INTRODUCTION

Prior research has shown that an individual with a large forefoot varus has a greater risk of having hip pain from osteoarthritis and is five times as likely to have a total hip replacement\(^1\). However, the biomechanical mechanisms that link foot structure to injury are not well understood. It is proposed that this may be because of two factors. First, the traditional clinical measure of foot structure has poor reliability and questionable validity\(^2\). Second, few studies include forefoot kinematics when investigating the relationship between foot structure and injury. The purposes of this study were twofold: 1) to determine the relationship between a newly developed non-weight bearing clinical measure of forefoot and rearfoot orientation, and measures of forefoot and rearfoot orientation at ground contact during gait; and 2) to determine the difference in duration and amplitude of pronation between two groups divided on degree of varus foot orientation.

METHODS

Fourteen subjects participated (23.6 ± 4.9 years of age). All subjects had a right forefoot varus greater than or equal to 15° using a new clinical orientation measure. For this measure, clinical rearfoot and forefoot orientations were obtained from digital photographs using Canvas X (ACD Systems). The photographs were taken with the participant in prone position. The newly developed measure assessed orientation relative to an external (vs. internal) reference frame. Specifically, the new rearfoot orientation was assessed as the angle formed by a line bisecting the calcaneus and the horizontal edge of the table (Fig 1, A). The new forefoot orientation was determined by the angle formed by the line connecting the first and fifth metatarsal heads and the table (Fig 1, B).

Figure 1: New clinical measure: Rearfoot (90° - A) and Forefoot (B) orientation to the ground with the ankle joint held in neutral

Three dimensional (3D) kinematics of the right foot were obtained using a motion capture system, during over ground walking. Data were collected using eight cameras arranged around a force plate. Participants wore sandals (Bite LLC). Thirteen ankle and foot markers were used based on the model of Leardini et al (1997)\(^3\).

Participants walked at three speeds: slow, preferred and fast. 3D segment angles were calculated using Visual 3D software with an x (flexion/extension), y (abduction/adduction), and z (axial rotation) Cardan rotation sequence. Stance interval was identified using ground reaction force data. Angles were referenced to those measured during standing and time normalized from 0-100 percent. Forefoot orientation and rearfoot orientation were measured at forefoot and rearfoot contact respectively as determined from marker data. Duration of forefoot...
pronation was defined as the percent of stance between contact and forefoot re-supination.
Likewise, duration of rearfoot pronation was the percent of stance between contact and rearfoot re-supination. A General Estimating Equation Analysis (GEE, Linear) was used to test if the new clinical forefoot and rearfoot orientation measures could predict forefoot and rearfoot orientation at contact. Participants in this study were grouped twice into equal groups of Large or Moderate orientation angles: once based on forefoot varus orientation and once based on rearfoot orientation at contact (Table 1). Two separate two factor ANOVAs were performed for forefoot and rearfoot. The two factors were group (Large and Moderate) and speed (preferred, slow, fast).

![Figure 2: Mean trajectories of groups indicating amplitude and duration of forefoot pronation. Vertical lines indicate where pronation ended for the Moderate (dotted) and Large (solid) groups.](image)

The relation between increased hip injury risk and increased pronation amplitude and duration can be explained by the functional relationship between the foot and the hip. The relative timing of forefoot, rearfoot, tibia and femur motion may be disrupted in an individual when forefoot pronation is prolonged. Consistent with Gross et al’s (2007) finding that a large forefoot, not rearfoot, varus is associated with injury, this study suggests that it is a large forefoot varus which predicts greater and prolonged forefoot pronation associated with injury. In contrast, most studies investigating mechanisms of injury report only rearfoot kinematics and most orthoses prescribed for foot related injuries only address rearfoot structure and movement.

### RESULTS AND DISCUSSION

The new clinical measure of forefoot orientation predicted the forefoot orientation at ground contact (p<.01, W=18.7). This indicates that an individual with a greater clinical forefoot varus will have a larger forefoot varus orientation when the forefoot contacts the ground. Clinical rearfoot orientation did not predict rearfoot orientation at contact (p =1.0, W=.00). Speed did not influence either rearfoot or forefoot contact orientations.

The group of individuals with large forefoot varus orientation at forefoot contact had greater amplitude (4.1° ± .7 versus 7.8° ± .7, p < .01) and duration (64.1% ± 1.1 versus 67.7% ± 1.1, p = .05) of forefoot pronation than the group with a moderate forefoot varus orientation at forefoot contact (Fig 2). The Large and Moderate groups based on rearfoot varus orientation at contact were not significantly different in amplitude (3.5° ± .80 versus 5.6° ± .80, p =.1) or duration (71.0% ± 2.2 versus 72.1% ± 2.2, p=.75) of rearfoot pronation.

### Table 1: Means and S.E of Group Orientation Angles at contact

<table>
<thead>
<tr>
<th>Groups</th>
<th>Forefoot Grouping</th>
<th>Rearfoot Grouping</th>
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<tbody>
<tr>
<td>Moderate</td>
<td>2.6° ± 1.1</td>
<td>0.7° ± 0.5</td>
</tr>
<tr>
<td>Large</td>
<td>5.4° ± 1.4</td>
<td>3.1° ± 1.3</td>
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### CONCLUSION

This study suggests that a new clinical measure of forefoot structure using an extrinsic reference frame can predict forefoot behavior during gait and that forefoot structure may significantly contribute to musculoskeletal injuries associated with foot function.

### REFERENCES