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BIOMECHANICS OF FLATFOOT DEFORMITY – PART 2

The lower-than-normal height of the medial longitudinal arch (MLA) seen in flatfoot deformity is accompanied not only by changes in the alignment of the bony skeleton of the foot but also by alterations in pedal joint position. As the MLA becomes flatter during standing and other weightbearing activities, the talus will necessarily plantarflex, adduct and medially translate relative to the calcaneus and the ground. Because of these abnormal rotations and translations of the talus seen in flatfoot deformity, profound changes in the biomechanical function of the foot and lower extremity are likely to occur during weightbearing activities, which will be the focus of discussion for the remainder of this newsletter.

One of the most important biomechanical changes that occur within the foot with a decreased MLA height while in the weightbearing position is the plantarflexion, adduction and the medial translation of the talus. On superficial inspection, this "over-pronated" position of the subtalar joint (STJ) that results from abnormal talar rotations and translation may seem to be an insignificant factor in foot and lower extremity function. However, upon detailed analysis of this abnormal relative spatial location of the talus, it becomes clear that these spatial alterations in the talus can cause a multitude of biomechanical abnormalities within the foot.

First of all, it must be emphasized that in all scientific research that has been performed over the past 80+ years, the STJ axis has been determined to have a relatively constant anatomical anterior exit point from the foot, piercing from the center of dorsal talar neck [1) Manter JT: Movements of the subtalar and transverse tarsal joints. Anat Rec, 80:397-410, 1941, 2) Hicks JH: The mechanics of the foot: the joints. J Anatomy, 87:345-357, 1953, 3) Isman RE, Inman VT: Anthropometric studies of human foot and ankle. Pros Res, 10:97-129, 1969, 4) Inman VT: *The Joints of the Ankle.* Williams and Wilkins Company, Baltimore, 1976, 5) Sarrafian SK: *Anatomy of the Foot and Ankle*, J.B. Lippincott Co., Philadelphia, 1983, p. 387, and 6) Van Langelaan EJ.: A Kinematical Analysis of Tarsal Joints. Acta Orthop. Scand., 54:204, 135, 1983.]

Therefore, as the talus plantarflexes, adducts and medially translates, the STJ axis must also plantarflex, adduct and medially translate relative to the ground (Kirby KA: Subtalar joint axis location and rotational equilibrium theory of foot function. JAPMA, 91:465-488, 2001). Since the STJ is the only joint of which allows significant inversion and eversion of the foot skeleton relative to the tibia, then having this important inversion-eversion joint axis of the rearfoot in the proper spatial location relative to ground reaction force (GRF) and extrinsic foot muscle forces is of extreme biomechanical importance. Let's look first at how STJ axis location can have a significant effect on whether GRF will be causing a net STJ pronation rotational force (i.e., pronation moment), a net STJ supination rotational force (i.e., STJ supination moment) or a properly balanced amount of pronation/supination moments acting across the STJ axis during weightbearing activities.

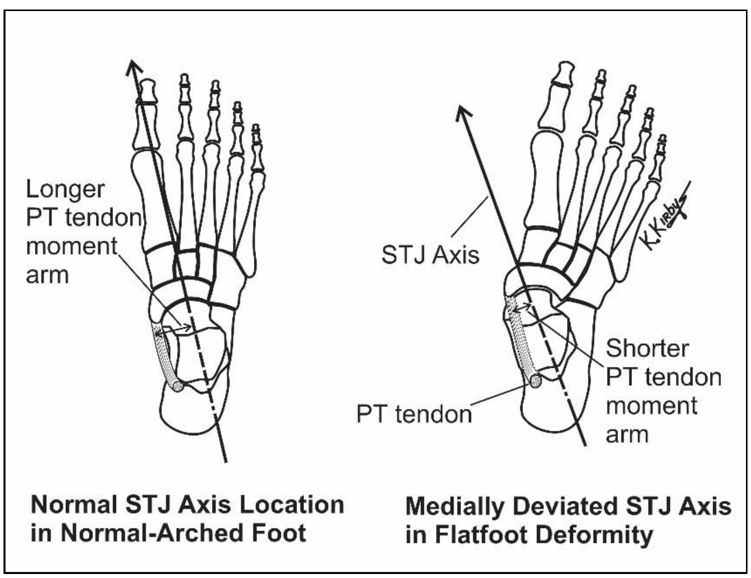

Figure 1. In the foot with a normal medial longitudinal arch (MLA) height, the normal subtalar joint (STJ) spatial location will allow for a longer supination moment arm for the posterior tibial (PT) muscle/tendon (left). However, in the flatfoot deformity, the corresponding medial STJ axis deviation will shorten the PT tendon supination moment arm which, in turn, will decrease the supination strength of the PT muscle/tendon complex (right).

The amount of GRF acting on the plantar foot ranges from about 0.5x body weight (BW) during bipedal standing, to 1.0x BW in unipedal standing, to about 1.25x BW in walking, to 2.5-3.0x BW in running and up to 5x BW in sprinting activities (Nilsson J, Thorstensson A: Ground reaction forces at different speeds of human walking and running. Acta Phys Scand, 136:217-227, 1989). Because of these relatively large magnitudes of external force acting on the plantar aspect of the human foot, any change in spatial location of the STJ axis relative to these potentially large magnitudes of GRF will have quite significant effects on both the magnitude and rotational direction of the supination and pronation moments acting across the STJ axis during any weightbearing activity. Importantly, it must also be remembered that the foot is the only structure of the human body that is routinely subjected to external forces greater than 1x BW during its daily activities, with no other part of the body being routinely subjected to these magnitudes of external force.

Let's look at an example of an individual standing with both feet on the ground. In this example, the GRF acting on the plantar aspect of the medial calcaneal tubercle is given to be 200 Newtons (about 45 pounds). This amount of GRF acting on the plantar heel with a normal MLA height and a normal STJ axis spatial location will cause a significant amount of STJ supination moment. If the STJ axis in this normally-structured foot is 20 mm (0.02m) lateral to the center of GRF acting on the medial calcaneal tubercle, then the net supination moment acting across the STJ axis would be as follows: 200N x 0.02 meters = 4.0 Nm. However, if a flatfoot has a STJ axis which is 15 mm more medially-deviated than normal, this would then mean that the same 200N of GRF acting on the medial calcaneal tubercule would only produce one-quarter of the STJ supination moment compared to a normal foot (200N x 0.005m = 1.0 Nm). In other words, with only a 15 mm medial shift in STJ axis location in the flatfooted individual, a 4-fold decrease in STJ supination moments will be generated by GRF acting on the plantar aspect of the medial calcaneal tubercle.

In addition, the STJ moments generated by the tension forces from the extrinsic foot muscles/tendons during weightbearing activities will also be significantly affected by any medial deviation of the STJ axis seen in flatfoot deformity (Fig. 1). For example, if the posterior tibial (PT) tendon has a 30 mm supination moment arm relative to the STJ axis in a normal-arched foot (i.e., the PT tendon is 30 mm medial to the STJ axis), then a tension force of 100N (about 22.5 pounds) generated by PT muscle contractile activity would result in a net STJ supination moment of 3.0 Nm (100 N x 0.03 m = 3.0 Nm). However, if the STJ axis becomes medially deviated by 20 mm from its normal location due to a flatfoot deformity, giving the PT tendon only a 10 mm supination moment arm, there will be a 3-fold reduction in STJ supination moment when the PT tendon pulls with a tension force of 100 N (100 N x 0.01 m = 1.0 Nm). In this example, where the 20 mm of medial STJ axis deviation in the flatfoot deformity results in a great reduction in PT muscle supination strength, the PT muscle and tendon would need to exert a 3-fold increase in tension force to be able to exert the same magnitude of STJ supination moment from PT muscle contractile activity as in the normal-arched foot. This biomechanical fact may be the prime cause for the progressive flatfoot deformity and PT tendon pathology commonly seen in the disabling pathology of posterior tibial tendon dysfunction (Kirby KA: Conservative treatment of posterior tibial dysfunction. Podiatry Management, 19:73-82, 2000).

In conclusion, the flatfoot deformity with a lower MLA height can present with multiple biomechanical problems due to its flat-arched structure. One of the most important functional problems with flatfoot deformity is that the decrease in MLA height occurs along with significant medial deviation of the STJ axis due to the plantarflexed, adducted and medially-translated position of the talus relative to the foot skeleton and ground. This medially-deviated STJ axis not only reduces the STJ supination moments that occur from the actions of GRF acting on the plantar aspect of the medial calcaneal tubercle and plantar foot, but also significantly reduces the STJ supination moment that occurs due to the tension forces from the supination-producing extrinsic foot muscles, such as the PT muscle. Having a better understanding of the biomechanical relationship between the decrease in MLA height and the medial deviation of the STJ axis in the flatfoot deformity will allow the podiatrist to better appreciate pronation-pathologies of the foot, which will allow for a better grasp of the best conservative and surgical biomechanical treatments for the flatfoot deformity.

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