

Biomechanical Problems of the Foot

Henry C. Hilario, DPM

Frank Aviles Jr., PT, CWS, FACCWS, CLT-LANA, ALM, AWCC, DAPWCA

June 2018

The feet are the foundation of the human body. They provide support, locomotion, and balance. Unlike the foundation of a house, our feet must provide us with static support — for when we are upright and stationary — as well as dynamic support — for when we are active. Much like a home's foundation, however, if something is not correct or is distorted within the body's framework, problems will migrate while becoming more noticeable and severe over time. This article will discuss the anatomy of the foot, the intricacies of gait, and the impact that foot deformity and diabetes have on foot biomechanics and overall health. Treatment strategies and methods of pain relief will also be shared.

ANATOMY OF THE FOOT & FOOT DEFORMITY

As a baseline, understanding the anatomy and function of the foot is imperative, as is knowing how the shape and function of the foot is altered by deformity and disease (Figure 1). One of the most complex structures on the body, the foot has many moving parts, including 26 bones; 33 joints; and more than 100 muscles, tendons, and ligaments. A network of blood vessels is also present. Anatomically speaking, the foot can be divided into the following sections:



Forefoot – contains the toes (phalanges) and metatarsals (connecting bones). Each toe has three small bones, except the big toe (hallux), which has two. The joint where the toe meets the head of the metatarsal is known as the metatarsophalangeal joint (MPJ)

and is given a number based on the toe that it's directly involved with. The forefoot bears half the body's weight and balances pressure on the ball of the foot.

Midfoot – contains five tarsal bones, forms the foot's arches, and serves as a shock absorber. These bones are connected to the forefoot and hindfoot by ligaments and muscles.

Hindfoot – forms the heel and ankle, contains three joints, and connects the midfoot to the lower leg. The talus connects with the lower leg to form the ankle and allows the foot to move up and down.

Muscles and ligaments – hold bones in position and stabilize joints while allowing movement.

Blood vessels – blood supply to the foot is primarily carried by the peroneal artery, posterior tibial artery, and anterior tibial artery. Adequate arterial circulation must be established.

Arches – three arches act as a spring and shock absorber during ambulation. The three arches consist of two longitudinal (medial and lateral) and one anterior transverse arch. These arches are formed by tarsal and metatarsal bones that are held together by ligaments and tendons.

What follows is a list of common foot problems and deformities:

Callus – thick, hardened layers of skin that develop when the skin tries to protect itself against friction and pressure. Causes may include ill-fitting shoes and increased plantar pressures due to foot problems or abnormal biomechanics.

Flatfoot (pes planus) – loss of longitudinal arch, feet may ache (Figure 2).



High arch (pes cavus) – high medial longitudinal arch, ability to absorb shock during ambulation is lost, increased stress on the ball and heel of the foot. Pain can move to proximal joints, such as in the ankle, knee, and hip (Figure 3).



Hallux rigidus – the big toe becomes stiff and difficult to bend. Arthritis may set in. This joint stiffness will increase abnormal pressure on the toe during gait, thus creating calluses and ulcerations.

Equinus – ankle dorsiflexion is limited, thus possibly increasing plantar pressures on the ball of the foot. May be caused by tightness of the Achilles tendon or soleus/gastrocnemius musculature.

Hammer toe – a deformity that may be flexible or rigid, where the middle joint is bent downward. This deformity is progressive, so early recognition is important (Figure 4).



Claw toe – deformity in which the middle and end joint of the toe are contracted. Occurs in toes 2-5. Often, foot movement is limited, creating increased pressure at the ball of the foot.

Charcot foot – condition affecting the bones, joints, and soft tissues of the foot and ankle characterized by inflammation in the earliest phase. Documentation indicates occurrence as a consequence of various peripheral neuropathies (diabetic neuropathy being the most common). Characterized by midfoot collapse and described as a “rocker bottom” foot.

Overpronation – excessive rolling inward movement of the foot when walking or running. Predisposes lower extremity injuries and causes heavier wear of shoes on the inner margin. Collapsing arches occur while walking.

Supination – a rotation of the foot and leg in which the foot rolls outward with an elevated arch so that the foot tends to come down on its outer edge when walking. Leads to shoes wearing on the outer edge and high arches.

Patients can also develop arthritic conditions of the foot and ankle through previous traumas or overuse injuries (Figure 5). As a joint becomes arthritic, it can lead to decreased range of motion that can alter gait and the mechanics of the foot and ankle. In the sensate foot, arthritic conditions may not significantly affect patients' lives. However, in the neuropathic patient, any deviation of normal foot mechanics can pose an ulcer risk. Patients with flat feet or high arches can also have an increased ulcerative risk due to their foot mechanics. Charcot neuroarthropathy is a syndrome that can affect neuropathic patients in which there are multiple fractures and dislocations of bones and joints without any specific trauma. There is often a delay in diagnosis due to vague initial presentation, however, this can be a devastating condition that causes severe deformity and leads to high risk of amputation. As the foot conforms to rocker bottom, the midfoot bears most of the weight and is a significant ulcerative risk. Previous infections and surgical debridement can also pose future risk for ulceration. As plantar wounds need to be debrided, devitalization of ligamentous or tendinous structures can alter mechanics and gait.



WALKING & THE “GAIT CYCLE”

The average American walks about 5,900 steps per day, according to the Louisiana-based Walking Behavior Laboratory at Pennington Biomedical Research Center, which is only slightly more than half of the recommended 10,000 steps per day. Reports estimate that 33% of the elderly (65 years of age and older) experience falls

at least once per year, with about 40% of these falls requiring hospitalization.¹ Ambulation technically means “the act of walking,” or “to move from place to place.” Gait refers to the manner in which one walks and represents a complex series of events that occur through multiple joints involving the nervous, musculoskeletal, and cardiorespiratory systems, all of which play a vital function to accomplish simple ambulation. Limitation in one of these systems and/or a foot deformity can cause gait dysfunction, which has the potential to delay wound healing. Foot deformities, neuropathy, and dysfunction in the lower extremities are known risk factors that increase plantar peak pressure and, as a result, the risk of developing foot ulcers in patients living with diabetes. We can analyze gait by looking at the patient’s gait cycle, a progression of events that occur during normal walking. An appreciation for the function of the foot is also rooted in knowledge of this cycle, which is measured from the point in which one heel strikes the ground up to the next heel striking the ground. Deformities of the foot may also result in abnormal pressures on the foot or affect other joints proximally. Alterations in gait can also increase the risk of injury, as balance is affected. During ambulation, an abnormal gait pattern leads to abnormal transfer of weight into a different location, thus also increasing peak plantar pressures. The actions that occur during the gait cycle are described by a two-phase perspective: the stance phase and the swing phase. One’s walking pattern is considered to be “normal” gait when the stance phase accounts for 60% of the cycle and the swing phase accounts for 40% of the cycle.² Each sequence of limb action involves a period of weight-bearing (stance) and an interval of self-advancement (swing).² The exact duration of these intervals varies with walking speed, which will vary among individuals for many reasons.² For example, one study found that sex-specific differences in gait patterns are apparent in healthy older adults.³ Trauma, disease, age, lack of range of motion, weakness, and/or abnormal biomechanical issues will affect gait. When evaluating gait, the reciprocal action of the lower limbs is timed to trade their weight-bearing responsibility during a period of double stance (ie, when both feet are in contact with the ground) and usually involves the initial and terminal 10% intervals of stance.² The middle 40% is a period of single stance (single-limb support). During this time, the opposite limb is in swing.² The foot is not bearing weight in this phase. Joints must have necessary range of motion throughout the cycle, and various muscles will be activated to provide normal gait. The stages of both phases are explained in the following lists:

Stance phase:

- Heel strike (initial contact) – the initial point of contact between the foot and the ground. The ankle assumes a neutral position (0°), the knee is flexed ($0-5^\circ$), and the hip is flexed (approximately 30°).
- Foot flat (loading response) – the foot is completely contacting the ground. This is a controlled movement, the ankle plantarflexes ($5-10^\circ$), and the knee is flexed ($15-20^\circ$) while the hip moves towards extension (20° flexion).
- Mid-stance – the rest of the body moves over the limb. The ankle is in slight dorsiflexion (5°), the knee extends ($0-5^\circ$), and the hip continues to extend (0° flexion).
- Heel off – the heel is starting to lift off the ground. The ankle is in dorsiflexion (10° flexion) progressing to plantarflexion, the knee moves from extension to flexion ($0-5^\circ$), and the hip is hyperextended (-20° hyperextended).
- Toe off (terminal stance) – the toes leave the ground to end the stance phase. The ankle is plantarflexed (15°), the knee is in flexion (40°), and the hip is hyperextended (-10° hyperextended). At the same time, the opposite foot is foot flat.

Swing phase:

- Acceleration (pre-swing) – the ankle moves into dorsiflexion (5° plantarflexed) while the knee ($60-70^\circ$ flexion) and the hip (15° flexion) continue to flex.
- Mid-swing – the ankle is in a neutral position (0°) and the knee is in flexion (25°) as the hip continues to flex (25° flexion).
- Deceleration (terminal swing) – the ankle is neutral (0°), the knee is almost in full extension ($0-5^\circ$ flexion), and the hip is in flexion (20°).

Our feet play an important role in providing normal gait, but normal range of motion and adequate muscular strength is a prerequisite. The ankle joint has multiaxial motions to allow normal movement while muscles, ligaments, and tendons provide stability and/or movement. During ambulation, the lower extremities experience certain movements, and the foot and its associated structures will transition from a shock absorber for weight support to a rigid lever needed for forward progression. After heel strike, the lateral border of the foot remains on the ground and begins to pronate inward. The arch then begins to drop, and the ankle turns inward. Then, at

mid-stance, minimal force is experienced on the sole as weight is divided evenly over the foot (with the foot being pronated). This is followed by heel lift, in which the weight is shifted to the ball of the foot and the foot supinates (rotates outward) as the toes bend. Any deviations or deformities will increase pressure in unwanted areas, creating injuries or trauma.

The measurement of gait is conducted by examining such things as stride length, step length, and cadence. Stride length is the distance traveled from one heel strike to the next heel strike on the ipsilateral foot. Step length is the distance traveled between heel strikes on both feet. Cadence is the number of steps taken per minute. The average cadence is 101-122 steps per minute, depending on one's height. Common examples of abnormal gait include antalgic gait, a limp that develops as a means to minimize pain on the weight-bearing structures related to foot pain or pain in other areas of the lower extremity that decreases the amount of time a patient is in the stance phase (often, a decrease in stride length and cadence will be seen); drop foot, a condition that results in excessive ankle plantarflexion in the terminal swing as a result of insufficient dorsiflexors; and high-steppage gait, a condition typically seen among patients with drop foot or weakness of the anterior tibialis musculature in which the foot may slap the ground during heel strike due to lack of muscle strength and uncontrolled motion.

One's support and ability to move changes whenever the foot is injured or there is a change in structure. Changes in structure will vary depending on the level of insult impacting the foot, as will the challenges associated with daily ambulation. If these changes to our feet continue over time, other parts of our body will be impacted. In all essence, when our feet contact the ground it is the complex foot that must serve multiple functions to allow normal movement. Consider what it is like trying to ambulate with an ankle sprain, an ingrown toenail, a stress fracture, or a stubbed toe. All of these ailments will alter gait patterns and the manner in which we walk. Now, imagine not being able to feel these types of injuries and how the foot can continue to be traumatized (and the injuries worsened), potentially to the point of limb-threatening conditions. The risk of falling is said to be 15 times greater among people experiencing diabetic neuropathy than those living with diabetes absent of neuropathy.⁴ These patients may require an assistive device and/or assistance if their cadence (speed), balance, and stability are affected. In the neuropathic patient, secondary protruding metatarsals, toe deformity, callus development, and ulcerations

from unrelenting tension due to loss of protective sensation are also common. The formation of ulceration in the insensate or pathologic foot can occur from a single acute episode or repeated low-intensity contact. The breakdown will occur at the lowest weight-bearing area of the arch or forefoot.⁵ To determine the mechanism of injury to a foot wound, in addition to analyzing gait, foot deformity and shoe wear must be assessed. It is advisable to also determine the patient's ankle/foot strength and range of motion, factors that can alter walking patterns and possibly create further injury.

CONSIDERATIONS FOR THE CLINIC

When it comes to providing care in the wound clinic, there's an expansion of products and interventions. At times, this plethora of treatment options may seem overwhelming to new clinicians, not to mention the many moving parts of the operational side. As our healthcare system continues to navigate a value-based methodology that focuses on outcomes, most clinics will follow implemented algorithms that should be based on best practices.

These algorithms are only beneficial, however, when appropriately and consistently utilized by all members of the wound care team. Lower extremity wounds may be challenging due to possible etiologies compounded by factors that impede healing. Determining cause should lead to the proper treatment path, but when it comes to wounds of the foot, sometimes treatment may fall short, especially if ongoing trauma persists from unrecognized and/or untreated structural foot deformities or abnormal gait patterns. Once there's a callus and/or an ulceration on the plantar foot, clinicians typically provide patients with various forms of offloading, which can be defined as removing unwanted pressure from a desired location and distributing it across the plantar surface of the foot. There are a variety of choices, such as total contact casting, removable cast walkers, assistive devices, and surgical interventions. Healing rate and patient compliance varies depending on the offloading method utilized (with balance deficit, patient compliance, and clinician skill/competency being barriers to proper offloading). Plantar wounds may encounter increased pressures that predispose patients to ulceration, especially if neuropathy is present. What follows is a list of suggested nonsurgical treatment strategies for some of the aforementioned problems/deformities:

Callus – treatment aimed at alleviating symptoms, followed by addressing underlying cause.

Flatfoot – orthotic devices, weight loss, immobilization, shoe modifications, and physical therapy. (Podiatric surgeons can be consulted for available surgical interventions when nonsurgical treatment is inadequate.)

High arch – orthotic devices and shoe modifications. (Surgical interventions may be considered if nonsurgical treatment fails).

Hallux rigidus – shoe modifications, orthotic devices, medications to decrease inflammation and pain, and physical therapy.

Equinus – splints, heel lifts, and physical therapy. (Surgical interventions may be indicated.)

Hammer toe – padding, changes in footwear, and orthotic devices. (Surgical interventions may be warranted if the deformity becomes rigid and painful.)

Claw toe – typically will need shoe to accommodate, otherwise the toe will rub against the shoe and the end of the toe will be pressed against the bottom of the shoe.

Charcot foot – providing proper shoe wear, such as a CROW boot. (Surgical options are also available and based on individual needs).

Additionally, digital contractures such as hammer toes, claw toes, and mallet toes tend to cause ulcerations at the plantar tip of the digits or plantar aspect of the MPJ due to retrograde pressure. If the deformity is flexible, meaning it can manually be straightened, the patient may benefit from a percutaneous tenotomy of the flexor tendon. This procedure can be done in the office through a 4-mm stab incision that removes the deforming force. If the deformity is rigid, meaning that it cannot be straightened manually, arthroplasty or arthrodesis may be needed. This involves removing a section of the underlying bone to shorten the toe and decompress the contracture. Equinus can lead to ulcerations of the forefoot and can be properly tested by the Silfverskiöld test.⁶ The targeted treatment area depends on which posterior muscles the equinus affects. If the Achilles tendon is affected, a percutaneous lengthening can be performed, allowing for decreased forefoot pressure. Otherwise, a

gastrocnemius fascia recession can be performed, which allows for quicker return to weight-bearing and less risk of iatrogenic rupture.

As it pertains to antalgic gait, treatment will include locating the pain source and possibly utilizing assistive devices. Treatment for high-steppage gait may include wearing an ankle-foot orthosis. When an injury occurs to the foot, such as a bone fracture, the healthcare provider should recommend non-weight-bearing on that extremity for healing to occur. The same solution should also be made for most plantar wounds. Wound care clinicians should include the expertise of a podiatrist, orthotist, and physical therapist (PT) as part of any care plan involving the feet in order to pinpoint the cause of abnormal gait and address foot deformities to prevent further trauma, reulceration, and/or risk of falls. Podiatrists and PTs are trained in assessing and analyzing gait. Proper diagnosis and treatment of foot problems can also help eliminate chronic issues. A study on foot deformities and plantar pressures concluded that hallux valgus and hallux rigidus appeared to increase pressure under the medial foot, and a high body mass index appeared to increase the pressure under the lateral forefoot, thus demonstrating that deformities can be attributed to increased plantar peak pressure and ulcerations.⁷ A callus or hyperkeratosis may develop due to repeated load and exposure to a specific area. With time, the likelihood of this area to become ulcerated increases. It is important to note that calluses are the body's "warning sign" of excessive friction. As a similarity, a callus is the "check engine light" signifying that more problems could lie ahead if not addressed. Any callus that is found on a patient should be considered further by identifying possible causes.

DIABETES & THE FOOT

Diabetes can cause pathologic conditions of the foot and ankle that contribute to the formation of diabetic foot ulcers (DFUs). One of those causes can be peripheral neuropathy, which includes motor, sensory, and autonomic functions. Motor neuropathy can lead to toe deformities and contractures that increase pressure points of the foot. Sensory neuropathy can lead to wounds going unnoticed for prolonged amounts of time. Autonomic neuropathy decreases skin hydration, leading to higher chances of developing pre-ulcerative callouses. This dangerous triad can lead to serious foot infections and risk of amputation. Hammer toe is one of the more common pathologies seen in patients living with neuropathy. Over time, these contractures become rigidly fixed and can lead to increased pressure points on the

foot that cause difficult ulcers. Diabetes can also lead to glycation of the collagen that makes up the tendons in the foot and ankle. This leads to tissue stiffness, limitation of motion, and is commonly seen in the Achilles tendon (leading to equinus). This leads to higher pressure in the forefoot because the ankle cannot reach past 90° with the leg and can lead to a higher risk of new or recurring ulcerations. Treatment for DFUs still includes the basic pillars of local wound care. Infection must be eradicated and there should be debridement of nonviable tissue, adequate vascular supply to the wound, and appropriate offloading of the ulceration. The “why” of these wounds should also be added to the treatment plan. Patients should be examined standing and walking in the treatment room to see if biomechanics plays a role in the recurrence or regression of the wound. Many ulcerations are at risk of reopening, which can be controlled with accommodative insoles and extra-depth shoes, however, some ulcers still will reopen due to difficult biomechanical forces. For recurrent wounds or wounds that have failed to show improvement, patients should be evaluated by a multidisciplinary wound care team that includes a podiatrist and physical therapist.

Frank Aviles Jr. is wound care service line director at Natchitoches (LA) Regional Medical Center; wound care and lymphedema instructor at the Academy of Lymphatic Studies, Sebastian, FL; PT/wound care consultant at Louisiana Extended Care Hospital, Lafayette; and PT/wound care consultant at Cane River Therapy Services LLC, Natchitoches. Henry C. Hilario is a podiatric surgeon at ArkLaTex Foot & Ankle Specialists, Shreveport, LA.

References

1. Kane RL, Ouslander JG, Abrass IB, Resnick B. *Essentials of Clinical Geriatrics*. 3rd ed. New York, NY. McGraw-Hill Education;1994.
2. Murray MP, Drought AB, Kory RC: Walking patterns of normal men. *J Bone Joint Surg Am*. 1964;46:335-60.
3. Ko S, Tolea MI, Hausdorff JM, Ferrucci L. Sex-specific differences in gait patterns of healthy older adults: results from the baltimore longitudinal study of aging. *J Biomech*. 2011;44(10):1974-9.
4. Kelly VE, Mueller MJ, Sinacore DR. Timing of peak plantar pressure during the stance phase of walking. a study of patients with diabetes mellitus and transmetatarsal amputation. *J Am Podiatr Med Assoc*. 2000;90(1):18-23.

5. Mrdjenovich DE. Off-loading practices for the wounded foot: concepts and choices. *J Am Col Certif Wound Spec.* 2011;3(4):73-8.
6. Singh D. Nils Silfverskiöld (1888-1957) and gastrocnemius contracture. *Foot Ankle Surg.* 2013;19(2):135-8.
7. Tang UH, Zügner R, Lisovskaja V, Karlsson J, Hagberg K, Tranberg R. Foot deformities, function in the lower extremities, and plantar pressure in patients with diabetes at high risk to develop foot ulcers. *Diabet Foot Ankle.* 2015;6 [published online June 17, 2015].