FOOT BONE MOTION DURING MIDSTANCE

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INTRODUCTION

Foot bone motion during weight-bearing is not completely understood. Previous research has employed X-ray photogrammetric techniques to describe the axes of foot joints (Lundberg et al., 1989a; Lundberg et al., 1989b; Lundberg et al., 1989c) or MR imaging to quantify nonweight-bearing motion (Udupa et al., 1998). Cadaveric models have been used to study weight-bearing conditions, although the motion of the individual bones of the foot was not quantified (Sharkey, 1998).

Our laboratory has developed a test protocol to simulate weight-bearing conditions on cadaveric feet (Ching et al., 1999; McCormack et al., 1998). Tests have been conducted to study well aligned, low arched (pes planus or flat foot) and high arched (pes cavus) feet.

This abstract will discuss bony rotations of well aligned feet for several loading conditions. Loads were applied to the tibia and Achilles tendon while the foot was in midstance position and the motions of the individual bones of the foot were measured.

METHODS

Ten fresh cadaver lower leg and foot specimens were obtained through the University of Washington Department of Biological Structure. Radiographic screening was performed to rule out pre-existing pathology. The soft tissue surrounding the tibial shaft was removed from each specimen, thereby exposing the extrinsic muscle tendons; only the Achilles tendon was used in the aspect of the study discussed here. Carbon fiber pins were placed into the tibia (ti), calcaneus (ca), talus (ta), navicular (na), cuboid (cu), first metatarsal (1m), and fifth metatarsal (5m). An acrylic rod was inserted into the intra-medullary canal of the tibia and cross-locked to allow for axial compressive loading of the foot. Each foot was then wrapped with moist towels and stored in plastic bags at -20°C until used.

For this study, only tibial and Achilles tendon loads were applied. A custom, acrylic foot-loading frame was fabricated. A pneumatic cylinder was used to load the foot via the tibial intramedullary rod, and a nylon cable and tendon clamp were used to connect the Achilles tendon to a second pneumatic cylinder. By adjusting the air pressure to each cylinder, the tibial compressive (T) and Achilles tendon tensile (A) loads could be controlled to generate the following loading conditions (in Newtons): T100-A0, T200-A0, T300-A0, T200-A100, T400-A200, and T600-A300. Since no other extrinsic muscles are included, these tests are only meant to simulate conditions that are on the order of physiologic loads.

Polhemus electromagnetic motion sensors (Fastrak 3-Space, Polhemus Inc., Colchester, VT) were used to record the 3-D motions of the foot bones. The sensors were attached via acrylic mounting blocks to the carbon fiber pins inserted in the seven bones of interest. Each sensor tracked the full six degree-of-freedom motion of the bone to which it was attached relative to a fixed transmitter. The motion data were recorded using a standard desktop personal computer. Positional and rotational accuracy of the sensors were verified to within 1-mm translation and 0.25-degree rotation.

RESULTS

The measured foot bone motions were similar, for the most part, to the motions expected due to bone morphology. As an example, the calcaneus plantar flexed under the applied loading conditions (Figure 1). Additionally, the relative bony rotations were expected. To demonstrate this concept, the rotation of all six bones for the T600-A300...
loading condition in the three cardinal planes was given (Figures 2, 3 and 4). The tibia, although instrumented, was not included since the frame restricted its motion.

Figure 1: The rotation of the calcaneus in the sagittal plane (+ = dorsiflexion, - = plantar flexion) for the various conditions.

Figure 2: Rotation of the foot bones in the frontal plane (+ = eversion, - = inversion) for the T600-A300 condition.

Figure 3: Rotation of the foot bones in the sagittal plane (+ = dorsiflexion, - = plantar flexion) for the T600-A300 condition.

Figure 4: Rotation of the foot bones in the transverse plane (+ = internal, - = external) for the T600-A300 condition.

DISCUSSION
The bones of the foot demonstrated rotations that were mostly consistent with their bony morphology. Increased loading led to increased calcaneal motion in the sagittal plane. Note the effect of the Achilles tendon; the motion of the calcaneus increased when the tendon was loaded (compare T200-A0 to T200-A100 in Figure 1). The inversion of the talus was not expected, while the eversion of the remaining bones was (Figure 2). The plantar flexion of the talus, calcaneus, navicular and cuboid, and the dorsiflexion of the first and fifth metatarsal (Figure 3) demonstrated that the expected motion in response to loading the tibia and the Achilles tendon. The talus internally rotated more than the other bones (Figure 4), indicative of talar escape. The navicular and cuboid bones moved in very similarly in all planes, which was expected due to the tight ligamentous structures between them. Future work will involve physiologic loading simulations with all of the extrinsic muscles.

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REFERENCES