Clinical Biomechanics 24 (2009) 776–780

Contents lists available at ScienceDirect

Clinical Biomechanics

journal homepage: www.elsevier.com/locate/clinbiomech

Effects of foot orthoses on the work of friction of the posterior tibial tendon

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ARTICLE INFO

Article history:
Received 2 December 2008
Accepted 22 July 2009

Keywords:
Foot
Ankle
Work of friction
Orthotics
Biomechanics

ABSTRACT

Background: Posterior tibial tendon dysfunction is a significant contributor to flatfeet. Non-operative treatments, like in-shoe orthoses, have varying degrees of success. This study examined changes to the work of friction of the posterior tibial tendon under three conditions: intact, simulated flatfoot, and flatfoot with an orthosis. It was hypothesized that work of friction of the posterior tibial tendon would significantly increase in the flatfoot, yet return to normal with an orthosis. Changes to bone orientation were also expected.

Methods: Six lower limb cadavers were mounted in a foot simulator, that applied axial and a posterior tibial tendon load. Posterior tibial tendon excursion, gliding resistance, and foot kinematics were monitored, and work of friction calculated. Each specimen moved through a range of motion in the coronal, transverse, and sagittal planes.

Findings: Mean work of friction during motion in the coronal plane were 0.17 N cm (SD 0.07 N cm), 0.25 N cm (SD 0.09 N cm), and 0.23 N cm (SD 0.09 N cm) for the intact, flatfoot, and orthosis conditions, respectively. Motion in the transverse plane yielded average WoF of 0.36 N cm (SD 0.28 N cm), 0.64 N cm (SD 0.25 N cm), and 0.57 N cm (SD 0.38 N cm) in the same three conditions, respectively. The average tibio-calcaneal and tibio-metatarsal valgus angles significantly increased in the flatfoot condition (5.8° and 9°, respectively). However, the orthosis did slightly correct this angle.

Interpretation: The prefabricated orthosis did not consistently restore normal work of friction, though it did correct the flatfoot visually. This implies that patients with flatfeet may be predisposed to developing posterior tibial tendon dysfunction due to abnormal gliding resistance, though bone orientations are restored.

1. Introduction

Posterior tibial tendon dysfunction (PTTD) has been recognized as the most common cause of acquired flatfoot deformity in adults (Augustin et al., 2003; Myerson and Corrigan, 1996). It is reported that approximately 50% of patients with PTTD have a history of trauma (Mann and Thompson, 1985b). Symptoms manifest themselves as pain, swelling, tenderness, and increased warmth about the posteromedial hindfoot and ankle, weak supination strength, difficulty completing the single heel rise tests, and eventually progression to a full flatfoot deformity. Patients who are not effectively treated during the early stages of PTTD risk progression to a severely deformed and rigid hindfoot, advanced hindfoot arthritis, calcaneofibular impingement, ankle instability, and ankle arthritis. Late phases of PTTD present several problems ranging from synovitis of the tendon without anatomic abnormality nor collapse of the longitudinal arch, severe valgus of the heel, and abduction of the forefoot (Mann and Thompson, 1985b). It was also reported that excessive weight appears to accelerate flatfoot development, due to increased repetitive load absorbed by the posteromedial soft tissues (Holmes and Hansen, 1993). Because of hypovascularity and inhomogeneous distribution of blood vessels (Petersen and Hohmann, 2001), restoration of posterior tibial tendon (PTT) function after damage can be difficult. If untreated the tendon attenuates, elongates, and thickens causing spontaneous tendon ruptures (Johnson, 1983; Mosier et al., 1999).

The prevalence of severe flatfoot as well as the link between PTTD and flatfeet has prompted several investigations into treatment options for PTTD. Unfortunately comparisons across in vivo studies cannot be made, due to participant differences. Cadaveric models of flatfeet have been described in the literature (Kitaoka et al., 1998; Deland et al., 1992; Friedman et al., 2001). These studies are important because they allowed longitudinal comparison of the affects of flatfeet.

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0268-0033/$ - see front matter © 2009 Elsevier Ltd. All rights reserved.
doi:10.1016/j.clinbiomech.2009.07.009

Many conservative and surgical treatments have also been described (Johnson and Strom, 1989; Mann and Thompson, 1985a). Conservative treatments are important to consider because all patients do not desire surgery, while others may not be candidates for surgical intervention. Orthotics are one example of conservative treatment these aim to support the longitudinal arch and decrease valgus angulations of the calcaneus, while immobilizing and supporting the hind and midfoot (Wapner and Chao, 1999). The University of California Biomechanics Laboratory (UCBL) orthosis (Elftman, 2003) is one such device; however, it has shown varying degrees of success (Havenhill et al., 2005).

One characteristic of the PTT affected by pathologies and treatment is the gliding resistance. This is the friction that occurs between the tendon and the surrounding sheath as the tendon moves. In healthy tendons, this friction is very small; however, injury and repair have been shown to alter this resistance (Zhao et al., 2001). A method to measure tendon gliding resistance was developed and validated previously using the flexor tendons of the hand (Uchiyama et al., 1997). These techniques were translated to the ankle complex by measuring the gliding resistance of the PTT (Uchiyama et al., 2006). Results showed that flatfeet and/or the position of the hindfoot in dorsiflexion increased the gliding resistance of the PTT. Later this same method studied the work of friction (WoF) specifically in the retromalleolar region of PTT in an intact and simulated flatfoot (Arai et al., 2007). WoF is of particular interest because it quantifies the amount of energy lost from friction, during movement. It was reported that the WoF increased with tendon loading and was greater in the flatfoot than the intact condition.

While it is fairly well understood that PTT WoF is changed from flatfeet the question remains, what are the specific effects of orthoses on the WoF of the PTT? The purpose of this study was to examine changes to the PTT WoF as a function of foot posture, under distinct conditions: the intact foot, simulated flatfoot, and simulated flatfoot treated with a custom orthosis. It was hypothesized that the WoF would significantly increase as a result of a flatfoot, but this same WoF would decrease with the addition of the custom orthosis. Furthermore, it was also hypothesized that changes to the WoF would be accompanied by altered bone orientations resulting from a flatfoot.

2. Methods

2.1. Surgical procedures

Each specimen was prepared for testing by a foot and ankle surgeon. After removal of the soft tissues from the tibia and fibula, two custom-made force transducers (1.5 cm diameter) were attached to the distal and proximal ends of the PTT. The distal sensor was sutured to the tendon using the Bunnell suture method, while the proximal sensor was attached using a modified Krackow suture technique. The flatfoot was created by sectioning the peritalar soft tissues: spring ligament, long and short plantar ligaments, medial talocalcaneal ligament, talocalcaneal interosseous ligament, and tibionavicular portion of superficial deltoid ligament (Kitaoka et al., 1998). The changes in tarsal bone positions were determined to confirm the severity of the flatfoot condition, examining the calcaneus relative to the tibia, and the forefoot (metatarsal) relative to the tibia.

2.2. Study design

Six fresh-frozen cadaver specimens without any visual or radiographic evidence of foot or ankle abnormality were utilized. The average age of the specimens was 74.3 years old, (range 55–83 years). Four donors were female and two were male. Data was collected in three conditions: an intact foot, after a flatfoot was created, and a flatfoot treated with an orthosis (Fig. 1), during movement in three different planes. Five prefabricated orthoses reported in previous studies (Kitaoka et al., 1997, 2002) were used here. Each was manufactured by UCO International (Wheeling, IL, USA), molded from a thermoplastic and cork mixed with nylon. Medial and lateral flanges started around the heel and extend into the midfoot region. This particular device is currently used clinically for flexible flatfeet and midfoot arthritis. The best fitting orthosis was determined by placing each prefabricated orthosis on the foot. The device with a tight fight around the heel was used for each specimen.

Fig. 1. Example of a prefabricated orthosis.

The entire specimen was mounted in a custom-made six degree-of-freedom ankle testing apparatus (Fig. 2). The tibia was fixed to the test frame using threaded rods with the proximal and distal tibio-fibula physiological neutral configuration maintained. The plantar aspect of the foot itself was placed flat on a moveable plate. This device functioned to produce repeatable unconstrained moments about the foot in prescribed planes. The ankle testing apparatus was comprised of three computer controlled motors that moved the aforementioned foot plate, a low-friction unconstrained *X–Y* translation table in the transverse plane, a linear crosshead along the axis of the tibia and a load cell. The entire apparatus was controlled by a custom-made Labview (Texas Instruments, Inc., Austin, TX, USA) program. To create the initial neutral foot position, no axial load was applied to the intact foot. During testing, a 222 N axial load was applied through the tibia-fibula, and is slightly less than 1/3 body weight. Preliminary studies proved this load did not excessively damage bone or soft tissues, given the high number of repetitions within the protocol. A static load of 9.8 N was applied to the PTT via a calibrated pneumatic actuator. This particular load was chosen as it allowed the PTT to be in tension during movement. In addition this amount was the proper proportion of the total force acting through the PTT during the second rocker position. This proportion was based on the reduced axial load, muscle PCSA, muscle volume, and calculated stresses in the muscle. The foot plate was passively moved for five cycles, with an angular velocity of 3°/s. The total range of motion of the foot plate in the sagittal plane was (30° plantarflexion–10° dorsiflexion), coronal plane (20° inversion–20° eversion) and transverse plane (20° internal rotation–20° external rotation). Foot plate motion in the coronal and transverse planes was larger than the physiologic ranges of motion in order to ensure a full range of joint motion. Three-dimensional kinematics of the forefoot (first metatarsal relative to the tibia) and hindfoot (calcaneus and relative to the tibia) were monitored with an optoelectronic tracking