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FUNCTIONAL ANATOMY, TERMS, AND COMMON FOOT CONDITIONS

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FUNCTIONAL ANATOMY, TERMS, AND COMMON FOOT CONDITIONS

INTRODUCTION AND ABSTRACT

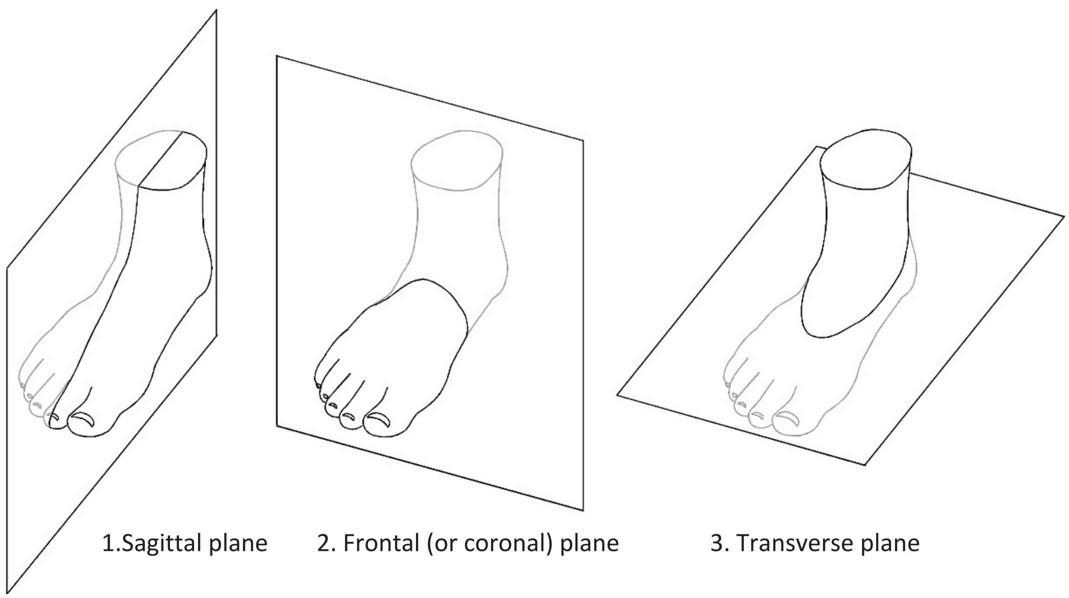
This paper provides a brief overview of some important functional anatomy terms and concepts from a medical perspective. The scope of this paper is not to serve as a comprehensive review of all the factors that are important in footwear design but to introduce functional anatomical and biomechanical terms and concepts along with a brief discussion of the most common foot conditions and their relevance to the health implications of footwear. This paper is considered a companion paper to IEEE SA 3D Body Processing Industry Connections *Comprehensive Review of Foot Measurements Terminology in Use* paper.

Footwear has been customized to address pain and pathology since shoes were first worn. Medical professionals (and some bespoke footwear manufacturers) currently provide this service for those with foot pathology but the emerging technologies will enable more access to custom footwear on a dramatically larger scale. Many early adopters of mass customized footwear will likely have foot conditions that have not been satisfactorily addressed with off-the-shelf shoes. Footwear manufacturers and retailers cannot be expected to diagnose and treat medical conditions but nevertheless, those providing custom footwear will need a basic understanding of some anatomical and biomechanical concepts.

To follow are sections on terminology, functional anatomy, biomechanics, and common conditions of the feet. The terms and concepts discussed in this paper can be found in most medical textbooks on anatomy and the musculoskeletal system. The references used for this overview are listed at the end of the paper and numbered as [1], [2], [3], [4], [5].

1. TERMINOLOGY OF ORIENTATION AND MOTION

There are three cardinal planes that are used as reference points for describing orientation and motion. An anatomical plane can be thought of as a 2D slice through the 3D human body. Each of these imaginary planes has an axis through the center of the body that divides the body in half. The three cardinal planes can also be applied to anatomical segments such as a limb or the foot. In the context of this paper, we will describe the planes of the foot (FIGURE 1).



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1. **Sagittal plane** divides body into left and right halves. Motions in the sagittal plane are flexion and extension for the foot.
2. **Frontal** (or **coronal**) **plane** divides body into front and back halves. Motions in the frontal plane are inversion and eversion for the foot.
3. **Transverse plane** divides body into top and bottom. Motions in the transverse plane are abduction and adduction for the foot.

FIGURE 1 Cardinal Planes as shown on the foot

Orientation terms are useful to provide location and reference points when discussing anatomy (FIGURE 2). The terms "**media**l" and "**latera**l" refer to the sagittal plane axis. Medial means toward the midline and lateral means away from the midline. The big toe side of the foot is referred to as the medial side and the little toe is the lateral side. The terms "tibiale" and "fibulare" are occasionally used as synonyms for medial and lateral respectively since the tibia bone of the lower leg is medial and the fibula is lateral.

"**Distal**" and "**proximal**" are also used in reference to the trunk or the transverse plane axis. Distal means farther away from the trunk while proximal means closer to the trunk. For example, the toes are distal while the heel is proximal. The top of the foot is referred to as "**dorsa**l" and the bottom as "**plantar**." The digits are numbered 1–5 medial to lateral. The front of the lower leg and ankle are referred to as **anterior** and the back as **posterior**.

Superficial and **deep** are used to describe structural locations in relation to the anatomical surface**.** For example, the bones are deep to the skin and the skin is superficial to all other structures. Each of the terms can also be used in reference to other structures. For example, the arch is distal to the heel and the fourth digit is lateral to the second digit.

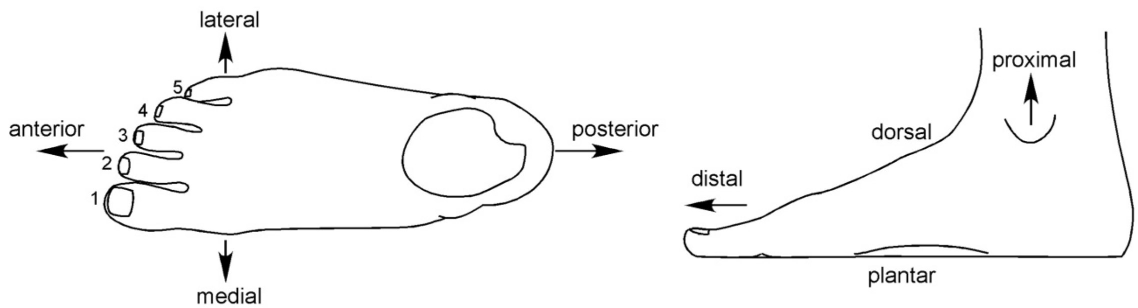

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FIGURE 2 Terms of Orientation

Motion

Motion terms are useful when describing movement of the segments of the foot and ankle. Because there are 33 joints in each foot, movement is very complex and many joints function together to create motion in more than one plane at a time and these motions occur rapidly in precise sequences during each foot step. Each of the terms described below are paired with a second term in order to describe movement in opposite directions.

Flexion and extension are motions in the sagittal plane (FIGURE 3 and FIGURE 4). Flexion refers to a movement that decreases the angle between two segments while extension increases the angle. For example, bending the knee is flexion (the angle between the thigh and lower leg is decreased) and straightening the knee is extension (the angle between the thigh and low leg is increased). In the foot and ankle, more specific terminology is required because there are so many segments that can be used as reference points. In the foot and ankle, "**dorsiflexion**" and "**plantarflexion**" are used. Dorsiflexion of the ankle or toes refers to bending the ankle or toes up (or towards the dorsal surface of the foot) while plantarflexion refers to bending the ankle or toes down (or towards the plantar surface of the foot).

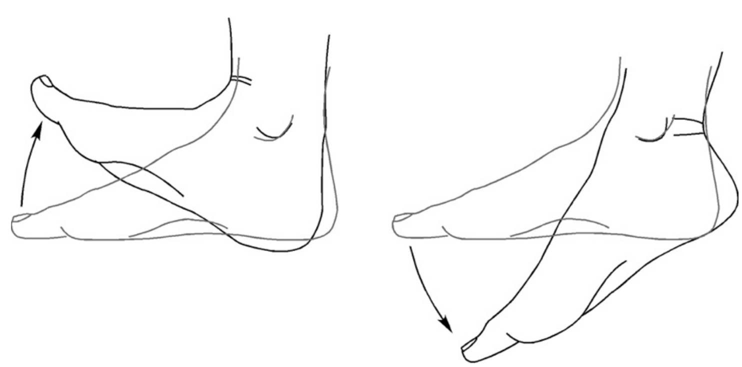

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FIGURE 3 Dorsiflexion and plantarflexion of ankle joint

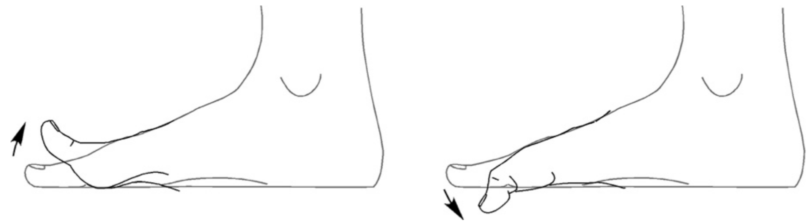

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FIGURE 4 Dorsiflexion and plantarflexion of the digits

Inversion and eversion are motions in the frontal plane (FIGURE 5). Inversion rotates the ankle and foot so that the plantar surface faces medially or inwards while eversion is the opposite rotation where the sole of the foot rotates outward. Ankle sprains are often called “inversion sprains” because they are a traumatic form of inversion that causes injury to ligaments. The terms “varus” and “valgus” are sometimes used interchangeably with inversion/eversion or to describe a static position in the frontal plane.

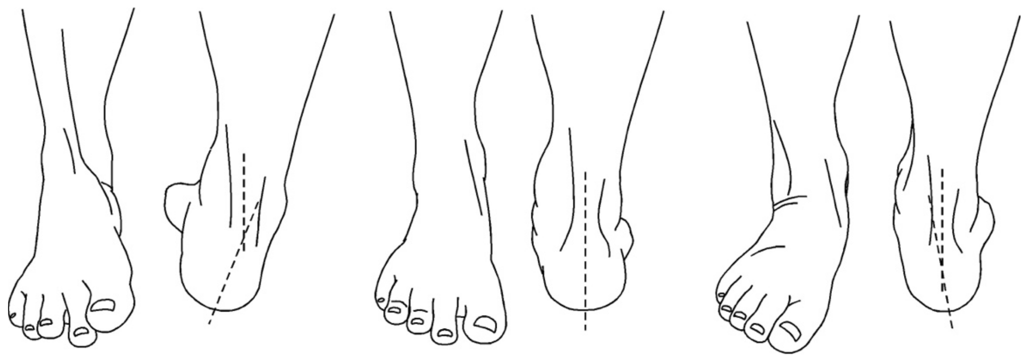

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FIGURE 5 Inversion and eversion of the right foot:
Left: inversion, middle: neutral, right: eversion

Adduction and abduction are motions in the transverse plane (FIGURE 6). Adduction is motion towards the midline, while abduction is motion away from the midline. For example, in-toeing while walking is sometimes called an “adducted gait” while out-toeing is called an “abducted” gait. A bunion is also known as “Hallux Abducto Valgus” deformity because the Hallux is abducted and in valgus alignment. Internal rotation and external rotation are also terms used to describe this motion. It is normal to walk with the feet slightly adducted (externally rotated).

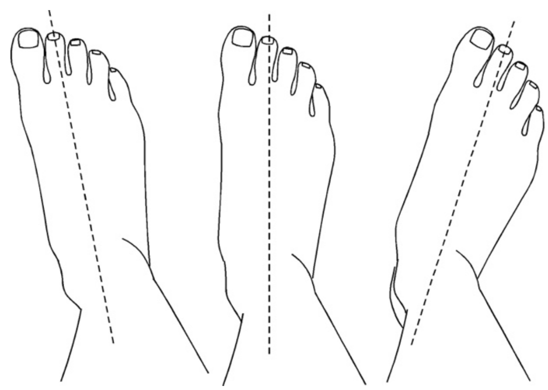

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FIGURE 6 Foot adduction (left), neutral alignment (middle), and abduction (right)

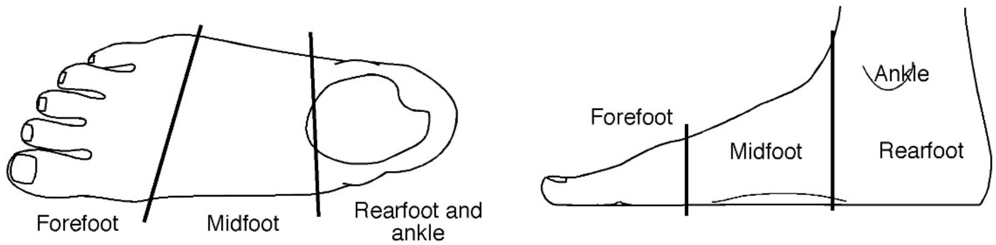
Pronation and supination are movements of multiple joints in the rear foot and ankle with motion occurring in all three cardinal planes. Pronation consists of eversion, dorsiflexion, and abduction of the subtalar and midtarsal joints. When the foot is pronating, it is a “mobile adapter” which allows it to absorb impact and adapt to the landing surface. Immediately after the foot has reached maximal pronation it begins to supinate by the opposite motions- inversion, plantarflexion, and adduction in order to become a “rigid lever” for propulsion. When walking, these motions occur in about 1 second, but when running they occur in 0.1 to 0.4 seconds. The term “over pronation” is widely overused to describe a foot that has been subjectively judged to be excessively pronated, unstable, flat, or hypermobile by the lay public, some shoe fitters, and some medical professionals. However, there is no universally agreed upon criteria for what constitutes over pronation.

2. FUNCTIONAL ANATOMY AND BIOMECHANICS

The foot is able to withstand thousands of footsteps and long periods of weight-bearing activity every day. It functions statically as a platform to stand and dynamically to provide the ability to absorb impact and propel the body forward on every foot step when moving. The foot must be flexible in order to absorb the impact forces of foot strike when walking, running, and jumping, yet also rigid enough to propel us forward into the next step over and over again day after day. Impact forces of walking are 1–1.5 times bodyweight, running are 2.5–3 times bodyweight, and jumping can be 5–7 times bodyweight. Active individuals can take 10,000 or more steps per day.

2.1. BONES AND JOINTS

There are 26 bones in each foot, 28 including the small sesamoids under the great toe joint. Each of these bones articulate with other bones at joints which allow for motion. The smallest bones and joints are in the forefoot and the largest in the rearfoot. The regions of the foot are interdependent with each contributing unique functions for gait. There may be some overlap between segments and there is no universally agreed upon dividing line between each (FIGURE 7).



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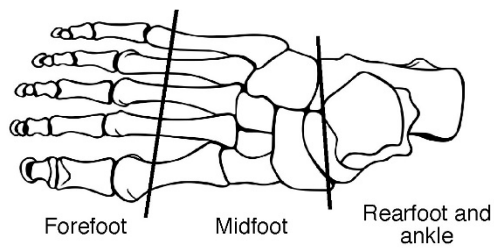

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FIGURE 7 Segmentation of the foot
Breaking the foot up in to segments can help when discussing the different functions, anatomy, biomechanics, and conditions

The **forefoot** consists of the distal metatarsals and digits (FIGURE 8). The digits are numbered 1–5 with the large toe (or hallux) being number 1 and the little toe being number 5. The first toe is also referred to as the hallux, great toe, big toe and first digit. The phalanges are the small bones of the digits. The hallux has two phalanges while digits 2–4 have three. The fifth digit is variable; sometimes it has two phalanges and sometimes it has three. The phalanges articulate with each other at the interphalangeal joints. In digits with three phalanges, the distal joints are called the distal interphalangeal joints (DIPJs) and the proximal joints are called the proximal interphalangeal joints (PIPJs).

The metatarsals are the long, thin bones that span the midfoot and forefoot. The first metatarsal has a larger diameter than metatarsals 2–5 because it is under more load than the others and is more integrated into supporting the medial longitudinal arch. The five digits and phalanges articulate with the metatarsals at the **metatarsophalangeal** joints (MTPJs). The joints are numbered 1–5 to correspond with the digits and metatarsals. The transverse arch of the foot is made up the metatarsals and midtarsal bones and is important in providing stability. The first MTPJ has two additional bones on the bottom (or plantar aspect) of the joint called sesamoids. These paired bones are embedded within ligaments and tendons and are part of a pulley system that functions in gait. The digits and MTPJs primarily move in flexion and extension in the sagittal plane and are important to provide balance, stability, and power especially during the propulsive phase of gait.

The metatarsals articulate in the **midfoot** with the midtarsal bones at the tarsometatarsal joints also numbered 1–5. The midtarsal bones are a group of bones consisting of the navicular, medial cuneiform, middle cuneiform, lateral cuneiform and cuboid. These bones contribute to all three arches of the feet (discussed below). Stability of the midfoot is provided by the architecture of the midtarsal bones and are important when transferring weight from the heel to the toe during gait. The midfoot articulates with the rearfoot at two joints—the calcaneocuboid joint and the talonavicular joint—that are collectively referred to as the midtarsal joint.

The **rearfoot** bones are the largest bones of the feet. The heel bone is the calcaneus and the bone that sits on top of the calcaneus is called the talus. The articulation of these two bones is called the subtalar joint. Movement of the subtalar joint is coupled with movement of the ankle joint providing motion in all three cardinal planes (sagittal, frontal, transverse) simultaneously.

The **ankle** joint is the articulation of three bones—the talus, tibia, and fibula. The ankle is also known as the talocrural and sometimes the tibiotalar joint. Experts in biomechanics refer to the ankle and rear foot joints as the "ankle joint complex" because their movements are so interdependent.

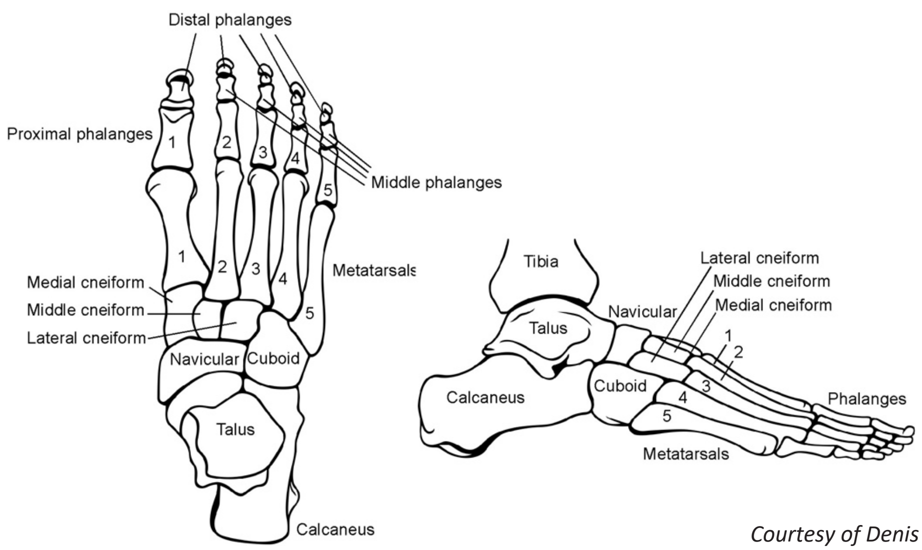

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FIGURE 8 Bones of the foot

2.2. JOINTS

There are 33 joints in each foot (FIGURE 9). The ends of the bones that articulate with another bone are covered with cartilage that, along with the lubrication of synovial fluid, provides a smooth surface for gliding. Some joints move in one plane much like a hinge on a door while others move in multiple planes at a time and/or are coupled in their movement with adjacent joints. With so many joints and bones in such a small area, it can be appreciated that there is a complex interaction of many structures on every step that have a direct effect on whole body movement and health.

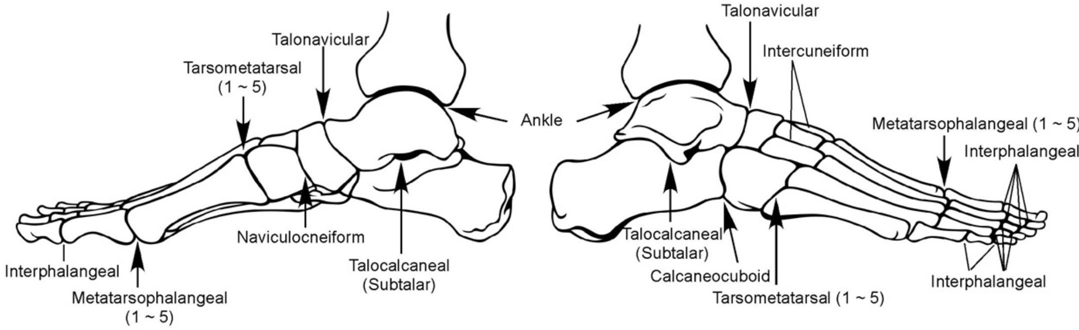

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FIGURE 9 Joints of the foot. Left: medial view, right: lateral view

Ligaments attach one bone to another and provide stability and help maintain alignment. There are multiple ligaments at each joint and more than 100 ligaments in each foot.

Tendons attach muscles to bones in order to provide movement. Unlike ligaments, muscle-tendon units have the ability to contract in order to move and/or stabilize joints and segments of anatomy.

Muscles have the ability to contract which allows the foot to dampen the vibration of impact, stabilize the foot, and also provide movement. There are more than 20 intrinsic foot muscles which are small muscles that originate within the foot. Their main function is to stabilize the foot and provide small amounts of motion. The extrinsic muscles originate in the lower leg and extend long tendons into the foot in order to provide movement. The calf muscles are comprised of the gastrocnemius and soleus and attach to the heel via the largest tendon in the body, the Achilles tendon. Other extrinsic muscle tendon units include the peroneals, anterior and posterior tibial, and long flexors and extensors.

2.3. THE ARCHES

Three important arches span the different segments of the foot (FIGURE 10). The transverse, the lateral longitudinal, and the medial longitudinal arch all play a role in providing energy return and stability during stance and gait. There can be significant variability in the morphology and biomechanics of the arches.

The medial longitudinal arch gets more attention than the other arches because it is more easily visualized and even the lay person observes differences person-to-person. Most people will classify themselves as having a high, medium, or low arch (FIGURE 11). A myth has been perpetuated for decades about a high arch as being a “supinated” foot and a low or flat arch as being a “pronated foot” and a normal arch being a “neutral foot” with the resultant classification being predicative of what shoe is best or what injury may be expected. The “wet paper towel test” has been promoted as a method to assess this whereby an individual would get their foot wet and then stand on a paper towel to then assess their arch as high, neutral, or low. This oversimplified classification of only three “foot types” has never been scientifically validated. The reality is that arch morphology exists more on a continuum and injury patterns cannot be reliably predicted based on arch height. The other complicating factor is that a static assessment of the arch such as the wet paper towel test or a static scan does not accurately reflect how the foot functions dynamically in gait.

A more detailed discussion of the function of the arch can be found in the gait cycle section (2.4).

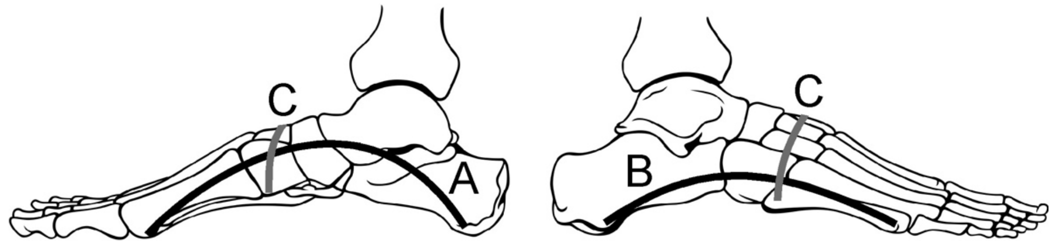

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FIGURE 10 Three arches of the foot
A: Medial longitudinal arch, B: Lateral longitudinal arch, C: Transverse arch

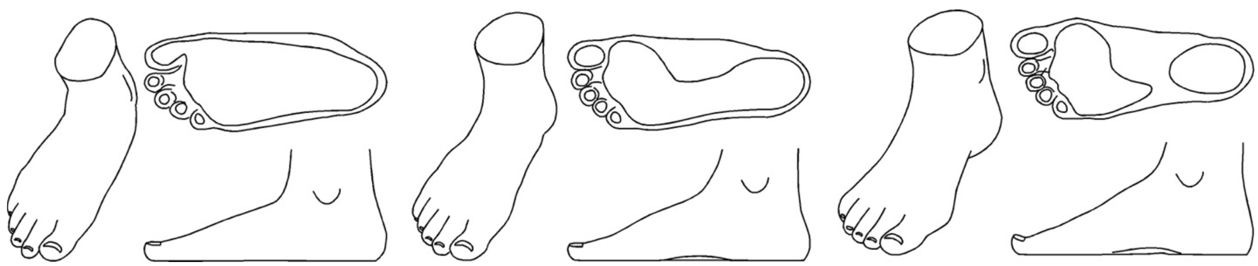

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FIGURE 11 Variation of the medial longitudinal arch
Left: flat (planus), middle: average, right: high (cavus)

2.4. BRIEF DESCRIPTION OF THE GAIT CYCLE

Each walking step occurs in the span of 0.7–1.0 seconds. The gait cycle is divided into a swing phase and a contact phase (FIGURE 12). The foot is unweighted and swinging through the air to the next step in the swing phase. The contact phase, which lasts for approximately 60% of the cycle, is further divided into sub-phases. During the early contact phase, the foot pronates to function as a “mobile adaptor” as it absorbs impact and adapts to the terrain. As weight transfers to the mid and forefoot and the heel starts to lift, the foot then supinates to become a “rigid lever” to provide propulsion into the next step. This dramatic change from mobile to rigid occurs through a complex interaction of the many joints, muscles, and other structures via the sensory input from the plantar aspect of the foot. When running, this happens in 0.1–0.4 seconds. Footwear can alter this movement but not always in predictable ways.

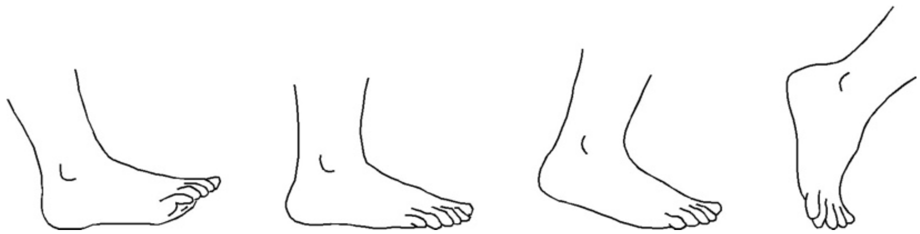

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FIGURE 12 Foot images at four sub-phases of the contact phase of gait (lateral view) From left to right: Heel strike, mid-stance (foot flat), heel lift and toe-off

All joints have numerous ligaments and muscle tendon units that attach to provide stability, balance, and movement. The Windlass Mechanism, first described by Hicks in 1954, engages all three segments of the foot to provide a means of supporting the arch passively via the boney structures as a truss, the metatarsophalangeal joints as a pulley and the plantar fascia, a large ligament, as a cable. The Windlass Mechanism is engaged as the ankle plantarflexes, the heel starts to lift and the digits dorsiflex during the propulsive phase of gait.

The **plantar fat pad** is a cushion of fat that is important in protecting the foot from impact especially at the ball of the foot and heel. Atrophy of the plantar fat pad is common in older individuals and can contribute to pain and calluses on the bottoms of the feet.

Vascular structures such as arteries, veins and the lymphatic system are important for delivering oxygen to the foot and returning de-oxygenated blood and fluid back to the heart for recirculation. Vascular conditions that can affect the feet include swelling, varicose veins, and skin changes caused by decreased blood flow.

Neurologic structures provide sensation, muscle activation and regulation of temperature and blood flow. The sensory feedback provided by the feet is often overlooked but is important in allowing us to balance, adapt to footwear, adapt to terrain and sense warnings of injury. There is evidence in the research that different regions of the feet have different levels of sensitivity. For example, the heel is less sensitive than the arch or forefoot. Some individuals have highly sensitive feet which can make it difficult for them to find comfortable footwear. A nerve condition that is more common in older individuals or those with diabetes is peripheral neuropathy which can cause numbness, burning, and pain in the feet.

Other important anatomical structures of the foot include other types of **connective tissue**, **skin,** and **nails**. Connective tissue is just as it sounds, tissue that connects anatomical structures and includes the bones, muscles tendons but also other dense fibrous tissue, elastic tissue, adipose tissue, cartilage and fluids. It is beyond the scope of this paper to discuss all in detail. The skin on the bottom of the foot is twice as thick as the rest of our skin, which is important in withstanding weight bearing forces. Toenails are hard in order to protect the phalanges from injury.

3. COMMON CONDITIONS OF THE FEET

This section provides a brief overview of some of the most common conditions of the feet and considerations regarding footwear for each.

3.1. TOE ALIGNMENT CONDITIONS: BUNIONS, HAMMERTOES, AND BUNIONETTES

The forefoot is a common area for discomfort, pain, and difficulty fitting footwear. It is natural and normal in shoe wearing cultures to experience toe alignment changes, stiffer joints, and soft tissue atrophy, especially with age. Each of these can contribute to pain and to difficulty fitting footwear. Bunions and hammertoes are among the most common causes of forefoot pain and problems fitting shoes. As with most orthopedic conditions, they can be treated conservatively or surgically corrected. In early stages of these conditions, footwear changes often relieve pain; however, in later stages, footwear changes no longer provide relief and surgery is warranted. Bunions and hammertoes cannot be reversed with footwear changes but accommodation of the painful areas can reduce pain.

Both bunions and hammertoes develop very gradually over years and decades. They are progressive and so will gradually worsen over time. They are caused by a combination of factors including genetic susceptibility, footwear choices, muscle imbalances, biomechanical faults, and hormonal fluctuations. Systemic conditions such as rheumatoid arthritis can contribute as well.

A **bunion** (FIGURE 13) is also referred to as "Hallux Abducto Valgus" because the alignment change results in abduction and valgus alignment (eversion) of the hallux. The hallux starts to angle toward the second digit and also rotates or everts. FIGURE 14 shows normal X-ray alignment of the hallux and great toe joint. Bunions are not solely caused by "bad" shoes as some suggest. While tight, narrow, high-heeled shoes can contribute, there are other contributing factors as mentioned previously. Women are certainly more vulnerable to bunions than men—not just due to footwear choices but also due to hormonal differences. Wider shoes with soft upper materials have been shown to reduce bunion pain.

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FIGURE 13 Clinical presentation and X-rays of a woman with a severe bunion on the left foot and a moderate bunion right. The left bunion is also causing alignment changes to digits 2 and 3.

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FIGURE 14 Normal alignment of first MTP joint (great toe joint)

A **hammertoe** (FIGURE 15) is a flexion contracture of a digit and are relatively common to digits 2–5. The digit starts to contract in plantarflexion as the muscles become unbalanced and over time the toe becomes stiffer in the contracted position. There are different shapes to the toe that can occur with the flexion contracture and terms like mallet toe, or claw toe are also used to describe them. The hammertoe will often rub on shoes, which causes pain and/or calluses. Painful calluses and hammertoes can be managed with padding on the toes and by using footwear with more volume in the toe box either via width, round shape, more depth, or more elastic upper materials. Attempts to splint the toe into a straight position are not typically tolerated. Once a toe has contracted, only surgery can straighten it.

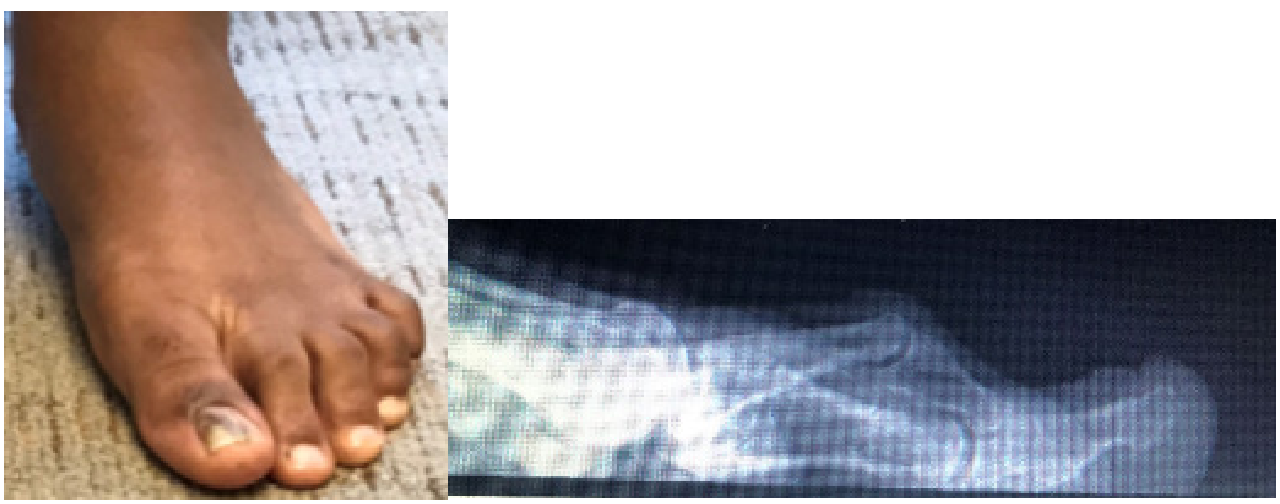

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FIGURE 15 Hammertoes of digits 2, 3, 4, and 5
X-ray image of second digit hammertoe illustrates how the contracted toe would be affected by depth of the footwear toe box and upper material

A **Bunionette** (FIGURE 16), also known as a Tailor's bunion is a painful enlargement of the fifth metatarsal head. It is much less common than a bunion but can cause pain and difficulty fitting shoes. Often swelling will accompany increase in pain. Tightly fitting shoes especially with narrow or pointed toe box can worsen this condition. As with bunions and hammertoes, initial treatment consists of footwear changes with surgery as a last resort. Wide shoes with soft upper materials can help minimize pressure and pain.

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FIGURE 16 Bunionette with swelling to lateral forefoot evident both clinically and on X-ray

3.2. ARTHRITIC CONDITIONS OF THE FOOT

Arthritis is inflammation and degeneration of a joint which causes stiffness and pain. Arthritis can be caused by systemic diseases, trauma, infection and normal wear and tear. Cartilage, which provides a smooth gliding surface for a joint where two or more bones articulate with each other, can wear thin and break down which results in stress and friction being imparted to the bones. Osteoarthritis (FIGURE 17) is the most common form of arthritis and is caused by a gradual wearing down of the cartilage. Any joint can be affected by arthritis but the first MTP joint is the most common joint to get arthritis in the foot. Other joints that are commonly affected are in the midfoot. Footwear considerations focus on relieving pressure on any boney prominences and utilizing stiffer mid/outsoles or rockerbotton outsoles to minimize bending forces.

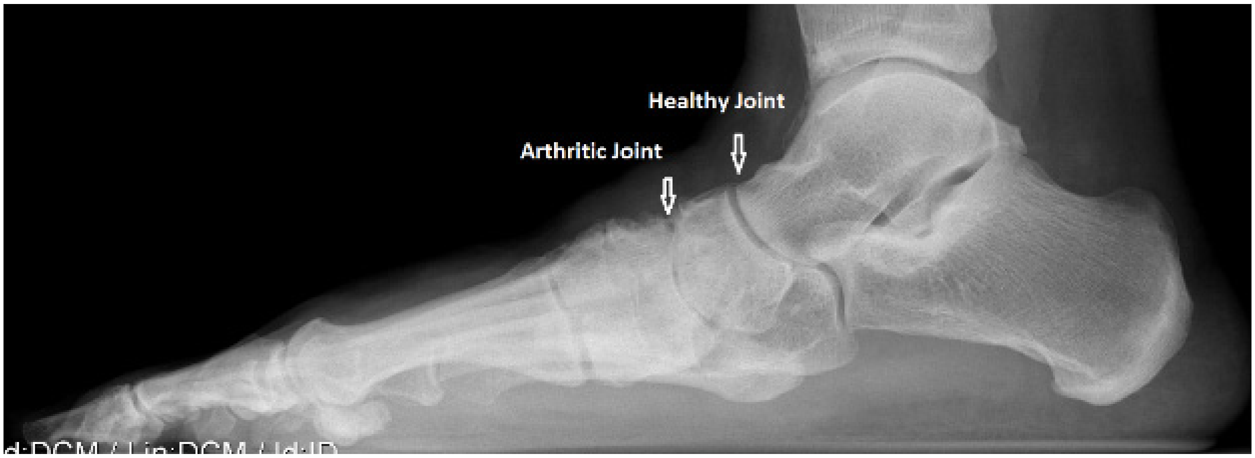

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FIGURE 17 The healthy joint has distinct, smooth, and symmetric joint margins while the arthritic joint has rough, irregular margins with asymmetric joint space narrowing

Hallux Rigidus (FIGURE 18) is an arthritic condition that affects the first MTP joint. Of the 33 joints in each foot, this is the most common joint to become arthritic. Hallux Rigidus is sometimes confused with a bunion because there is an enlargement of the first metatarsal head. But unlike bunions, the boney prominence is primarily on the top of the joint and the hallux is straight, not angled. Enlargement of the bone with bone spurs, irregular bone margins and asymmetric joint space narrowing are evident on X-rays. Arch support and stiffer shoes especially with forefoot rockers can minimize pain by reducing bending forces and range-of-motion demand of the first MTP joint.

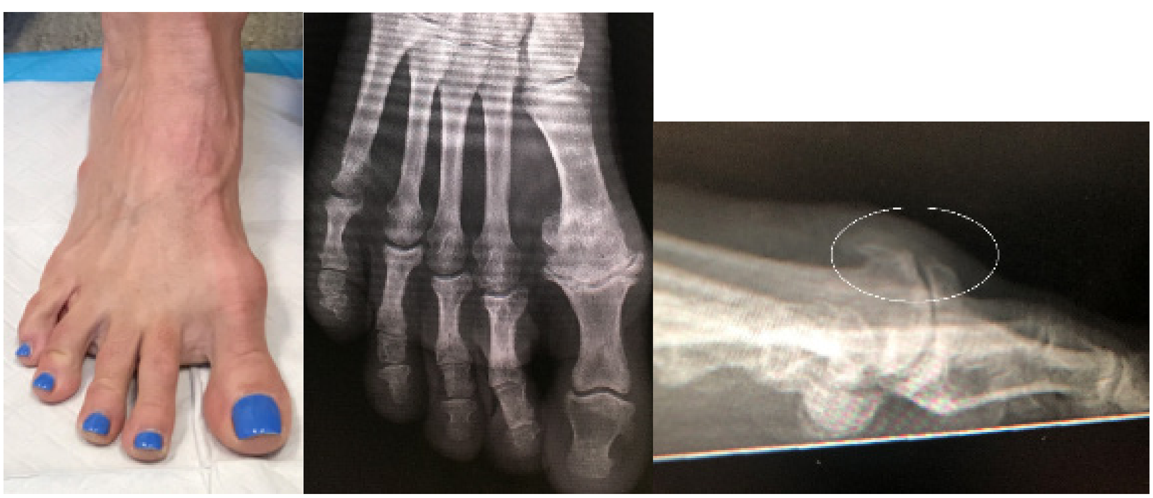

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FIGURE 18 Hallux Rigidus: note that the great toe is straight in contrast to a bunion, which is angled. Note the rough, irregular margins with asymmetric joint space narrowing of the first MTP joint as well as the dorsal bone spur

Plantar Fasciitis is one of the most common causes of foot pain in both active and sedentary individuals. It can also be referred to as “heel spur syndrome” because approximately 50% of those affected will have a heel spur (FIGURE 19) evident on X-ray (heel spurs do not need to be surgically removed to treat this condition). The plantar fascia is a long ligament that attaches the heel to the toes to provide stability to the medial longitudinal arch. It is under load when standing and moving. Plantar fasciitis typically causes pain to the plantarmedial heel but can occasionally cause pain into the medial arch as well. Risk factors for plantar fasciitis include: standing work duties, Body Mass Index over 30, increasing fitness activities too rapidly, improper footwear, and limited ankle range-of-motion among others. There is evidence in the research that supporting the medial arch can relieve strain and therefore pain of plantar fasciitis.

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FIGURE 19 Plantar and posterior calcaneal spurs

Retrocalcaneal Exostosis, (FIGURE 19) also known as a Haglund’s bump or a “pump bump”, is a boney prominence on the back of the heel. It originates at the site of attachment of the Achilles tendon and can be associated with Achilles tendinopathy. Risk factors include tightness of the tendon and limited ankle range-of-motion. Irritation from footwear can cause pain, swelling and bursitis (inflammation of a fluid-filled sac). Open back footwear, soft heel counters or heel cup modifications as well as physical therapy can be used to manage this condition before surgery is considered.

Dermatologic conditions: (FIGURE 20) **Toenail conditions** such as ingrown nails or thickening/fungal changes can cause pain that may be aggravated by tight footwear. Proper nail care can usually manage nail conditions. The most common skin condition of the forefoot are corns and calluses. For clarification corns and calluses are the same thing. We will use the term callus. A **callus** is a thickening of the skin in response to pressure or friction and typically arises in an area of a boney prominence. Calluses are very common on the digits where a toe is either contracting or becoming stiffer and rubbing on the shoe or the digit next to it. Calluses can also arise due to atrophy of soft tissue such as the plantar fat pad or skin, which occurs naturally with aging. Calluses on the plantar surface of the foot can be due to biomechanical problems and arthritis. Boney prominences from bunions or bunionettes can also cause calluses. It is important to understand that calluses are a symptom of pressure or friction which is why they cannot just be shaved or cut out and expected to never return. Footwear modifications such as changes to toe box shape and upper materials as well as foot bed changes such as metatarsal pads and cushioning can relieve pressure which contribute to pain and callus formation.

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FIGURE 20 **Calluses caused by hammertoes left, calluses caused by atrophy of plantar fat pad and bunion, middle, toenail changes with hammertoes right**

Metatarsalgia means “achy metatarsal” and is a very common source of forefoot pain. Weight bearing forces are highest to the metatarsals and the metatarsal- phalangeal joints during the propulsive phase of gait after the heel has lifted and weight is transferred through the midfoot, forefoot and then the toes until toe-off. Metatarsalgia can be the result of atrophy of the plantar fat pad, stiffness and/or arthritis of the joints around the metatarsals, improper footwear, long periods of activity, weakness of the foot muscles, decreased bone density, limited ankle motion among other causes. Distributing plantar pressures as evenly as possible with such devices as stiffer outsoles, metatarsal pads, and contoured insoles can help reduce the pain of metatarsalgia.

A **Morton’s Neuroma** is an enlarged and inflamed nerve that causes tingling, burning pain, and numbness to the ball of the foot that can radiate into the toes. The nerve may be irritated by tight footwear. Wider shoes, more rounded toe box, and a metatarsal pad can relieve pressure and symptoms for some.

4. CONCLUSION

In conclusion, the ability to customize footwear on a large scale presents both opportunities and challenges. The feet are very complex both anatomically and biomechanically and are subjected to highly repetitious weight bearing forces every day. They are also vulnerable to conditions that can cause pain and difficulty fitting shoes. These can be musculoskeletal conditions or systemic conditions. In addition, there is tremendous variability in foot morphology and function. Because of this, footwear has significant effects on health. Those providing custom footwear will need to understand the concepts discussed in this paper and have an appreciation of the health implications of footwear.

5. REFERENCES

The following list of sources either has been referenced within this paper or may be useful for additional reading:

[1] Marcinko DE, Medical and Surgical Therapeutics of the Foot and Ankle, Baltimore, MD, Williams & Wilkins, 1992, 847–878.

[2] Root ML, Orien WO, Weed JH, Normal and Abnormal Function of the Foot, Clinical Biomechanics corp., Los Angeles, CA, 1977, 350–370, 435–431, 452–459.

[3] Valmassy RL, Clinical Biomechanics of the Lower Extremities, Mosby-Year Book Inc., St. Louis, MO, 1996, 1–57.

[4] McGlamry ED, Banks AS, Downey MS, Comprehensive Textbook of Foot Surgery, Baltimore, MD, Williams & Wilkins, 1992, 459–468.

[5] Seidel HM, Ball JW, Dains JE, Benedict GW, Mosby's Guide to Physical Examination, Mosby-Year Book Inc., St. Louis, MO, 1995, 683–685.

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