PROLAB
ORTHOTICS
Evidence-Based
Medicine

Biomechanics & Orthotic Therapy Newsletter
September 2025

BIOMECHANICS OF FLATFOOT DEFORMITY – PART 3

When podiatrists identify a foot as a "flatfoot deformity", other than a flatter medial longitudinal arch (MLA) height, what are the biomechanical consequences of such a deformity? Flatfoot deformity can cause multiple alterations in foot and lower extremity biomechanics of the individual during weightbearing activities which may lead to painful pathologies and gait disturbances. Some of these biomechanical problems caused by flatfoot deformity, such as increased subtalar joint (STJ) pronation moments due to medial STJ axis deviation, have already been reviewed in recent ProLab newsletters. A few other significant biomechanical changes caused by the lower MLA seen in flatfoot deformity will be reviewed in this newsletter.

As noted in the last ProLab newsletter, the talus in the flatfoot deformity will always be more adducted (i.e., internally rotated) and plantarflexed than in a normal-arched foot. Since the STJ axis consistently pierces the osseous skeleton of the foot at the center of the dorsal neck of the talus, this inward swing of the talar head and neck that occurs with the excessive talar adduction seen in flatfoot deformity will always cause increased medially deviation of the STJ axis. The plantarflexion of the talus relative to the calcaneus in flatfoot deformity is largely responsible for the decrease in height of the MLA since talar plantarflexion lowers the talar head and talo-navicular joint (TNJ) toward the ground, thus reducing the height of the TNJ to the ground.

This adduction and plantarflexion of the talar head and TNJ consistently seen in flatfeet can cause very profound alterations in not only STJ biomechanics, but also in midtarsal joint (MTJ) biomechanics. Unfortunately, many podiatrists still erroneously believe that the MTJ has two fixed, simultaneously-occurring, hinge-like axes, the oblique MTJ and longitudinal MTJ which are based on very primitive research papers from 1941 by Manter (Manter JT: Movements of the subtalar and transverse tarsal joints. Anat Rec, 80:397-410, 1941) and Hicks in 1953 (Hicks JH: The mechanics of the foot. I. The joints. J Anatomy. 87:25-31, 1953). These false MTJ ideas were later reinforced in 1977 by Root et al. which may also be a reason for the misconceptions that podiatrists have about MTJ biomechanics (Root ML, Orien WP, Weed JH: Normal and Abnormal Function of the Foot. Clinical Biomechanics Corp., Los Angeles, CA, 1977).

The notion that the MTJ has two fixed, simultaneously-occurring, hinge-like axes has been disproven decades ago by investigators who used modern research methods to determine the continually-changing spatial locations of both the TNJ and calcaneo-cuboid joint (CCJ) axes during weightbearing activities (Van Langelaan EJ: A kinematical analysis of the tarsal joints: An x-ray photogrammetric study. Acta Orthop Scand, 54:Suppl. 204, 135-229, 1983; Benink, RJ: The constraint mechanism of the human tarsus. Acta Orthop Scand, 56: (Suppl) 215, 1985.). These researchers found that the MTJ does not have two imaginary hinge-like axes that are fixed in space and which coexist simultaneously. Rather, the axis of motions of the TNJ and CCJ were found to be constantly moving in space. In addition, the axis of motion of the MTJ was found to be solely determined by the direction of motion occurring at the MTJ at any instant in time (Nester CJ et al.: Scientific approach to the axis of rotation of the midtarsal joint. JAPMA, 91(2):68-73, 2001).

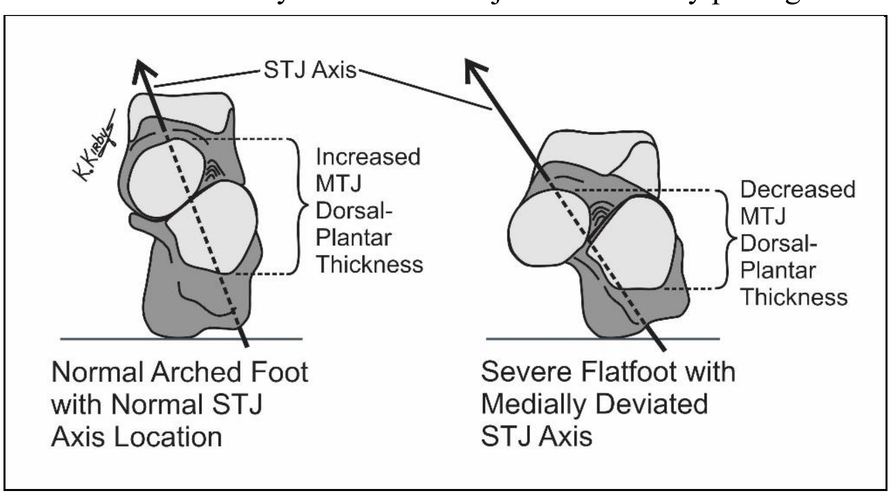

Figure 1. In a normal arched foot, with a more normal subtalar joint (STJ) axis location, the talo-navicular joint (TNJ) is stacked more on top of the calcaneo-cuboid joint (CCJ), increasing its dorsal-plantar thickness and its midtarsal joint (MTJ) stiffness (left). However, in the flatfoot deformity, the plantarflexed and adducted talus causes both a medially deviated STJ axis and an "unstacked" TNJ and CCJ, decreasing MTJ dorsal-plantar thickness and greatly reducing the dorsiflexion stiffness of the MTJ (right).

The other odd notion that has been taught to generations of podiatrists is that MTJ motion is increased with STJ pronation because of "parallel MTJ axes", while MTJ motion is decreased with STJ supination due to "angled MTJ axes". This idea seems to have originated from Manter's 1960 paper where he simply looked with the "eye of a connoisseur" at the articular surfaces of the TNJ and CCJ and then conjured up four MTJ axes from viewing their shapes. Elftman felt that these imaginary "axes" would be more parallel to each other in pronation allowing more MTJ motion and would be more angled to each other in supination allowing less MTJ motion (Elftman H: The transverse tarsal joint and its control. Clin. Orthop., 16:41-44, 1960).

Fortunately, a more biomechanically-plausible explanation for the increased MTJ motion seen in the flatfoot deformity is available which is based on sound engineering principles, rather than on the opinions of a single author from 65 years ago who looked at the MTJ facets with the "eye of a connoisseur". In this more acceptable engineering-based explanation of MTJ flexibility, the supinated foot with a laterally deviated STJ axis and increased MLA height will have its TNJ more "stacked" on top of the CCJ, thus making the foot thicker in frontal plane cross-section. This increased TNJ/CCJ stacking makes the forefoot more resistant to dorsiflexion on the rearfoot. In addition, in the more pronated, lower-arched foot, the TNJ is less "stacked" on top of the CCJ, decreasing the dorsal-plantar thickness of the MTJ which allows the forefoot to dorsiflex more on the rearfoot during weightbearing activities (Fig. 1). This idea that differences in TNJ/CCJ "stacking" are responsible for the increased dorsiflexion motion of the forefoot on the rearfoot in flatfoot deformities offers a more credible biomechanical explanation for the functional differences seen in MTJ biomechanics between the flatfoot deformity and the foot with a normal MLA or an increased MLA height.

In the more severe flatfoot deformity, this increase in dorsiflexion range of motion of the forefoot on the rearfoot at the MTJ can be seen clinically in what has been called the "rocker bottom" flatfoot deformity that undergoes "banana peel" propulsion during walking gait. In the initial stages of "banana peel" propulsion, the heel will lift-off from the ground while the rest of the forefoot stays on the ground. This excessive sagittal plane instability of the MTJ during gait results in the patient having little to no ability to use the forefoot as a rigid lever during propulsion in order to improve their metabolic efficiency while walking or running.

The concept that a thinner material will be more flexible than a thicker material should be familiar to anyone who has worked with wood, where it is common knowledge that a wooden beam with a thicker cross-section will have greatly increased bending stiffness. For example, if you were to take a length of 2" x 4" wooden lumber supported on both ends by bricks and then stand on this lumber, your weight would bend the 2" x 4" piece of lumber. In fact, real-life experience has shown many of us that wood lumber will bend more if we the stand on the lumber while it is supported on its flat side, than if we stood on the same piece of lumber while it is lying supported on its edges. This common-place observation is due to the engineering concept that the bending stiffness of a beam is determined by the cube of its thickness. In other words, an increase in lumber cross-section of two-fold will not increase its stiffness by two-fold, but rather will increase its stiffness by 2^3, or eight-fold (Kidder FE: *Strength of Beams, Floor and Roofs*. McMaster Press, 2009, pp. 1-18).

Therefore, medial deviation of the STJ axis which is always seen in flatfoot deformity also directly affects MTJ mechanics due to the associated adduction and plantarflexion of the talus, which makes the TNJ become located relatively more medial and plantar to the CCJ, thus thinning the dorsal-plantar structure of the MTJ or, put another way, causing the TNJ and CCJ to "unstack". This "unstacking" of the TNJ to a more medial and plantar position relative to the CCJ in the flatfoot will decrease MTJ dorsiflexion sagittal plane stiffness which will, in turn, result in a less rigid lever for propulsion when dorsiflexion loads are placed on the forefoot during gait. Thus, the increased medial deviation of the STJ axis and the increase in MTJ flexibility seen in flatfoot deformity are biomechanically interrelated and are directly caused by the three-dimensional changes in spatial orientation of the TNJ relative to the CCJ seen in these flatfoot deformities.

Kevin

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