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Original article

Clinical measures of hip and foot–ankle mechanics as predictors of rearfoot motion and posture

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ABSTRACT

Health professionals are frequently interested in predicting rearfoot pronation during weight-bearing activities. Previous inconsistent results regarding the ability of clinical measures to predict rearfoot kinematics may have been influenced by the neglect of possible combined effects of alignment and mobility at the foot–ankle complex and by the disregard of possible influences of hip mobility on foot kinematics. The present study tested whether using a measure that combines frontal-plane bone alignment and mobility at the foot–ankle complex and a measure of hip internal rotation mobility predicts rearfoot kinematics, in walking and upright stance. Twenty-three healthy subjects underwent assessment of forefoot–shank angle (which combines varus bone alignments at the foot–ankle complex with inversion mobility at the midfoot joints), with a goniometer, and hip internal rotation mobility, with an inclinometer. Frontal-plane kinematics of the rearfoot was assessed with a three-dimensional system, during treadmill walking and upright stance. Multivariate linear regressions tested the predictive strength of these measures to inform about rearfoot kinematics. The measures significantly predicted ($p \leq 0.041$) mean eversion–inversion position, during walking ($r^2 = 0.40$) and standing ($r^2 = 0.31$), and eversion peak in walking ($r^2 = 0.27$). Greater values of varus alignment at the foot–ankle complex combined with inversion mobility at the midfoot joints and greater hip internal rotation mobility are related to greater weight-bearing rearfoot eversion. Each measure (forefoot–shank angle and hip internal rotation mobility) alone and their combination partially predicted rearfoot kinematics. These measures may help detecting foot–ankle and hip mechanical variables possibly involved in an observed rearfoot motion or posture.

1. Introduction

Development of painful musculoskeletal conditions has been attributed to altered pronation of the foot (commonly measured as eversion around a longitudinal axis of the foot) (Willems et al., 2007; Barton et al., 2009; Barton et al., 2010). Thus, health professionals are frequently interested in identifying clinically measurable variables that influence rearfoot pronation and that are susceptible to intervention (Hamill et al., 1989; Hunt et al., 2000; Cornwall et al., 2006). Varus/valgus bone alignment of forefoot, rearfoot and tibia-fibula have been considered as variables that affect pronation magnitude (Root et al., 1977; Michaud, 1993). However, studies that investigated these relationships produced inconsistent results (Hamill et al., 1989; McPoil & Cornwall, 1996a; Donatelli et al., 1999; Cornwall et al., 2004). It is possible that the mobility provided by midfoot soft tissues, in the frontal plane (i.e. around the longitudinal axis of the foot), also influence rearfoot kinematics. When the forefoot is on the ground, in weight bearing, eversion of the rearfoot is accompanied by motions at the midfoot joints (Neumann, 2002). These motions permit the metartarsal heads, as a unit, to invert relative to the rearfoot and stay horizontally supported (Neumann, 2002). Thus, the soft tissues that resist this collective inversion of the midfoot joints may also resist weight-bearing rearfoot eversion (Fig. 1). The mobility of collective midfoot inversion index this resistance such that the greater the mobility, the smaller the resistance. Therefore, together with varus bone alignment, greater midfoot inversion mobility would contribute to greater weight-bearing rearfoot eversion.

Soft tissues at the hip may also influence foot kinematics by affecting lower-limb axial rotations (Fonseca et al., 2007; Snyder et al., 2009; Souza et al., 2010). According to traditional theories, shank axial rotation would be transferred to the talus and, due to

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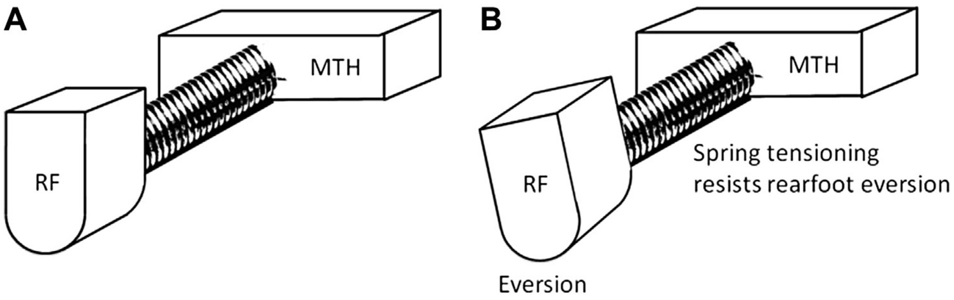

Fig. 1. (A) Model of the soft tissues of the midfoot joints as a torsion spring connecting rearfoot to forefoot, which would influence rearfoot eversion in weight-bearing activities. The figure shows a posterior-lateral view of the right foot, and the forefoot is represented as a bar corresponding to the metatarsal heads horizontally supported on the ground. (B) The torsion spring resists rearfoot eversion relative to the metatarsal heads (i.e. inversion of the metatarsal heads relative to the rearfoot). MTH: metatarsal heads; RF: rearfoot.

the oblique axis of the subtalar joint, talus adduction–abduction would lead to calcaneus eversion–inversion (Root et al., 1977). There would be no axial rotations of the talus in the talocrural joint (Michaud, 1993). Although bone-pin studies questioned these mechanisms at individual joints (Arndt et al., 2004; Nester et al., 2007; Lundgren et al., 2008), the whole ankle complex makes lower-limb internal rotation and rearfoot eversion to be relatively interdependent and simultaneous (Snyder et al., 2009; Souza et al., 2010). Therefore, hip soft tissues that resist internal rotation may also resist foot pronation indirectly. Greater values of hip internal rotation mobility would be associated with greater values of rearfoot eversion.

The aim of this study was to investigate whether a measure of hip internal rotation mobility and a measure that combines midfoot inversion mobility and varus/valgus bone alignment predict rearfoot kinematics, during walking and upright stance.

2. Methods

2.1. Subjects

Twenty-three young and healthy subjects (9 men, 14 women) participated in the study. Their mean (±SD) age, mass and height were 24.6 ± 4.01 years, 69.59 ± 12.22 kg, and 1.71 ± 0.09 m, respectively. They constituted a convenience sample from the university community, who met the following inclusion criteria: not having symptoms or any pathology in the lower limbs and lumbo-pelvic complex during the six months previous to the study; not having undergone orthopedic surgery; not having used any kind of foot orthoses; and having a maximum body mass index of 25 kg/m^2. One lower limb of each subject was studied. The dominant limb was chosen for standardization and was defined as the limb that the subject would use to kick a ball. The sample size was estimated considering a moderate effect size ($r = 0.5$) for the association of foot kinematics with the combination of both clinical measures, with significance level of 0.05 and statistical power of 0.8 (Portney & Watkins, 2000). Moderate association was considered due to the multifactorial nature of foot kinematics. The participants signed a consent form and the Institution's Ethics Committee approved this study.

2.2. Procedures

2.2.1. Clinical measures

2.2.1.1. Forefoot–shank angle. This measure was developed to include varus/valgus bone alignments of the foot–ankle complex as well as midfoot inversion mobility (Holt & Hamill, 1995). The assessment was carried out with a goniometer by measuring the angle between the forefoot and a line drawn on the posterior aspect of the shank, with the subject lying prone (Mendonça et al., 2013) (Fig. 2A). The shank line connects a proximal reference, at the midpoint between the medial and lateral extremes of the tibial plateau, and a distal reference, at the midpoint between the medial and lateral malleoli. These references were obtained with an analogic caliper rule. Initially, the examiner placed the ankle at 0° of flexion–extension and measured it with a goniometer. Then, the subject was asked to actively maintain this position while the examiner measured the forefoot–shank angle. The required muscle contraction hampers palpation of the talus. Thus, the subtalar joint was not placed in neutral position as in traditional measures (Michaud, 1993). To measure the forefoot–shank angle, the fixed arm of the goniometer was aligned with the shank line and the moving arm was visually aligned with a rod fixed with velcro® on the plantar surface of the metatarsal heads (Fig. 2A). To standardize the transverse-plane position of the assessed lower limb, the posterior aspect of the calcaneus was maintained facing upwards by positioning the contralateral lower limb with hip external rotation and knee flexion. The same examiner conducted this measurement in all subjects. Three repetitions were carried out and their mean value was registered for each subject. For this measure, greater inversion angles of forefoot–shank result from a combination of greater varus alignments and midfoot inversion mobility (Fig. 3). Positive scores represented inverted positions. The description of ankle–foot alignment and mobility components is shown below.

2.2.1.2. Components of foot–ankle bone alignment. Since the forefoot–shank angle is a relationship between the metatarsal heads and a line on the shank, varus/valgus bone alignments of rearfoot and forefoot influence this angle (Fig. 3) (Mendonça et al., 2013). The shank line used, instead of the traditional line representing only the distal third of the shank (Tomaro, 1995), allowed including also tibio-fibular varus/valgus in the final angle obtained (Fig. 3).

2.2.1.3. Component of midfoot inversion mobility. The forefoot–shank angle is also influenced by the inversion mobility at the midfoot joints (Fig. 3D). Activity of the tibialis anterior muscle was required to maintain the ankle positioned at 0° of flexion–extension (Fig. 2B). Because the insertions of this muscle on the mid- and forefoot are medial, contraction pulls the midfoot joints into inversion. The result is inversion of the line of the metatarsal heads (Fig. 3D). The amount of inversion depends on the mobility at the midfoot joints, such that the greater the mobility, the greater the inversion produced (Holt & Hamill, 1995; Mendonça et al., 2013).

2.2.2. Mobility of hip internal rotation

The passive mobility of hip internal rotation was measured as the "position of first resistance" described by Carvalhais et al. (2011) (Fig. 4), with an analogic inclinometer. Hip internal rotation values