varus loading on the lateral column

procedure is the Achilles tendon lengthening (TAL). The TAL can be conducted percutaneously or in an open fashion along the distal 1/3 of the Achilles tendon. This procedure is performed to heal plantar forefoot ulcers by decreasing the plantarflexory force of the posterior leg muscle group [19]. This technique utilizes a triple hemisectioning approach commonly performed percutaneously through three incisions into the tendon alternating from midline lateral-medial-lateral.

The tendon transfer involves rerouting a tendon from one location to another. This procedure involves detaching part or all of a tendon from its insertion and relocating and reattaching via anchor or screw (with or without a washer) to the surface of another bone. Alternatively, if the tendon is long enough, the tendon can be rerouted through the bone and anastomosed onto itself. The concept is to decrease the deforming force in one location and augment the opposing force. An example of this kind of procedure is the Jones tenosuspension [20]. This procedure is used when retrograde buckling of the hallux occurs, and there is an increase in the pressure under the 1st metatarsal head causing ulcer formation or chronicity. In this case, the extensor hallucis longus tendon is one of the major causes of this buckling. This tendon is transected near its insertion and rerouted through the 1st metatarsal neck and anastomosed to itself. This tendon now functions as a sling and elevates the first ray as well as eliminating the retrograde buckling of the hallux. The interphalangeal joint is fused at the same time to prevent hallux claw toe contracture.

Osseous Procedures Osseous procedures involve the removal or realignment of bone or fusion of joints (arthrodesis) (Table 6.5). Any one of these procedures or the combination of these procedures can be conducted for the same surgical case. Thus, the selection of the most appropriate procedure depends on other factors as discussed in the previous paragraphs. Osseous procedures are typically performed for nonreducible (rigid) deformities or for joint instability in the case of fusion of joints. The use of plain film radiographs and/or advanced imaging is helpful for these procedures to determine osseous relationships for surgical planning. A radiopaque marker placed at the wound site allows for visualization of the wound in relation to the underlying bony structures. Abnormal angular relationships between osseous structures in the forefoot can be identified and templated for correction utilizing plain film radiographs or computerized tomography (CT). The degree of technical complexity advances from exostectomies, arthroplasties, and osteotomies to arthrodesis.

Bone resection procedures include exostectomies and arthroplasties. An exostectomy is utilized to remove a bony prominence which can be located plantarly, dorsally, medially, or laterally. A plantarly located bony prominence is particularly problematic causing the development of a wound or contribute to the chronicity of the wound. Although this procedure is simple in concept and execution, if there is continued underlying instability of the bone segment or joint, the ulcer will recur with weight bearing. An example is a collapse of the medial column at the 1st metatarsal cuneiform joint causing a plantar ulcer. An exostectomy can be performed to remove the prominence. However, if the joint is unstable there will be further collapse with weight bearing causing the area to become prominent again thereby leading to ulcer recurrence [21]. An arthroplasty refers to procedures that remove segment of bone around joints most often including the cartilaginous surface. An example in the forefoot is resecting the head of the proximal phalanx of a digit for the correction of a nonreducible hammertoe deformity with an overlying ulcer at the proximal interphalangeal joint or distal tip of the toe. Percutaneous fixation with a Kirschner wire can be used to maintain correction until the surrounding soft tissue adapts to its new position. An isolated metatarsal head resections or multiple metatarsal head resections can be conducted for ulcers on the balls of the feet.

Osteotomies are procedures that involve cutting through and realigning bone. The bone segment is then fixated in its new position using internal and/or external hardware. Osteotomies can correct for angular deformities or shorten or lengthen bone segments. For example, a long 2nd metatarsal creates an abnormal parabola which can cause a focal area of pressure on the plantar aspect of the foot [22]. The altered pressure distribution may result in a nonhealing ulcer. Shortening of the metatarsal by cutting through the metatarsal obliquely and shifting the segment proximally will reduce the area of increased pressure. Typically, fixation is required using a wire, screw, or plate.

Table 6.5 Osseous procedures

Indication	Procedure	Comment
Pes planus		The selected procedure will depend on the degree of deformity. Midfoot and rearfoot surgery is often needed for more complex deformities
	Exostectomy	Exostectomies are most effective for less complex, stable (without progressive collapse) deformities of the medial column
	Arthrodesis	Arthrodesis of the 1st metatarsal cuneiform joint can be performed with angular cuts to reduce the deformity or through the use of wedge-shaped bone grafts
Pes cavus	Osteotomy	Dorsally based osteotomies of the metatarsals can elevate the metatarsals. The apex of the deformity has to be identified which may be in the midfoot and/or rearfoot. In this case, metatarsal osteotomies would be ineffective
	Arthrodesis	Arthrodesis can be performed for more severe deformities utilizing a dorsally based wedge resection across the Lisfranc's joint
Hammer toes	Exostectomy	Exostectomy can be effective for removal of prominent condyles or bone spurs that may underlie the ulcer
	Arthroplasty	Removal of the head of the proximal or middle phalanx of the toe will allow for reduction of a nonreducible digital contracture deformity
	Arthrodesis	This may include resection of the base of the corresponding more distal phalanx to perform an arthrodesis
Hallux abducto valgus (bunion)	Exostectomy	An exostectomy of the dorsomedial eminence does not directly address the biomechanical problem. However, the resection of the bony prominence may be all that is required to heal the overlying wound
	Osteotomy	An osteotomy at the head, shaft, or base of the 1st metatarsal can be performed to reduce the medial deviation
	Arthrodesis	An arthrodesis with angular osteotomies at the 1st metatarsal cuneiform can be conducted to reduce the deformity
	Arthroplasty	Arthroplasty (removal) of the head of the 1st metatarsal (arthroplasty) should be reserved for severe deformities, the bone infection, complex hosts, or limited functional demand due to the significant impact this has to the function of the foot

(continued)

Table 6.5 (continued)

Indication	Procedure	Comment
Tailor's bunion	Exostectomy	An exostectomy of the dorsolateral eminence does not directly address the biomechanical problem. However, the resection of the bony prominence may be all that is required to heal the overlying wound
	Osteotomy	Similar to the hallux abducto valgus, an osteotomy can be performed, and distal portion of the osteotomy can be reduced in the medial corrected position
	Arthroplasty	Arthroplasty (removal) of the 5th metatarsal head is less biomechanically impactful than at the 1st metatarsal but again should be reserved for more complex deformity, bone infection, complex hosts, or limited functional demand
Hallux rigidus	Exostectomy	An exostectomy of the dorsal spur does not directly address the biomechanical problem. However, the resection of the bony prominence may be all that is required to heal the overlying wound
	Arthroplasty	Arthroplasty is typically performed at the base of the hallux to decompress the joint to reduce retrograde buckling on the 1st metatarsal or to allow for some range of motion in this nonfunctional joint
	Arthrodesis	Arthrodesis creates absolute stability across the metatarsophalangeal joint. However, without any motion of this joint, the corrected position may cause ulcer recurrence or transfer ulcers if not placed in the ideal position
Parabola asymmetry	Exostectomy	Exostectomy can be performed to remove the plantar bony prominence for the digits or metatarsals
	Arthroplasty	An arthroplasty (removal) of the head of a long metatarsal can be effective; however, pressure will be redistributed to adjacent metatarsal resulting in transfer ulcers
	Osteotomy	An osteotomy is the preferred method to shorten a long metatarsal by creating an oblique osteotomy at the head/neck and sliding the capital fragment proximally. This can be done in a controlled manner to the desired position with or without fixation

Arthrodesis (fusion) is performed across joint surfaces in cases of joint instability or rigid deformities. An underlying wound can occur in both cases. The joint cartilage is typically resected and prepared for healing across the joint to occur. Angular corrections can be conducted at the same time by making angular bone cuts to realign the bone segments in a more neutral position (Fig. 6.4). Internal and/or external fixation is utilized and provides stability until the joint fuses. Again, the prior paragraphs example of an ulcer under the first metatarsal cuneiform joint due to a collapse of the medial column is an illustration where arthrodesis may need to be performed. A complex case is one that involves Charcot neuroarthropathy (CN) in the diabetic foot. CN typically involves significant bone fractures and dislocations

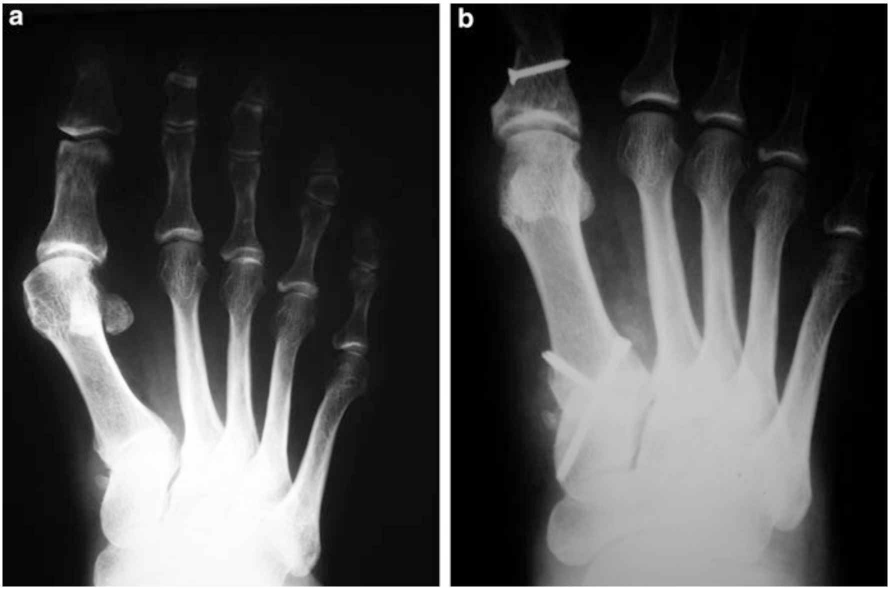

Fig. 6.4 (**a**) A preoperative weight-bearing anterior-posterior projection plain film radiograph of a patient with a severe hallux abducto valgus deformity with medial deviation of the 1st metatarsal causing an ulcer on the medial aspect. (**b**) A postoperative weight-bearing anterior-posterior projection plain film radiograph of the same patient. Note the apex of the deformity was at the 1st metatarsal cuneiform joint. Hence, an arthrodesis was performed with an angular osteotomy to reduce the deformity

with a potentially high rate of surgical complications [23]. The surgical reconstruction typically includes realignment and arthrodesis across multiple joint segments. The medial column is reduced to a neutral position, and an arthrodesis is performed to maintain the correction. For osseous procedures, the internal fixation is typically not removed after bone healing unless it becomes an issue such as backing out of a screw causing skin irritation or causing a wound.

Amputation Procedures Amputation can be functional and is a viable option in some patients (Table 6.6). Partial digital, digital, partial ray, ray, transmetatarsal (TMA), and Lisfranc's amputations are the procedures performed in the forefoot. Typically, forefoot amputations are performed due to extensive soft tissue loss from infection and/or ischemia. Amputations reduce functional ability of the foot by decreasing the efficiency due to a shortened lever arm. Further, a transfer of plantar pressure occurs which can result in ulcers in other locations. Partial and complete digital amputations do not significantly impact overall foot function. However, a shortened or absent toe alters the parabola and transfers more pressure to adjacent toes and also effects balance. In the diabetic population, a cascade of serial toe amputations may result [24]. If more than two toes are amputated including the hallux, the remaining toes will deviate and be a nidus of chronic ulcers (Fig. 6.5). Thus,

Table 6.6 Amputation procedures

Procedure	Description	Functional impact
Partial digital	At least the base of the proximal phalanx remains	Minimal with possible transverse deviations of adjacent digits due to the loss of a buttress from the partially amputated toe. Minimal impact on function
Digital	Disarticulation at the level of the metatarsophalangeal joint	Transverse deviations of adjacent digits to be expected. Balance and propulsion is compromised
Pan digital	Disarticulation of all digits at the level of the metatarsophalangeal joint	Can be functional as long as the metatarsal parabola is normal
Partial ray	Includes the digit and part of the associated metatarsal	Loss of intrinsic stability since the metatarsophalangeal joint complex is compromised. Transfer lesions can occur due to the resultant uneven pressure distribution
Ray	Includes the digit and the entirety of the metatarsal	Likelihood of transfer ulcers high if not appropriately accommodated. Medial and ray resections can be the most problematic with the loss of insertion from extrinsic muscle insertions
Transmetatarsal	Includes the digits and distal metatarsal	Can be highly functional with the use of accommodative inserts and rigid shank with a rocker-bottom shoe
Lisfranc's	Disarticulation at the Lisfranc's joint	Significant impact due to shortened lever arm and irregular parabola

a pan digital amputation may be the preferred option rather than leaving isolated remaining toes.

Partial or complete ray resections are most often conducted in the presence of osteomyelitis when there is compromise to the structure of the bone. These procedures also create more mobility of the surrounding soft tissue in order to close a defect primarily. Ray resections significantly alter the pressure distribution on the plantar aspect of the foot. The forces that are normally dispersed across the five metatarsal heads, and to a lesser degree, the corresponding digits are altered with ray resections. The effect is less impactful if one ray, or a central ray, is resected. Complete ray resections of the 1st and 5th metatarsals are particularly biomechanically impactful due to the insertion of portions of the anterior tibial and posterior tibial tendons on the 1st metatarsal and the insertion of the peroneus brevis at the base of the 5th metatarsal. The loss of these insertions results in the overpowering of the opposing muscle groups. This biomechanical compromise causing significant alterations in sagittal and shear forces experienced in the foot leading to high reamputation rates [25]. If two or more rays are resected, a TMA should be considered as a more biomechanically stable construct.

Fig. 6.5 A photograph of a foot with a prior healed hallux amputation. Note the deviation of the 2nd toe with an ulceration due to altered biomechanics

Symmetry at the amputation site is important. Specifically, the maintenance of parabolas is a central concept to successful forefoot amputations. For TMAs, osteotomies performed on the 2nd or 3rd metatarsals should be the longest as compared with the other metatarsals. Further, the osteotomies of the metatarsal should be conducted in an oblique fashion (30°–45°) to the weight-bearing surface to create a rocker-bottom effect at the distal aspects of the metatarsals. An equinovarus deformity due to the overpowering of the posterior muscle group can occur after a TMA is performed due to the loss of the opposing long extensor insertions on the toes. Thus, a TAL or gastrocnemius recession should be conducted as an adjunctive procedure with the TMA to prevent distal plantar ulcer development. The TMA has been demonstrated to be a durable amputation with acceptable long-term results [26]. The plantar skin and underlying adipose tissue should be preserved if possible and dorsally rotated for durability of the amputation when weight bearing. However, the rotation of tissue for closure should be based on which artery provides the best blood supply to the incisional area. A Lisfranc's amputation is not a preferred procedure due to the lack of symmetry and loss of anatomical parabola. Further, the lever arm necessary for propulsion is very short; thus, the Lisfranc's amputation has limited functional capacity. This procedure should be reserved for situations in which a TMA is not an option due to the lack of soft tissue coverage. If a Lisfranc's amputation procedure is chosen, an Achilles tenectomy (complete transection) should be performed to prevent the development of the equinovarus deformity.

Postoperative Care

As with preoperative planning, the immediate and long-term postoperative care is critical to achieving good outcomes. Immediate postoperative care after forefoot surgery includes edema control, adequate immobilization, and modification of weight bearing. Edema control decreases tension along the incision and reduces the likelihood of hematoma/seroma formation. The patient should be instructed to elevate the lower extremity above the level of the heart for the first 2–3 weeks postoperatively for the majority of the time. Compression dressings will assist in edema control when the lower extremity is in a dependent position which is applied in the operating room and can be reapplied at every dressing change. Immobilization of the extremity after forefoot surgery includes the use of a surgical shoe, surgical boot, splint, or cast. Specially designed surgical shoes and boots are available with multidensity inserts and a rocker bottom for ischemic or neuropathic patients. The degree of immobilization needed will dictate which type of immobilization device is selected. The purpose of immobilization is to protect the surgical site from trauma and to limit the range of motion surrounding the surgical site. If the surgery is limited to the digits, then a surgical shoe may be adequate. If an osteotomy is performed, or a more proximal amputation is performed in a compromised host, then a greater degree of immobilization is needed utilizing a surgical boot or cast. A posterior splint is an option that immobilizes and allows for easy access to the surgical site if necessary. However, a posterior splint is a less rigid construct as compared with a surgical boot or cast and should not be used for weight bearing.

Immediate postoperative weight-bearing status is very important. Full, unlimited weight bearing should be discouraged in all cases. Limited weight bearing is permissible for (1) digital surgery; (2) small soft tissue defect coverage or closure; (3) distal tenotomies, lengthenings, and transfers; (4) metatarsal osteotomies with limited need for fixation; and (5) digital amputations. Nonweight bearing on the surgical extremity is preferred for the following conditions:(1) plantar incisions, (2) large soft tissue defect coverage or closure, (3) more proximal tenotomies, lengthenings, and transfers, (4) tenuous fixation, and (5) partial ray, ray, TMA, or Lisfranc's amputations. Nonweight bearing is difficult even with the use of assistive devices such as crutches or a walker. The patient's upper body strength and balance will dictate whether a wheelchair is a preferred method. For forefoot surgery, heel weight bearing for transfers is acceptable. However, during ambulation, heel weight bearing is not realistic because the weight will shift forward on the foot during propulsion regardless of how compliant the patient. The author is not in favor of the use of forefoot offloading wedge surgical shoes because it is difficult for the patient to maintain balance on only the heel and tend to slap the forefoot onto the ground with each step. The duration of limited to nonweight bearing is dictated by the surgery performed and patient factors including age and comorbidities. As a general rule, soft tissue will heal faster than bone. Typically, 4–6 weeks of immobilization and modified weight bearing is necessary after forefoot surgery. A progression to less rigid immobilization and advancing to greater degree of weight bearing should be conducted over time. Prolonged immobilization causes muscle atrophy and joint rigidity; thus, physical therapy may be necessary for full rehabilitation. For procedures involving bone, serial plain film radiographs should be taken during the postoperative course to ensure progressive healing.

It is important to recognize that the foot has been structurally changed after surgery. The structural change will alter the biomechanics of not only the foot but the

Fig. 6.6 A custom shoe for a diabetic patient after forefoot surgery. The shoe is constructed to provide stability and assist in ambulation. Note the custom accommodative insert to distribute pressure on the plantar aspect of the foot

entire body. Long-term accommodation may be necessary after forefoot procedures. This includes the use of custom-molded inserts, braces, or ankle-foot orthoses. Custom-molded inserts may include toe or forefoot fillers (after amputation) to reduce or prevent movement in a shoe (Fig. 6.6). The diabetic patient with peripheral neuropathy requires special attention with the use of trilaminate multidensity materials to better distribute the forces experienced on the plantar foot. A specially modified shoe with a seamless interior and a rigid shank and a rocker bottom may also be necessary to assist in more efficient ambulation. Further, knee- or thigh-high compression hose may also be indicated for long-term edema control.

Discussion

The forefoot deserves special attention because of its terminal anatomical location and its propensity for injury leading to wounds. The demands of ambulation require an understanding of the biomechanics of the foot especially when considering surgical intervention. The majority of noncomplex wounds will heal without the need for surgical intervention. However, surgery may be necessary for larger, deeper wounds with possible bone involvement. Surgical intervention for the acute complex wound in a non-compromised host still requires attention to biomechanics because the selected procedure may affect the biomechanics of the foot especially when bone is resected or altered which changes the architecture of the foot. Further, in the cases of chronic ulcers, there is almost always an underlying biomechanical fault leading to its development and chronicity.

The maintenance or improvement of function should be the central goal in procedure selection. Forefoot surgery may address the underlying biomechanical component of the wound and/or decreases the likelihood of future development, recurrence, or transfer. This is conducted through an array soft tissue, tendon, and/or bone procedures. The determinants of success or failure of forefoot surgery are no different than any other surgery. Appropriate patient selection, accurate deformity identification, proper procedure selection, and diligent perioperative care will dictate the outcome.

References

1. Cavanagh PR, Ulbrecht JS, Caputo GM. New developments in the biomechanics of the diabetic foot. Diabetes Metab Res Rev. 2000;16(Suppl 1):S6–S10.
2. Attinger CE, Brown BJ. Amputation and ambulation in diabetic patients: function is the goal. Diabetes Metab Res Rev. 2012;28(Suppl 1):93–6.
3. Wukich DK, McMillen RL, Lowery NJ, Frykberg RG. Surgical site infections after foot and ankle surgery: a comparison of patients with and without diabetes. Diabetes Care. 2011;34(10):2211–3.
4. Attinger CE, Evans KK, Bulan E, Blume P, Cooper P. Angiosomes of the foot and ankle and clinical implications for limb salvage: reconstruction, incisions, and revascularization. Plast Reconstr Surg. 2006;117(7 Suppl):261S–93S.
5. Forsythe RO, Hinchliffe RJ. Assessment of foot perfusion in patients with a diabetic foot ulcer. Diabetes Metab Res Rev. 2016;32(Suppl 1):232–8.
6. Dalal S, Widgerow AD, Evans GR. The plantar fat pad and the diabetic foot – a review. Int Wound J. 2015;12(6):636–40.
7. Peters EJ, Armstrong DG, Lavery LA. Risk factors for recurrent diabetic foot ulcers: site matters. Diabetes Care. 2007;30(8):2077–9.
8. Yavuz M, Erdemir A, Botek G, Hirschman GB, Bardsley L, Davis BL. Peak plantar pressure and shear locations: relevance to diabetic patients. Diabetes Care. 2007;30(10):2643–5.
9. Arosi I, Hiner G, Rajbhandari S. Pathogenesis and treatment of callus in the diabetic foot. Curr Diabetes Rev. 2016;12(3):179–83.
10. Davis B, Crow M, Berki V, Ciltea D. Shear and pressure under the first ray in neuropathic diabetic patients: implications for support of the longitudinal arch. J Biomech. 2017;52:176–8.
11. Frykberg RG, Bevilacqua NJ, Habershaw G. Surgical off-loading of the diabetic foot. J Vasc Surg. 2010;52(3 Suppl):44S–58S.
12. Urfalioglu A, Gokdemir O, Hanbeyoglu O, Bilal B, Oksuz G, Toker M, et al. A comparison of ankle block and spinal anesthesia for foot surgery. Int J Clin Exp Med. 2015;8(10):19388–93.
13. Lichtenfeld NS. The pneumatic ankle tourniquet with ankle block anesthesia for foot surgery. Foot Ankle. 1992;13(6):344–9.
14. Cardinal M, Eisenbud DE, Armstrong DG, Zelen C, Driver V, Attinger C, et al. Serial surgical debridement: a retrospective study on clinical outcomes in chronic lower extremity wounds. Wound Repair Rregen. 2009;17(3):306–11.
15. Cook EA, Cook JJ, Badri H, Mostafa J. Bioengineered alternative tissues. Clin Podiatr Med Surg. 2014;31(1):89–101.
16. Lavery LA, Fulmer J, Shebetka KA, Regulski M, Vayser D, Fried D, et al. The efficacy and safety of Grafix((R)) for the treatment of chronic diabetic foot ulcers: results of a multi-centre, controlled, randomised, blinded, clinical trial. Int Wound J. 2014;11(5):554–60.
17. Garwood CS, Steinberg JS. Soft tissue balancing after partial foot amputations. Clin Podiatr Med Surg. 2016;33(1):99–111.
18. Scott JE, Hendry GJ, Locke J. Effectiveness of percutaneous flexor tenotomies for the management and prevention of recurrence of diabetic toe ulcers: a systematic review. J Foot Ankle Res. 2016;9:25.

19. Mueller MJ, Sinacore DR, Hastings MK, Strube MJ, Johnson JE. Effect of Achilles tendon lengthening on neuropathic plantar ulcers. A randomized clinical trial. J Bone Joint Surg Am. 2003;85-A(8):1436–45.
20. Dayer R, Assal M. Chronic diabetic ulcers under the first metatarsal head treated by staged tendon balancing: a prospective cohort study. J Bone Joint Surg Br. 2009;91(4):487–93.
21. Laurinaviciene R, Kirketerp-Moeller K, Holstein PE. Exostectomy for chronic midfoot plantar ulcer in Charcot deformity. J Wound Care. 2008;17(2):53–5, 7–8.
22. Molines-Barroso RJ, Lazaro-Martinez JL, Aragon-Sanchez J, Garcia-Morales E, Carabantes-Alarcon D, Alvaro-Afonso FJ. The influence of the length of the first metatarsal on the risk of reulceration in the feet of patients with diabetes. Int J Low Extrem Wounds. 2014;13(1):27–32.
23. Eschler A, Gradl G, Wussow A, Mittlmeier T. Prediction of complications in a high-risk cohort of patients undergoing corrective arthrodesis of late stage Charcot deformity based on the PEDIS score. BMC Musculoskelet Disord. 2015;16:349.
24. Chu YJ, Li XW, Wang PH, Xu J, Sun HJ, Ding M, et al. Clinical outcomes of toe amputation in patients with type 2 diabetes in Tianjin. China Int Wound J. 2016;13(2):175–81.
25. Izumi Y, Satterfield K, Lee S, Harkless LB. Risk of reamputation in diabetic patients stratified by limb and level of amputation: a 10-year observation. Diabetes Care. 2006;29(3):566–70.
26. Thorud JC, Jupiter DC, Lorenzana J, Nguyen TT, Shibuya N. Reoperation and reamputation after transmetatarsal amputation: a systematic review and meta-analysis. J Foot Ankle Surg. 2016;55(5):1007–12.