EFFECTS OF SIMULATING FOREFOOT VARISM INCREASES ON LOWER EXTREMITY KINEMATICS DURING THE STANCE PHASE OF WALKING

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This study investigates the effects of simulating forefoot varism increases on lower extremity kinematics during the stance phase. Sixteen volunteers walked on a walkway in three conditions: wearing flat sandals; wearing a 5º and a 10º laterally wedged sandal. Data were obtained with a 3-D motion analysis system. The variables analyzed were: subtalar eversion/inversion; shank internal/external rotation; knee internal/external rotation; hip internal/external rotation. The simulations of 5º and 10º increases in forefoot varism increased subtalar pronation ($P \leq .007$) and the simulation of 10º increased internal rotation of the shank in relation to the pelvis and of the hip ($P = .001$). The results suggest that forefoot varism can lead to kinematic patterns related to the occurrence of overuse injuries.

KEY WORDS: gait, forefoot, varism, kinematics, simulating, stance phase.

INTRODUCTION:

Excessive subtalar pronation, during sports and daily-living activities, has been related to the occurrence of several musculoskeletal injuries (Michaud, 1993; Tiberio, 1988; Willems et. al., 2006). Biomechanical theoretical models suggested that an increase in subtalar pronation during walking causes an increase in the lower extremity internal rotation (Powers, 2003). Talus adduction is one component of the talus motion that occurs during the subtalar pronation in a closed kinematic chain (Rockar Jr, 1995). Therefore, an increase in this movement could lead to an excessive internal rotation of the shank and thigh segments and of the knee and/or hip joints (Michaud, 1993). Although these statements are frequently accepted they have been rarely tested (Nester et al., 2003).

Subtalar joint motion and lower extremity transverse plane rotation during activities performed in closed kinetic chain can be influenced by forces proximally originated at the hip joint (Powers, 2003) and distally originated at the subtalar joint (Bellchamber e van den Bogert, 2000). The alignment of foot structures has been considered one of the distal factors that influence subtalar motion (Tiberio, 1988). The presence of excessive forefoot varism is frequently related to the occurrence of excessive subtalar pronation (Donatelli et. al., 1999) and to the development of many pathologies such as shin splints (Sommer e Vallentyne, 1995), lower limb stress fractures (Korpelainen et. al., 2001) and patellofemoral pain (Lun et. al., 2004). Therefore, in consequence of this altered alignment, excessive subtalar pronation and increased lower extremity internal rotation could occur as compensatory movements (Tiberio, 1988; Michaud, 1993).

Donatelli et al. (1999) investigated the differences between forefoot alignment of professional baseball players who did or did not present the subtalar joint in a pronated position during the whole stance phase of walking. They observed that subjects who maintained the subtalar joint pronated had greater values of forefoot varism. Cornwall et al. (2004) compared frontal plane subtalar movement of asymptomatic subjects who had forefoot varus with subjects who had forefoot neutral and valgus. In contrast to Donatelli et al. (1999), they did not find any significant difference related to the magnitude of subtalar pronation during walking. These contradictory results may be due to the great between-subjects variability of the lower limb kinematic behavior during walking, which may decrease the power of these studies statistical analyses or their ability to detect a possibly existent difference.

Furthermore, the variability of frontal and transverse planes walking kinematics is greater than the variability of sagittal plane kinematics (Kadaba, 1989). Therefore, between-subjects comparisons of the lower extremity kinematics in these motion planes make it difficult to identify the effect of one isolated factor on these movements and could have influenced the determination of the real effect of excessive forefoot varism presence on the subtalar kinematic behavior.

Consequently, there is not a consensus about the influence of the excessive forefoot varism on subtalar and lower extremity movements during walking. Thus, the aim of this study was to investigate, using within-subject comparisons, the effects of simulating increases in forefoot varism on lower extremity kinematics during the stance phase of walking.

METHOD:

Subjects: Sixteen young health subjects (8 men and 8 women) were recruited with mean age, mass and height of 23.4 years (SD 2.40), 63.8Kg (SD 7.60) and 1.70m (SD 0.06), respectively, participated in the study. To be included in the study the volunteers should present rearfoot, forefoot and tibial maximum varism of 4º, 7º and 4°, respectively. They should also present at least 10° of passive eversion and 28° of passive inversion in the subtalar joint, and 30° of active internal rotation and 40º of active external rotation in the hip joint. Furthermore, the participants could neither have leg length discrepancy more than 1cm nor have presented any pain or pathology in the lower limb.

Instrumentation and Procedures: A 3-dimensional motion analysis system (ProReflex, Qualisys Medical AB, Gothenburg, Sweden) was used to capture passive markers positions and obtain kinematic data about the pelvis and right lower extremity. The anatomic markers were positioned on specific locations in order to allow the construction of the rigid bodies and coordinate systems for the all bodies segments. Rigid clusters with tracking markers, were attached to the pelvis, right thigh, right shank and right calcaneus. It was used a 120Hz collection frequency. The participants walked in their natural speed throughout a 10m walkway wearing tracking sandals in three randomized conditions: wearing flat sandals on both feet (control); wearing a 5º laterally wedged sandal; wearing a 10º laterally wedged sandal. Ten trials were carried out for each condition.

Data Processing and Analysis: The data were processed through the Visual 3D Motion Analysis Software (C- Motion, Inc., Rockville, USA). The movement of the subtalar joint was defined as the movement of the foot in relation to the shank of the same lower limb. The cluster which determined foot motion was attached isolated to the calcaneus what permitted to calculate the movement of the calcaneus in relation to the shank. Subtalar pronation/supination was then measured in the frontal plane (X-axis) through the eversion/inversion component of this joint movement. The duration of the stance phase of each trial was determined visually by two tracking markers attached to the sandal's sole. This procedure made it possible to identify the following events: heel contact (HC), forefoot contact (FC), heel rise (HR), and toe off (TO). The stance phase was then divided into 3 subphases: loading response, mid stance, and late stance.

The following dependent variables were obtained during the data reduction for each study condition: Subtalar eversion/inversion: mean value of the subtalar motion in the frontal plane (X-axis); Shank internal/external rotation in relation to the pelvis: mean value of the shank movement relative to the pelvis in the transverse plane (Z-axis); Knee internal/external rotation: mean value of the knee motion in the transverse plane (Z-axis); Hip internal/external rotation: mean value of the hip motion in the transverse plane (Z-axis). Each joint angle was calculated for each of the 3 stance subphases in a total of 12 dependent variables (4 joint angles X 3 subphases of stance).

One-way repeated measures analyses of variance (ANOVA) were used to compare each dependent variable in each subphase of stance between the study conditions with the α level at .05. Pre-planned contrasts were made to locate significant differences. Bonferroni corrections were made according to the number of contrasts (6 comparisons), dividing the α level (.05) by the numbers of comparisons (6), setting the α level for the contrast analyses at .008.

RESULTS:

Subtalar eversion/inversion

The ANOVA demonstrated significant differences in subtalar movement between the conditions and stance subphases ($F_{8.120}$ = 23.89, P<.001). The contrast analyses located significant differences between the control condition and each experimental condition, only during the mid stance subphase. The 5°EC and 10°EC caused a mean (±SD) increase in subtalar eversion of 0.88° ± 1.13° (95% CI, 0.27-1.49, $F_{2.30}$ = 9.65, P = .007) and 1.35° ± 1.03° (95% CI, 0.80-1.90, $F_{2.30}$ = 27.78, P<.001), respectively, compared to the control condition.

Shank internal/external rotation in relation to the pelvis

The ANOVA demonstrated significant differences in the movement of the shank in relation to the pelvis between the conditions and stance subphases ($F_{8.120}$ = 6.33, P<.001). The contrast analyses located significant differences between the control condition and the 10°EC, only during the mid stance subphase. The 10°EC caused an increase in shank internal rotation relative to the pelvis of 1.41° ± 1.36° (95% CI, 0.68-2.13, $F_{2.30}$ = 17.03, P = .001) in comparison to the control condition.

Knee internal/external rotation

The ANOVA demonstrated significant differences in knee movement between the conditions and stance subphases ($F_{8.120}$ = 36.57, P<.001). However, the contrast analyses did not find any significant difference between the control condition and each experimental condition in the stance subphases (P>.008).

Hip internal/external rotation

The ANOVA demonstrated significant differences in hip movement between the conditions and stance subphases ($F_{8.120}$ = 29.57, P<.001). The contrast analyses located significant differences between the control condition and the 10°EC, only during the mid stance subphase. The 10°EC caused an increase in hip internal rotation of 1.38° ± 1.33° (95% CI, 0.67-2.10, $F_{2.30}$ = 17.35, P = .001) in comparison to the control condition.

DISCUSSION:

Simulations of 5° and 10° increases in forefoot varism caused the subtalar joint to pronate significantly more. These results suggest that forefoot varism may be a causing factor for excessive subtalar pronation during walking. This effect was only observed during the mid stance subphase, after the forefoot had reached the ground.

There was an internal rotation increase of the shank with respect to the pelvis in the 10°EC, during the mid stance. This result agrees with the theoretical models which have stated that excessive subtalar pronation can lead to increased mechanical stress on the anatomical structures that link the shank to the pelvis, as a result of a greater shank internal rotation (Krivickas, 1997). This altered movement may result in iliotibial band friction (Krivickas, 1997) and patellofemoral pain syndromes (Powers, 2003).

There were no changes in knee transverse plane movement in the experimental conditions even with the increase in shank internal rotation relative to the pelvis in the 10ºEC. In addition, the 10ºEC caused a significant increase in hip internal rotation during the mid stance. These finding confirms the existence of rotational kinetic energy transfer from the shank to the thigh through knee intersegmental force and supports the biomechanical models that suggested this transverse plane coupling between subtalar joint and hip during the stance phase of walking, leading to the development of overuse pathologies such as grater trochanteric bursitis and low back pain (Michaud, 1993). It is important to stress that the effects demonstrated in the study are due to immediate interventions, permitting only temporary viscoelastic tissue adaptations.

CONCLUSION:

The simulations of 5º and 10º increases in forefoot varism cause increases in subtalar joint pronation and the simulation of 10º increase can lead the shank and the hip joint to internally rotate more, during the mid stance. This study demonstrated a cause-and-effect relationship between increased subtalar pronation and increased lower extremity internal rotation during the stance phase of walking. These results suggest that the presence of excessive forefoot varism can lead to lower limb kinematic changes frequently associated to the development of several musculoskeletal pathologic conditions and that forefoot alignment should be assessed in clinical practice.

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