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ORIGINAL ARTICLES

Biomechanics of the First Ray Part V: The Effect of Equinus Deformity

A 3-Dimensional Kinematic Study on a Cadaver Model

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The positional change of the medial column of the foot in closed kinetic chain with variable Achilles tendon tension was investigated in seven fresh frozen cadaver specimens using a 3-dimensional radio wave tracking system. The distal tibia and fibula and the intact ankle and foot and were mounted on a non-metallic loading frame. The frame allowed positioning of the foot to simulate midstance phase of gait while the tibia and fibula were axially loaded to 400 N. To record osseous motion, receiving transducers were attached to the first metatarsal, medial cuneiform, navicular, and talus. Movements of these bones in 3-dimensional space were measured as specimens were axially loaded and midstance motor function was simulated using pneumatic actuators. To simulate a progressive equinus influence, force was applied to the Achilles tendon at tensile loads of 0%, 30%, and 60% of predicted maximum strength during each test trial. Osseous positions and orientations were collected and analyzed in all three cardinal planes utilizing data recorded. As Achilles load increased, the position of the first metatarsal became significantly more inverted ($P < .05$*). Although not statistically significant, remarkable trends of arch flattening motion were detected in the distal segments of the medial column with varied Achilles load. Increased Achilles load reduced the influence of peroneus longus on the medial column.* (The Journal of Foot & Ankle Surgery 44(1):114-120, 2005)

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Equinus deformity is the most profound causal agent in foot pathomechanics and is frequently linked to common foot pathology (1–3). With the Achilles tethering ankle joint dorsiflexion, pathologic forces of equinus are transmitted through the foot. Intuitively, as a result of structural variability of the arch, it is felt that an identical destructive influence can induce a variety of pathological compensations. These include Achilles tendinopathy (4), posterior tibial tendonitis (4), flatfoot conditions (1, 5, 6), plantar fasciitis (4), Lisfranc arthrosis (5), Charcot arthropathy (7–9), hallux valgus (10), hallux limitus (11), plantar ulcerations (9, 12–14), forefoot calluses (4, 11), metatarsalgia (4, 6), and hammertoe contractures (15). Although equinus is blamed for the genesis of various foot deformities, cause-and-effect relationships have not been thoroughly investigated.

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Biomechanical Influence of Triceps Surae

The triceps surae functions across the ankle and subtalar joints with the gastrocnemius component affecting the knee as well (8). The gastrocnemius muscle is the most consistently active muscle during static stance due to the center of gravity projecting anterior to the ankle (16, 17). The maximum forces attained by the gastrosoleal complex are: medial head of gastrocnemius 500 N, lateral head of gastrocnemius 700 N, and soleus 900 N.

Approximately 450 N of tension is created by the Achilles tendon during midstance (18).

Equinus

Equinus deformity is defined as the inability to dorsiflex the ankle sufficiently enough to allow the heel to contact the supporting surface without subtalar or midtarsal joint pronation (19). Controversy exists regarding the magnitude of equinus that is clinically important. Nonetheless, there is a strong consensus that the ankle must dorsiflex past perpendicular for smooth ambulation. Schuster described the amount of ankle motion needed in walking as the "walking angle"(20). Because values for normal vary in the literature, the normal amount of ankle motion is best described as a range of values between 3 to 15 degrees of dorsiflexion past perpendicular (19, 21–33). Hansen theorized a tight Achilles tendon as an atavistic trait similar to how Lapidus attributed first ray malalignment to atavism (10, 34–36).

The effects of treating equinus were studied by Sgarlato, who found that tendo Achilles lengthening (TAL) relieved calf and arch pain, leg fatigue, plantar keratomas, symptoms from hallux valgus deformity and tarsal coalition. This is one of the few studies that has attempted to evaluate the cause and effect relationship of equinus and foot pathology. Unfortunately, the TAL was done in conjunction with other procedures that contribute many variables (11).

Compensation for Equinus

The subtle pathomechanics of a shortened gastrocnemius aponeurosis has been known for over 100 years (37). Since these early descriptions, the various types of equinus compensations have become more clearly understood. Common modes of compensation for lack of ankle dorsiflexion include triplanar rearfoot motion (pronation), hypermobile flatfoot, an early heel-off (bouncy gait), and an abducted gait pattern (1, 19, 38). Proximal compensatory mechanisms for equinus have also been described, including lumbar lordosis, hip flexion, and genu recurvatum (9). If only partially compensated, an equinus deformity will result in increased forefoot load causing calluses, metatarsalgia, and forefoot ulcerations (6, 13, 19, 38–40).

Opposing Forces

An antagonistic relationship exists between the triceps surae and the structures of arch retention. These structures include tibialis posterior, peroneus longus, plantar fascia, and the plantar ligaments. In open kinetic chain, Duchenne described Achilles and peroneus longus as having opposing roles (24). While in closed kinetic chain, investigators have observed the triceps as having an arch-flattening effect (26, 41). Thus, the analogy of a "tug-o-war" can be used to describe the triceps surae along with weight bearing load vs. their antagonists and other structures of arch retention.

As determined by dynamic electromyography, the tibialis posterior fires at approximately 10% of the gait cycle, while the gastrosoleus contracts later (42). Thus, a foot with an equinus influence will generate premature passive loading of the Achilles applied to the arch from foot flat to heel lift in addition to the normal dynamic loads. This passive influence can oppose the active function of the tibialis posterior and lead to arch insufficiency (43, 44).

First Ray Hypermobility

Although Duchenne described first ray mobility in the 1800s by stating, "The joints of the medial border of the forefoot have a certain amount of vertical motion," (24) Morton advanced the concept of first ray hypermobility. Morton's criteria for hypermobility of the first ray included clinically demonstrable "hyperextension" (dorsiflexion of the first ray), widening of the space between the first and second cuneiforms, and a thickened second metatarsal shaft (28, 45–47).

First ray motion has been studied by numerous investigators (19, 48–53). Klaue et al suggested a direct relationship between painful hallux valgus deformity and hypermobility of the first metatarsocuneiform joint (52). Thordarson et al, through the use of a 3-dimensional tracking system, found that the unopposed pull of peroneus longus consistently abducted the forefoot in the transverse plane (41).

In Part I in this series of investigations on biomechanics of the first ray, the authors found peroneus longus to evert the medial column creating a locking effect of the first ray (54). In Part II, the intermetatarsal angle was demonstrated to have an influence on mobility of the first ray (55). Part III demonstrated that arthrodesis of the first metatarasocuneiform joint increases the efficiency of peroneus longus stabilizing action on the medial column (56). The findings in Part IV suggest that open kinetic chain range of motion of the first ray is a blend of motions of joints comprising the medial column (57). The present study aims to further characterize the contribution of equinus deformity in first ray pathomechanics and focuses on the compensation patterns using a weight bearing cadaver model. We wanted to determine the effect of increased Achilles tension (equinus) on first ray mechanics, particularly how it affects peroneus longus' stabilizing action on the first ray.

Materials and Methods

This research design has been presented previously in more detail (54) and is summarized as follows.