The musculoskeletal diabetic foot exam

Tanzim Khan and David G. Armstrong

Over the past generation, attention has been rightly focused on assessing the vascular and neurological status of people with diabetes to assess overall risk for ulceration and amputation. While musculoskeletal assessment has been discussed, it has often not received direct attention in the recent medical literature. In this article, the authors describe methods to perform a thorough musculoskeletal exam to better assess potential pathomechanics leading to foot and ankle deformities in order to provide specific prophylactic and therapeutic treatment. For each anatomic location, the authors will describe the basis for the examination, the examination technique and define abnormal findings.

Of people diagnosed with diabetes, about one third will develop a diabetic foot ulcer at some point in their life. This is a complication that can lead to infection and subsequent amputation (Armstrong et al, 2017). Ideally, one can identify potential complications before they start. This identification begins with a quality diabetic foot exam. The importance of assessing vascular and neurological status of the extremity has been stressed as a screening method for healthcare providers. The musculoskeletal status may be considered just as important, but has not been stressed in the recent literature (Wrobel and Armstrong, 2008).

One of the pathological processes of diabetes is the non-enyzmatic glycosylation of the skin and connective tissue (Brownlee et al, 1984; Delbridge et al, 1985). This glycosylation, along with decreased collagen production, affects the elasticity of tissue by increasing stiffness (Spanheimer et al, 1988; Brownlee, 1992). In turn, stiffness results in limited range of motion and pathomechanics in the function of the foot and ankle. This is most notably demonstrated in the achilles tendon, where a shortened, stiff achilles tendon limits ankle dorsiflexion (Grant et al, 1997). This pathology, better known as equinus, has been shown to have a significant association with diabetic foot ulcers. (Frykberg et al, 2012). Limited joint mobility is not exclusive to the ankle joint, as other joints with decreased range of motion have also demonstrated association with foot ulcerations (Delbridge et al, 1988; Fernando et al, 1991; Zimny et al, 2004). The disruption of motor nerves in diabetic neuropathy is said to be a potential cause of intrinsic muscle wasting in the foot. The atrophy of these muscles can lead to muscle imbalances, which can be seen in clawed digit deformities (Bus et al, 2002; Andersen et al, 2004).

Musculoskeletal deformities may also be present before the onset of diabetes. These deformities have several different aetiologies, some of which include trauma, congenital, ill-fitting shoe gear, and neuromuscular disease. Regardless of the time of onset and the aetiology, foot and ankle deformities pose a particular set of problems. For one, these feet are confined to shoe gear that is not made to fit abnormal anatomy. Constraint in unforgiving shoe gear cause excessive pressure and shear over osseous deformities, which may go unnoticed in an insensate foot (Reddy et al, 1989). The second issue, is abnormally elevated peak plantar pressures in the foot (Armstrong et al, 1998; Lavery et al, 2003; Bus et al, 2005). Shifting of plantar pressures will

Citation: Khan T, Armstrong DG (2018) The musculoskeletal diabetic foot exam. *The Diabetic Foot Journal* 21(1): 17–28

Article points

1. The musculoskeletal exam is an essential component of the diabetic foot exam.
2. Pathomechanics found in the foot and ankle place patients at risk for cutaneous complications.
3. A detailed exam can help clinicians identify deforming forces and apply specific treatments to neutralise these forces.

Key words

- Deformity
- Diabetic foot
- Musculoskeletal
- Physical exam
- Screening
- Ulcer

Authors

Tamzin Khan is Clinical Instructor and Fellow, The Southwestern Academic Limb Salvage Alliance (SALSA), Department of Surgery, Keck School of Medicine of University of Southern California (USC), Los Angeles, California, USA; David G. Armstrong is Professor of Surgery, Co-Director, SALSA, Department of Surgery, Keck School of Medicine of University of Southern California (USC), Los Angeles, California, USA

Figure 1. Assessment of Hallux Interphalangeal Joint range of motion with stabilisation of proximal hallux.

Page points

1. A foot and ankle deformity in itself can cause pain and debilitation due to the altering of the biomechanical function of the lower extremity.
2. The musculoskeletal exam of the foot and ankle comprises three components: the sitting exam, the standing exam and the gait exam. Each components plays a part in establishing the correct diagnosis for musculoskeletal pathology of the foot and ankle.

cause excessive pathological pressure in focal areas of the foot, which do not alarm the insensate foot due to the blunting of the pain response. Therefore, repeated injury to the high pressure area will lead to hemorrhagic hyperkeratotic tissue and eventual deterioration of the cutaneous envelope, resulting in a diabetic foot ulcer.

A foot and ankle deformity in itself can cause pain and debilitation due to the altering of the biomechanical function of the lower extremity. In combination with either or both, diabetic neuropathy and peripheral arterial disease, significant complications can arise in the diabetic foot (Fernando et al, 1991; Bus, 2008). Assessment of these deformities require a particular assessment, which will allow the proper modality to either restore or alter pathological forces by means of nonoperative and operative intervention. Surgically correcting a deformity can reduce the risk level of a diabetic foot ulceration, in particular, one with concomitant sensory neuropathy (Frykberg et al, 2010). An orthosis with an orthopedic shoe, total contact cast, or removable cast walker can offload the areas of pressure and redistribute peak plantar pressures (Boulton, 2004; Bus et al, 2004; Piaggesi et al, 2016). The following sections aim to explain the technique of the foot and ankle exam, and the pathology that may arise in the diabetic foot with an abnormal exam. For each anatomic location, we will describe the basis for the examination, the examination technique and discuss abnormal findings.

Exam components

The musculoskeletal exam of the foot and ankle consists of three components: the sitting exam, the standing exam and the gait exam. Each of these phases of the exam are important in establishing the correct diagnosis for musculoskeletal pathology of the foot and ankle.

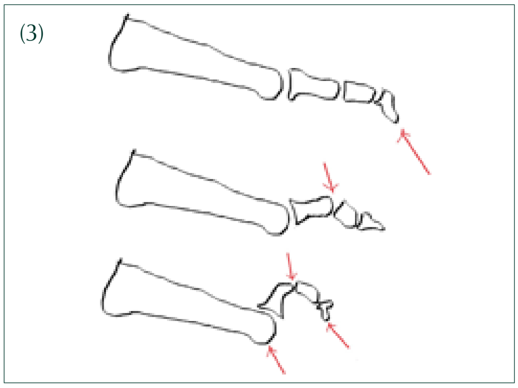
The sitting exam is important for ascertaining the overall gross appearance of the foot and ankle. It is also easy to appreciate the range of motion (ROM) of the joints of the foot and ankle in this position. When assessing ROM, the examiner must determine if there is a smooth motion or one that is rough with crepitus. If there is a limitation in range of motion, the examiner must note the end feel of the range of motion. This may be hard and abrupt, which is synonymous with an osseous block, or it may be spongy, like that found due to soft tissue constraints. It is also important for the examiner to assess if the deformity is flexible and can be reduced by hand, or is rigid and non-reducible. Rigid deformities are due to degenerative osseous changes or joint contractures from long-standing deformities and often require different operative and non-operative management strategies.

The standing exam allows the examiner to assess the posture of the foot and ankle with an influence of the forces of gravity and weight bearing. This is important, as loading of weight may change the mechanics of the foot and ankle by increasing the severity of a deformity or unmasking pathology that is not seen in the sitting exam. An example of this would be normal range of motion of the first metatarsophalangeal joint while sitting, with a limitation in range of motion at the first metatarsophalangeal joint while weight bearing; These are clinical signs of a functional hallux limitus.

The gait exam allows a dynamic examination of the foot and ankle. This part of the exam can uncover compensatory mechanisms for various foot and ankle deformities. The gait exam can be assessed as soon as the patient walks to the exam table, especially to have an unadulterated look at the patient's gait. However, a proper gait exam should be performed unshod. The patient should be observed from the front, the back, as well as the sides, with emphasis placed on the patient to walk as naturally as possible.

Figure 2. First ray hypermobility assessed by dorsiflexing ankle, stabilising heads 2–5, and placing first metatarsal through sagittal plane motion.

Figure 3. Digital deformities with red arrows demonstrating potential sites of pressure. (Top) Mallet toe. (Middle) Hammer toe. (Bottom) Claw toe.



Hallux interphalangeal joint

The hallux interphalangeal joint (IPJ) consists of the articulation of the proximal and distal hallux. It it a hinge joint, which typically has significantly less available extension range of motion (ROM) compared to flexion. The extension range of motion is around 0.5–2 degrees, while flexion is said to be 60-66 degrees (Munuera et al, 2012).

Exam technique: assess static position of the distal hallux and the proximal hallux for extension or flexion deformities. To test range of motion, grasp the proximal hallux and place the distal hallux in range of motion (*Figure 1*).

Abnormal exam: a flexion deformity that is either rigid or reducible may be associated with a hammered hallux, cavus foot, neuromuscular sequelae, or a contracted flexor hallucis longus tendon. The examiner must be cautious of cutaneous manifestations at the dorsal aspect of the interphalangeal joint, as well as the distal pulp of the toe. Cutaneous manifestations can either be abrasions, callus, and bullae, or ulceration of skin. An extension deformity or excessive extension ROM is usually associated with limited first metatarsophalangeal joint extension ROM or first ray hypermobility as a compensatory mechanism. The examiner must be cautious of cutaneous manifestations in the plantar hallux IPJ in this scenario.

First metatarsophalangeal joint

The first metatarsophalangeal joint (MPJ) is an essential joint for ambulation. The joint is variable in terms of range of motion, with 45–90 degrees of extension and 10–40 degrees of flexion (Coughlin et al, 2014). There needs to be adequate amount of available extension ROM for propulsion of the foot during gait.

Exam technique: assess for static deformities such as an extension deformity at the first MPJ. Assess range of motion by grasping the first metatarsal head dorsally and plantarly, and place the hallux through ROM by grasping the proximal hallux only.

Abnormal exam: an extension deformity may be present as a result of hammered hallux, cavus foot type, chronic plantar plate rupture, or plantarflexed first ray. The examiner must be cautious of cutaneous manifestations at the plantar first metatarsal head, as well as the cutaneous pathology that may accompany a flexion deformity at the hallux IPJ. A first MTPJ that is rigid or limited in extension ROM is usually associated with a hallux limitus/rigidus. The examiner in this scenario must be cautious of cutaneous manifestations at the dorsal first metatarsal head, especially if there is an osseous prominence and a hard feel to the end of range of motion. They must also assess the plantar skin of the hallux IPJ, as there is often compensatory hallux IPJ extension and retrograde forces to the plantar hallux IPJ. A transverse deformity may also be present, such as abduction of the hallux due to hallux abducto valgus deformity. With this deformity there is retrograde pressure on the first metatarsal, which results in a prominent dorsal medial eminence — a source for cutaneous manifestations. Due to the alignment of the digit, the patient may roll off the plantar medial hallux IPJ during the toe off phase of gait. Therefore, the examiner needs to assess this area for cutaneous manifestations as well.

First ray mobility

The first ray of the foot consists the medial cuneiform, first metatarsal, sesamoids, and the hallucal phalanges. The clinic exam of first ray mobility assesses the range of motion between the base of the first metatarsal and the medial cuneiform. This is often a difficult exam to quantify and reproduce (Coughlin et al, 2014). Pathology is typically encountered when there is excessive dorsiflexion of the first ray. The normal excursion of the first ray is said to be 5 mm or less (Coughlin et al, 2014).

Exam technique: the examiner grasps metatarsal heads 2–5 with one hand, and with the other hand the examiner grasps the first metatarsal head and places the first metatarsal through dorsiflexion and plantarflexion with the ankle dorsiflexed (*Figure 2*) (Grebing and Coughlin, 2004). While maintaining metatarsals 2–5 in static alignment, the examiner determines the excursion of the metatarsal head. If there is >5 mm elevation of the first metatarsal relative to the less metatarsals, the exam is positive for hypermobility.

Abnormal exam: first ray hypermobility is often associated with various different conditions. It may be present with a pes planus (flatfoot) deformity, as the pronated foot type unlocks the distal joints to make it more adaptive. It may be associated with a functional hallux limitus, which demonstrates adequate first MPJ extension ROM during a sitting exam and limited first MPJ ROM when standing or walking. First ray mobility may also be associated with hallux abducto valgus, although there is controversy whether it is a cause or a result of it (Coughlin et al, 2014). The functional hallux limitus can present with similar cutaneous manifestations as a hallux rigidus due to the fact that ground reaction forces will elevate the first metatarsal head and prevent first MPJ extension and cause jamming due to the spatial alignment of the metatarsal. Other vulnerable sites in the cutaneous envelope due to first ray hypermobility correlate to the associated abnormal examination characteristics.

Lesser digits and metatarsophalangeal joints

The lesser digits consist of digits 2–5 and their accompanying joints, the distal interphalangeal joint (DIPJ), proximal interphalangeal joint (PIPJ), and the metatarsophalangeal joint (MPJ). The exact degrees of range of motion throughout these joints are not as important as determining if there are static or dynamic deformities and if the joints are rigid or flexible.

The biomechanics of the lesser digits are important, as atrophy of the intrinsic musculature of diabetics can be a cause of imbalance and deformity. Typically, the extensors are responsible for dorsiflexion at the metatarsophalangeal joint, while the intrinsic muscles are responsible for the dorsiflexion at the PIPJ and the DIPJ (Coughlin et al, 2014). Conversely, the flexors are responsible for plantarflexion at PIPJ and DIPJ, while the intrinsic muscles are responsible for plantarflexion at the MPJ (Coughlin et al, 2014). The intrinsic musculature also assists with transverse plane stability, along with the plantar plate and collateral ligaments.

Exam technique: the examiner begins with inspecting for any obvious deformities while the patient is sitting. If there are deformities present, the next step would be to manually reduce the digits by hand for an assessment of flexibility. Next, the examiner should apply pressure to the plantar metatarsal heads as well place the ankle in maximal dorsiflexion. In this position, the examiner will see if the deformity reduces at the level of the metatarsophalangeal joint, as well as visualise the PIPJ and DIP for increased flexion contracture.

Abnormal exam: if there is a single flexion contracture at the DIPJ of the digit, it is considered a mallet toe. If this deformity is found, there will often be cutaneous manifestations at the tip of the digit. If there is plantar flexion of the middle phalanx at the PIPJ with accompanying extension of the proximal phalanx at the MPJ, there is said to be a hammertoe toe deformity. The examiner must assess for cutaneous manifestations at the dorsal PIPJ and at the plantar metatarsal head for a hammertoe. If there is a flexion deformity at PIPJ and DIPJ, as well as extension at the MPJ, it is said to be a claw toe (*Figure 3*). The cutaneous manifestations for this complex deformity can be potentially found at the tip of the digit, the dorsal PIPJ, as well as the plantar metatarsal head. Abduction and adduction deformities need careful assessment of adjacent digits, as well as the interspaces for cutaneous manifestations, which are at risk for infection at the intertriginous zones.

Figure 4. Demonstrates the examiner's hand placement for evaluating subtalar joint range of motion (a) and neutral position (b).

Subtalar joint

The subtalar joint, the articular complex between the talus and the calcaneus, is an essential joint for ambulation. The subtalar joint (STJ) works in concert with the talonavicular and calcaneocuboid joints to convert the foot into a supple, weight accepting unit to a rigid lever for propulsion. The subtalar joint typically demonstrates a range of motion that consists of inversion and eversion in a ratio of 2:1 of inversion to eversion.

Exam technique: In either the supine or prone position, the examiner grasps the fifth metatarsal head and places the ankle into dorsiflexion. With the opposite hand the examiner cups the calcaneus and places their thumb over the talonavicular joint (*Figure 4*) (Coughlin et al, 2014).

The examiner then assesses frontal plane motion by inverting and everting foot using the calcaneus as a joystick. Placing the ankle in dorsiflexion, the talus sits into the mortise and the malleoli act as osseous stops to decrease ankle inversion and eversion from influencing the exam. The movement is subtle and best compared to the contralateral extremity for evaluation. The subtalar neutral position is obtained by inverting and everting the calcaneus and locating the point where the navicular just covers the talar head (Coughlin et al, 2014). If the patient is prone, the subtalar neutral position can be obtained by placing the calcaneus inline with the tibia.

Abnormal exam: If the joint is rigid with no available range of motion, there is a possibility there is a tarsal coalition. Rigidity and limited range of motion may also be present due to contractures or degenerative joints from long standing deformities. If there is more eversion ROM compared to inversion ROM with violation of the 2:1 inversion:eversion ratio, then the foot may be associated with a pes planus foot type. Conversely, if there is limited eversion ROM with normal increased inversion ROM, the foot may be associated with a pes cavus type. In the everted heel or valgus heel, cutaneous manifestations may be present over the plantar medial calcaneus. In the case of an inverted heel, or varus heel, there may be cutaneous manifestations over the plantar lateral heel. In severe cases of a varus heel, cutaneous presentations may be present over the lateral malleolus.

Midtarsal joint

The midtarsal joint (MTJ), also known as the Chopart's Joint, consists of the talonavicular joint (TN), as well as the calcaneocuboid joint (CC). The subtalar joint influences the range of motion available at the midtarsal joint (Magee, 2013; Miller and Thompson 2015). An everted calcaneus will result in a parallel alignment of the axis of ROM of the TN and CC joints. This unlocks ROM in these joints and allows the foot to become a mobile adaptor to the terrain and absorb ground reactive forces. When the heel is inverted, the axis of the two joints are oblique and ROM is therefore limited, as the goal is the create a rigid platform for the limb to propulse over. The range of motion available in the midtarsal joint is rotation, which consist of inversion and eversion. There is also translational motion in the transverse plane, which is adduction and abduction. The midtarsal joint is the link between the hindfoot and the forefoot. In normal mechanics, heel inversion will result in plantarflexion of the first metatarsal or forefoot eversion, to maintain contact with the ground distally. An everted heel will have the opposite effect as the plantar medial heel is in contact with the ground, the forefoot will invert to maintain fifth metatarsal head contact.

Exam technique: while in the subtalar neutral position mentioned earlier, the examiner releases the fifth metatarsal head while maintaining the calcaneus in the neutral position. The examiner then compares the relationship of the plantar metatarsal heads to the plantar surface of the calcaneus (*Figure 5*). In a normal relationship between the rearfoot and the forefoot the two surfaces are parallel (*Figure 6*). Next, the examiner maintains the position of the calcaneus while assessing range of motion of the MTJ by inverting, everting, abducting and adducting the foot.

Abnormal exam: if the forefoot to rearfoot relationship demonstrates a first metatarsal head that is elevated compared to the plane of the plantar calcaneus, this is labeled as a forefoot varus. This deformity is often seen as a compensatory mechanism to a long-standing pes planus deformity (flatfoot), however, it can have several other aetiologies. With this deformity the examiner must be suspicious of cutaneous lesions in the plantar aspect of the lateral metatarsal heads. When the first metatarsal head is plantar to the plane of the plantar calcaneus, it is said to be a forefoot valgus deformity. The forefoot valgus deformity is often associated with a pes cavus foot deformity (high arched) as either a driving force for the deformity or as compensatory mechanism for a chronically inverted heel. In the case of the forefoot valgus, the examiner must be suspicious for cutaneous manifestations below the first metatarsal head. An abducted forefoot may be present, which is typically seen in the spectrum of deformities that fall under the pes planus foot type. The examiner must assess for cutaneous lesions in the lateral fifth metatarsal head, as well as over the medial talonavicular articulation. In the adducted foot type, the examiner must be suspicious for cutaneous manifestations over the styloid process of the fifth metatarsal, as well as the medial first metatarsal head.

Windlass mechanism

The plantar fascia of the foot has a specialised role in gait, especially in the final stages of stance. The plantar fascia attaches the plantar calcaneus to the proximal bases of the phalanges. The windlass mechanism of the plantar fascia functions by tightening the plantar fascia when the digits are dorsiflexed, which depresses the metatarsal heads, inverts the calcaneus, and prevents the collapse of the midfoot by stabilising the longitudinal arch. (Miller and Thompson 2015)

Exam technique: the examiner dorsiflexes the digits of the foot at the level of the MTPJ. While the digits are dorsiflexed, the examiner should palpate for a prominent central band of the plantar fascia (*Figure 7, Top*). Next, while continuing to dorsiflex the digits, the examiner applies pressure to the plantar first metatarsal head in an attempt to elevate it (*Figure 7, Bottom*).

Abnormal exam: if the examiner is unable to palpate the plantar fascia or can elevate the first metatarsal head easily, there is dysfunction of the windlass mechanism. This may be due to a tear in the plantar fascia or could be a result of an attenuated plantar fascia due to a chronic pes planus posture of the foot. With windlass mechanism dysfunction, we may see cutaneous

manifestations that correlate with a functional hallux limitus. This is typically seen as lesions in the plantar hallux IPJ. If consistent with a pes planus foot type, the examiner should assess the at risk regions that are associated with that foot type.

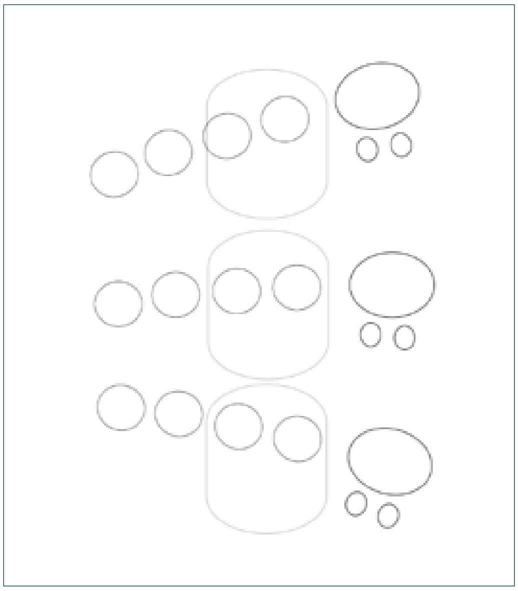


Figure 5. (Top) Demonstrates a forefoot varus alignment. (Middle) Demonstrates a neutral alignment. (Bottom) Demonstrates a forefoot valgus alignment.

Figure 6. Clinical example of a neutral alignment of the forefoot to the rearfoot.

Figure 7. (a) Placing dorsal pressure to the plantar first metatarsal head while the plantar fascia is taut. (b) Plantar fascia visible with dorsiflexion of the digits.

Ankle joint

The ankle joint consists of the articulation between the talus, tibia and fibula. The motion found in the ankle is primarily dorsiflexion and plantarflexion with corresponding ROM of 10–15 degrees of dorsiflexion and 40–50 degrees of plantarflexion. (Coughlin et al, 2014). The mechanics of the ankle are essential for proper ambulation in every phase of gait.

Exam technique: the examiner grasps the heel and places the foot on the forearm with the same hand (*Figure 8*). The examiner then dorsiflexes the foot at the ankle as the axis of rotation. This is initially performed with the knee flexed. While the examiner keeps the foot dorsiflexed, the knee is allowed to fall into extension. This allows the examiner to experience dynamic changes in ROM, as described as the Silfverskiold test.

Abnormal exam: the examiner first determines if there is a limitation in ROM in dorsiflexion with the knee flexed or with the knee flexed and extended, which are considered gastrocnemius and gastrocnemius-soleal equinus respectively. This contracture may be of soft tissue in nature or osseous, as seen with osteophytes of the talus and tibia in anterior ankle impingement. With these pathomechanics, the examiner must be suspicious of cutaneous manifestations at the plantar metatarsal heads, as well as cutaneous manifestations that correlate with a pes planus foot type. This is due to the fact that the foot becomes more mobile as a compensation to the limited dorsiflexion. The examiner should also inspect the plantar medial hallux IPJ, as those with equinus externally rotate as a compensation of the lack of ROM, and tend to roll off the medial aspect of the hallux.

Muscle function

Assessing muscle function is an important part of the physical exam since it may uncover imbalances and compensatory mechanisms that can correlate with other exam findings to help establish a diagnosis.

The tibialis anterior is primarily a dorsiflexor of the foot. It it assessed by initially placing the foot in maximal plantarflexion and asking the patient to dorsiflex against gravity and then resistance. If excessive toe dorsiflexion is noted with this maneuver, the examiner should ask the patient to keep the toes plantarflexed as the foot is dorsiflexed against resistance. If the patient is unable to perform this maneuver with the tibialis anterior now isolated, the patient is most likely compensating with the extensors of the digits, which may be a cause of dynamic hammer toe deformity.

The tibialis posterior is the primary inventor of the foot. It is assessed by flexing the knee, externally rotating the limb, and placing the leg over the contralateral leg (*Figure 9*). The patient then inverts against gravity, as well as resistance from a maximally everted position.

The gastrocnemius and soleus are the primary plantarflexors of the foot. They are tested by maximally dorsiflexing the foot and having the patient against resistance. If the patient is unable to perform this, then patient is either placed prone or on their knees, and asked to plantarflex against gravity. Next, the examiner squeezes the calf at the widest portion to see if the foot plantarflexes. If it does not, there is likely a discontinuity of the achilles tendon.

The peroneus longus everts the forefoot by plantarflexing the first ray due to its insertion on the plantar medial cuneiform and first metatarsal. To test in isolation, the first metatarsal head is maximally dorsiflexed with examiner's thumb and the patient is asked to plantarflex the first ray against resistance (*Figure 10*).

The peroneus brevis everts the hindfoot. It is assessed by maximally inverting to the foot at the level of the hindfoot/midfoot and asking the patient to evert against resistance.

Figure 8 (above top). Assessing ankle range of motion with entire plantar foot placed on examiner's forearm and axis of rotation through the ankle.

Figure 9 (above bottom). Assessing the tibialis posterior muscle.

Standing exam

Anterior exam: while the patient is facing the examiner, it is important to place the patient in proper rotation, by having the patient's patella facing the examiner. Starting with the digits, inspect for any gross digital deformities. Assess for increased clawing of the digits with the loaded foot. Recognise both abducted and adducted forefoot to rearfoot relationships. If the medial calcaneus is visible when inspecting the foot and ankle directly anterior to posterior, this is know to be the "peek-a-boo" heel sign, which is usually associated with a varus heel

Medial and lateral exam: When examining in this view, sagittal plane deformities become more apparent. This is true of digital deformities as well as assessment of the arch. It is is important to note if there is an arch present, and if so, is it exceedingly

Figure 10 (above top). Assessing the Peroneus Longus Muscle.

Figure 11. (a) Exam of the medial foot. Note the low arach present. (b) Positive Jack Test with elevation of the longitudinal arch.

high. The examiner is typically able to place a finger under the longitudinal medial arch, if it is present. In this view the examiner should also perform the Jack Test (*Figure 11*). While weight bearing, the examiner dorsiflexes the hallux at the level of the metatarsophalangeal joint, and monitor elevation of the longitudinal arch. If the longitudinal arch does not elevate with this maneuver, the Jack Test is considered negative, which may be due to rigidity, functional hallux limitus, or failure of the windlass mechanism.

Posterior exam: during this portion of the exam, the patient faces away from the examiner. While the limb is in neutral rotation, the examiner observes the relationship of the calcaneus to the tibia. The heel may be found to be in neutral, valgus, or varus. The concavity of the achilles tendon may also assist in determining the deformity. For example, an increased concavity of the lateral achilles tendon correlates to a valgus heel. The patient is then asked to stand on their toes. With this maneuver, the heels should move into an inverted position (*Figure 12*). If this does not happen, this maybe due to rigidity or failure of the posterior tibial tendon. The patient should then be inspected for a prominent talonavicular joint, also known as talar beaking. The examiner should then inspect to see if they can see the forefoot digits, while looking directly posterior the heel. If they are present, it is said to have a positive "too many toes" sign, an indication of of an abduction deformity. Both the talar beaking and the too many toes sign fall under the umbrella of deformities associated with a pes planus foot type.

Gait

Swing

During the swing phase of gait, the foot and ankle must work in concert with the hip and knee to clear the ground and allow limb advancement. Failure to do so, may present in various ways to the examiner. For an uncompensated lack of ankle dorsiflexion, the toes may drag along the ground during swing. For a weak tibialis anterior, we may see extensor substitution, which is excessive toe dorsiflexion as a result of the extensor digitorum longus assisting in ankle dorsiflexion. For a failure of dorsiflexion by the anterior compartment, we may see a steppage gait or a circumductive gait.

Contact

During the contact phase of gait, the foot makes contact with the ground, starting with the heel and eventually the entire foot with the goal of accepting weight and attenuating shock by the ground. Those with a weak anterior compartment may have a foot slap gait, where the entire foot initially makes contact with the ground. Those with significant equinus may initially make contact with ground with the metatarsal heads. Those with a fixed heel varus will not have eversion of the heel for proper weight acceptance that is accomplished by the pronated foot.

Midstance

During midstance the foot converts from a supple load acceptor to a rigid lever as the leg advances over the foot. With an equinus deformity we can see several different pathomechanics in this phase. In an uncompensated equinus, we may see an early heel lift, or no heel contact at all. For compensated mechanisms we may see a "break" in the midfoot, which is excessive dorsiflexion in the midtarsal joints. With a pes planus foot type we will see excessive pronation which can be demonstrated by the aforementioned break in the midfoot, lack of longitudinal arch, as well as flexor stabilisation. Flexor stabilisation occurs with deficiency of the posterior tibial tendon. The flexors of the digits may fire to help eccentrically control pronation, which can be seen by contractures of digits during this phase of gait.

Propulsion

During propulsion the foot is a rigid lever to setup the limb for swing and limb advancement for the next step. During this phase there may be a pathologic everted heel due to several factors, such as rigidity, posterior tibial tendon dysfunction, or failure of the windlass mechanism. We may see an externally rotated limb with roll off of the plantar medial hallux due to an abducted foot, compensation for equinus, or compensation for first metatarsophalangeal joint deformity, such as hallux limitus/rigidus or hallux abducto valgus.

Imaging

When any abnormal findings are observed, it may be helpful to obtain weight-bearing plain radiographs when possible. These radiographs when correlated to a thorough physical exam, can be used to confirm or establish a diagnosis.

Figure 12. Inversion of the heel with heel rise manoevre.

Additional imaging such as ultrasound, CT and MRI may be used for surgical planning or for further assessment of infection involving the musculoskeletal system.

Conclusion

The musculoskeletal component of the physical exam for the foot and ankle is in many cases as essential as vascular and neurological status. With a detailed musculoskeletal exam, a specific diagnosis can be made to identify one of the contributing etiologies for diabetic foot complications. This will allow providers to provide more precise management of deformities with or without associated neuropathy and peripheral vascular disease. It may also go a long way to helping us better assess and measure what we manage. ■

Andersen H, Gjerstad MD, Jakobsen J (2004) Atrophy of foot Muscles. *Diabetes care* 27(10): 2382–5

Armstrong DG, Peters EJ, Athanasiou KA, Lavery LA (1998) Is there a critical level of plantar foot pressure to identify patients at risk for neuropathic foot ulceration? *Journal Foot Ankle Surgery* 37(4): 303–7

Armstrong DG, Boulton AJM, Bus SA (2017) Diabetic foot ulcers and their recurrence. *New Engl J Med* 376(24): 2367–75

Boulton AJM (2004) Pressure and the diabetic foot: clinical science and offloading techniques. *Am J Surg* 187(5A): 17S–24S

Brownlee M (1992) Glycation products and the pathogenesis of diabetic complications. *Diabetes Care* 15(12): 1835–43

Brownlee M, Vlassara H, Cerami A (1984) Nonenzymatic glycosylation and the pathogenesis of diabetic complications. *Ann Int Med* 101(4): 527–37

Bus SA, Maas M, de Lange A et al (2005) Elevated plantar pressures in neuropathic diabetic patients with claw/hammer toe deformity. *J Biomech* 38(9): 1918–25

Bus SA (2008) Foot structure and footwear prescription in diabetes mellitus. *Diabetes Metab Res Rev* 24(Suppl 1): S90–5

Bus SA, Yang QX, Wang JH et al (2002) Intrinsic muscle atrophy and toe deformity in the diabetic neuropathic foot. *Diabetes Care* 25(8): 1444–50

Bus SA, Ulbrecht JS, Cavanagh PR (2004) Pressure relief and load redistribution by custom-made insoles in diabetic patients with neuropathy and foot deformity. *Clin Biomech* 19(6): 629–38

Coughlin MJ, Saltzman CL, Anderson RB (2014) *Mann's Surgery of the Foot and Ankle* (9th ed.) Saunders/Elsevier, Philadelphia

Delbridge L, Perry P, Marr S et al (1988) Limited joint mobility in the diabetic foot: relationship to neuropathic ulceration. *Diabetic Med* 5(4): 333–7

Delbridge L, Ellis CS, Robertson K, Lequesne LP (1985) Non-enzymatic glycosylation of keratin from the stratum corneum of the diabetic foot. *Br J Dermatol* 112(5): 547–54

Fernando DJ, Masson EA, Veves A, Boulton AJ (1991) Relationship of limited joint mobility to abnormal foot pressures and diabetic foot ulceration. *Diabetes Care* 14(1): 8–11

Frykberg RG, Bowen J, Hall J et al (2012) Prevalence of equinus in diabetic versus nondiabetic patients. *J Am Podiatr Med Assoc* 102(2): 84–8

Frykberg RG, Bevilacqua NJ, Habershaw G (2010) Surgical off-loading of the diabetic foot. *J Am Podiatr Med Assoc* 100(5): 369–84

Grant WP, Sullivan R, Sonenshine DE et al (1997) Electron microscopic investigation of the effects of diabetes mellitus on the Achilles tendon. *J Foot Ankle Surg* 36(4): 272–8; discussion 330

Grebing BR, Coughlin MJ (2004) The effect of ankle position on the exam for first ray mobility. *Foot Ankle Int* 25(7): 467–75

Lavery LA, Armstrong DG, Wunderlich et al (2003) Predictive value of foot pressure assessment as part of a population-based diabetes disease management program. *Diabetes Care* 26(4): 1069–73

Magee DJ (2013) *Orthopedic Physical Assessment*. Elsevier Health Sciences, Amsterdam

Miller MD, Thompson SR (2015) *DeLee & Drez's Orthopaedic Sports Medicine: Principles and Practice*. Elsevier/Saunders, Philadelphia

Munuera PV, Trujillo P, Güiza I (2012) Hallux interphalangeal joint range of motion in feet with and without limited first metatarsophalangeal joint dorsiflexion. *J Am Podiatr Med Assoc* 102(1): 47–53

Piaggesi A, Goretti C, Iacopi E et al (2016) Comparison of removable and irremovable walking boot to total contact casting in offloading the neuropathic diabetic foot ulceration. *Foot Ankle Int* 37(8): 855–61

Reddy PV, Vaid MA, Child DF (1989) Diabetes and incorrectly fitting shoes. *Practical Diabetes International* 6(1): 16–8

Spanheimer RG, Umpierrez GE, Stumpf V (1988) Decreased collagen production in diabetic rats. *Diabetes* 37(4): 371–6

Wrobel JS, Armstrong DG (2008) Reliability and validity of current physical examination techniques of the foot and ankle. J Am Podiatr Med Assoc 98(3): 197–206

Zimny S, Schatz H, Pfohl M (2004) The role of limited joint mobility in diabetic patients with an at-risk foot. *Diabetes Care* 27(4): 942–6