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KINEMATICS OF THE FIRST AND FIFTH METATARSALS AS DETERMINED BY HIGH-SPEED DUAL FLUOROSCOPY

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Introduction

Tarsometatarsal and metatarsophalangeal osteoarthritis (OA) is a degenerative condition that affects one or more of the joints in the midfoot. While it is more prominent in older patients, younger patients may show signs of the disease as well. Osteoarthritis in this area can cause limited joint function, pain, and stiffness, in addition to restricting activity and increasing the risk of falling[6].

Foot OA may be caused by excessive flexion and wear of the ligaments surrounding the tarsometatarsal and metatarsophalangeal joints.[3] Several biomechanical models of the foot have been developed to independently investigate motions, such as flexion, in the hindfoot, midfoot, forefoot, and hallux.[1,2] However, these models often assume that multiple bones move together as a single rigid body for these segments. One previous study showed that the 1st metatarsal undergoes rotation during the midstance phase of the gait cycle and suggested that the metatarsals are dynamic systems subject to their own unique translations and rotations.[5] The objective of this study was to use dual fluoroscopy (DF) to quantify individual movement of the first and fifth metatarsals in healthy control subjects during stair descent so as to establish normative data in which to compare to patients with foot and/or ankle OA in the future.

Methods

A DF system consisting of two X-ray emitters, two image intensifiers, and two high-speed cameras were placed around two custom wooden steps. The fluoroscopes were approximately 90° from one another, which allowed for the quantification of three-dimensional (3D) *in vivo* bone motion within the combined field-of-view of the fluoroscopes. Three healthy control subjects (1 female; age: 29.7 ± 5.0 yo; BMI: 23.3 ± 2.9 kg/m^2) were enrolled in this study (Institutional Review Board #65620). Dual fluoroscopy images of the foot and ankle were acquired at 200 Hz while subjects stood in a static position and descended two stairs. The calcaneus and first and fifth metatarsals were segmented from computed tomography scans acquired of each subject from the mid-tibia through toe-tips. Bone segmentations were used to create digitally reconstructed radiographs (DRRs). Custom model-based tracking software was used to semi-automatically align the DRR of each bone with the DF images to quantify the 3D position and orientation of each bone throughout each activity.

Anatomical landmarks were used to determine coordinate systems for each bone. The coordinate systems of all bones were aligned in the static position. Model-based tracking results were used to determine rotation angles of the first and fifth metatarsals relative to the calcaneus according to the Grood and Suntay method[4]. Translations were calculated as the distance between bone origins in the medial-lateral, anterior-posterior, and superior-inferior directions. Rotational and translational range of motion (ROM) was calculated as the absolute value of the maximum rotation or translation minus the minimum rotation or translation during stair descent. Differences between the first and fifth metatarsal ROM were compared using a two-sided paired t-test.

Results

On average, the first and fifth metatarsals exhibited similar dorsi/plantarflexion (D/P) angles in relation to the calcaneus during stair descent. However, the fifth metatarsal exhibited greater mean dorsiflexion than the first metatarsal at initial loading (Figure 1, top). Besides a spike in eversion for the fifth metatarsal at foot strike, the first and fifth metatarsals demonstrated similar mean inversion/eversion (In/Ev) angles in relation to the calcaneus during stair descent (Figure 1, middle). The first and fifth metatarsals demonstrated similar mean internal/external rotation (IR/ER) angles in relation to the calcaneus during stair descent. (Figure 1, bottom).

The In/Ev ROM of the fifth metatarsal was significantly greater than that of the first metatarsal ($p < 0.05$) (Figure 2). Although the translational ROM for the first metatarsal was consistently greater than that of the fifth metatarsal in all directions, the results were not significant ($p > 0.05$) (Figure 2)

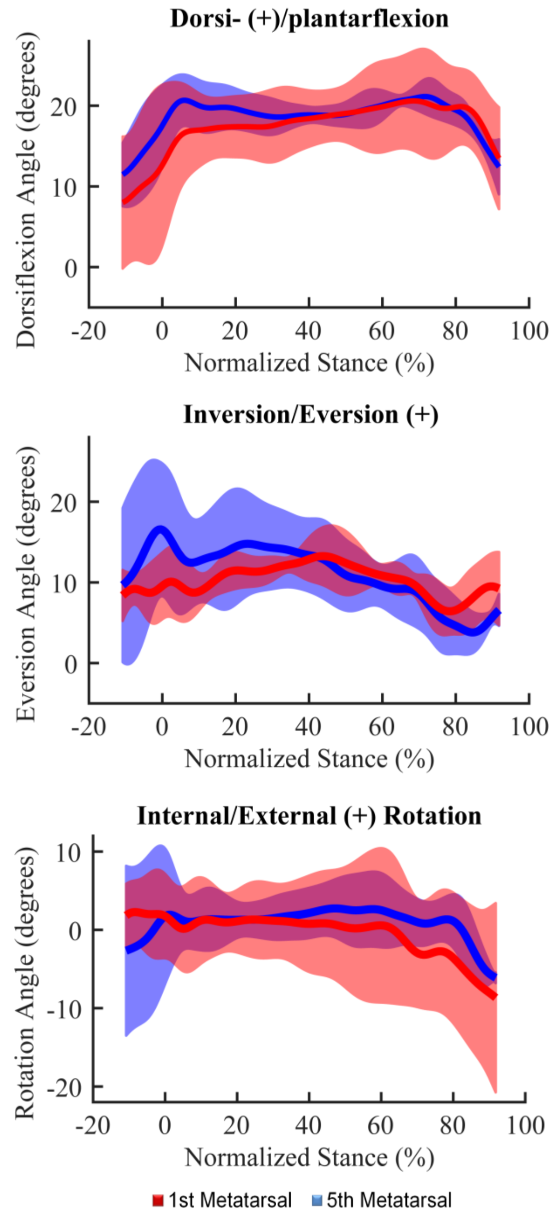

Figure 1: Mean ± 1 standard deviation dorsi/plantarflexion (top), inversion/eversion (middle), and internal/external rotation (bottom) angles for the first (red) and fifth (blue) metatarsals relative to the calcaneus during stair descent for the three subjects. Thick lines represent mean angles; shaded areas represent ± 1 standard deviation from the mean.

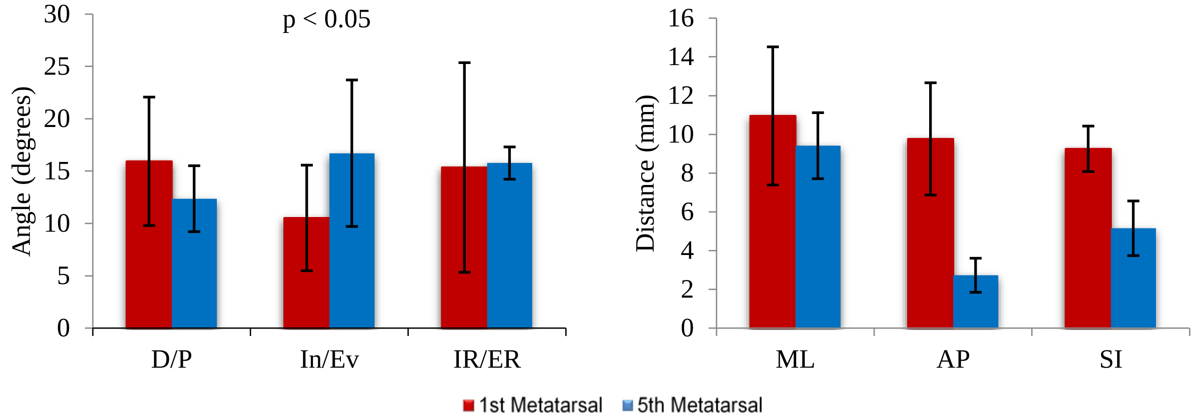

Figure 2: Mean rotational (left) and translational (right) range of motion for the first (red) and fifth (blue) metatarsals during stair descent. Error bars represent 1 standard deviation. Rotations: D/P = dorsi/plantarflexion, In/Ev = inversion/eversion, and IR/ER = internal/external rotation. Translational directions: ML = medial-lateral, AP = anterior-posterior, and SI = superior-inferior.

Discussion

Despite the similarities between the first and fifth metatarsal angles, there are some slight differences during the loading and unloading portions of stair descent. Specifically, these results indicate that there may be greater variation across subjects for first metatarsal IR/ER during unloading and fifth metatarsal In/Ev during loading. However, a greater subject sample size may show that the differences in movement between first and fifth metatarsals are negligible. Future studies will investigate individual metatarsal movement in a variety of activities to ascertain if this trend is consistent across loading modalities. As the first and fifth metatarsals exhibited similar mean motion throughout stair descent, musculoskeletal models that assume the forefoot to be one rigid segment may be sufficient for motion analysis, depending on the application. However, evaluation of individual metatarsal arthrokinematics may be necessary to fully understand the pathomechanics of osteoarthritis in the tarsometatarsal and metatarsophalangeal joints.

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