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BIOMECHANICAL DIFFERENCES IN MEDIAL AND LATERAL ARCHES OF THE FOOT

In last month's newsletter, the structural differences between the medial longitudinal arch (MLA) and the lateral longitudinal arch (LLA) of the foot were discussed. Due to the MLA having four joints, the MLA will necessarily be less stiff (i.e., more flexible) to arch-flattening forces than the LLA. In addition, the point was also made that since the arch-span of the MLA was greater than the arch-span of the LLA, the joints of the MLA are subjected to greater magnitudes of bending forces simply due to the fact that there is a much greater unsupported proximal-to-distal arch length within the MLA than in the LLA. In other words, the MLA almost always has a longer gap of ground non-support, from proximal to distal, than does the LLA.

As a result of the decreased stiffness within the MLA when compared to the LLA, the MLA will flatten more than the LLA when subjected to the same magnitude of arch-flattening forces. This means that the MLA will also elongate more than the "more stable" LLA during weightbearing activities. In order to better understand why this difference in arch-stiffness between the medial and lateral longitudinal arches may be very beneficial for the bipedal human, it is important to first review what are the main forces acting on the foot which cause the flattening forces on both the MLA and LLA.

To simplify the discussion, let's look at a relatively simple weightbearing activity such as relaxed bipedal standing. The forces which tend to flatten the longitudinal arches of the foot come from both external forces, such as the ground reaction force (GRF) acting on both the plantar rearfoot and forefoot, and also internal forces, such a joint compression forces and muscular contractile forces. During relaxed bipedal standing, individuals will tend to position the center of mass (CoM) of their body anterior to the ankle joint axis so that the GRF acting on both the plantar aspect of the rearfoot and forefoot is averaged to be anterior to the ankle joint axis. This average point of all the GRF which acts on all locations onto the plantar foot is known as the center of pressure (CoP), which can be measured by a pressure insole, a pressure mat or a force plate (Winter, David A.: A.B.C. (Anatomy, Biomechanics and Control) of Balance During Standing and Walking. Waterloo Biomechanics, Waterloo, Ontario, Canada, 1995).

In order for an individual to maintain upright balance during relaxed bipedal standing and position their CoM anterior to the ankle joint axis, the gastrocnemius-soleus complex (GSC) will be tonically active in order to create an ankle joint plantarflexion moment in order to resist gravity from pushing the CoM of the body rapidly more anterior to the ankle joint axis and causing a loss of balance and, possibly, a forward fall. The most likely reason that the bipedal human chooses the GSC as the main set of muscles by which to maintain balance during bipedal standing is that the GSC is much larger, and likely stronger, than all the other combined muscles of the

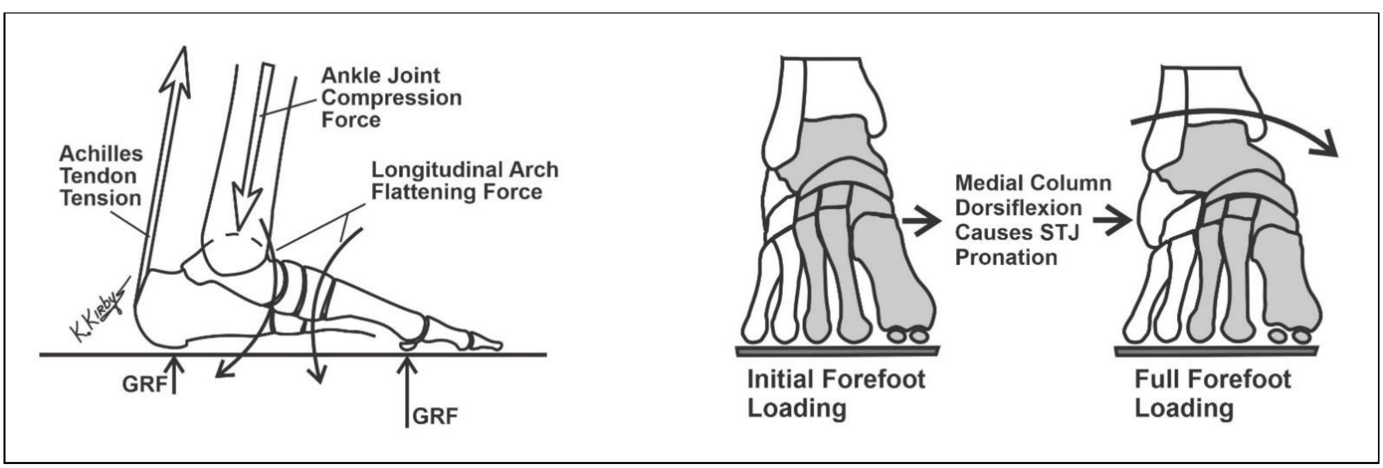

Figure 1. The combination of Achilles tendon tension and ankle joint compression forces acting within the foot, and ground reaction forces (GRF) acting on the plantar foot creates a longitudinal arch flattening force (left). When the forefoot initially loads onto the ground, there is little GRF plantar to the medial forefoot (middle). However, as gait progresses and GRF increases plantar to the medial forefoot, the medial column will dorsiflex tending to cause subtalar joint (STJ) pronation, especially in the foot with a more compliant medial longitudinal arch (right).

leg (Ito J, Moriyama H, Inokuchi S, Goto N. Human lower limb muscles: an evaluation of weight and fiber size. Okajimas folia anatomica Japonica, 80 (2.3):47-56, 2003).

Therefore, during bipedal standing, the combined effects of the external forces from GRF acting plantar to the rearfoot and forefoot, combined with the internal forces of the weight of the body pushing the tibia downward onto the talus and GSC muscle tonic activity creating an ankle joint plantarflexion moment, will cause an *arch-flattening moment* on both the MLA and LLA (Fig. 1). It is also important to understand that the joint compression forces at the ankle are greatly increased by muscular contractile forces from the GSC and other lower leg muscle during standing, and are more greatly increased during walking and especially running and jumping activities. In fact, previous research has demonstrated that ankle joint compression forces are magnified to five-times body weight during walking since, during late midstance, the GSC, and other deep posterior compartment and peroneal muscles, tend to all forcefully compress the distal tibia more firmly down onto the talus (Seireg A et al.: The prediction of muscular lad sharing and joint forces in the lower extremities during walking. Journal of biomechanics, 8(2), 89–102, 1975).

During walking gait, these arch-flattening forces on the MLA and LLA from the GSC and other lower leg muscles will be at a minimum early within the stance phase, when more GRF is on the plantar rearfoot than on the plantar forefoot (Fig. 1). Then, as the CoM moves forward relative to the planted foot, the MLA and LLA arch-flattening forces will rapidly increase during the midstance phase of walking gait and will likely be at their maximum at the end of midstance, just before heel-off, due to GSC contractile activity and plantar fascia tension reaching their peak at this instant of gait (Erdemir A, Hamel AJ, Fauth AR, Piazza SJ, Sharkey NA: Dynamic loading of the plantar aponeurosis in walking. JBJS, 86A:546-552, 2004).

Clinically, the evidence that the flattening forces on the MLA and LLA are at their greatest at the end of midstance phase of walking gait, can often be seen in gait examination of the foot, especially when viewing the foot from the side with slow-motion video. In these conditions, and especially in feet which have less stiff (i.e., more flexible) MLAs, it is often noted that the LLA undergoes much less flattening motion from early midstance to the end of late midstance while the more flexible MLA undergoes considerable flattening motion, especially during late midstance when the arch-flattening forces are at their greatest. Bone pin research by Lundgren et al. on live subjects does confirm that, during walking gait, the total sagittal plane motion that the MLA joints undergo is 39% greater than the total sagittal plane motion of the LLA joints (Lundgren P, Nester C, Liu A, Arndt A, Jones R, Stacoff A, Wolf P, Lundberg A: Invasive in vivo measurement of rear-, mid- and forefoot motion during walking. Gait and Posture, 28:93-100, 2008).

In consideration of all of the above, could there be any biomechanical advantage for the bipedal human to have an MLA which is more flexible than its LLA? One likely possibility is that the MLA, having twice the number joints as the LLA, is designed to have more range of motion than the LLA which will allow the forefoot to better adapt to surface irregularities, which allows the plantar forefoot to have more potential for frontal plane range-of-motion, thus enabling the forefoot to remain plantigrade on uneven or sloped surfaces and/or during side-to-side activities. In addition, the more flexible MLA may also facilitate the necessary STJ pronation during the early stance phase to help provide shock absorption as the foot strikes the ground during walking and running activities (Fig. 1). Likewise, a possible advantage of having a stiffer LLA than MLA is that, with only two joints, the LLA offers the ability of the human foot to have more direct force transfer from the powerful GSC muscles to the ground. In other words, when the GSC starts to contract more vigorously during late midstance and early propulsion, the power of the GSC can be transmitted more effectively to the ground for propulsion when the LLA is more stiff, and stable, than if it is too flexible. These biomechanical functions of the MLA and LLA should be remembered when considering either conservative or surgical treatment of patients with mechanically-related foot and lower extremity pathologies.

Kevin

Kevin A. Kirby, D.P.M.
Biomechanics Director