

REVIEW ARTICLE

Edward W. Campion, M.D., *Editor*

Evaluation and Management of Lower-Extremity Ulcers

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LOWER-EXTREMITY ULCERS ARE VERY COMMON, WITH AN ESTIMATED prevalence of 1 to 2% among U.S. adults,¹ and they have a major effect on public health. Lower-extremity ulcers are divided into two groups — leg ulcers and foot ulcers — because of differences in causes, pathogenesis, and treatment. Even with the best care currently available, 25 to 50% of leg ulcers and more than 30% of foot ulcers are not fully healed after 6 months of treatment. Approximately 70% of leg ulcers are caused by venous disease, and roughly 20% are caused by arterial insufficiency or mixed arteriovenous disease.^{1,2} Approximately 85% of foot ulcers are caused by peripheral neuropathy, often complicated by arterial disease.

Risk factors for venous leg ulcers include advanced age, female sex, family history of venous leg ulcer, white race, history of deep-vein thrombosis or phlebitis, previous leg injury, chronic leg edema, sedentary lifestyle, and prolonged standing. Risk factors for any arterial ulcers include diabetes mellitus, hypertension, hyperlipidemia, obesity, and smoking.³⁻⁶ Risk factors for foot ulcers include lack of sensation, limited joint mobility, anatomical abnormalities, diabetes mellitus, vascular disease, and repetitive high pressure.

The annual costs associated with venous leg ulcers and diabetic foot ulcers in the United States are approximately \$14.9 billion⁷ and \$9 billion to \$13 billion,⁸ respectively. Patients with venous leg ulcers require more medical resources than patients in a demographically matched control population.⁷ They also miss more days of work, owing to ulcer-related complications or need for follow-up, which results in costs from the loss of work that are nearly a third higher than those in a matched population. Patients with diabetic foot ulcers are often hospitalized more frequently, require more home health care, and have more emergency department visits and outpatient office visits than patients in a matched population.⁸

In this article, we describe our approach to the management of lower-extremity ulcers. Whenever possible, we have based our recommendations on findings from randomized trials. Because some recommendations are based on findings from small, observational studies or expert opinion, we recognize that there is disagreement regarding some recommended approaches; nevertheless, the approach we advise has been shown to be useful in our practices.

PATHOPHYSIOLOGICAL FEATURES OF ULCER TYPES

VENOUS ULCERS

When the valves in leg veins are damaged or the veins are dilated, retrograde blood flow results in venous hypertension. Sustained ambulatory venous pressure leads to extraction of fluid and proteins, which causes edema and extravasation of red cells that results in hemosiderin deposition and pigmentation. Mechanical disrupt-

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tion of the endothelial cells and their glycocalyx coating results in margination and activation of white cells,⁹ which leads to persistent inflammation and oxidative stress, along with the expression of multiple cytokines and chemokines.¹⁰ Overexpression of matrix metalloproteinases alters collagen turnover and results in destruction of the dermal tissues and subsequent ulcer formation.¹¹ Pericapillary fibrin cuffs trap growth factors and disrupt the diffusion of oxygen, thereby contributing to local tissue hypoxia. The end result is open, draining wounds with overlying slough and surrounding induration.

ARTERIAL ULCERS

Arterial ulcers result from impaired tissue perfusion. In addition to intramural restriction of blood flow, extramural strangulation and mural thickening also contribute to reduced perfusion. Causes of reduced arterial blood flow include peripheral vascular disease due to atherosclerosis, macrovascular and microvascular disease due to diabetes mellitus, vasculitis, and microthrombi.² Reduced perfusion of the skin and soft tissues results in ischemia and subsequent necrosis, leading to leg ulceration. Recurring episodes of ischemia and reperfusion also contribute to tissue injury.¹²

DIABETIC ULCERS

Causes of diabetic foot ulcers are multifactorial and include arterial insufficiency and neuropathy, which confer a predisposition to injury and ulcer formation.¹³⁻¹⁶ The loss of protective sensation in patients with diabetes makes them vulnerable to physical trauma; therefore, patients with diabetes should receive meticulous foot care and undergo frequent inspection of their feet. Deficient sweating and altered perfusion in the foot lead to dry skin that is easily injured by minimal and repetitive trauma.¹³⁻¹⁵ Autonomic neuropathy leads to foot deformities (e.g., the Charcot foot) that result in pressure over prominent areas of the foot.¹⁶ Other abnormalities related to diabetes mellitus (such as defective white-cell function) impair wound healing and lead to the perpetuation of ulcers and secondary infection.

PRESSURE ULCERS

Pressure ulcers are caused by unrelieved pressure over bony prominences such as the heel and usually develop in nonambulatory patients. Prolonged

compression of the tissues, along with friction and shear, results in local tissue ischemia and necrosis, which lead to ulcer formation.¹⁷

DIAGNOSIS

IDENTIFYING ULCER TYPE

Most ulcer types can be identified on the basis of their appearance and location (Fig. 1). History taking should focus on coexisting medical conditions, such as diabetes mellitus, peripheral arterial disease, and deep-vein thrombosis, that may point to the underlying cause of the ulcer. In addition to an examination of the wound and surrounding skin, physical examination should include a neurovascular evaluation aimed at identifying neuropathy and arterial insufficiency.

Venous Ulcers

Venous leg ulcers typically occur over the medial aspect of the lower leg between the lower calf and the medial malleolus and are associated with edema, pigment deposition (combined hemosiderin and melanin), venous dermatitis, atrophie blanche (porcelain white scars, telangiectasia, and dyspigmentation), and lipodermatosclerosis. Patients often report aching or burning pain (or both) and swelling in the leg that progress during the day and lessen with leg elevation. A patient's history may also include deep-vein thrombosis, trauma, or surgery in the affected leg. Venous leg ulcers are shallow and irregularly shaped and contain granulation tissue or yellow fibrin (Fig. 1). Venous reflux can be diagnosed by means of duplex ultrasonography of the lower leg.

Arterial Ulcers

Arterial ulcers are more common among smokers and among patients with diabetes mellitus, those with hyperlipidemia, and those with hypertension. Patients may have a history of intermittent claudication or pain while at rest that worsens when the leg is elevated and lessens when the leg is in a dependent position. Arterial ulcers may involve the distal foot at areas of trauma (e.g., toes and heels) and the anterior aspect of the leg where arterial redundancy is lacking. The ulcers are often dry and appear "punched out," with well-demarcated edges and a pale, non-granulating necrotic base (Fig. 1). Arterial ulcers may also be very deep. Findings of abnormal pedal pulses, coolness in only one leg or foot, a

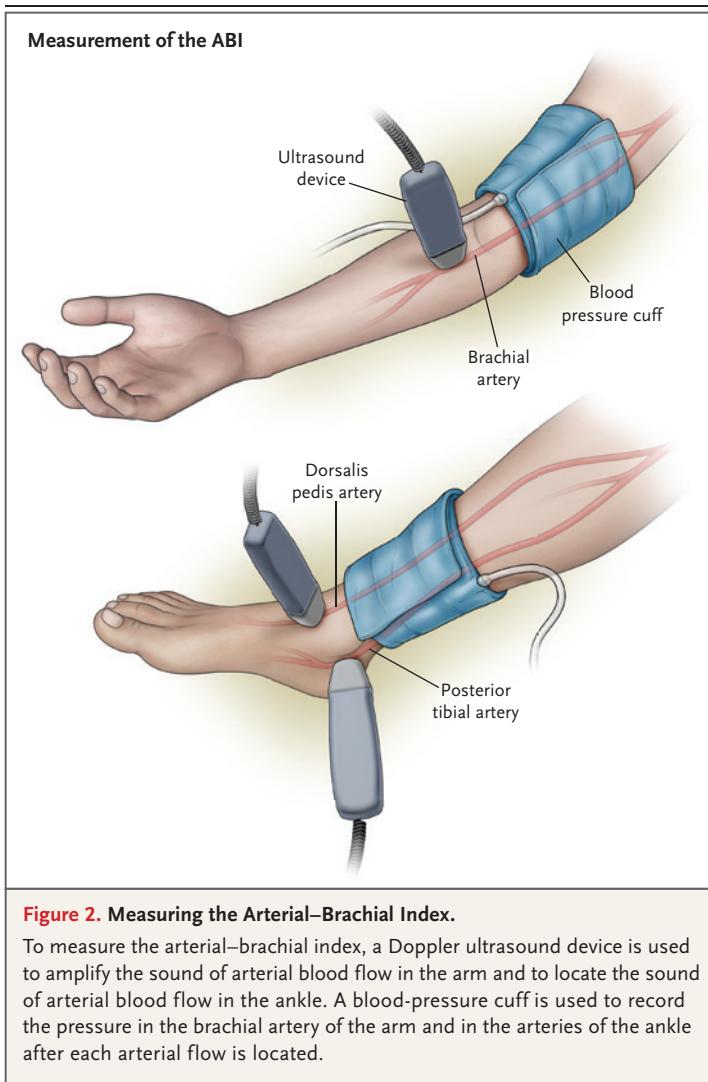
Feature	Ulcer Type			
	Venous	Arterial	Neuropathic Diabetic	Pressure
Underlying condition	Varicose veins, previous deep-vein thrombosis, obesity, pregnancy, recurrent phlebitis	Diabetes, hypertension, smoking, previous vascular disease	Diabetes, trauma, prolonged pressure	Limited mobility
Ulcer location	Area between the lower calf and the medial malleolus	Pressure points, toes and feet, lateral malleolus and tibial areas	Plantar aspect of foot, tip of the toe, lateral to fifth metatarsal	Bony prominences, heel
Ulcer characteristic	Shallow and flat margins, moderate-to-heavy exudate, slough at base with granulation tissue	Punched out and deep, irregular shape, unhealthy wound bed, presence of necrotic tissue, minimal exudate unless infected	Deep, surrounded by callus, insensate	Deep, often macerated
				
Condition of leg or foot	Hemosiderin staining, thickening and fibrosis, eczematous and itchy skin, limb edema, normal capillary refill	Thin shiny skin, reduced hair growth, cool skin, pallor on leg elevation, absent or weak pulses, delayed capillary refill, gangrene	Dry, cracked, insensate, calluses	Atrophic skin, loss of muscle mass
Treatment	Compression therapy, leg elevation, surgical management	Revascularization, anti-platelet medications, management of risk factors	Off-loading of pressure, topical growth factors	Off-loading of pressure; reduction of excessive moisture, shear, and friction; adequate nutrition

Figure 1. Venous, Arterial, Neuropathic Diabetic, and Pressure Ulcers.

prolonged venous filling time, and a femoral bruit facilitate the diagnosis of peripheral arterial disease.¹⁸ Findings of delayed capillary refill and discoloration, skin atrophy, and lack of hair on the foot are probably not helpful in establishing a diagnosis. An ischemic foot sometimes appears pink and is relatively warm because of arteriovenous shunting. Leg elevation may worsen pain, because it results in drainage of blood, and the foot becomes pale (elevation pallor).

Delayed return of red color or prolonged venous filling when the leg is in a dependent position may also be signs of decreased perfusion.

In addition to palpation of arterial pulses in the leg and foot, a simple method for identifying decreased lower-extremity perfusion is measurement of the ankle-brachial index (ABI). The measurements are performed with a standard blood-pressure cuff and a Doppler ultrasound device (Fig. 2). An ABI lower than 0.9 indicates arterial



insufficiency and should lead to further investigation by a vascular surgeon.¹⁹ Lower ABIs are associated with more severe vascular disease, and ABIs lower than 0.5 are often seen in patients who have ulcers that developed as a result of arterial insufficiency. Falsely normal or even elevated ABIs may be seen in patients with non-compressible vessels, in patients with diabetes that is caused by glycation of blood vessels, and in elderly patients with vessel calcification. Computed tomographic angiography and magnetic resonance angiography may be used if the diagnosis is unclear. Transcutaneous oxygen tension (oxygen level of the tissue below the skin), when it can be measured, is a good indicator of critical limb ischemia. A recent meta-analysis showed that a transcutaneous oxygen tension of 20 mm Hg

was a valid cutoff value for predicting the need for limb amputation and that a transcutaneous oxygen tension of 30 mm Hg was an appropriate value for predicting wound healing after limb amputation.²⁰

Neuropathic Diabetic Ulcers

Neuropathy usually occurs in patients with diabetes mellitus and is an important risk factor for foot ulceration. A simple blood-sugar (or glycated hemoglobin) measurement should be obtained to assess for hyperglycemia, and a sensory examination of the legs and feet should be performed to assess for neuropathy. Neuropathic ulcers are usually located at sites of trauma (often repetitive) or at sites of prolonged pressure such as the tip of the toe (e.g., because of hammer toe), the medial side of the first metatarsal phalangeal joint, or the plantar surface of the feet (Fig. 1). A simple assessment that uses a 10-g filament has been validated as a measure of the foot's ability to detect sensation, regardless of whether it is performed along with an assessment of the foot's ability to sense vibration from a standard tuning fork.²¹ Testing for neuropathy should not be performed over areas of callus.²²

Pressure Ulcers

Pressure ulcers occur because of the inability to sense (e.g., neuropathy) or relieve (e.g., debilitation) prolonged pressure over the skin, typically on the heel of the foot. Skin atrophy and loss of muscle mass, common conditions in debilitated patients, further contribute to the susceptibility to pressure-ulcer formation.

IDENTIFYING INFECTION

Although recognition of infection in lower-extremity ulcers may be difficult, it is essential. Of all lower-extremity ulcers, diabetic foot ulcers are the most prone to infection, with more than half involving clinical infection at the time of a patient's presentation to a health care practitioner.²³ Early identification of infection in diabetic foot ulcers is critical, because one in five patients with an infected foot will eventually undergo amputation.²⁴ Diagnosis of infection is made clinically and should not be based on findings from wound-surface swabs. Microbiologic findings support and direct antibiotic therapy. Signs and symptoms of localized infection include local warmth, erythema, tenderness or pain, swelling,

and purulent discharge. Systemic infection and subsequent host response is suggested by the presence of fever, chills, leukocytosis, and expanding erythema and lymphangitis. Deep swabbing of the wound, aspiration of purulent discharge, and tissue biopsies can help identify a causative agent and may assist in identifying the appropriate antibiotic therapy, if initial antibiotic therapy is unsuccessful. Most acute infections that have not been treated with antibiotics are caused by gram-positive organisms such as staphylococci.²⁵ Chronic infections, especially after administration of antibiotics, are generally polymicrobial, with gram-positive, gram-negative, and anaerobic bacteria.²⁶ Severe necrotizing infections are characterized by the presence of crepitus, bullae, and extensive necrosis and warrant urgent consultation with a vascular surgeon. Underlying osteomyelitis is not uncommon in diabetic foot ulcers and should be suspected in the case of deep, chronic ulcers over bones. A sterile blunt metal probe can be inserted into the depth of the wound. In hospitalized patients, osteomyelitis can be diagnosed with greatest predictive value by identification of bone at the depth of the ulcer (hard gritty feel).²⁷ Although the criterion standard for diagnosing osteomyelitis is a bone biopsy, infections can be confirmed by noninvasive methods such as plain radiography or magnetic resonance imaging, which is more sensitive than plain radiography.²⁸

TREATMENT

GENERAL PRINCIPLES

There are a number of guidelines for the management of lower-extremity ulcers.²⁸⁻³⁴ General principles of management include wound débridement, infection control, application of dressings, off-loading of localized pressure, and treatment of underlying conditions such as diabetes mellitus and peripheral arterial disease. Lifestyle changes (e.g., smoking cessation and dietary modifications) should also be made to help manage underlying diseases.

Wound Débridement

Débridement, which involves removal of devitalized tissue, reduces bacterial burden.³⁵⁻³⁷ Careful, sharp surgical débridement (with the use of a scalpel, sharp scissors, or both) down to viable bleeding tissue, with removal of senescent fibro-

blasts in the wound bed and phenotypically and genotypically abnormal keratinocytes at the edge of the wound, is the most rapid method. Autolytic dressings (such as alginates, hydrocolloids, and hydrogels) and enzymatic agents (such as collagenase) may also be considered³⁸; although these options are slower than surgical débridement, they are less painful and traumatic.

Infection Control

A systematic review of 45 randomized, controlled trials involving a total of 4486 patients showed no evidence that supported the routine use of prophylactic systemic antibiotics for lower-extremity ulcers.³⁹ Although the review showed evidence that supported the topical use of cadexomer iodine, no evidence supported the prolonged or routine use of silver-based or honey-based products in noninfected wounds.³⁹ In our practices, topical cadexomer is used for contaminated ulcers that have no clear-cut evidence of infection and as an adjunct to systemic antibiotics in infected ulcers.

If infection is suspected because of the presence of malodorous purulent discharge or because healing does not progress after routine débridement, infection can be confirmed with tissue biopsies (if available) or validated quantitative wound swabs (these are not required in the case of obvious infection).^{30,34} For ulcers that have a high bacterial burden ($>10^6$ colony-forming units per gram of tissue or any level of beta-hemolytic streptococci) after adequate débridement, topical or systemic antibiotic therapy targeting gram-positive bacteria should be started, such as dicloxacillin, cephalexin, or clindamycin. In our practices, topical antibiotics are used first, unless there is evidence of obvious infection. Because of the multiple bacterial causes in patients with diabetes, wide-spectrum systemic antibiotics that cover gram-positive and gram-negative bacteria as well as anaerobes should be used in these patients. Potential agents include a combination of a penicillin and a beta-lactamase inhibitor or a fluoroquinolone or linezolid alone.

Patients with spreading erythema from cellulitis or clinically significant evidence of systemic infection (e.g., fever, chills, or lymphangitis), patients with clinically significant coexisting medical or immunocompromising conditions (e.g., uncontrolled diabetes mellitus or use of systemic glucocorticoids), and patients with local infection that is worsening or not responding to

oral antibiotic agents should generally receive intravenous antibiotics. Consultation with an infectious disease specialist should be considered for refractory or complex infections.

Wound Dressings

Wound dressings that promote an appropriate level of moisture (while limiting maceration) and protect the ulcer from further injury and shear stress should be used. A large number of wound dressings are available, including hydrocolloids, alginates, and foams. Many advanced dressings may be left in place for up to a week unless they are malodorous or saturated with exudate. The decision of which dressing to use should be based on the preferences of the patient and practitioner. In general, dry wounds should be treated with moisture-promoting dressings, whereas exudative wounds should be managed with absorptive dressings. Dressings are also available in combination with antiseptic agents (e.g., nanoparticles of silver); these may be helpful in the short term to reduce the concentration of bacteria when infection is present, but they are not recommended for long-term use. Foam dressings, despite their frequent use, are no more effective than other standard dressings.⁴⁰

Pressure Relief

Avoiding or minimizing pressure over bony prominences plays a vital role in the prevention and management of pressure ulcers.³³ Proactive assessment of the risk of pressure ulcers (e.g., the Braden scale) should be performed in all hospitalized patients.⁴¹ Frequent repositioning of patients and the use of pressure-reducing surfaces (e.g., an alternating pressure mattress) and orthotics that relieve pressure from the ulcer and minimize shear stress are recommended.⁴²⁻⁴⁴

SPECIFIC THERAPIES BASED ON THE TYPE OF ULCER

Venous Ulcers

Compression therapy is strongly recommended for venous leg ulcers.³⁰ The compression dressing is applied from the toes to the knees and should include the heel. Graded pressure is applied, with more pressure applied distally. Each successive wrap should overlap the previous one by 50%. Several large clinical trials and systematic reviews have concluded that compression therapy, as compared with no compression, promotes the healing of venous leg ulcers and re-

duces the risk of recurrence and is similar to surgical intervention.^{45,46} Multicomponent systems that contain an elastic bandage appear to be more effective than those that have only inelastic components. The recommended compression pressures for the treatment of venous leg ulcers with varicose veins, the postthrombotic syndrome, or lymphedema are between 30 and 40 mm Hg.⁴⁶

In our practices, we modify compression therapy in patients with mild-to-moderate arterial disease (e.g., an ABI between 0.5 and 0.8) by using inelastic wraps or by reducing the number of layers of compression, and we follow the patients weekly to ensure that arterial flow is adequate. In severe cases (ABI <0.5), compression should not be used because it may further reduce arterial flow. Venous ablation appears to reduce the incidence of recurrence and may facilitate the healing of venous leg ulcers, although evidence for this from well-performed studies is still lacking. A meta-analysis of studies that included patients with venous leg ulcers indicated that 45% of all ulcers are due to superficial vein reflux only, and 88% of patients with venous leg ulcers have reflux in the superficial system.⁴⁷ Superficial vein reflux can be treated with outpatient procedures such as sclerotherapy or venous ablation with the use of laser or radiofrequency.⁴⁸

Because inflammation is thought to play a role in the pathogenesis of venous leg ulcers, two small randomized, controlled trials evaluated the efficacy of adding aspirin, administered orally at a dose of 300 mg per day, to compression therapy; the results suggested a benefit.⁴⁹ However, the small sample size and issues related to study quality (short follow-up and poor description of placebo) limit the ability to draw conclusions regarding the benefits and harms of regular use of aspirin for venous leg ulcers. In our practices, aspirin is used in patients with venous leg ulcers when not contraindicated.

Despite a lack of data from randomized, controlled trials, autologous split-thickness skin grafting is often used for débrided, noninfected, chronic lower-extremity ulcers that fail to heal, especially venous leg ulcers, with a success rate of up to 90% at 5 years.⁵⁰ Because surgery (e.g., high ligation and vein stripping) has been shown to reduce the incidence of recurrence of venous leg ulcers,⁵¹ patients with chronic lower-extremity ulcers that have not healed despite débridement should be considered for referral to a vascular

surgeon for consideration of venous intervention. Endovenous intervention with compression may be considered for venous leg ulcers that are caused by small varicose veins other than those of the saphenous type.⁵²

Arterial Ulcers

The most effective method to accelerate healing of arterial ulcers is to restore local blood flow by revascularization.³¹ A systematic review of the effectiveness of revascularization of the ulcerated foot by endovascular therapies or by surgical bypass techniques in patients with diabetes mellitus and peripheral arterial disease concluded that there were insufficient data to recommend one method of revascularization over another.⁵³ The decision of whether to perform an endovascular procedure or open bypass surgery should be based on the characteristics and preferences of the patient, as well as on the experience and preferences of the surgeon.

Neuropathic Diabetic and Pressure Ulcers

Careful inspection of the patient's footwear may help identify improper fit, wear and tear, or the presence of foreign bodies that contribute to ulcer formation. Off-loading of pressure in neuropathic ulcers is essential. Off-loading may be achieved with the use of total-contact casts (i.e., nonremovable casts), removable boots, instant total-contact casts (i.e., removable walking casts that are made nonremovable by the addition of plaster), fiberglass boots, and wheelchairs — and to a lesser extent with healing sandals, crutches, and walkers.^{22,54} In two meta-analyses, nonremovable methods (total-contact casts or instant total-contact casts) were more effective at healing plantar ulcers than removable methods (relative rate of healing, 1.43⁵⁵ and 1.17⁵⁶). Specialized pressure-measurement systems that measure off-loading while the patient is walking barefoot or wearing a shoe may help tailor therapy.⁵⁷ Patients should also be referred to a foot and ankle specialist to consider correction of any bone abnormalities. However, many surgical off-loading procedures are more effective in preventing ulcer recurrence than in treating active ulcers.⁵⁸

ADVANCED THERAPIES

If a wound does not respond to standard care (with response typically defined as a reduction in wound size of 30% for venous leg ulcers and

50% for diabetic foot ulcers within 4 weeks after the initiation of treatment), advanced care and referral to a wound specialist are indicated. For venous leg ulcers, adjunctive treatments that are considered to speed healing include oral medications such as pentoxifylline,⁵⁹ aspirin,⁴⁹ simvastatin,⁶⁰ and sulodexide,⁶¹ as well as cell-based and tissue-based products such as bilayered living skin construct,⁶² porcine small-intestine submucosa,⁶³ a synthetic matrix made of poly-N-acetyl glucosamine,⁶⁴ or granulocyte-macrophage colony-stimulating factor.⁶⁵ Adjunctive therapies that may be considered for diabetic foot ulcers include platelet-derived growth factor,⁶⁶ platelet-rich plasma,⁶⁷ placental membranes,⁶⁸ human amniotic membrane,⁶⁹ bilayered skin equivalent,⁷⁰ dermal skin substitutes,^{71,72} negative-pressure wound therapy,⁷³ and hyperbaric oxygen therapy.⁷⁴ Other therapies that have shown promise include ultrasound therapy,⁷⁵ electrical stimulation,⁷⁶ extracorporeal shock-wave therapy,⁷⁷ and spinal cord stimulation.⁷⁸ Further details of advanced therapies for lower-extremity ulcers are provided in Table S1 in the Supplementary Appendix, available with the full text of this article at NEJM.org.

PATIENT DISPOSITION

Patients with any limb-threatening or life-threatening conditions should be admitted to the hospital, and a vascular surgeon or wound specialist should be consulted immediately. Patients with systemic infection and patients with expanding local infection that does not respond to oral antibiotics should be admitted to the hospital to receive intravenous antibiotics. Patients who cannot care for themselves or their wounds may require home health care or admission to a skilled nursing facility or hospital. All other patients may be treated with a wound dressing and off-loading of pressure (when indicated) and referred to their primary care physician or wound specialist. Referral to an orthotist for prosthetic footwear evaluation as a preventive measure should also be considered. Finally, given the burden of lower-extremity ulcers, health care practitioners should focus not only on early intervention but also on prevention in patients at risk for lower-extremity ulcers.

No potential conflict of interest relevant to this article was reported.

Disclosure forms provided by the authors are available with the full text of this article at NEJM.org.

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