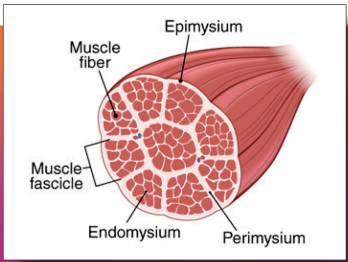

Fundamentals of Care in Biomechanics—Part 1

Understanding this science is the key to prevention and treatment.

BY MARK MENDESZOON, DPM

Goals and Objectives

After the completion of this CME, the reader will:

1) Appreciate the different scientific fields that are applicable to biomechanics

2) Recognize the construct of the human musculature and its actions

3) Appreciate the three major biomechanical theories applicable to foot and ankle motion

4) Understand the phases of the gait cycle

5) Differentiate between walking and running biomechanics

6) Appreciate anatomy and physiology of the lower extremity

7) Recognize and appreciate closed and open chain kinetics

8) Understand the role of the midtarsal joint and pathomechanics

9) Understand the different lower extremity deformities and their impact on overuse injuries10. 10. Realize the impact of pathomechanics and overuse injuries

Biomechanics is the specialty that applies the laws of mechanics and physics to human performance in order to gain a greater understanding through modeling, simulation, and measurement.[1] Biomechanics requires knowledge in anatomy, kinesiology, physiology, engineering, and physics, such that the mechanisms of injury are highly understood and thus treatment can be effectively executed.

Anatomical Considerations

Before one can comprehend the magnitude of biomechanics, our foundation in anatomy and physiology is paramount. The human body has over 600 muscles and over six billion muscle fibers. Of the three types of muscles: cardiac, smooth, and skeletal, our primary focus will be on the skeletal muscle system.

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Forty percent of the body's mass is composed of skeletal muscle. Muscle fibers are typically long and cylindrical, measuring 1-40 mm in length and 10-100 microns in diameter.

The functional structure of the human muscle is the sarcomere. It is through the regulation of calcium that muscle contraction is performed (Figure 1). The neuromuscular unit is the area where the nerve cell (motor neuron) meets the muscle fiber (motor end unit). There is only one neuromuscular unit per muscle and it works on an "all or none" principle.[2]

Muscle macrostructures include muscle, tendons, and ligaments which all have a direct effect on bone, mobility, and function. Muscles have three types of actions (Figure 2). The best-known action is concentric motion in which the fibers shorten and develop significant tension. The best example of this motion is the bicep curl. In exercise, this is known as a positive repetition.

The second action is the eccentric motion in which the muscles elongate and tension is created. The best example of this is running downhill, when the quadriceps must elongate to adjust to picking up too much speed, which could cause injury. This action is known as a braking action or a negative repetition in exercise. This type of muscle activity is the one that causes delayed onset muscle soreness (DOMS). Typically, this occurs 24 hours after exercise.

The last muscle action is the isometric motion, in which the muscle length maintains the same length, and tension develops in time, resisting motion. Holding a dumbbell weight totally straight is a perfect example of this action.[3]

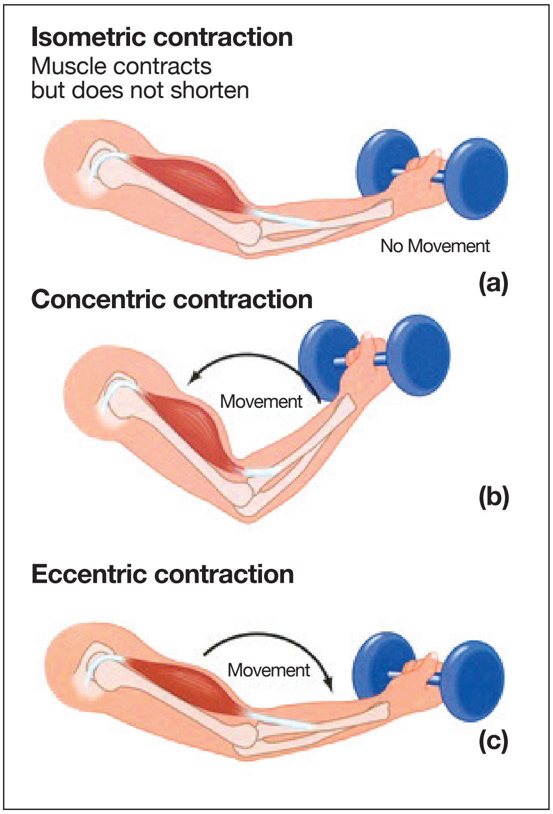

Figure 2: Three types of gross muscle actions

The human body has over 600 muscles and over six billion muscle fibers.

Tendons

Tendons, also known as sinew, are thick and dense connective tissue that transmits the mechanical force of muscle upon bone. The main cells of the tendons are the fibrocytes. Over 98% percent of tendons are composed of Type 1 collagen. Tendons that change direction in the body typically are protected by a tendon sheath, which has synovial fluid to lubricate the tendon. In the lower extremity, there are two major tendons that do not have tendon sheaths—the patella and the Achilles tendon. They both have a paratenon to provide some nourishment and protection to the tendons. Unlike muscles, tendons generally have less than optimal blood supply and thus are at higher risk for injuries and longer recoveries if injured[4] (Figure 3).

The technical term for tendon pathology is tendinopathy. The term tendonitis is a generalized term used when dealing with injuries of the tendons, and this term should be applied to conditions of the tendon only if acute injury or inflammation is involved. Tendonosis is the term utilized for chronic intra-substance disease of the tendon. Tenosynovitis is degeneration of the tendon sheaths. As mentioned before, the patella and Achilles tendon cannot develop tenosynovitis for lack of a tendon sheath.[5]

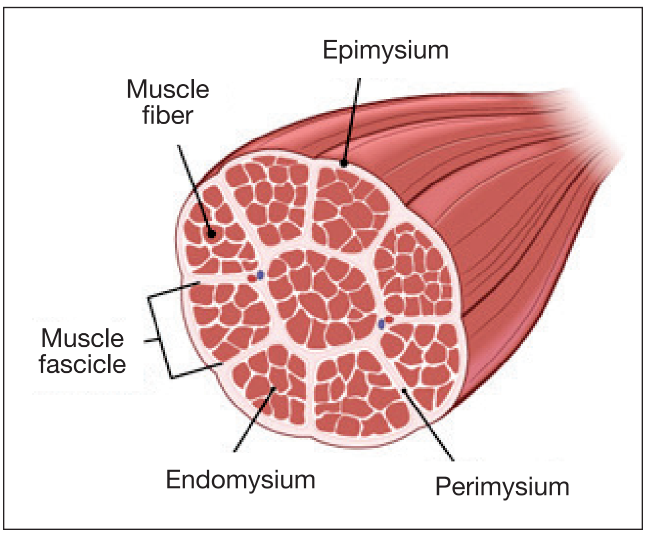

Figure 1: Cross section human muscle fiber

Ligaments

Ligaments are the dense, fibrous connective tissue that connects bone to bone. Ligaments are comprised of attenuated collagen fibers. These fibers are designed to provide stability to the joints and control forces applied throughout the joints. There are three types of ligaments in the lower extremity: 1) Capsular ligaments are part of the articular capsule; they

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surround synovial joints and provide mechanical reinforcement to the joint. An example is part of the deltoid ligament of the ankle. 2) Extra capsular ligaments, such as the calcaneal fibular ligament, provide joint stability. 3) Iintracapsular ligaments allow for more joint motion but generally are weaker ligaments. Examples are the anterior and posterior cruciate ligaments of the knee.[6]

Historical Background

Foot and ankle biomechanics commenced as an interest to physicians in 1935, when Morton discussed anatomic size and hypermobility of the foot and ankle.[7] In 1942, Manter investigated the subtalar joint and transverse tarsal joint motion.[8] In 1953, Hicks reviewed normal foot and ankle mechanics, while in 1960, Elfman evaluated the mechanical relationship between the subtalar joint and mid-tarsal joints.[9]

However, in 1954-1966, Dr. Merton Root truly evaluated lower extremity mechanics and defined the normal foot, pathomechanics, and the science behind the fabrication of functional foot orthoses. This was termed foot morphology theory. Root mechanics identifies the subtalar joint position and motion. Ideally, the subtalar joints have three planes of motion, but motion is mainly in the frontal plane. A total of 30 degrees of motion is ideal and thus a 2-1 ratio of inversion to eversion is within normal limits (Figure 4). This has been used as the primary biomechanical foundation in podiatric medical school.[10] Inversion is typically 20 degrees, while eversion is 10 degrees.

In recent decades, two more biomechanics theories of some merit have been explored. Kirby emphasized the tissue stress theory, which relies on the fact that mechanically-based pathologies of the foot and lower extremity all result from pathological magnitudes of stress acting within the structural components of the foot and lower extremity. Stress is an internal measure of how an object resists a loading force. One measures this by dividing the cross-sectional area of that object by the loading force being applied.[11]

The functional structure of the human muscle is the sarcomere.

Dananberg proposed the sagittal plane theory. During walking, the center of body mass must pass from behind the weight-bearing foot to in front of it.[12] As all of these theories have merit, and as biomechanics is not an absolute science, it has been found over the years that utilization of all three theories is in the best interest of patient care.

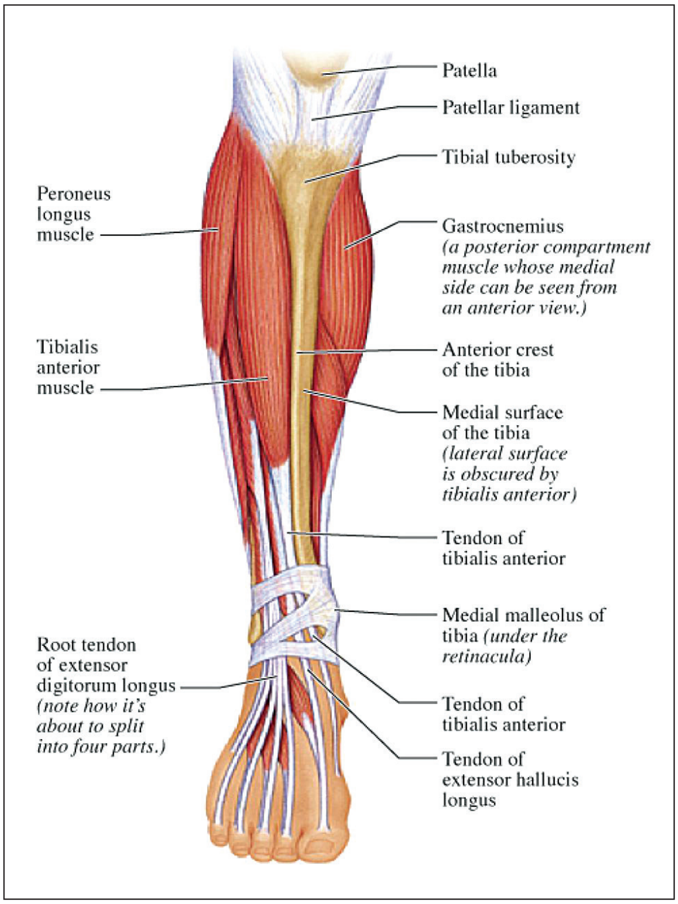

Figure 3: Lower leg anatomy

Classification of Foot Pathology

Classification of foot pathology can be divided into rearfoot varus and valgus as well as forefoot varus and valgus. Rigid or structural rearfoot varus will remain in a fixed position due to alignment of the tibia, calcaneus, or the position of the subtalar joint. A flexible rearfoot varus will be determined by the midtarsal joint. Coleman block testing is very helpful in assessing this type of foot deformity. The direct connection of the rearfoot to the forefoot is via the midtarsal joint. The midtarsal joint consists of the talonavicular joint and the calcanealcuboid joint.

Chopart described this joint in detail, and thus it is known as Chopart's joint. The midtarsal joint also has triplane motion like the subtalar joint, but it also has its majority of motion in the frontal plane, leading mainly to inversion and eversion of the joint. There are two axes of motion that comprise the midtarsal joint: the longitudinal axis and the oblique axis. The longitudinal axis is parallel with the transverse and sagittal planes. Therefore, motion is only in the frontal plane—inversion and eversion. Due to the unique alignment of the oblique axis, it has minimal motion technically in the sagittal and transverse plane. The average angulation of the midtarsal joint is approximately 55 degrees from the sagittal and transverse planes (Figure 5).

The midtarsal motion is directly related to the subtalar joint's position. As the subtalar joint goes from maximal pronation to supination, the longitudi-

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nal axes of the two midtarsal joints progressively diverge, and thus congruity of the midtarsal joint is lost and motion decreases. This relationship of the subtalar and midtarsal joints provides the ideal standard clinical index position in normal foot mechanics and is known as being ' locked and loaded'. This position provides the forefoot with all five metatarsal heads being on the same plane and parallel. The calcaneus is perpendicular to the long axis of the tibia and perpendicular to the ground (Figure 6).

Forefoot Varus

Forefoot varus will require the subtalar joint to be in a supinated position. Midtarsal joint motion is diminished, and the forefoot is in a varus position in which the forefoot's plantar plane is inverted. Typically in this foot type, a significant pressure will be placed underneath the fifth metatarsal.

Forefoot Valgus

Forefoot valgus will require the subtalar joint to be maximally pronated, resulting in an increased range of motion of the midtarsal joint, with the forefoot plane everted. Opposed to a forefoot varus deformity, a valgus deformity will cause significant pressure underneath the first metatarsal.

As motion and forces continue to move forward from the subtalar and midtarsal joints, there are requirements for the first metatarsal phalangeal joint to work effectively. These requirements will necessitate for the subtalar joint to be in a supinated position and for the midtarsal joint to be stable—'locked and loaded'.[13] This will allow for the first metatatarsal head to plantarflex below the plane of the second metatarsal, therefore engaging the windlass mechanism of the plantar fascia. As the first metatarsal head plantarflexes with forward momentum, the hallux proximal base will glide on the dorsal aspect of the metatarsal head allowing for adequate dorsiflexion. Intrinsic factors such as a normal metatarsal head and center of axis, along with sesamoid and soft tissue pliability, will assist in this mechanism of action. Ideally, approximately eighty plus percent of the body's weight will move along the first metatarsal phalangeal joint, and the joint should dorsiflex greater than 40 degrees in the ideal foot.

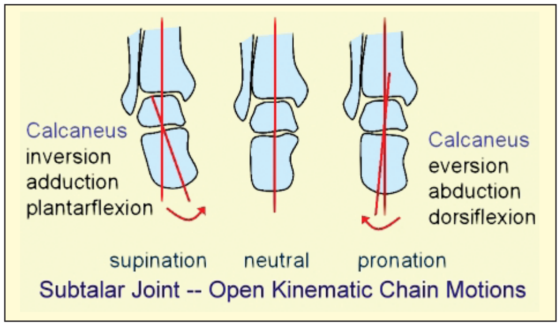

Figure 4: Normal subtalar joint motion

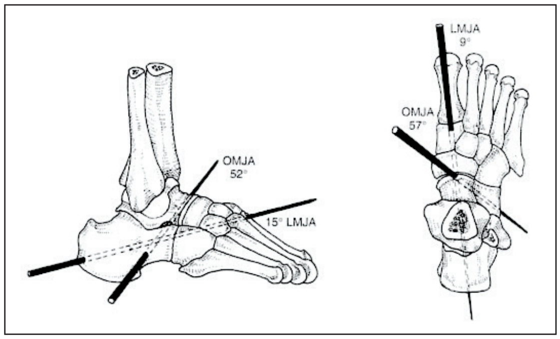

Figure 5: Midtarsal joint axes of motion

Delayed onset muscle soreness (DOMS) typically occurs 24 hours after exercise.

When faulty mechanics ensue via the subtalar joint excessively pronating and the midtarsal joint becoming mobile, the first ray will also have impaired mechanics. Instability of the first ray will be caused by the peroneal longus losing its mechanical advantage and its ability to plantarflex the first ray, causing dorsiflexion of the first ray and affecting normal range of motion of the joint. In turn, the windlass mechanism weakens or reverses, and this allows for further dorsiflexion of the first ray, which limits motion. The line of progression changes and shifts medially, which causes excessive medially forefoot loading (Figures 7 & 8). Eventually, a hallux limitus or hallux abductovalgus deformity will develop and over time, a cascade of compensatory conditions will ensue, such as lesser metatarsalgia, hammertoes, hyperkeratotic skin conditions, and even arthritis.[14]

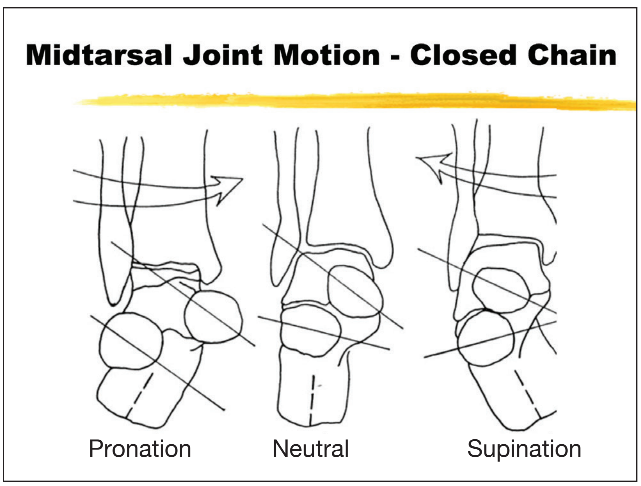

Figure 6: Subtalar and midtarsal joint motion relationship

Pes Plano Valgus

The etiology of pes plano valgus deformity can be derived from genetics, trauma, age, and of course biomechanical factors. Pes plano valgus can be further divided into rigid and flexible classifications. Rigid classifications, which are less prevalent, include congenital vertical talus and tarsal coalitions. Congenital vertical talus generally needs immediate surgical correction in the infant and tarsal

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coalition typically will be addressed as a teenager due to the secondary ossification centers of the tarsal bones. Regardless, both conditions typically lead towards arthritis with age and thus altered biomechanics.[15]

Flexible Flatfoot

Flexible flatfoot deformity is the most common type of foot deformity and is directly related to impaired biomechanics. Understanding planar dominance of deformity is necessary to institute a proper treatment plan for the patient. The three planes of deformity are sagittal plane, frontal plane, and transverse plane. Sagittal plane deformities include posterior leg muscle group equinus, plantarflexion of the talus, medial column breach, and elevated first ray. Frontal plane deformities include calcaneal valgus and everted forefoot. Transverse plane deformity, which is least appreciated, will have an abducted forefoot to rearfoot relationship.

It is imperative to obtain weight-bearing radiographs to determine the planar dominance of deformity. The important anterior to posterior radiographic measurements to recognize are that the talo-calcaneal angle will be increased. Talonavicular joint coverage, which typically should be 80-90%, is diminished. A bisection of the talus and first metatarsal should be a straight line that will have the talus bisection line exit medially to the first metatarsal. A resultant angle will form. The calcaneal-cuboid angle typically should be 0 degrees and will have an increased angle. In severe cases, a skew foot deformity may present itself and several faults on radiographs will be noted.[16]

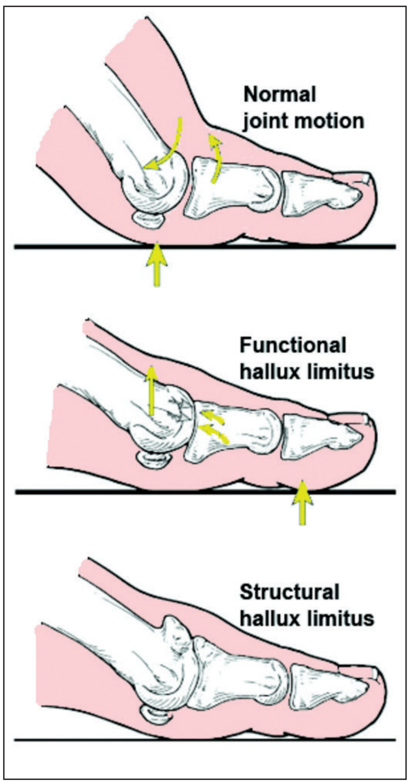

Figure 7: Normal first ray mechanics

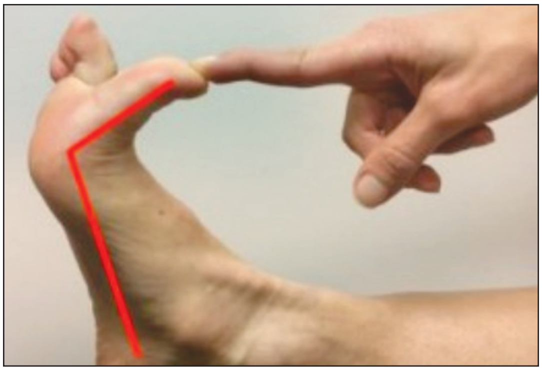

Figure 8: First ray range of motion

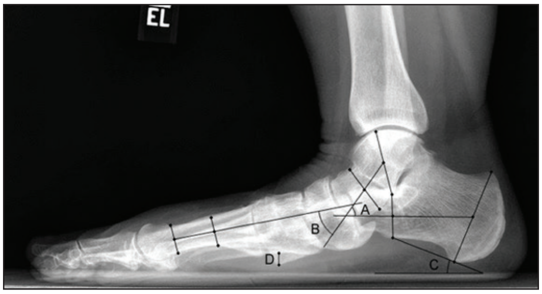

Figure 9: Lateral radiograph pes plano valgus

Flexible flatfoot deformity is the most common type of foot deformity and is directly related to impaired biomechanics.

Sagittal plane radiographs will reveal a low calcaneal inclination angle less than the ideal 20 plus degrees. Plantar flexion of the talus will be noted. Bisection of the talus and first metatarsal should be a straight line and 0 degrees; however, in a flat foot deformity, the talus line will extend below the first metatarsal and create an angle.

The navicular and cuneiform alignment should be parallel, and in a pes planus deformity there will be a 'fault or sag' at the joint level. In some situations, the first ray may be elevated with the metatarsal head dorsiflexed compared to the base of the hallux phalanx base (Figure 9).

A calcaneal axial and sesamoid axial view will evaluate the calcaneal position and plane of the metatarsal heads and determine if they are neutral or in valgus or everted position. As pes plano valgus deformity is progressive, it is necessary to obtain ankle radiographs to evaluate if there is ankle joint deformity. All radiographs should be evaluated for arthritis.[17]

Gait Cycle

The human adult walking gait cycle is developed at about the age of 4. The adult cycle requires a single leg stance. The walking gait cycle is comprised of two sections: the swing phase and the contact phase. Although the swing phase has a subtle impact on biomechanics, it is the contact phase which is the leading cause of lower extremity injuries. The contact phase is approximately 62% and the swing phase 38% of the gait cycle. The contact phase has three segments: heel contact, midstance, and propulsion. The average time it takes to cycle through the contact phase is about 0.4 seconds. With walking, there is roughly four times the body weight applied with each step and the average person should achieve between 5,000 and 10,000 steps per day with the goal of surpassing the higher number.

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Running Gait Cycle

The running gait cycle differs from the walking gait cycle in that there are greater forces applied, a shorter stance phase, longer swing phase, and unlike the walking gait cycle, there is a float phase. This float phase is where the body is actually completely off the ground. Thus with the float phase in running, the body will absorb up to eight times the body weight with each stride. Running one mile could take about an average of 1,500 steps. Regardless of walking or running, It is within the mid-stance phase that the majority of chronic overuse injuries develop (Figure 10).

When evaluating a patient for a biomechanical examination, it is imperative that an open chain or non-weight-bearing and weight-bearing or closed chain examination are performed. Evaluate the patient from head to toe and investigate for general body relationship and symmetry, muscle flexibility and strength, joint range of motion, leg-length discrepancy. Evaluation of shoes and sock gear is a must. In addition to evaluating the patient lying and sitting down, attempt to evaluate standing and walking as well. A thorough history and physical is paramount in assessing a patient's condition before actual examination.

The majority of overuse conditions develop in the midstance part of the gait cycle.

Once a general overview of the body is evaluated, a lower extremity focus should start at the core and its relative structures. The core is the link to providing good posture and trunk stability allowing for the back, legs, and feet to function more efficiently and effectively. The saying "core to the floor" or "floor to the core" emphasizes the direct relationship of the lower extremity.

Functional screening tests to evaluate core strength include: single leg stands and squats, step down squats, star excursion tests (SEBT), swing test, and one in which the patient, sitting crisscross or Indian style, attempts to stand up without leaning towards one side or using hands. **PM**

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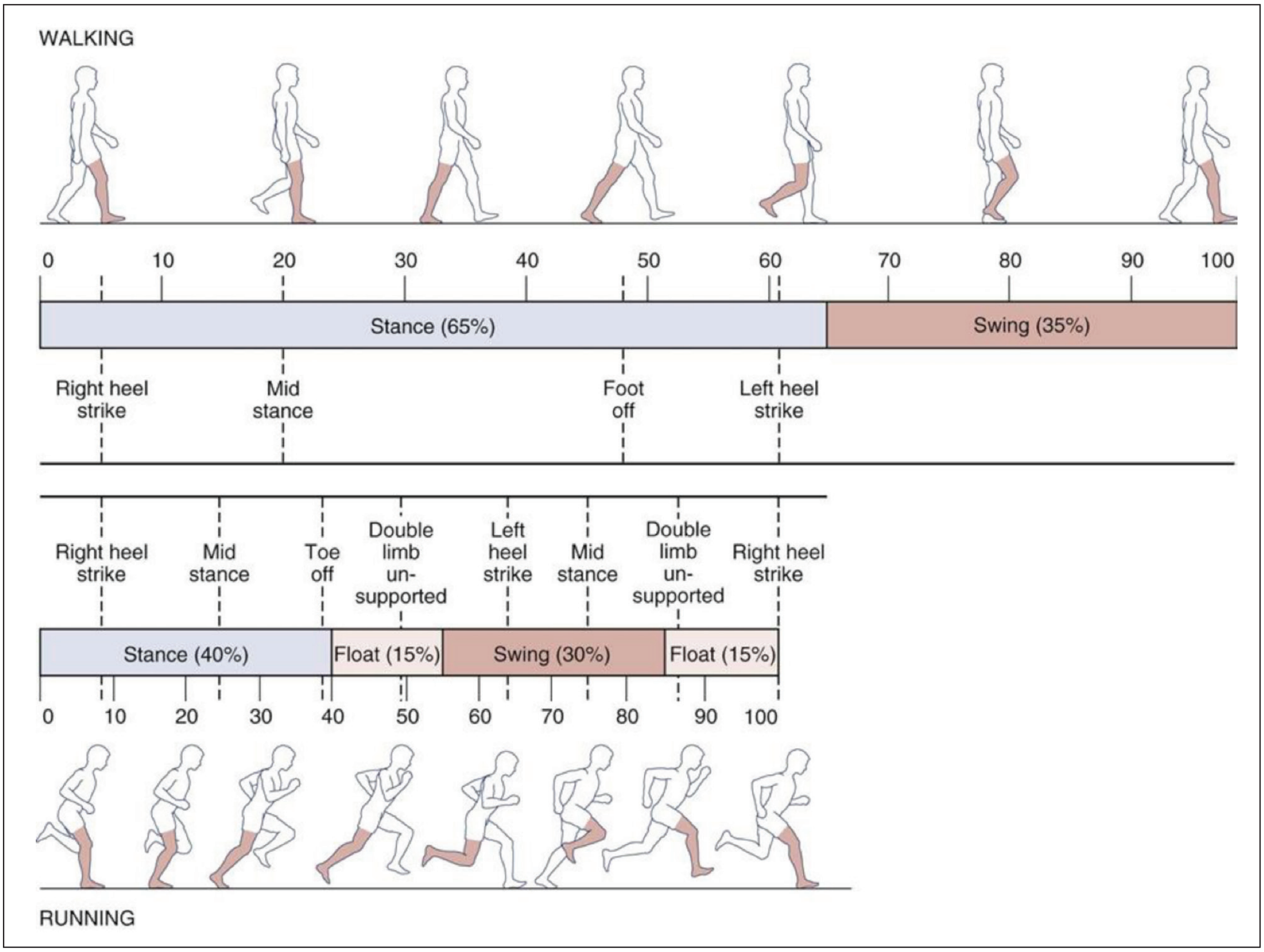

Figure 10: Walking & running gait cycle

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