Basic Biomechanics

Biomechanics is the study of the body in motion. Foot biomechanics studies the relationship of the foot to the lower leg. During walking and running the musculoskeletal system generates forces to propel the body forward. The foot serves two main functions. It acts as a mobile adaptor to adjust to varying terrain, and as a rigid lever for forward propulsion in locomotion. The two functions are time specific in that when the foot spends too much time being a mobile adaptor it is not spending enough time being a rigid lever and vice versa. Biomechanics of the foot analyzes how the various structures of the foot, work together to perform specific functions (timing being of utmost importance.) Excessive or prolonged motion or lack of motion will cause various deformities and pathologies discussed in the next section. Proper biomechanics allow human beings to walk, run, jump, and move freely without pain or dysfunction.

The following are important terms used frequently in the study of the biomechanics of the foot:

1. Gait cycle (see Figure 2.5) - a complete gait cycle is from heel strike (when the heel comes in contact with the ground), to the next heel strike of the same foot. The gait cycle consists of two sub-phases; the stance phase and the swing phase.
2. Stance phase (see Figure 2.6) - the portion of the gait cycle when the foot is in contact with the ground (weight bearing).
3. Swing phase - the portion of the gait cycle when the foot is in the air (non-weight bearing).
4. Subtalar joint - neutral position - the position of the subtalar joint in which the foot is neither pronated nor supinated. When the hindfoot is neutral, the bisector of the calcaneus is at 90° to the supporting surface.

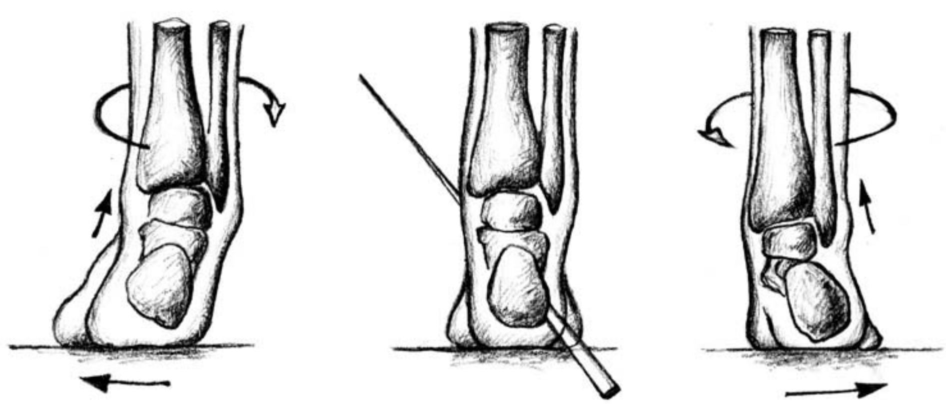

Figure 2.1 (neutral position shown in center, supinated position displayed on left and pronated position displayed on right)

5. Subtalar joint pronation - is a coordinated tri-plane motion of the foot which involves three planes of motion: abduction, dorsiflexion and eversion.

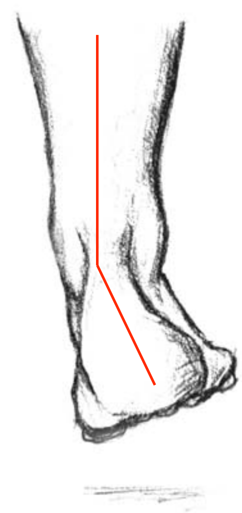

Figure 2.2 Pronation (back of right foot).

6. Subtalar joint supination - a coordinated tri-plane motion of the foot which involves three planes of motion: adduction, plantarflexion and inversion.

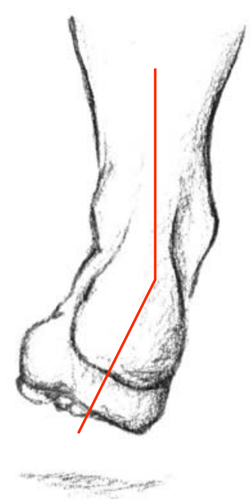

Figure 2.3 Supination (back of right foot).

7. Pronated and supinated - adjectives which describe the position of the foot (they do not describe the action of pronation or supination). Thus a "pronated foot" is one which is in a pronated position as compared to a neutral position.

8. Degrees of pronation and/or supination - this is measured by the degrees of inversion (in the case of supination) or eversion (in the case of pronation) away from the neutral position.

9. Normal centre of pressure line (gait line) - is the average vector of all forces that act on the bottom of the normal foot as it goes through the stance phase of gait. Figure 2.5 shows the progression of the forces in the "Normal centre of pressure line" as the foot goes from contact phase to propulsion.

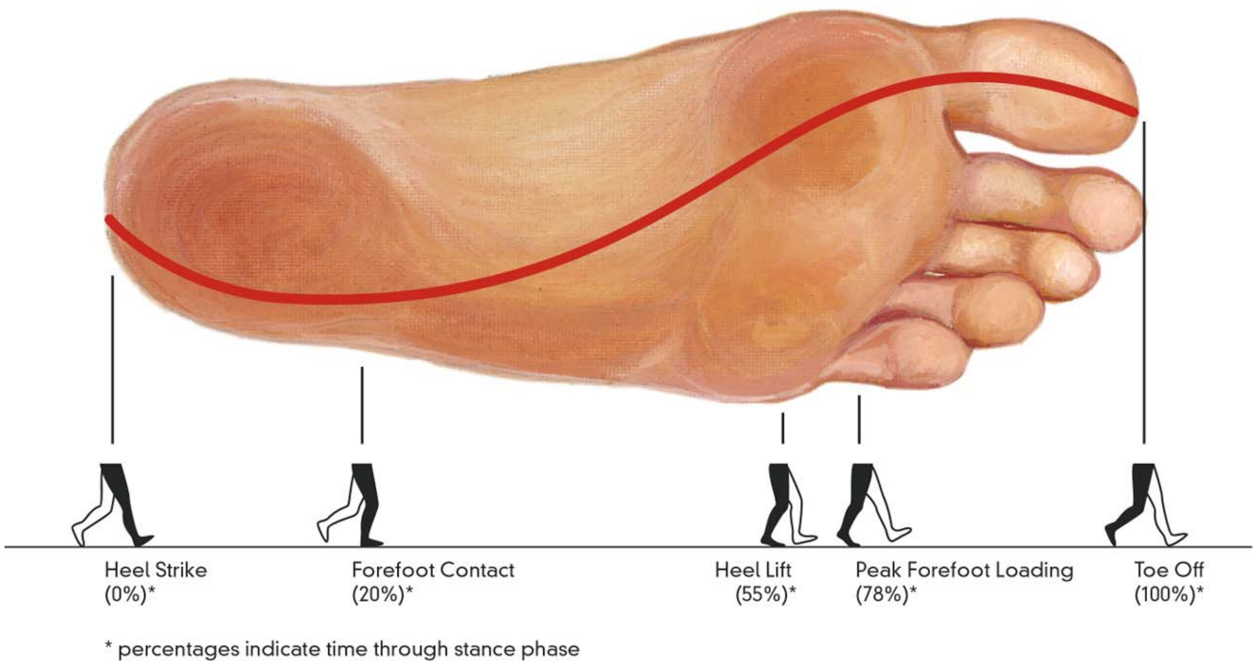

Figure 2.5

Critical Biomechanical Principals

In this section we are primarily dealing with normal gait and understanding how normal gait functions. In understanding normal gait, it is important to recognize six important criteria for normalcy (see figure 2.6).

Six criteria for normalcy:

1. The bisection of the lower 1/3 of the leg is parallel to the bisection of the calcaneus.
2. The horizontal plane of the forefoot is perpendicular to the bisection of the calcaneus.
3. There is a minimum 10° ankle dorsiflexion.
4. Leg must be vertical to the ground in frontal plane.
5. Leg must be vertical to the ground in sagittal plane.
6. There is no horizontal plane rotation in limb above.

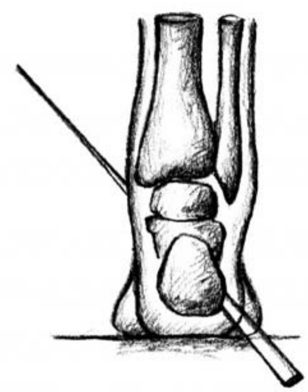

Figure 2.6

Neutral position, right foot shown from the back.

Normal biomechanics in the gait cycle

Human gait is a very complicated, coordinated series of movements. Walking is divided into two main phases. The stance phase is the weight bearing portion of each gait cycle. It is initiated by heel strike and ends with toe off of the same foot. Swing phase is initiated with toe off and ends with heel strike.

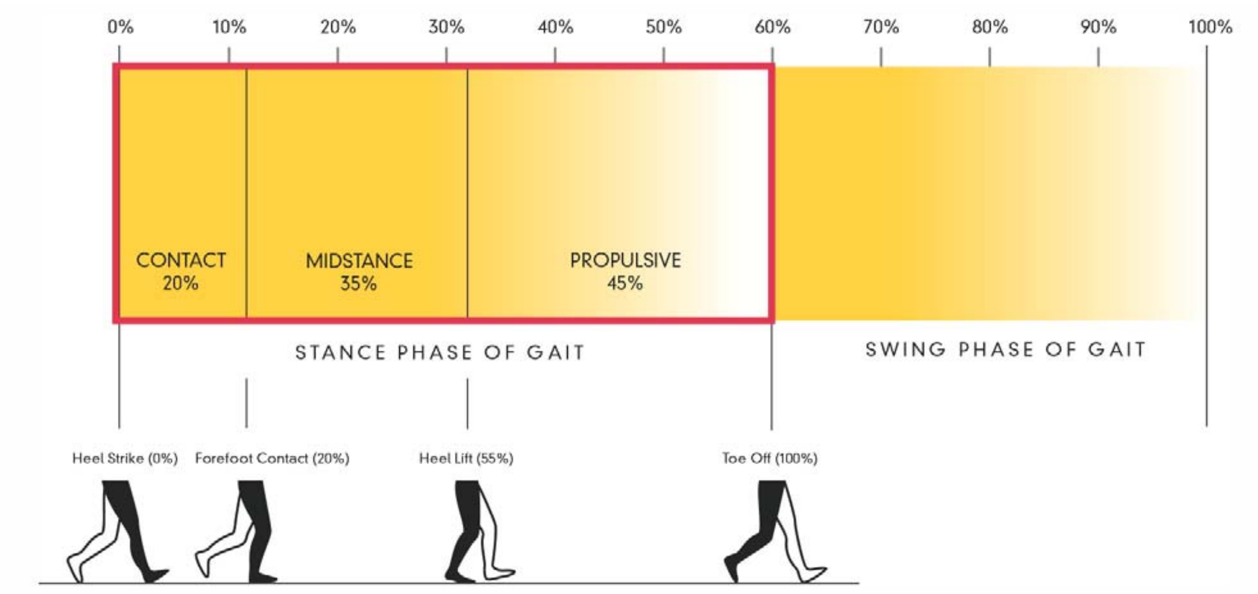

Figure 2.7

The two periods when both feet are on the ground, are called initial double support and terminal double support. Initial double support occurs from heel strike of support limb to toe-off of the opposite limb. Terminal double support occurs from opposite limb heel strike to support limb toe-off. Single limb support is identical to the period of swing of the opposite limb.

The kinetic foot during the normal stance phase of gait

In normal gait the foot strikes the ground at the beginning of the contact phase in a supinated position of approximately 2°. The foot moves through 5 1/2 - 6° of pronation (passing through neutral position) to a position of approximately 3 1/2 - 4° pronated (allowing the foot to function as a mobile adaptor, adjusting to variances in terrain). At 3 1/2 - 4° pronation, the beginning of the mid-stance phase occurs. The foot begins to re-supinate and passes through neutral position, where the foot begins the propulsive phase continuing in supination through toe-off.

As a result of the foot supinating during the mid-stance propulsive periods, the foot is converted from a “mobile adaptor” (which it is during the contact period) to a “rigid lever” as the midtarsal joint locks in supination. By having the foot function as a “rigid lever’ (as a result of a locked midtarsal joint) during the time immediately preceding toe-off, the weight of the body is propelled more efficiently.

If the foot over-pronates during mid-stance and propulsion, and is in a pronated position at toe-off, the foot acts more as a “mobile adaptor” (i.e. a relatively “loose bag of bones”), rather than a “rigid lever” in these latter stages. It would, therefore, take more muscle energy to propel the weight of the body off of such a platform and the foot remains more mobile (a “loose bag”) than it should be for propulsion.

Certain types of foot pathologies cause abnormal pronation during propulsion and a pronated position at the end of propulsion. As a result, there is significant foot and leg fatigue secondary to overuse of muscles. In addition to this, abnormal pronation during the propulsive period causes hypermobility (an unstable state of joints), that in turn produces joint subluxations. These distortions of the joints lead to trauma and damage of the joints and soft tissue. For example, abnormal shearing forces between the bones and skin of the forefoot produce skin calluses and corns.

Stance phase and its sub-phases

The following is a simplified description of the foot anatomy and motions involved in a complete normal single stance phase of gait. This period is from heel strike to toe-off. The stance phase consists of 60% of normal gait cycle.

The stance phase is divided into three sub-phases: Contact, Mid-stance and Propulsion. The end of one sub-phase denotes the beginning of the next sub-phase. The three sub-phases are:

Contact phase - (heel strike until the first sign of forefoot loading)

The heel hits the ground slightly lateral of center. The calcaneus is inverted about 2°. At this point the foot aids in shock absorption and accepts leg rotation from above. The calcaneus begins to pronate at heel strike and continues until about 22% of the stance phase when a position of almost 4° of pronation is reached (total pronation =almost 6°). Forefoot loading terminates contact phase.

Midstance phase - (first sign of forefoot loading until heel lift)

Midstance begins with forefoot loading. Motion at the subtalar joint is continuous supination from 22% to 100% of the stance phase. The end of midstance is heel lift of the support limb. This occurs at about 50% of the stance. Stability of the limb is required at this point and to achieve this, the foot must be in a position to lock the midtarsal joint. Near the end of mid-stance, at about 55% of stance phase the subtalar joint should be in neutral position (which means the midtarsal joint is locked).

Propulsive phase - (heel lift until toe off)

This is the final 50% of the stance phase. The foot continues to supinate (for a total of 6°) and attains about a 2° supinated position. The midtarsal joint is locked and maximum forefoot loading takes place at about 75-80% of the stance phase. Toe off is at a 2° supinated position. The leg moves into swing phase.

Swing phase

The swing phase consists of 40% of normal gait cycle and occurs from toe-off to heel strike. During this phase the foot remains supinated.

Supination shortens the foot, which helps it to clear the ground. Supination also minimizes the energy expenditure necessary for ground clearance as the non weight-bearing limb passes the weight-bearing limb. Supination stabilizes the bony architecture of the foot thus preparing it for heel strike, when the foot must absorb the shock of striking the ground.

Abnormalities in the latter part of swing phase which lead to the foot striking the ground in a pronated position inevitably lead to significant damage to the joints of the ankle, knee, and hip as the “rigid lever” capability imparted by supination to the foot are lost.

The five core parameters of normal gait

Once normal foot function and biomechanics are understood, it is important to understand interpretation of normal foot function when reviewing patient data displayed in the Footmaxx software. When analyzing foot function using the preliminary patient data displayed on the Footmaxx clinical software, the clinician needs to consider these five core parameters:

- What does the Centre of Pressure Line (COPL) look like? Is it straight or curved?

  -straight is indicative of over-pronation

- When does forefoot loading occur? (17%-24%)

  -signifies the end of contact phase and beginning of mid-stance

- When does heel lift occur? (50%-65%)

  -signifies the end of mid-stance and the beginning of propulsion

- When does <u>full</u> forefoot peak pressure occur? (73%-80%)

  -75% indicates functional stability

- Where does red appear?

  -E.g. Red in the heel could indicate leg length discrepancy, heel spur, limp, etc.

the role of the tibia and femur in the gait cycle

The tibia and femur bones of the leg work in conjunction with the foot as it is pronating and supinating through normal gait. This is due to the fact that the tibia is “locked in” to the talus in the talus’ abduction (causing external rotation of the tibia) and the talus’ adduction (causing internal rotation of the tibia). It has been demonstrated that a foot that is 3° pronated causes the tibia to be 5° internally rotated. This is illustrated best by working with the skeletal model in three dimensions and in Figure 2.8. It has also been shown that a foot, which is 2° supinated causes the tibia to be 10° externally rotated. Therefore, as the foot is going through its normal pronation and supination in the stance phase of gait, the tibia rotates a full 15°. The range of motion is from an initial contact phase position of 10° externally rotated (when the foot is 2° supinated) to 5° internally rotated at the end of contact phase (when the foot is 3° pronated). Figure 2.8 shows these various movements.

In normal gait, the tibia and femur rotate simultaneously and in the same direction. In other words, the femur is internally rotating while the tibia rotates internally (during pronation) and the femur is externally rotating while the tibia externally rotates (during supination).

In the case of abnormal pronation, the femur and tibia can counter-rotate causing the patella (knee cap) to track improperly. See Pathology section under "Chondromalacia Patella".

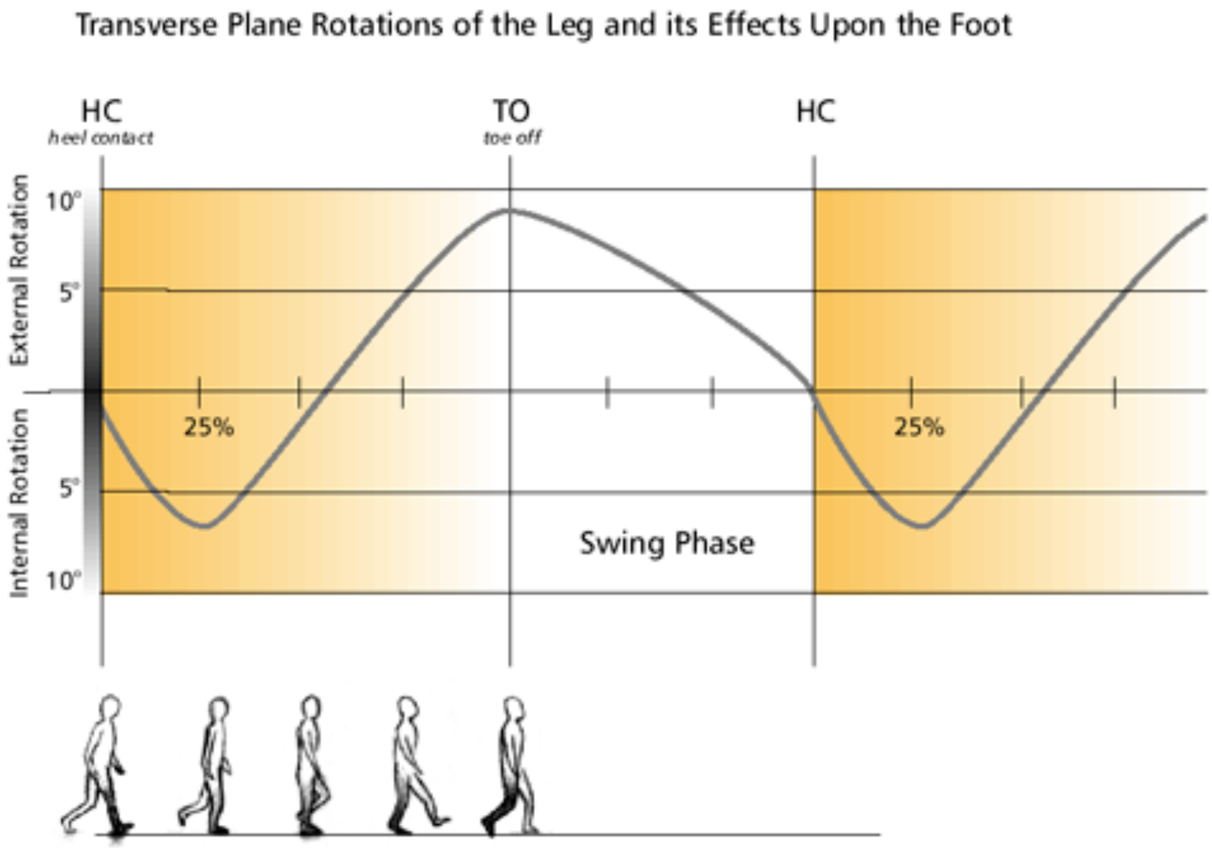

Figure 2.8
Transverse plane rotations of the leg and its effect on the foot.