Preventing Foot Ulcers in Patients With Diabetes

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AMONG PERSONS DIAGNOSED AS having diabetes mellitus, the lifetime risk of developing a foot ulcer is estimated to be 15%.[1] Based on recent studies, the annual population-based incidence ranges from 1.0% to 4.1%[2] and the prevalence ranges from 4% to 10%, which suggests that the lifetime incidence may be as high as 25%.[3,4] Lower extremity disease, including peripheral arterial disease, peripheral neuropathy, foot ulceration, or lower extremity amputation, is twice as common in diabetic persons compared with nondiabetic persons and it affects 30% of diabetic persons who are older than 40 years.[5] Foot ulcers cause substantial emotional, physical, productivity, and financial losses.[6-9] The estimated costs of treating a diabetic foot ulcer were $28 000 in a 1999 US study,[10] and $18 000 (with no amputation) and $34 000 (with amputation) in a 2000 Swedish study.[11]

The most costly and feared consequence of a foot ulcer is limb amputation, which occurs 10 to 30 times more often in diabetic persons than in the general population.[12,13] Diabetes underlies up to 8 of 10 nontraumatic amputations, of which 85% follow a foot ulcer.[1,3,14] The age-adjusted annual incidence for nontraumatic lower limb amputations in diabetic

See also Patient Page.

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Context Among persons diagnosed as having diabetes mellitus, the prevalence of foot ulcers is 4% to 10%, the annual population-based incidence is 1.0% to 4.1%, and the lifetime incidence may be as high as 25%. These ulcers frequently become infected, cause great morbidity, engender considerable financial costs, and are the usual first step to lower extremity amputation.

Objective To systematically review the evidence on the efficacy of methods advocated for preventing diabetic foot ulcers in the primary care setting.

Data Sources, Study Selection, and Data Extraction The EBSCO, MEDLINE, and the National Guideline Clearinghouse databases were searched for articles published between January 1980 and April 2004 using database-specific keywords. Bibliographies of retrieved articles were also searched, along with the Cochrane Library and relevant Web sites. We reviewed the retrieved literature for pertinent information, paying particular attention to prospective cohort studies and randomized clinical trials.

Data Synthesis Prevention of diabetic foot ulcers begins with screening for loss of protective sensation, which is best accomplished in the primary care setting with a brief history and the Semmes-Weinstein monofilament. Specialist clinics may quantify neuropathy with biothesiometry, measure plantar foot pressure, and assess lower extremity vascular status with Doppler ultrasound and ankle-brachial blood pressure indices. These measurements, in conjunction with other findings from the history and physical examination, enable clinicians to stratify patients based on risk and to determine the type of intervention. Educating patients about proper foot care and periodic foot examinations are effective interventions to prevent ulceration. Other possibly effective clinical interventions include optimizing glycemic control, smoking cessation, intensive podiatric care, debridement of calluses, and certain types of prophylactic foot surgery. The value of various types of prescription footwear for ulcer prevention is not clear.

Conclusions Substantial evidence supports screening all patients with diabetes to identify those at risk for foot ulceration. These patients might benefit from certain prophylactic interventions, including patient education, prescription footwear, intensive podiatric care, and evaluation for surgical interventions.

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persons ranges from 2.1 to 13.7 per 1000 persons.[2] Mortality following amputation ranges from 13% to 40% at 1 year, 35% to 65% at 3 years, and 39% to 80% at 5 years—worse than for most malignancies.[2]

In light of the enormous disease burden of diabetic foot ulcers, it is crucial

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to know if they are preventable. This review summarizes and critically evaluates evidence on the efficacy of identifying diabetic persons at high risk for foot ulcers and of interventions designed to prevent them.

METHODS

Assisted by a medical librarian, we conducted a systematic literature search using the EBSCO (EBSCO Information Services, Birmingham, Ala), MEDLINE, and the National Guideline Clearinghouse databases for articles published between January 1980 and April 2004 and used the following phrases: *diabetes or diabetic*, *foot ulcer or infection*, and *prevention or preventing*. The EBSCO database includes the American Medical Association Collection, Comprehensive Biomedical Reference Collection, Cumulative Index to Nursing and Allied Health Literature, Cochrane Database of Systematic Reviews, Cochrane Controlled Trials Register, Database of Abstracts of Reviews of Effectiveness, Health Business Fulltext Elite, International Pharmaceutical Abstracts, Comprehensive Nursing and Allied Health Collection, and the American Medical Association's Archive. We also searched (1) the bibliography of each identified article; (2) the National Guideline Clearinghouse Web site (http://www.guidelines.gov); (3) an extensive printed diabetic foot reference collection[15]; and (4) several Web sites specializing in issues related to the diabetic foot.

This search identified 165 articles that addressed preventing diabetic foot ulcers, including 22 randomized controlled studies, most of which measured changes in the rates of foot ulceration and amputations related to various interventions. For topics on which there were only a few randomized controlled studies, we focused on selected case-control and cohort studies.

Pathophysiology of Diabetic Foot Ulcers

Causative Factors. The causal pathways leading to foot ulceration include several component causes, the most important of which is peripheral neuropathy.[16] This is present to some degree in more than 50% of diabetic persons older than 60 years.[17] Peripheral neuropathy must usually be profound before leading to loss of protective sensation; the consequent vulnerability to physical and thermal trauma increases the risk of foot ulceration 7-fold.[18,19] A second causative factor in foot ulceration is excessive plantar pressure.[20] This is related to both limited joint mobility (at the ankle, subtalar, and first metatarsophalangeal joints) and to foot deformities.[21-23] In one study of patients with peripheral neuropathy, 28% with high plantar pressure developed a foot ulcer during a 2.5-year follow-up compared with none with normal pressure.[24] A third component cause is trauma, especially when repetitive. Among 669 persons with a foot ulcer, 21% were attributed to rubbing from footwear, 11% were linked to injuries (mostly falls), 4% to cellulitis complicating tinea pedis, and 4% to self-inflicted trauma (eg, cutting toenails).[25] Persons who had a previous foot ulceration could withstand fewer cycles of stress to their feet before an ulcer recurred.[26]

Contributory Factors. Once a foot ulcer develops, several factors may contribute to adverse outcomes. The most important is atherosclerotic peripheral vascular disease, which is twice as common in persons with diabetes as in persons without diabetes[5] and particularly affects the femoropopliteal and smaller vessels below the knee, while frequently sparing the pedal vessels.[27] Diabetes is also associated with several intrinsic wound-healing disturbances, including impaired collagen cross-linking and matrix metalloproteinase function,[27,28] and immunologic perturbations, especially in polymorphonuclear leukocyte function.[29,30] Furthermore, persons with diabetes have a higher rate of onychomycosis and toe-web tinea infections that can lead to skin disruption.[31-34]

Having a foot ulcer dramatically worsens physical, psychological, and social quality of life.[6-8,35,36] The obesity and poor vision that are associated with diabetes may also impair self-care. Optimal prevention (and treatment) outcomes require both a motivated patient and an effective medical care system.

Screening to Identify Patients at Risk for Diabetic Foot Ulcers

Preventing foot complications begins with identifying those at risk. Primary care clinicians should inquire about factors known to be associated with foot ulcers, namely, previous foot ulceration (relative risk [RR], 1.6; 95% confidence interval [CI], 1.2-2.3; $P=.004$),[37] prior lower extremity amputation (RR, 2.8; 95% CI, 1.8-4.3; $P<.001$),[37] long duration (>10 years) of having diabetes (odds ratio [OR], 3.0; $P<.04$),[38] poor glycemic control (glycosylated hemoglobin $>9\%$; OR, 3.2; $P<.03$),[38] and impaired vision (acuity $<20/40$; RR, 1.9; 95% CI, 1.4-2.6; $P<.001$).[37] Clinicians should also examine the feet for structural abnormalities (eg, calluses, hammer or claw toes, flat feet, bunions), reduced joint mobility, dry or fissured skin, tinea, or onychomycosis,[39,40] and also inspect footwear to ensure proper fit.

Screening for Loss of Protective Sensation. Nerve conduction studies are generally considered the criterion standard for diagnosing peripheral neuropathy. They are less useful in screening for loss of protective sensation (ie, degree of neuropathy beyond which the patient has a measurably increased risk for diabetic foot ulceration),[41] and are not widely available.

Monofilament. The most frequently used instrument for detecting neuropathy is the nylon Semmes-Weinstein monofilament.[42] Inability to perceive the 10g of force a 5.07 monofilament applies is associated with clinically significant large-fiber neuropathy (**FIGURE**). In 3 prospective studies, the Semmes-Weinstein monofilament identified persons at increased risk of foot ulceration with a sensitivity of 66% to 91%, a specificity of 34% to 86%, a positive predictive value of 18% to 39%, and a negative predictive value of 94% to 95%.[37,45,46] Certain brands of monofilaments are more accurate than others[47] and they should not be used on more than 10 patients without a recovery period of 24 hours.[42,47]

While authorities recommend testing 8 to 10 anatomic sites, testing just 4 plantar sites on the forefoot (great toe and base of first, third, and fifth metatarsals) identifies 90% of patients with an insensate site.[48] Most consider a lack of perception at any site(s) to be abnormal, but as the threshold for an abnormal test is raised from 1 to 4 insensate sites, the sensitivity remains higher than 90% while the specificity improves from 60% to 80%.[44] Asking the patient to say "yes" or "no" when asked if he/she believes the Semmes-Weinstein monofilament is being applied is equally accurate and quicker than the "forced-choice" method (asking the patient to correctly identify whether it was at time "A" or "B" that the monofilament was applied).[49]

Biothesiometer. A biothesiometer (Xilas Medical, San Antonio, Tex) is a handheld device that assesses vibration-perception threshold.[50] A rubber tactor is applied to the distal aspect of the toe and the amplitude is increased to a maximum of 100 V (converted from microns).[41,46] In one study, a vibration-perception threshold of more than 25 V had a sensitivity of 83%, a specificity of 63%, a positive likelihood ratio of 2.2 (95% CI, 1.8-2.5), and a negative likelihood ratio of 0.27 (95% CI, 0.14-0.48) for predicting a foot ulceration over 4 years.[19,51] A case-control study with 255 diabetic persons found that having either abnormal Semmes-Weinstein monofilament perception or a vibration-perception threshold of more than 25 V predicted foot ulceration with a sensitivity of 100% and a specificity of 77%.[43]

Tuning Fork. The tuning fork provides an easy and inexpensive test of vibratory sensation. With a conventional fork, an abnormal response occurs when the patient loses vibratory sensation while the examiner still perceives it.[37] With a graduated (Rydel-Seiffer) fork (Gebrueder Martin, Tuttlingen, Germany), persons indicate first loss of vibration at the plantar hallux as the intersection of 2 virtual triangles moves on a scale exponentially from 0 to 8 in a mean (SD) of 39.8 (1)

seconds.[52] This test correlates more strongly with biothesiometer results (r, –0.90; $P<.001$)[53] than the conventional tuning fork,[54] but the latter predicted foot ulceration in 2 studies.[37,55] Tuning fork results are less predictive of ulceration than results from using the monofilament.[37]

Screening for Patients With Elevated Plantar Pressure. Devices identifying high plantar pressure include mats to measure barefoot plantar load distribution and transducers distributed in a removable shoe insole to measure pressure inside footwear.[56] The numerical values generated are often device-specific and cannot easily be compared. There is no generally accepted plantar pressure level associated with an increased risk of diabetic foot ulceration. In case-control studies using the EMED pressure platform system (Novell, Minneapolis, Minn), a peak barefoot dynamic pressure of 70 N/cm^2 had a sensitivity of 70.0% and a specificity of 65.1%, while a cutoff of 87.5 N/cm^2 had a sensitivity of 64%, a specificity of 46%, a positive predictive value of 17%, and a negative predictive value of 90% (**TABLE 1**).[57,58]

Figure. Monofilament Test for Light Touch Sensation
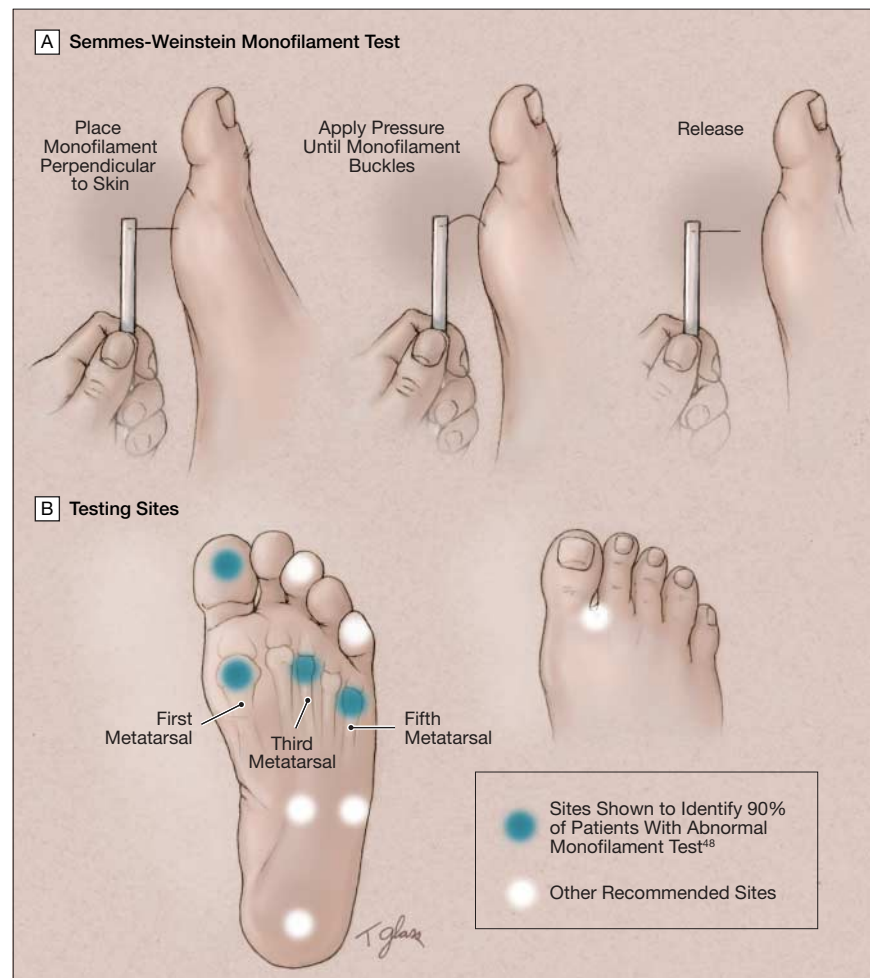
The 5.07 Semmes-Weinstein monofilament consists of a plastic handle supporting a nylon filament. The filament is placed perpendicular to the skin, and pressure is applied until the filament buckles. The filament is held in place for approximately 1 second, then released. Inability to perceive the 10*g* of force it applies is associated with clinically significant large-fiber neuropathy.[42,43] Testing 10 sites (as shown) evaluates all dermatomes of the foot and may improve the sensitivity and specificity compared with testing a single site.[44]

Screening for Peripheral Vascular Disease. Peripheral vascular disease is most easily detected by the ankle-brachial index (ABI), which is the ratio of systolic blood pressure in the ankle to that in the brachial artery. An ABI of 0.90 or less suggests peripheral vascular disease, while higher than 1.1 may represent a falsely elevated pressure caused by medial arterial calcinosis.[59] This test is easily performed, objective, and reproducible.[59] One large study found that the ABI was strongly related to the risk of foot ulceration (0.3 higher ABI is associated with an RR of 0.83; 95% CI, 0.73-0.96; $P=.01$).[37]

Arterial oxygen supply can also be measured by transcutaneous oximetry.[59] A transcutaneous oxygen tension higher than 30 mm Hg correlates with a high likelihood of wound healing.[59] Transcutaneous oxygen tension is also inversely associated with the risk of foot ulceration (15 mm Hg higher dorsal foot transcutaneous oxygen tension is associated with an RR of 0.80; 95% CI, 0.69-0.93; $P=.004$).[37] Because accurately measuring transcutaneous oxygen tension requires expensive equipment and a trained technician, it is not routinely used.

Educational Interventions to Prevent Foot Ulceration

Patient Education. Most patient education studies emphasize foot care, but have been short-term and have measured changes in behavior and cognition rather than the incidence of relevant clinical outcomes such as ulceration. Patient education formats have included lectures, hands-on workshops, skills exercises, behavioral modification programs, and telephone reminders (**TABLE 2**).

Two recent reviews concluded that patient education improves short-term knowledge and may modestly reduce risk of foot ulcerations and amputations.[51,67] Larger randomized clinical trials are needed to assess which patient education formats are the most effective, how often periodic reinforcement is required, and the long-term effectiveness of various programs.

Physician Education. Health care organizations have used various strategies to improve clinicians' performance with patient education.[68,69] In one strategy, a computerized registry reminded physicians to enter the patient's risk status for lower extremity amputation. After 28 months, the percentage of patients who had received foot screening and risk assessment increased from 15% to 76%.[68] Project LEAP (Lower-Extremity Amputation Prevention), developed by the US Department of Health and Human Services, is a 1-day workshop on diabetes foot care. When given to 560 clini-

cians from 85 organizations, it improved the rate of documenting foot care education from a baseline of 38% to 62% after 9 months.[70] More importantly, appropriate foot care self-management increased from 32% to 48%, and there was a trend toward reduced lower extremity amputations.[70]

Another approach is implementing foot care clinical practice guidelines. An Indian Health Service diabetes program observed 669 patients during a standard care period (1986-1989) with routine foot screening; a public health period (1990-1993) with an annual foot examination and initial risk stratification to give those at high-risk special interventions; and a staged diabetes management period (1994-1996) during which clinicians used clinical practice guidelines.[71] The average lower-extremity amputation incidence per 1000 diabetic person-years was 29 during the standard care period, 21 during public health, and 15 during staged management. The overall reduction in lower extremity amputation was 48% ($P=.02$), and the incidence of first amputation decreased from 21 per 1000 to 6 per 1000 from the first to the third period ($P<.001$).[71]

Clinical Practice Guidelines on the Diabetic Foot. Published guidelines[72-77] (**TABLE 3**) uniformly recommend that all diabetic persons have an

Table 1. Screening Methods to Identify Persons With Diabetes at Increased Risk for Foot Ulceration

	Monofilament (Light Touch Sensation)	Biothesiometer (Vibratory Sensation)	Tuning Fork (Vibratory Sensation)	Pressure Mat or Platform (Plantar Pressure)
No. and type of studies	3 Prospective cohort studies[37,45,46]	2 Prospective cohort studies[19,46]	1 Case-control study[55]; 1 prospective cohort study[37]	1 Case-control study[57]; 2 prospective cohort studies[46,58]
Criteria for positive screening test result	≥1 Insensate site	Vibration perception threshold >25 V	Patient loses vibration while examiner still perceives it	Cutoffs: ≥59 N/cm^2 [46]; ≥70 N/cm^2 [57]; ≥87.5 N/cm^2 [58]
Sensitivity, %	66-91	83-86	55-61	57; 70; 64
Specificity, %	34-86	57-63	59-72	70; 65; 46
Predictive value, %				
Positive	18-39	20-32	16*	31; 49; 17
Negative	94-95	95-97	93*	87; 82; 90
Likelihood ratio				
Positive	1.4-4.7	2.0-2.2	1.5-2.0	1.9; 2.0; 1.2
Negative	0.3-0.5	0.3	0.63-0.66	0.61; 0.46; 0.78
Comment	Inexpensive, quick, widely available, validated; number of test sites needed unclear	Accuracy similar to monofilament, but more expensive and not as widely available	Inexpensive, quick, widely available, less predictive than monofilament	Numerical value of plantar pressure is device-specific; optimal cutoff unknown

*Data not available in case-control study to calculate a positive and a negative predictive value.

annual foot examination that includes assessing for anatomic deformities, skin breaks, nail disorders, loss of protective sensation, diminished arterial supply, and improper footwear. The clinician should then assign the patient to a risk category by using any of several systems. The recommended interventions for various risk groups differ slightly among the guidelines, but persons at higher risk for foot ulceration should have more frequent foot examinations.[72-77]

Clinical Interventions to Prevent Foot Ulceration

Optimizing Glycemic Control. The Diabetes Complications and Control Trial reported a 57% reduction in the incidence of clinical neuropathy in patients managed with intensive compared with conventional glycemic treatment.[78] In the United Kingdom Prospective Diabetes Study, a 1% mean reduction in hemoglobin A_{1c} was associated with a 25% reduction in microvascular complications, including neu-

ropathy. There was also a nonsignificant reduction in amputations (by 36%) in the intensive compared with the conventional treatment group.[79]

Smoking Cessation. Some but not all studies have found a direct causal association between tobacco use and foot ulceration or amputation.[37] A case-control study of diabetic persons in the United Kingdom found the lower risk of leg amputation in those of South Asian compared with European ancestry (OR, 0.26; 95% CI, 0.11-0.65;

Table 2. Studies of Patient Education Programs Directed at Improving Foot Care in Persons With Diabetes

Effect Measured	No. of Patients, Intervention/ Control	Intervention	Duration of Intervention	Duration of Follow-up	Main Outcome for Intervention Group
Knowledge of foot care					
Kruger and Guthrie,[60] 1992	23/27	Hands-on session plus lecture vs lecture alone	1 wk	6 mo	No significant difference
Mazzuca et al,[61] 1986	263/269	Didactic instruction, skills exercises, behavioral modification, telephone follow-up vs usual care	Not stated	11.8-14.3 mo	No significant difference
Knowledge and incidence of foot lesions					
Barth et al,[62] 1991	32/38	4 Weekly ≈2-hour foot care sessions vs general diabetes mellitus education with 1 hour on foot care	4 wk (total of 9 h)	6 mo	Reduction in foot problems at 1 mo ($P<.006$) No significant difference in knowledge or presence of foot lesions at 6 mo
Bloomgarden et al,[63] 1987	165/180	9 Educational sessions about diabetes mellitus and foot care vs usual care only	Mean (SD), 1.6 (0.3) y	18 mo	Modestly increased knowledge for intervention group ($P = .007$) No significant difference in foot lesion rate between groups (RR, 0.83 [95% CI, 0.58 to 1.21]; ARR, −0.08 [95% CI, −0.24 to 0.80]; $P = .40$)*
Litzelman et al,[64] 1993	191/205	Sessions on foot care, telephone reminders, postcard reminders vs usual care	12 mo	12 mo	Fewer serious foot lesions (OR, 0.41 [95% CI, 0.16 to 1.00]; $P =.05$)† Higher average scores for self-reported care ($P<.001$)
Pieber et al,[65] 1995	53/55	4 Weekly sessions on diabetes mellitus education and foot care vs usual care	4 wk	6 mo	Significantly reduced callus formation and "poor nail care" compared with baseline
Incidence of amputations					
Malone et al,[66] 1989	103 (203 limbs)/ 100 (193 limbs)	1-Hour foot care class vs general diabetes mellitus education	1 h	24 mo	Lower incidence: Foot ulcers (4.5% vs 14.7%; RR, 0.31 [95% CI, 0.14 to 0.66]; ARR, −0.10 [95% CI, −0.16 to −0.04]; $P = .002$)* Amputations (4.0% vs 11.9%; RR, 0.33 [95% CI, 0.15 to 0.76]; ARR, −0.07 [95% CI, −0.13 to −0.02]; $P = .009$)*

Abbreviations: ARR, absolute risk reduction; CI, confidence interval; OR, odds ratio; RR, relative risk.
*Calculated measures of effect using STATA statistical software (version 8, STATA Corp, College Station, Tex).
†Measure of effect calculated by authors of original study.

P=.004) partly attributable to their lower rates of smoking (31% vs 57%; P=.03).[80] Similarly, a cross-sectional study of 1142 patients with type 2 diabetes in Jordan found smoking to be a strong predictor of amputation.[81]

Foot Examination by a Clinician. Foot examinations did not significantly reduce amputations among 244 diabetic patients in 1 case-control study (OR, 0.55; 95% CI, 0.2-1.7; P=.31).[82] These results may reflect the study's limited sample size, high rates of foot examination in both case and control pa-

tients, different degree of risk between the groups, as well as the unusually high rates of diabetes and amputations among the Pima Indian population studied.[83] Another randomized study of diabetic persons (N=91) with a previous foot ulceration found a significantly reduced risk for ulceration recurrence (RR, 0.52; 95% CI, 0.29-0.93; P = .03) at 1 year for those who received routine podiatric care.[84] Thus, screening foot examinations are unlikely to reduce the incidence of foot complications unless they eventuate in

appropriate specialist referrals (eg, for intensive podiatric care and customized footwear; TABLE 4).

Custom Footwear and Orthotics. Prescription shoes for high-risk patients should reduce areas of high plantar pressure and friction and accommodate foot deformities (eg, with a deep, wide toe box and ample padding).[85] Similarly, shoe inserts should cushion the plantar surface and redistribute pressure over a greater surface area.[85] Clinical data supporting the benefits of prescription footwear are surprisingly

Table 3. Summary of Available Recommendations From Professional Organizations on Screening to Prevent Diabetic Foot Ulcers in Persons With Diabetes*

Organization	Risk Stratification Category	Description of Risk Category	Recommended Interventions for Various Risk Strata	Recommended Footwear
International Working Group on the Diabetic Foot[74,75]	0	No sensory neuropathy	Annual foot examination	
	1	Sensory neuropathy only	Foot examination every 6 mo	Shoes with appropriate fit
	2	Sensory neuropathy plus peripheral vascular disease and/or foot deformities	Foot examination every 3 mo	Special footwear (including insoles and orthoses)
	3	Previous foot ulcer	Foot examination every 1-3 mo	Special footwear (including insoles and orthoses)
American Diabetes Association[77]	Low risk	No risk factors for foot ulcer		
	High risk	Peripheral neuropathy, altered biomechanics, increased pressure, bony deformity, peripheral vascular disease, history of foot ulcer or amputation, or severe nail pathology	More frequent evaluation, patient and family education Neuropathy: foot inspection by clinician at every clinic visit	Neuropathy or increased plantar pressure: well-fitted walking shoes or athletic shoes Foot deformities: extrawide or deep shoes Severe bony deformities: custom-molded shoes
US Veterans Health Agency and Department of Defense[76]	High risk	Lack of protective sensation, peripheral vascular disease, foot deformities, history of foot ulcer or nontraumatic amputation	Refer to foot care specialist	Foot deformities and neuropathy: extradeep shoes and/or pressure-reducing insoles Foot deformities not accommodated by deep shoes: custom-molded shoes
American College of Foot and Ankle Surgeons[72]		No universally accepted system, but includes International Working Group's categorization	General recommendations about preventative podiatric care, protective shoes, reducing high pressure Elective prophylactic surgery to correct selected deformities	High risk: therapeutic shoes with insoles and high toe box Severe foot deformities: custom-molded shoes
Collaborative Group From the United Kingdom†[73]	Low risk	Normal sensation, palpable pulses	Foot care education	
	At risk	Neuropathy, absent pedal pulses, or other risk factor	Foot examination every 3 to 6 mo and enhanced education	
	High risk	Risk factor plus foot deformity, skin changes, or previous ulcer	Specialist foot examination every 1-3 mo Specialist footwear and insoles Frequent skin and nail care	Specialist footwear and insoles

*All organizations recommend at least an annual foot screening for all persons with diabetes.
†Consists of the Royal College of General Practitioners, the British Diabetic Association, the Royal College of Physicians, and the Royal College of Nursing.

meager. In the largest of several studies, 400 persons with a history of a foot ulcer (but without a severe deformity) were randomized to receive extradeep, extrawide therapeutic shoes with customized neoprene-covered cork inserts; therapeutic shoes with nylon-covered polyurethane inserts; or instructed to wear usual footwear.[86] Persons assigned to therapeutic shoes had a similar incidence of foot ulcer recurrence as controls.[86] These surprising findings may have resulted from excluding patients with severe foot deformities, a person's low baseline prevalence (58%) of "foot insensitivity,"[87] and defining a foot ulcer as existing for 30 days or longer. This and other studies suggest that patients at low risk for foot complications may safely wear well-fitting, good-quality over-the-counter athletic or walking shoes, whereas those with neuropathy and foot deformities may benefit from custom shoes (TABLE 5). Larger randomized studies should explore which type of therapeutic footwear (including stockings) may best reduce ulceration in patients with neuropathy and deformities and whether patients with only neuropathy require prescription footwear.

Debridement of Calluses. Calluses (hyperkeratotic lesions caused by pressure) further increase pressure, which is a component cause of ulceration. Because debriding hyperkeratoses can reduce peak plantar pressure by 26%,[91] this should be routinely provided by trained personnel. Wearing proper footwear may not only prevent but also reduce development of calluses. Among 78 diabetic persons, the mean size of plantar calluses decreased in direct proportion with the amount of time spent wearing running shoes.[92] Similarly, among high-risk persons, those who visited podiatrists most frequently (every 3-4 weeks) had the lowest mean plantar pressure before and after callus removal.[93] The optimal frequency of podiatric evaluation and management is uncertain.

Foot Specialist and Multidisciplinary Team Care. A few studies have assessed the role of foot specialist care as the main intervention in preventing diabetic foot ulcers.[84,94] Among 91 diabetic persons with a healed foot ulcer, there were 20 ulcer recurrences in those randomized to podiatric care and 32 in the control group after a median follow-up of 386 days (RR, 0.52; 95% CI, 0.30-0.93; P = .03).[84] In another trial of diabetic persons with neuropathy, 235 were randomized to receive podiatric care at least twice a year and 263 to receive no podiatric treatment.[95] During the study period (≤3 years), there was no difference in the incidence of foot ulcers, but the podiatric care group had fewer deep ulcers (6 vs 12), infected ulcers (1 vs 10; P<.01), and hos-

Table 4. Prevention of Foot Ulceration in Persons With Diabetes: Recommended Management Based on Results of Clinical Evaluation

Clinical Evaluation	Specific Management
Inquire about factors associated with foot ulcers	
Previous foot ulcer	
Prior lower extremity amputation	
Duration of diabetes >10 y	
Poor glycemic control (hemoglobin A_{1c} >9%)	Optimize glycemic control
Impaired vision (visual acuity <20/40)	Opthalmologic evaluation
Examine feet	
Foot ulceration	Urgent treatment or referral to foot specialist*
Presence of gross structural abnormalities (calluses, hammer or claw toes, flat feet, bunions) or reduced joint mobility	Treat or refer to foot specialist(s)* for debridement of callus, custom shoes and/or orthotics, and/or possible prophylactic surgery†
Presence of dry or fissured skin	Educate about proper skin and nail care; prescribe skin moisturizer or emollient‡
Tinea pedis or onychomycosis	Treat fungal infection and instruct how to keep feet clean and dry
Loss of protective sensation† with monofilament or biothesiometer	Educate about foot precautions; provide visualization aids if necessary‡; ensure proper footwear†
Peripheral vascular disease (abnormal pedal pulses or ankle-brachial indices)	Additonal counseling on smoking cessation and cardiovascular preventive health; consider referral to vascular surgeon
Counsel	Reinforce importance of daily foot care and how to avoid foot problems (daily inspection, appropriate footwear, promptly reporting lesions); attempt to involve patient's family and caregivers in education and support
Plan schedule of follow-up clinical foot examinations according to foot risk status	
No neuropathy, deformities, history of foot ulcer or amputation	Yearly follow-up
Peripheral neuropathy only	Follow-up every 6 mo
Peripheral neuropathy and foot deformities	Follow-up every 3 mo
Peripheral neuropathy, foot deformities, and Charcot arthropathy, or history of ulcer or amputation	Follow-up every 1 to 3 mo

*Podiatrist, orthopedic surgeon, or wound care specialist.
†See prophylactic surgery and proper footwear sections in text.
‡These represent standard recommendations advocated in most guidelines; not all are supported by research studies.

pital admission days (24 vs 346; $P<.01$).[95]

Other studies have used multidisciplinary (eg, podiatrists, internists, surgeons, nurses, dieticians, social workers) care teams. In one study, 341 diabetic persons were examined to categorize baseline risk,[96] initiate appropriate education and interventions, and schedule follow-up foot examinations and podiatric care.[97] After 3 years, the incidence of lower-extremity amputation was only 1.1 per 1000 persons per year. Among high-risk persons, those who missed more than 50% of their appointments with the team were 54 times more likely to develop an ulcer and 20 times more likely to require an amputation than those who kept most appointments.[97]

Prophylactic Foot Surgeries. A dramatically increased interest in reconstructive surgery has occurred in the past 2 decades.[72,98-113] One proposed classification system divides nonvascular foot surgery into elective (to alleviate pain), prophylactic (to reduce risk of ulceration), curative (to heal an open wound), and emergent (to help control a limb-threatening infection).[114] Only a few small studies have reported long-term outcomes for prophylactic procedures, generally aimed at correcting deformities that increase plantar pressure

(TABLE 6). For example, a short Achilles tendon leads to increased pull on the calcaneus, elevated plantar-flexory movement about the ankle, and subsequent elevated forefoot plantar pressure; this may be improved by tendon lengthening. Preventing foot ulcers in patients with Charcot arthropathy usually requires an expert pedorthist and potentially a foot surgeon. In this condition, some advocate surgical options including removal of osseous prominences and reconstruction of the deformed foot or ankle, but controlled trials are lacking.[103,120]

Revascularization Surgery. Vascular surgeons have developed tech-

Table 5. Studies of Therapeutic Footwear Directed at Preventing Foot Ulceration in Persons With Diabetes

	No. of Patients	Intervention	Duration of Intervention	Duration of Follow-up	Main Outcome for Intervention Group
Randomized controlled trial Colagiuri et al,[88] 1995	9 Intervention and 11 control patients had foot calluses but no history of ulceration	Custom-made rigid orthotic device for ≥7 h/d vs routine podiatric care every 3 mo	1 y	1 y	Reduction in mean callus grade in those using orthoses (from 1.9 to 1.2), but not in those receiving podiatric care (increased from 1.6 to 1.7)
Reiber et al,[86] 2002	All had previous foot ulcer but without severe deformity		2 y	2 y	No significant difference in 2-y cumulative foot ulcer recurrence (No. of persons with ≥1 ulcer per person-years of follow-up)
	121	3 Pairs of extradeep and extrawide therapeutic shoes with customized cork inserts and neoprene cover			7.6% vs 9.0%; RR, 0.85 (95% CI, 0.44 to 1.59); ARR, −0.013 (95% CI, −0.062 to 0.035); $P = .59$*
	119	3 Pairs of therapeutic shoes with polyurethane inserts and nylon cover			7.6% vs 9.0%; RR, 0.84 (95% CI, 0.43 to 1.61); ARR, −0.013 (95% CI, −0.063 to 0.035); $P = .59$*
	160	Usual footware			
Prospective pseudorandomized (alternate allocation) study Uccioli et al,[89] 1995	33 Intervention and 36 control patients had a history of foot ulcer	Therapeutic extradeep, soft leather semirocker soles vs usual footwear	1 y	1 y	Lower foot ulcer relapse with therapeutic shoes: 27.3% vs 58.3%; RR, 0.47 (95% CI, 0.25 to 0.87); ARR, −0.31 (95% CI, −0.53 to −0.09); $P = .02$*
Prospective cohort study Busch and Chantelau,[90] 2003	60 Intervention and 32 control patients had a history of foot ulcer	"Stock" diabetic shoe: rocker-shaped sole, standardized shock absorption insole, and soft upper without stiff toe-cap vs usual footware	≤42 mo or ulcer relapse	≤42 mo or ulcer relapse	Lower rate of foot ulcer recurrence in diabetic shoe group: 15% vs 59%; RR, 0.25 (95% CI, 0.13 to 0.49); ARR, −0.44 (95% CI, −0.63 to −0.25); $P<.001$*

Abbreviations: ARR, absolute risk reduction; CI, confidence interval; RR, relative risk.
*Calculated measures of effect using STATA statistical software (version 8, STATA Corp, College Station, Tex).

niques (eg, bypass grafts from femoral to pedal arteries and peripheral angioplasty) to improve blood flow to an ischemic foot. While these procedures help heal ischemic ulcers, no prospective study shows that they reduce foot ulceration.[121] The reported effect of revascularization procedures on the incidence and site of amputations varies, but most recent studies suggest benefits.[122-124]

Cost-Effectiveness. A recent cost of illness model, based on published data about diabetic complications and the value of health resources from numerous sources found that the mean annual cost of treatment in 2001 was $9306 for an uninfected diabetic foot ulcer, $24 582 for an infected foot ulcer, and $45 579 for a foot ulcer with osteomyelitis.[125] Another review compiled cost data from 1990 to 1997 from 7 studies—4 conducted in the United States and 3 in other countries.[126] After inflation adjustment and currency conversion, the cost of treating foot ulcers not requiring amputation ranged from $993 to $17 519, and approached $30 724 in 1 study that spanned 2 years after diagnosis.

A few groups have modeled cost-utility analyses for strategies to prevent foot ulcers. A Markov model from Sweden of intensive prevention (patient education, use of appropriate footwear, and access to therapeutic foot care) for high-risk patients was cost-effective if the incidence of foot ulcers and lower extremity amputations was reduced by 25%.[127] A similar model for patients with newly diagnosed type 2 diabetes found that implementing a

Table 6. Studies of Prophylactic Foot Surgeries Directed at Preventing Foot Ulceration in Persons With Diabetes

	No. of Patients	Intervention	Duration of Follow-up	Main Outcome for Intervention
Case series				
Armstrong et al,[99] 1996	31 With diabetes mellitus and neuropathy 33 Without diabetes mellitus or neuropathy All had proximal interphalangeal joint contracture	Single, lesser digital resectional arthroplasty in all	3 y	2 Postoperative infections in patients with diabetes vs 0 in controls Recurrence of ulcer at site of digital arthroplasty in 1 patient with diabetes vs 0 in controls at 40 mo postoperatively
Armstrong el al,[100] 1999*	10 With neuropathy and previous plantar ulceration	Percutaneous Achilles tendon lengthening in all	8 wk	Mean (SD) reduction in peak plantar pressure of forefoot from 86 (9.4) N/cm^2 preoperatively to 63 (13.2) N/cm^2; $P<.001$
Hybrid case-control study				
Lin et al,[115] 1996	21 With healed foot ulcer 15 With a nonhealing ulcer All with limited ankle dorsiflexion	Achilles tendon lengthening vs no surgery	17 mo	Rapid healing of previously recalcitrant plantar wounds and lower rate of ulcer recurrence in surgical group vs controls (0% vs 19%; ARR, −0.19 [95% CI, −0.35 to −0.02]; $P = .13$)†
Randomized clinical trial				
Mueller et al,[116,117] 2003 and 2004	31 in Surgical group 33 in Total-contact cast group All with limited ankle dorsiflexion and recurrent or nonhealing forefoot ulcer	Percutaneous Achilles tendon lengthening plus total contact cast vs total contact cast alone	2 y	Lower ulcer recurrence rate (38% vs 81%; RR, 0.48 [95% CI, 0.28-0.80]; ARR, −0.42 [95% CI, −0.66 to −0.18]; $P = .004$)† and longer mean (SD) time to reulceration after healing (131.2 [189.9] vs 431.0 [364.4] days; $P = .03$) in surgical vs control group Nested study of 28 patients showed no change in functional limitations between groups and lower reported physical functioning in surgical vs control group at 8 months after initial healing
Piaggesi et al,[118] 1998	21 in Surgical group 21 in Control group All with noninfected foot ulcers	Surgical excision and/or bone segment removal vs nonsurgical treatment	6 mo	Improved ulcer healing rate (95% vs 79%; RR, 1.20 [95% CI, 0.96 to 1.51]; $P = .19$)† and reduced ulcer relapse rate (14% vs 42%; RR, 0.33 [95% CI, 0.11 to 1.10]; ARR, −0.28 [95% CI, −0.54 to −0.01]; $P = .08$)† in surgical vs control group
Retrospective cohort study				
Armstrong et al,[119] 2003	21 in Surgical group 20 in Control group All with hallux interphalangeal joint wounds	First metatarsophalangeal joint arthroplasties vs nonsurgical treatment	6 mo	Faster healing (mean [SD], 24.2 [9.9] vs 67.1 [17.1] days; $P<.001$) and lower ulcer recurrence rate in surgical group vs controls (4.8% vs 35.0%; OR, 7.6 [95% CI, 1.1-261.7]; $P = .02$),‡ but similar rates of infections and amputations

Abbreviations: ARR, absolute risk reduction; CI, confidence interval; OR, odds ratio; RR, relative risk.
*This study was also classified as a gait laboratory study.
†Calculated measures of effect using STATA statistical software (version 8, STATA Corp, College Station, Tex).
‡Measure of effect calculated by the authors of the original study.

guideline-based foot program that included intensive glycemic control, regular foot examinations, risk stratification, patient education, clinician education, and multidisciplinary foot care increased life expectancy and quality-adjusted life-years and reduced the incidence of foot complications.[128] The cost of achieving a 10% reduction in the incidence of foot lesions was less than $25 000 per quality-adjusted life-year gained.[128]

CONCLUSIONS

Diabetes confers a dramatically increased risk of foot ulceration, but available evidence suggests that this risk may be reduced to some degree by appropriate screening and intervention measures. Clinicians should screen all patients with diabetes to identify those at risk for foot ulceration. This includes reviewing relevant past history, identifying any current foot deformities, and especially assessing for loss of protective sensation with a monofilament. Other helpful screening methods include assessing for peripheral vascular disease by measuring ABIs, ensuring that the patient is wearing appropriate footwear, and checking for high plantar pressure when possible.

Screening allows the clinician to assign the patient to a risk category that dictates both the type and frequency of foot interventions needed. Effective interventions include patient (and clinician) education. Possibly effective interventions include optimizing glycemic control, smoking cessation, intensive podiatric care, and debridement of calluses. The value of prescription footwear for ulcer prevention is unclear. In selected cases, evaluation for surgical procedures may be indicated. Each of these interventions, when used appropriately, may reduce the risk of foot ulceration and its devastating consequences.

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In every outthrust headland, in every curving beach, in every grain of sand there is the story of the earth.
—Rachel Carson (1907-1964)