Surgical Treatment of the Infected Diabetic Foot

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Foot infections are common in the diabetic patient. Early recognition, proper assessment, and prompt intervention are vital. A combination of surgery and antibiotics is mandatory in virtually all foot infections. The aim of surgery is 2-fold: first, to control the infection, and second, to attempt to salvage the leg. The eventual goal is always to preserve a functional limb. Foot deformities resulting from surgery may cause reulceration and a high morbidity. The surgical treatment of the infection largely consists of draining of pus and removal of all necrotic and infected tissue. Frequently, revascularization of the foot is needed to save the limb; thus, there must be a close cooperation with the vascular surgical service. The surgeon must have a thorough knowledge of foot anatomy and must be familiar with the defects in wound healing that are caused by diabetes. The outcome of surgery mainly depends on the skill, care, and experience of the surgeon. The best results are achieved within a multidisciplinary setting.

Most deep infections are preceded by tissue breakdown, with local penetration of bacterial pathogens to the deeper tissues. In many cases, the extent of the infection is underestimated; in 10%–15% of mild infections and in ~50% of serious infections, an underlying contiguous osteitis can be demonstrated [1]. Familiarity with the several causative factors that lead to foot complications in diabetic patients and early recognition of the infection are crucial in ensuring proper treatment. A combination of surgical and antibiotic treatment is mandatory in virtually all deep foot infections.

Surgical therapy has several aims. The main goal is to control the deep infection, with the hope of salvaging the limb. This is accomplished by drainage of any pus, removal of all necrotic or infected tissues, and creating a healthy wound bed. It is also important to keep in mind the functional results after surgery. Residual foot deformities may lead to abnormal pressure points and, thus, reulceration. The surgeon must also consider the vascular status of the limb and the anatomic level at which a wound would be likely to heal. Furthermore, the surgeon must ensure that there is sufficient viable soft tissue to cover any deficits left by resections or amputations.

Foot infections can be classified in several ways: by the depth of the infection and its severity, by the anatomic site affected, by the tissues involved, and by the causative factors, including any arterial insufficiency. To ensure an optimal outcome, the surgeon must also possess an understanding of the microbiology and pathophysiological behavior of infection, wound management principles, and foot biomechanics. The surgeon’s training may be in orthopedic, vascular, or general surgery or, in some countries, podiatric surgery. What is important is the surgeon’s knowledge, experience, and interest in the problem.

DIAGNOSIS

Infection is diagnosed on primarily clinical rather than microbiological, laboratory, or radiological grounds. Although infection in diabetic patients may have a subclinical course, with absent or minimal signs and symptoms, it may sometimes progress rapidly in days or hours. This can lead to underestimation of the presence or severity of the infection [2, 3]. We consider infection to be present when the wound has purulent secretions or at least 2 of the following: redness, pain, tenderness, induration, warmth, lymphangitis, foul smell, or gas formation [4]. Pain on the plantar aspect of a foot that had previously been insensitive because of neuropathy...
may indicate a deep foot infection [5]. This can be further delineated by imaging tests such as MRI or by a simple needle aspiration at the bedside.

Infections in diabetic patients may cause recalcitrant hyperglycemia and malaise, but systemic inflammatory manifestations, such as fever and leukocytosis, may not be present. Patients with a serious infection, however, may have an elevated erythrocyte-sedimentation rate or C-reactive protein level [6]. Bone involvement is a concern with deep infections. In the presence of an ulcer, one study suggested a high specificity and positive predictive value for osteitis when bone can be felt with a sterile metal probe [7]. Clinical, radiological, and/or scintigraphic signs compatible with osteitis may lead to suspicion of the diagnosis, but MRI is the imaging procedure of choice for distinguishing osteomyelitis from other conditions, including neuroarthropathy [8]. A recent study showed that on MRI of the infected diabetic foot, the nonenhanced areas represent necrotic tissue. Lack of enhancement in these areas can mask the presence of abscesses and osteomyelitis. Sometimes, histological examination or bacteriologic culture is required to prove the presence of osteomyelitis [3, 7–9]; these procedures should be considered when either the diagnosis or the likely causative pathogens are in doubt.

**CLASSIFICATION AND ANATOMIC CONSIDERATIONS**

Wound infections can be classified as mild, moderate, or severe. From a surgeon’s perspective, it is perhaps more relevant to distinguish the infections that are not limb threatening from those that are limb threatening. Foot infection predisposes diabetic patients to amputation [10], and early, aggressive surgical intervention may reduce the need for above-the-ankle amputations [11–13]. Therefore, early recognition and treatment of infection is crucial for the survival of the limb.

In infections that are not immediately limb threatening, the patient manifests no signs of systemic toxicity. In general, if cellulitis is present, it does not extend for >2 cm around an ulcer. There should be no signs of deep abscesses (e.g., plantar pain at palpation), osteomyelitis, or gangrene. Ulcers that are not infected should be debrided to estimate their depth, their extent, and any potential penetration into bone or joints and along tendon sheaths. Evidence of extensive cellulitis, deep abscesses, osteomyelitis, or necrotic tissue, especially in the presence of limb ischemia, suggests a limb-threatening infection. When wound infection is present, several additional investigations should be considered. Appropriate samples of the wounds must be obtained for culture. Plain radiographs should be obtained, not only to evaluate potential bone involvement but also to search for foreign bodies and soft-tissue gas. Radiography may also reveal bony variants, such as accessory ossicles, foot deformities, fractures and bone deformities, prior surgical procedures and resections, and neuroarthropathic changes. MRI is also useful to delineate the extent of the infection and the presence of deep nonenhancing areas, such as necrosis and abscesses [8].

Local treatment of an infected foot is not likely to succeed when wound hypoxia, debris or necrotic tissue, nutritional deficiencies, or metabolic disorders coexist. These factors must be promptly identified and corrected. After local control of an infection in an ischemic foot, revascularization might be needed to save the limb. Results with low infragenual and pedal bypasses are good, with 36-month rates of limb salvage and vascular patency of up to 98% and 92%, respectively [14, 15].

Proper debridement and drainage of the infection requires a sound knowledge of foot anatomy. The usual routes of progression of the infection along anatomic pathways must be understood. Specialized anatomy makes the foot architecture well adapted to its function. In the sole of the foot, the plantar aponeurosis is the most superficial fascia. Its central portion is the thickest and is attached to the medial tubercle of the calcaneous. The fascia then spreads fanlike distally (figure 1). The plantar fascia forms the inferior boundary of the 3 plantar-
fascial compartments. The medial compartment is roofed by the inferior surface of the first metatarsal bone. The lateral boundary is formed by an intermuscular septum, which runs longitudinally from the calcaneous to the medial side of the first metatarsal head. This medial compartment contains all of the intrinsic foot muscles of the first toe. The central compartment is bounded by the intermuscular septum on the medial side and a second lateral intermuscular septum, which runs from the calcaneous to the fifth metatarsal head. The roof is formed by the tarsometatarsal structures. This compartment contains all intrinsic foot muscles of the second, third, and fourth toes. The lateral compartment, bounded by the 5th metatarsal bone and the lateral intermuscular septum, contains all intrinsic foot muscles of the 5th toe. A 4th compartment, called the interosseous, is bounded by the interosseous fascia of the metatarsals and contains the interosseus muscles (figure 2). These compartments play an important role in determining the spread of infection and the development of deep ischemia [16, 17].

SURGERY IN SUPERFICIAL, NON–LIMB-THREATENING INFECTIONS

After an infected wound has been assessed, rest is needed to control the inflammatory reaction. Sharp debridement is essential as part of the therapy for an infected ulcer, as noted in several national guidelines and textbooks [2, 10, 18–20]. There are, however, only a few studies to support the use of debridement [21]. In a study of 118 patients, frequent debridement of noninfected ulcers resulted in faster wound healing [22]. Other reports described wound debridement as a vital adjunct for the healing of diabetic foot ulcers [23, 24]. Indirect evidence in favor of debridement can be found in other studies showing that late foot complications, such as major amputations, can be reduced by an aggressive surgical approach to every infection [11, 25]. The purpose of sharp (surgical) debridement is 3-fold: drainage of necrotic tissue and pus, stimulation of healing of a (usually chronic) wound, and assessment of the extent of the infection. Moreover, debridement enables deep specimens to be obtained for culture. A wound with skin undermining creates a reservoir for bacterial proliferation. Therefore, the overlying tissue must be removed, even though this creates a larger wound [22]. Debridement of devitalized tissue is an essential step in preparation of the wound bed [26]. Only after removal of the slough and necrotic tissue can the real depth and destructions of the infection be determined [26, 27].

Surgical debridement must be considered a minor surgical procedure, with all of its possible complications. During any surgical procedure, the patient must be protected from feeling any pain. Apart from the discomfort to the patient, pain causes inadvertent motion, with consequent unintended damage. Un-

Figure 2. Transverse section of the foot: 1, lateral compartment; 2, central compartment; 3, medial compartment; 4, interosseous compartment. Arrows indicate the high-pressure areas that often lead to foot ulceration.

less the patient has severe sensory neuropathy, local anesthesia must be used. The surgeon must take into consideration the anatomic boundaries; unnecessary damage to healthy neighboring structures may lead to the loss of the limb. On the other hand, removal of all dead tissue is mandatory.

Mild infections pose minimal immediate risk in a well-perfused foot, because they are confined to the skin in the immediate vicinity of the ulcer. Treatment can be done in an outpatient setting, but only if certain criteria are fulfilled. Those who require urgent surgical intervention, multiple diagnostic tests, or several consultations or those who are immunocompromised may be more safely and expediently evaluated and treated with a brief hospitalization. Outpatient care requires that there be an appropriate oral antibiotic agent available, that the patient is reliable as well as willing and able to follow the prescribed treatments, and that there is good support at home. Outpatients should be seen again in the clinic to ensure that the infection is responding [2]. Debridement should be combined with antibiotics. In this stage, it is usually safe to start with narrow-spectrum oral therapy [28]. The wound dressing should be nonadherent, and the type selected depends on the amount of exudate [26]. Moderate infections pose a significantly greater level of risk to the foot. Although there is an extension of the infection, the patient is systemically well. These patients are usually hospitalized, and strict bed rest is required. After debridement, a proper antibiotic regimen is chosen. Absorptive dressings are used in wounds that are usually exudative.

SURGERY IN DEEP FOOT INFECTIONS

Eneroth et al. [6] demonstrated that deep foot infections in diabetic patients are a heterogeneous entity, and the type of infection is related to the outcome. Amputation was required more often for patients with deep soft-tissue infection, either
alone or in combination with osteomyelitis, than for those with osteomyelitis alone. Armstrong et al. [29] validated a diabetic-foot-wound classification system that demonstrated that the combination of infection and ischemia resulted in the worst outcome. Both of these studies emphasize the need for a thorough assessment of the infection.

Severe infections pose an immediate threat to the leg and, potentially, to the patient’s life. Thus, prompt surgical intervention is needed. Severe infections can occur when a mild to moderate infection is complicated by critical ischemia or when an adequately perfused foot shows a marked local involvement (e.g., necrotizing fasciitis or an infection with anaerobic gas-forming organisms) or systemic signs and symptoms (fever, hypotension, and vomiting, suggestive of bacteremia). Necrotizing fasciitis is a severe illness with a mortality rate of 24%–33%. It has classically been connected with β-hemolytic streptococci, but a recent review of 163 cases found that 71% of those with a positive result of tissue culture had polymicrobial infections [30]. Several reports have documented an association of necrotizing fasciitis with diabetes mellitus [31, 32]. The presence of severe pain with a deep plantar foot infection in a diabetic patient is often the first alarming symptom, especially in a patient with a previously insensate foot. Several factors may lead to quick deterioration and its attendant complications. Most ulcers occur on the plantar surface of the foot, at the head of the metatarsal bones. With infection and subsequent cellulitis, edema can develop in the underlying compartment, resulting in a compartment syndrome [17]. When pressure in a compartment exceeds capillary hydrostatic pressure, microvascular circulation is impaired. Patients with diabetic neuropathy may have higher compartment pressures than do nondiabetic patients [33]. This may result from the sorbitol pathway in the diabetic patient leading to an excess of split products; these, together with the hydrophilic sorbitol molecule, may lead to edema. Moreover, the oxygen concentration may be lowered by the greater oxygen affinity of glycosylated hemoglobin (hemoglobin A1c) than that of normal hemoglobin. The resulting increased capillary permeability leads to edema and high compartment pressure. This leads not only to tissue necrosis but also to thrombosis of the small arteries, resulting in a more extensive deep necrosis, even in a well-vascularized foot [17, 33].

Bad outcomes of these infections are largely related to delayed diagnosis and the attendant extensive destruction of the soft tissues [31, 33, 34]. Surgery is aimed at decompression and drainage of the involved compartment, followed by radical debridement of all necrotic tissue. If soft-tissue infection is accompanied by osteomyelitis of ≥1 metatarsal, a ray amputation is usually needed. Urgent surgical drainage must always be done before any revascularization procedure takes place. The revascularization procedure must be done, however, as soon as possible after the drainage procedure [35]. Hospitalization is usually needed, with intensive medical supportive care.

The above-mentioned conditions support the view of Eneroth et al. [6] that deep soft-tissue infections, with or without osteomyelitis, represent a different clinical entity than the chronic osteomyelitis without an infected soft-tissue component. Although the former condition represents a threat to the leg and even the patient’s life, the latter condition can be treated electively. Surgical excision of all dead and infected bone is considered by most clinicians to be the treatment of choice for chronic osteomyelitis. However, wound-healing problems caused by arterial insufficiency, and reulceration related to new pressure areas and to changed biomechanics, may subvert the benefits of these procedures. Minor involvement of a digit that has a good arterial perfusion can often be treated safely with amputation of the digit or ray. In the absence of clinical evidence of soft-tissue infection, the skin closure can be done immediately. In the case of edema or other signs of infection, the wound is left to heal by secondary intention. When multiple digits are involved, a transmetatarsal amputation may be necessary. Several retrospective studies suggest considerably better results of transmetatarsal amputations done after a revascularization procedure [36, 37]. If there is doubt about the arterial supply to the foot and if there is a realistic option for revascularization, this should be done before the amputation takes place.

The extent of tissue loss might be a reason to consider a major amputation. If multiple digits are involved or heel necrosis is present, a limb-salvage procedure is unlikely to be successful. A gangrenous foot is best treated with a major amputation. Overambitious surgical intervention may be a threat to the patient with advanced diabetic foot sepsis. Sometimes a patient is not medically capable of withstanding multiple salvage operations and the long hospital recovery that is required. For those patients, the best option may be primary limb amputation. Resections of toes, rays, or a forefoot require careful planning and should never be performed by an inexperienced surgeon.

**OUTCOME**

Surprisingly little is known about the long-term outcome of foot surgery for limb salvage. Most reports are retrospective, and the outcomes vary in the several reports. In an audit of 51 patients, the majority of whom had operations for deep infections in neuropathic feet, most required >1 procedure and multiple admissions [38]. Similarly, in a series of 212 urgent or emergent foot operations performed on 114 diabetic patients because of infection or ischemia, the average number of operations per limb was 1.5, and 48 limbs required revascularization. Ultimately, 36 needed major amputations up to 86 months after the initial operation, but the long-term salvage
rate was 73% for threatened legs [25]. These results are reasonably good, given that most of these operations were limb-salvage procedures. Another study reported on 162 patients requiring forefoot or toe amputations; 72% had diabetes, 73% did not have palpable foot pulses, and 83% underwent concomitant or subsequent limb revascularization. Major amputation was eventually necessary in 18.5% of cases. Multivariate analysis indicated that unsuccessful revascularization predicted lack of healing or major amputation [39].

Studies of toe amputations for osteomyelitis have yielded controversial results. In a review of 92 diabetic patients with presumed adequate circulatory status undergoing operations because of forefoot sepsis, 97 had a digit amputation. Complete healing was achieved in only 34%, and infection persisted in 36% of the operated limbs [40]. Another retrospective review of 90 diabetic patients who underwent amputation of the great toe and first ray found that 60% required a second amputation, and 17% subsequently underwent a below-the-knee amputation [41]. These studies are in contrast with the results described by Wong et al. [42], who retrospectively reviewed 54 local amputations that were due to diabetic foot infections and were done by surgeons with different levels of experience. Junior surgeons initially operated on the majority of the 22 patients who experienced failure, defined as the requirement for subsequent surgery. In contrast, all patients whose operations were done by senior surgeons healed, which demonstrates the importance of the experience of the surgeon.

In most cited studies, 15%–30% of the patients eventually required limb amputation, despite many operations and a prolonged hospital stay. Reasons for failures include underestimation of the arterial perfusion of the foot, progression of the infection caused by insufficiently aggressive surgical resection, the inexperience of the surgeon, inadequate antibiotic coverage, and poor compliance with an appropriate regimen of weight relief of the affected leg [43].

Every surgical procedure on the foot has the potential to alter the mechanics of the foot and thereby affect its function [44]. It is therefore essential to consider and plan for what function will remain after the surgery. Moreover, after surgery and healing of the wound, there is a substantial risk of reulceration [45]. Every healed ulcer should be evaluated on a monthly basis by a multidisciplinary team. The careful surgeon will consider the bony alignment, weight-bearing surfaces, and soft-tissue cover when planning an operation for diabetic foot infection.

**WHO SHOULD PERFORM SURGERY?**

Foot surgeons who are acquainted with the surgical anatomy, in close cooperation with a vascular surgeon, must be responsible for deep debridements and other operations on moderately or severely infected feet. These procedures must be conducted in the operating room; there is no precedent for operating on patients with these conditions in an outpatient setting or at the bedside. These infections call for a multidisciplinary approach, including a diabetologist or internist who can cope with the metabolic disturbances, a clinical microbiologist or infectious diseases specialist, a podiatrist, and an orthotist. In cases of mild infections, minor debridement, which can be performed in an outpatient setting, is usually combined with antibiotic therapy. The podiatrist, who is experienced in removing callus, can be trained to perform these superficial debridements.

**CONCLUSION**

Infection of the foot in diabetic patients is a serious complication that may lead to a major amputation. Early recognition and proper treatment are mandatory to avoid poor outcomes. Surgery must always be combined with antibiotics, and revascularization may also be necessary. The surgeon must have a thorough knowledge of the foot anatomy but also must be familiar with the defects in wound healing caused by diabetes. The outcome of surgery largely depends on the skill, care, and experience of the surgeon.

**References**