Strategies to Prevent and Heal Diabetic Foot Ulcers:
A Joint Publication of APMA and SVS
SPECIAL COMMUNICATION

Toe and Flow

Essential Components and Structure of the Amputation Prevention Team

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At the end of an anatomical peninsula, the foot in diabetes is prone to short- and long-term complications involving neuropathy, vasculopathy, and infection. Effective management requires an interdisciplinary effort focusing on this triad. Herein, we describe the key factors leading to foot complications and the critical skill sets required to assemble a team to care for them. Although specific attention is given to a conjoined model involving podiatric medicine and vascular surgery, the so-called toe and flow model, we further outline three separate programmatic models of care—basic, intermediate, and center of excellence—that can be implemented in the developed and developing world. (J Am Podiatr Med Assoc 100(5): 342-348, 2010)

Current estimates place the worldwide prevalence of diabetes at 300 million, a sobering statistic that by 2030 is predicted to increase to 425 million.¹ In the United States alone, an estimated 23.6 million people have diabetes.² Lower-extremity amputation is an unfortunate and often avoidable sequela of complicated diabetes. Foot ulceration due to neuropathy and repetitive trauma, often complicated by infection and ischemia, is the primary underlying pathway to amputation; such ulcers develop in up to 25% of those with diabetes during their lifetime.³ The annual incidence of diabetic foot ulcer is 1% to 2%.⁴ Eighty-five percent of amputations are preceded by a foot ulcer.⁵ Foot ulcers create a portal of entry for microorganisms, leading to infection. Host resolution of an extremity infection is impaired in diabetes due to immunopathy and peripheral arterial disease. Peripheral arterial disease, similar to other more central macrovascular diseases, is common in diabetes. Peripheral arterial disease can lead to critical limb ischemia, either alone or when combined with an injury such as a foot ulcer. The diabetic foot ulcer requires adequate circulation to heal; if the circulation is impaired such that tissue oxygen demand exceeds supply, critical limb ischemia ensues, placing the limb at risk.

Foot ulcers and amputations were estimated to have cost the US health-care system $29 billion in 2007.⁶ After amputation, the costs do not cease. Multiple prosthetic devices and mobility devices are often required. Disability is common after amputation, removing the patient from the workforce and causing additional economic burdens. Not only are productivity and quality of life diminished, but life expectancy is also reduced after major lower-extremity amputation.⁷

Factors Leading to Amputation

Effective amputation prevention strategies require an understanding of the natural history of amputa-
tion in diabetes. Figure 1 presents the common pathway to lower-extremity amputation in diabetes as steps in the “stairway to amputation.” The most common pathway is peripheral sensory neuropathy leading to unfelt repetitive trauma. This trauma causes a foot ulcer, piercing the protective dermal envelope. If there is underlying significant peripheral arterial disease, the wound will not predictably heal in the presence of critical limb ischemia. The longer an ulcer remains open and unhealed, the more likely it is to become infected. Infection is often the coup de grace leading to amputation.8

The Effective Team: Ideology and Environment

A team of dedicated specialists is required to prevent lower-extremity amputation in persons with diabetes because it would be rare to find a single practitioner capable of managing all aspects of care for the complicated diabetic foot. Individual team members should focus on one or more of the steps in the pathway to amputation, but screening and prevention, wound healing, infection management, and revascularization are paramount. The diabetic rapid response acute foot team guidelines9 suggest that the vascular surgeon and diabetic podiatric physician constitute the “irreducible minimum” in the formation of a diabetic foot team, with the frequent inclusion of additional specialists as available and necessary (Fig. 2).

Ideally, a center dedicated to amputation prevention would be located in a medical center given that the complex nature of the problem frequently requires advanced diagnostic studies, coordinated inpatient services, and a broad array of surgical therapy. The center must be able to rapidly diagnose and treat infection in inpatient and outpatient settings. Radiologic capabilities for investigation of deformities and osteomyelitis via conventional radiography, bone scan, and magnetic resonance imaging must be readily available. A noninvasive vascular laboratory containing suitable equipment for the diagnosis and quantification of peripheral arterial disease are additional requirements. Outpatient facilities must have the capability to perform wound debridement, to dispense and modify off-loading devices, and to apply negative-pressure wound therapy dressings. Twenty-four-hour operating room access is imperative to be able to surgically treat limb- and life-threatening infections through incision and drainage or emergency partial amputation.

Team Members

Podiatric Physicians

The podiatric physician should have specific expertise in diabetic foot care and wound healing. The podiatric physician’s role may be that of gatekeeper to the diabetic foot team because the foot ulcer is often the entry diagnosis. A simple foot ulcer is often a manifestation of a much larger underlying nexus of problems whose complete management
crosses multiple disciplines. The podiatric physician’s primary duty is to evaluate the foot ulcer, exclude or treat foot infections, rule out peripheral arterial disease or refer to vascular surgery, and create a comprehensive wound-healing plan that involves the other members of the team. Podiatric surgeons include foot surgery in the treatment plan, when necessary, to heal a wound or prevent its recurrence. The podiatric physician has particular expertise in biomechanics and pressure off-loading unique to the profession. The podiatric physician also performs a critical role in the identification and management of diabetic patients at highest risk for ulceration. Prevention clinics are a key component of comprehensive diabetic foot care.

**Vascular Surgeon**

The vascular surgeon is vital to the team because significant peripheral arterial disease that may cause or contribute to ulceration and failure of healing is present in at least one-third of patients with diabetic foot ulcer. Fellowship-trained vascular surgeons who are complete vascular specialists capable of risk factor management, performing and interpreting noninvasive vascular studies, diagnostic angiography, distal bypass, and endovascular interventions (including conventional angioplasty with or without stent placement, subintimal angioplasty, and tibial angioplasty) are necessary. Vascular surgeons are also thoroughly trained in the assessment and management of complex limb and foot infections and the treatment of sepsis. In addition to debridement and drainage of complex infections, vascular surgeons also perform toe, forefoot, guillotine, and major limb amputations when required.

**Infectious Disease Specialist**

The infectious disease specialist should be up to date on guidelines for treating diabetic foot infections. Infections in diabetic feet are limb- and, occasionally, life-threatening. Culture-specific, patient-appropriate antibiotics are required. Salvaging the limb is most delicate during the days before culture and sensitivity results are reported, requiring appropriate empirical therapy. This may include therapy for potentially drug-resistant organisms in frequently medically compromised patients.10

**Orthopedic Surgeon**

The orthopedic surgeon may be needed to perform lower-extremity amputations in cases of treatment failure. In international settings or in US settings where podiatric physicians are unavailable, a foot and ankle fellowship–trained orthopedic surgeon with particular interest in the diabetic foot can be valuable for performing deformity correction. In addition, in the United States, there are many centers where the foot and ankle–trained orthopedist plays a central role.

**Plastic Surgeon**

Plastic surgeons offer the team the option of covering large soft-tissue defects with free flaps or skin grafting. Some diabetic foot teams use the plastic surgeon as their gatekeeper.

**Diabetologist**

The diabetologist is necessary for adequate control of plasma glucose levels during what is many times a hospital stay with surgical intervention. Perioperative hyperglycemia is associated with an increased risk of postoperative infection. Patients with diabetic complications require a review of their compliance and outpatient diabetes care plan. Diabetologists provide comprehensive and long-term management of the underlying metabolic condition. In many centers in Europe, diabetologists lead the diabetic foot team.

**General Surgeon**

General surgeons are well versed in the management of acute wounds but should have specific expertise in chronic wound healing if they are to play a role in the amputation prevention program. The general surgeon can perform routine wound debridement and high-level amputations if needed.

**Pedorthist/Prosthetist**

The pedorthist is valuable in fabricating or modifying footwear to heal an ulcer or prevent its recurrence. Centers have varying relationships with pedorthists depending on facility, local, and national regulations. Pedorthists are sometimes employed by facilities but more often are independent contractors operating inside of the facility. This is frequently a better approach than referring patients off-site because essential communication is improved if the prosthetist is immediately available for consultation in the clinic and at the bedside.
Nonphysicians

Other invaluable nonphysician team members may include the certified wound and ostomy nurse, diabetes specialty/registered nurse, licensed practical nurse, medical assistant, diabetes educator, nutritionist, and physical/occupational therapist.

Teams that Work: Examples and Structure

The traditional American model for care of the diabetic foot involves primary-care and podiatric physicians in their private offices and hospital-based or outpatient wound care centers. The private office physician relies on his previous referral networks for specialized care. The wound care center model involves a panel of physicians of different specialties seeing patients in the same center but not often at the same time. The wound center model is frequently found to be lacking because there is often only a loose relationship among panel physicians. Although imperfect, improvements to these processes have been reported. Researchers have shown reductions in major limb amputations in the United States in Veterans Affairs hospitals when using referral-based protocols and in military hospitals with the founding of a limb preservation team. A single county hospital in the United States reduced major amputations by 72% after implementing a care process centered on podiatric medical and vascular services. The toe and flow model, consisting of podiatric and vascular surgery, seems to be a uniquely synergistic one, with overlapping yet complementary skill sets at the core of care (Table 1).

The developing international response to amputation prevention in patients with diabetes is worthy of discussion. In the traditional European and Asian models for diabetic foot care, the diabetologist usually serves as the gatekeeper; he or she coordinates care and refers to specialists in infectious disease, orthopedic surgery, and vascular surgery as necessary. More specific reports from the continent reveal improvements in outcomes when closer working relationships between specialists are facilitated. The implementation of multidisciplinary teams that include podiatric physicians has reduced amputations by 34% nationwide in the Netherlands. In Finland, there have been reductions in major amputations after more frequent inclusion of vascular surgeons on the team, an outcome that has been attributed to an increase in distal bypass procedures. Reports from Italy demonstrate that rates of hospitalization and major limb amputation are reduced via implementation of a multidisciplinary care referral system for high-risk diabetic feet. A prospective study in Lithuania reported fewer reulcerations in patients with diabetic foot ulcer after the institution of multidisciplinary diabetic foot teams. Diabetic foot teams covering various primary-care trusts in the United Kingdom have shown sustained reductions in amputations with the introduction of more organ­ized diabetic foot care with multidisciplinary care pathways. Other reports from Asia strongly indicate that teamwork and consistent application of diabetic foot protocols reduce amputation rates. Team-directed foot-care education has reduced amputation rates in India. In addition, progress has been reported in Australia since guidelines were developed to address the increasing incidence of foot ulcers and amputations.

Table 1. Complementary Skill Sets in a Toe and Flow Model

<table>
<thead>
<tr>
<th>Toe (Podiatric Medicine)</th>
<th>Flow (Vascular Surgery)</th>
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<tr>
<td>Screening and prevention</td>
<td>Vascular assessment and revascularization</td>
</tr>
<tr>
<td>Gait analysis and biomechanical intervention</td>
<td>Surgical debridement and drainage of complex infection</td>
</tr>
<tr>
<td>Pressure reduction, off-loading, and footwear</td>
<td>Postoperative monitoring of the high-risk foot</td>
</tr>
<tr>
<td>Surgical debridement and drainage of complex infection</td>
<td>Long-term monitoring of vascular reconstruction</td>
</tr>
<tr>
<td>Postoperative monitoring of the high-risk foot</td>
<td>Medical management of peripheral vascular disease</td>
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<tr>
<td>Prophylactic and curative reconstructive surgery</td>
<td>Wound care</td>
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<td>Wound care</td>
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Three Tiers of Care

Although individual teams (including many described previously herein) are constructed based on specific conditions in a community or region, they generally fall into one of three basic categories: basic, intermediate, and center-of-excellence care models (Table 2).26, 27

Basic Model of Care

The goal of this model of care is to provide a local community with preventive and basic curative diabetic foot care. The setting is often a private office or small health center, with a general practitioner or podiatric physician at the center of care. One of the key elements of this model is to develop and maintain close collaborations with second- and third-tier referral centers.

Intermediate Model of Care

The goal of this hospital-based program is to provide preventive and curative care for all types of patients. In addition, it may be equipped to deliver more advanced assessment and diagnosis than the basic model. The patient population is drawn from a larger catchment area than is that of the basic model, with possible referrals from greater distances based on its relationship with basic diabetic foot centers. Also, more clinicians are involved in care, frequently adding diabetes specialists and vascular surgeons to the mix. Administratively, it is essential that this model have a motivated coordinator to serve as leader, inspiring teamwork and frequent interdisciplinary interaction.

Center-of-Excellence Model of Care

This hospital-based model of care aims to provide preventive and specialized curative care for complex cases and to serve as a model to teach and disseminate information widely. Its catchment area is frequently regional, national, or even international. These centers are typically located in teaching hospitals.

Table 2. Summary of Clinical Levels of Care for Diabetic Foot Centers: Basic, Intermediate, and Center of Excellence Models

<table>
<thead>
<tr>
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<th>Basic Model</th>
<th>Intermediate Model</th>
<th>Center-of-Excellence Model</th>
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<tbody>
<tr>
<td>Aim</td>
<td>Prevention and basic curative care</td>
<td>Prevention and curative care for all types of patients; more advanced assessment and diagnosis</td>
<td>Prevention and specialized curative care for complex cases To advance the knowledge base and to teach other centers</td>
</tr>
<tr>
<td>Patients</td>
<td>Own population</td>
<td>From the regional catchment area of the hospital, possibly with additional referrals from outside the region</td>
<td>National, regional, or even international referral center</td>
</tr>
<tr>
<td>Setting</td>
<td>General practitioner’s office, health center, or small regional hospital</td>
<td>Hospital</td>
<td>Usually a large teaching or university hospital</td>
</tr>
<tr>
<td>Potential clinicians</td>
<td>General practitioner Podiatric physician Diabetic nurse</td>
<td>Diabetologist Vascular surgeon Podiatric physician Diabetic nurse</td>
<td>Diabetologist Vascular surgeon Podiatric physician Orthopedist Orthotist Educator Plaster technician Rehabilitation specialist Diabetic nurse Psychiatrist</td>
</tr>
<tr>
<td>Facilitating elements</td>
<td>Close collaboration with a referral center</td>
<td>Motivated coordinator to inspire team Exchange of experience with other centers Staff meetings to discuss patients with diabetic foot Active collaboration with other departments in the hospital Active collaboration with extramural facilities (general practices, nursing homes, etc)</td>
<td>Organize regional, national, or international meetings Allow providers to visit to improve knowledge and practical skills Active collaboration with other reference centers Active participation in the development of guidelines</td>
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hospitals and may include a variety of other specialists to assist in the management of commensurately more complex cases. These programs are frequently organizers of regional, national, or international meetings and host and train visitors from basic- and intermediate-care foot clinics.

Conclusions

The most common pathway leading to amputation in the person with diabetes begins with a simple neuropathic foot ulcer, frequently complicated by infection and ischemia due to peripheral arterial disease. The ideal care team should include specialists with expertise in these disciplines to be most effective. With the possible exception of the basic diabetic foot center, the podiatric physician and the vascular surgeon (toe and flow concept) are uniquely suited to clinically partner in the establishment of comprehensive programs aiming to prevent limb loss. Reports have shown reductions in major amputations and foot complications with multidisciplinary cooperation, suggesting that it is better communication and organization in concert with significant enthusiasm that makes the difference.

Financial Disclosure: None reported.
Conflict of Interest: None reported.

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