after a diabetes-related LEA has been reported to be as low as 28% to 31% (169, 170). Persons with renal failure or more proximal levels of amputation have a poor prognosis and higher mortality rate. Those who undergo a diabetes-related amputation have a 40% to 50% chance of undergoing a contralateral amputation within 2 years (36, 171, 172).

ASSESSMENT OF THE DIABETIC FOOT (Pathway 1)

The pedal manifestations of diabetes are well documented and potentially limb-threatening when left untreated. Recognition of risk factors and treatment of diabetic foot disorders require the skill of a specialized practitioner to diagnose, manage, treat, and counsel the patient. Integration of knowledge and experience through a multidisciplinary team approach promotes more effective treatment, thereby improving outcomes and limiting the risk of lower extremity amputation (30, 173).

The evaluation of the diabetic foot involves careful assimilation of the patient’s history and physical findings with the results of necessary diagnostic procedures (Pathway 1). Screening tools may be valuable in evaluating the patient and determining risk level (Appendix 1). Early detection of foot pathology, especially in high-risk patients, can lead to earlier intervention and thereby reduce the potential for hospitalization and amputation (100). This is also facilitated by an understanding of the underlying pathophysiology of diabetic foot disorders and associated risk factors. Identification of abnormal historical and/or physical findings can therefore improve the prognosis for a favorable outcome through appropriate—and early—referral (91, 174).

History

A thorough medical and foot history must be obtained from the patient. The history should address several specific diabetic foot issues (Table 2).

Physical Examination

All patients with diabetes require a pedal inspection whenever they present to any health care practitioner, and

<table>
<thead>
<tr>
<th>Table 2</th>
<th>Medical History</th>
</tr>
</thead>
<tbody>
<tr>
<td>Global History</td>
<td>Medical History</td>
</tr>
<tr>
<td>• Diabetes - duration</td>
<td>General</td>
</tr>
<tr>
<td>• Glycemic management/control</td>
<td>• Daily activities, including work</td>
</tr>
<tr>
<td>• Cardiovascular, renal and ophthalmic evaluations</td>
<td>• Footwear</td>
</tr>
<tr>
<td>• Other comorbidities</td>
<td>• Chemical exposures</td>
</tr>
<tr>
<td>• Treating physicians</td>
<td>• Callus formation</td>
</tr>
<tr>
<td>• Nutritional status</td>
<td>• Foot deformities</td>
</tr>
<tr>
<td>• Social habits: alcohol, tobacco, drugs</td>
<td>• Previous foot infections, surgery</td>
</tr>
<tr>
<td>• Current medications</td>
<td>• Neuropathic symptoms</td>
</tr>
<tr>
<td>• Allergies</td>
<td>• Claudication or rest pain</td>
</tr>
<tr>
<td>• Previous hospitalizations/surgery</td>
<td></td>
</tr>
</tbody>
</table>

THE JOURNAL OF FOOT & ANKLE SURGERY
they should receive a thorough lower extremity examination at least once annually (175). Patients with complaints relating to the diabetic foot require more frequent detailed evaluations. The examination should be performed systematically so that important aspects are not overlooked (62). It begins with a gross evaluation of the patient and extremities. Any obvious problem can then receive closer scrutiny.

Key components of the foot examination are presented in Table 3. Although not specifically mentioned in this section, it is assumed that a general medical assessment (including vital sign measurements) will be obtained.

**Diagnostic Procedures**

Diagnostic procedures may be indicated in the assessment and care of the diabetic foot. Consideration should be given to the following tests in concert with those suggested by members of the consulting team. It should be noted that many of the following tests lack the ability to impart a definitive diagnosis, necessitating clinical correlation.

**Laboratory Tests**

Clinical laboratory tests that may be needed in appropriate clinical situations include fasting or random blood glucose, glycohemoglobin (HbA1c), complete blood count (CBC) with or without differential, erythrocyte sedimentation rate (ESR), serum chemistries, C-reactive protein, alkaline phosphatase, wound and blood cultures, and urinalysis. Caution must be exercised in the interpretation of laboratory tests in these patients, because several reports have documented the absence of leukocytosis in the presence of severe foot infections (117, 122, 151, 176-178). A common sign of persistent infection is recalcitrant hyperglycemia despite usual antihyperglycemic regimens (150).

**Imaging Studies**

The diabetic foot may be predisposed to both common and unusual infectious or noninfectious processes, partially because of the complex nature of diabetes and its associated vascular and neuropathic complications. As a result, imaging presentations will vary due to lack of specificity in complex clinical circumstances (179-181). Such variability creates a challenge in the interpretation of imaging studies. Therefore, imaging studies should only be ordered to establish or confirm a suspected diagnosis and/or direct patient management. Distinguishing osteomyelitis from aseptic neuropathic arthropathy is not easy, and all imaging studies (Fig 4) must be interpreted in conjunction with the clinical findings (123, 151).

Plain radiographs should be the initial imaging study in diabetic patients with signs and symptoms of a diabetic foot disorder (180, 182). Radiographs can detect osteomyelitis, osteolysis, fractures, dislocations seen in neuropathic arthropathy, medial arterial calcification, soft tissue gas, and foreign bodies as well as structural foot deformities, presence of arthritis, and biomechanical alterations (183). Acute osteomyelitis might not demonstrate osseous changes for up to 14 days. Serial radiographs should be obtained in the face of an initial negative radiographic image and a high clinical suspicion of osseous disease (117, 123).

Technetium-99 methylene diphosphonate (Tc-99 MDP) bone scans are often used in diabetic foot infection to determine the presence of osteomyelitis. Although highly sensitive, this modality lacks specificity in the neuropathic foot (184, 185). Osteomyelitis, fractures, arthritis, and neuropathic arthropathy will all demonstrate increased radiotracer uptake. However, a negative bone scan is strong evidence against the presence of infection. To improve the specificity of nuclear imaging, white blood cells can be labeled with Tc-99 hexamethylpropyleneaminoxime (Tc-99 HMPAO), indium-111 oxime, or gallium-67 citrate (179, 186-189).

Indium-111 selectively labels polymorphonuclear leukocytes and is more specific for acute infections than Tc-99 MDP scanning. Chronic infections and inflammation are not well imaged with indium-111, because chronic inflammatory cells (ie, lymphocytes) predominate and are not well labeled with indium. Combining Tc-99 MDP and indium-111 increases the specificity of diagnosing osteomyelitis (190). This combined technique is useful, because the Tc-99 MDP scan localizes the anatomic site of inflammation and the indium-111 labels the infected bone (180, 191). The indium-111 scan is not typically positive in aseptic neuropathic arthropathy, although false-positive indium scans can occur (192-194). A 100% sensitivity and 89% specificity have been reported with the combined technique in evaluating diabetic infections (190, 191, 195).

In Tc-99 HMPAO scanning, white blood cells are labeled in a similar manner as in indium scanning. However, with Tc-99 MHPAO scans, imaging occurs 4 hours following administration versus 24 hours postadministration with indium scanning. Tc-99 HMPAO uses a smaller radiation dose, is less expensive, and offers improved resolution compared with indium scanning. The sensitivity and specificity of both techniques are comparable (186, 196). Tc-99 HMPAO scans cannot be combined with Tc-99 MDP scans because of similar labeling characteristics.

Tc-99 sulfur colloid is useful in distinguishing osteomyelitis from neuropathic arthropathy (183). This tracer is picked up by the bone marrow and any hematopoietically-active marrow will be positive. Infected bone replaces normal bone marrow, so it shows up as a relative
Table 3  

**Lower Extremity Diabetic Foot Exam**

### Vascular Examination
- Palpation of pulses  
  - Common femoral, popliteal  
  - Dorsalis pedis, posterior tibial  
- Handheld Doppler examination  
- Skin / limb color changes  
  - Cyanosis, erythema  
  - Elevation pallor, dependent rubor  
- Presence of edema  
- Temperature gradient  
  (ipsilateral and contralateral extremity)  
- Dermal thermometry  
- Integumentary changes  
  - Skin atrophy - thin, smooth, parchment-like skin  
  - Abnormal wrinkling  
  - Absence of hair growth  
  - Onychodystrophy  
- Previous hospitalizations/surgery

### Dermatologic Examination
- Skin appearance  
  - Color, texture, turgor, quality  
  - Dry skin  
- Calluses  
  - Discoloration / subcallos hemorrhage  
- Fissures (especially posterior heels)  
- Nail appearance  
  - Onychomycosis, dystrophic, grayish  
  - Atrophy or hypertrophy  
  - Paronychia  
- Hair growth  
- Ulceration, gangrene, infection  
  Note location, size, depth, infection status, etc.  
- Interdigital lesions  
- Tinea pedis  
- Markers of diabetes  
  - Shin spots - diabetic dermopathy  
  - Necrobiosis lipoidica diabeticorum  
  - Bullosum diabeticorum  
  - Granuloma annulare  
  - Acanthosis nigricans

### Neurologic Examination
- Vibration perception  
  - Tuning fork 128 cps  
  - Measurement of vibration perception threshold (biothesiometer)  
- Light pressure:  
  - Semmes-Weinstein 10 gram monofilament  
- Light touch: cotton wool  
- Two point discrimination  
- Pain: pinprick (sterile needle)  
- Temperature perception: hot and cold  
- Deep tendon reflexes: patella, Achilles  
- Clonus testing  
- Babinski test  
- Romberg test

### Musculoskeletal Examination
- Biomechanical abnormalities  
- Structural deformities  
  - Hammertoe, bunion, tailor’s bunion  
  - Hallux limitus/rigidus  
  - Flat or high-arched feet  
  - Charcot deformities  
  - Postsurgical deformities (amputations)  
- Prior amputation  
- Limited joint mobility  
- Tendo-Achilles contractures / equinus  
- Gait evaluation  
- Muscle group strength testing  
  - Passive and active, non-weightbearing and weightbearing  
  - Foot drop  
  - Atrophy - intrinsic muscle atrophy  
- Plantar pressure assessment  
  - Computerized devices  
  - Harris ink mat, pressure sensitive foot mat

### Footwear Examination
- Type of shoe (athletic, oxford, comfort, etc.)  
- Fit  
- Depth of toe box  
- Shoewear, patterns of wear  
- Lining wear  
- Foreign bodies  
- Insoles, orthoses
Figure 4  Diagnostic imaging plays an important role in the evaluation of diabetic foot infections. (A) This patient presented with a deep foul-smelling necrotic ulcer of the heel that had been present for more than 1 month. (B) In the past, a technetium bone scan typically would be performed, but the imaging is nonspecific and many false positive results interpretative as osteomyelitis were seen. (C) White blood cell tagged imaging with indium or technetium is a more reliable technique for detecting the presence of infection.
“cold spot.” This technique is best combined with indium scanning, and osteomyelitis would appear as a “hot” indium scan and a “cold” sulfur colloid scan (183, 193).

Computed tomography (CT) scans may be indicated in the assessment of suspected bone and joint pathology not evident on plain radiographs (180, 197). CT offers high anatomic detail and resolution of bone with osseous fragmentation and joint subluxation (198). Subluxation of the transverse tarsal or tarsometatarsal joints can be seen prior to being visualized on radiographs.

Magnetic resonance imaging (MRI) is usually preferred over CT for the investigation of osteomyelitis, because of its enhanced resolution and ability to visualize the extent of any infectious process (183, 199). MRI is often used in evaluating soft tissue and bone pathology. This scan may be indicated to aid in the diagnosis of osteomyelitis, deep abscess, septic joint, and tendon rupture. It is a readily available modality that has a very high sensitivity for bone infection and can also be used for surgical planning (123, 200-203). Despite its high cost, MRI has gained wide acceptance in the management of diabetic foot infections. When neuropathic arthropathy is present, the T1 and T2 bone images are hypointense (ie, decreased signal) and the soft tissues show edema. Increased signal on T-2 bone images is seen in osteomyelitis; however, tumors and avascular necrosis can also be hyperintense on T-2 (204). MRI is an excellent modality for assessing the presence of a soft tissue abscess, especially if gadolinium administration is utilized (205, 206). Postcontrast fat suppression images should be obtained, if available (207).

Positive emission tomography (PET) scanning is a promising new technique for distinguishing osteomyelitis from neuropathic arthropathy, but it currently is not widely available (109, 208, 209). A recent meta-analysis comparing the diagnostic accuracy of PET scanning with bone and leukocyte scanning found that PET scans were the most accurate modality for diagnosing osteomyelitis, providing a sensitivity of 96% and specificity of 91% (190). When PET scanning was unavailable, an indium-labeled leukocyte scan was found to be an acceptable alternative, offering a sensitivity of 84% and specificity of 80% in the peripheral skeleton (190).

The use of ultrasound for detecting chronic osteomyelitis has been shown to be superior to plain radiographs, providing sensitivity comparable to Tc-99 MDP bone scanning (210). Although ultrasound is a widely available, cost-effective imaging modality, MRI is more accurate and is the imaging study of choice if radiographs are normal and clinical suspicion is high for bone or soft tissue infection (211).

Vascular Evaluation

The lower extremity must be assessed for vascular and neuropathic risk factors. Although positive findings in the neurologic examination rarely require further evaluation, positive findings of vascular insufficiency may require further consultation. The indications for vascular consultation include an ankle brachial index of less than 0.7, toe blood pressures less than 40 mmHg, or transcutaneous oxygen tension (TcPO2) levels less than 30 mmHg, since these measures of arterial perfusion are associated with impaired wound healing (27, 47, 87, 90, 212, 213).

If the history and physical examination suggest ischemia (ie, absent pedal pulses) or if a nonhealing ulcer is present, further evaluation in the form of noninvasive testing is warranted (Pathway 2).

Noninvasive arterial studies should be performed to determine lower extremity perfusion. Such studies may include Doppler segmental arterial pressures and waveform analysis, ankle-brachial indices (ABI), toe blood pressures, and TcPO2 (89, 214, 215). Ankle-brachial indices may be misleading, because ankle pressures can be falsely elevated due to medial arterial calcinosis and noncompressibility of affected arteries (52, 216, 217). A growing body evidence suggests that toe blood pressures in diabetic patients may have a role in predicting foot ulceration risk as well as predicting successful wound healing (213, 218, 219). TcPO2 measurements have received similar support in the literature (47, 87, 212). Although not consistently predictive of wound healing outcomes, these physiologic measures of tissue oxygenation are highly predictive of wound healing failure at levels below 25 mmHg (87, 212, 220). Both tests can be performed distally on the foot regardless of arterial calcification in the major pedal arteries, and they are both favorable at pressures in the range of 40 mmHg (90, 212, 213).

Laser Doppler velocimetry and measurement of skin perfusion pressure (SPP) have primarily been used in research settings, but can accurately assess blood flow and oxygen tension in the superficial arterioles and capillaries of the skin (220-225). Several recent reports indicate that laser Doppler measurement of SPP can be highly predictive of critical limb ischemia and wound healing failure at levels less than 30 mmHg (223, 224).

Vascular consultation should be considered in the presence of abnormal noninvasive arterial studies or a nonhealing ulceration (30, 54, 173, 215, 226). Arteriography with clearly visualized distal runoff allows appropriate assessment for potential revascularization (227-229). Magnetic resonance angiography (230) or CT angiogram are alternatives for evaluation of distal arterial perfusion (229, 231).