THREE-DIMENSIONAL IN VIVO KINEMATICS OF THE FOOT IN DORSIFLEXION AND PLANTAR FLEXION

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Relevance to Musculoskeletal Conditions: Quantitative descriptions of 3D in vivo kinematics of the bones of the normal adult hindfoot, followed by the normal pediatric hindfoot, are necessary prerequisites for an engineering analysis of various pediatric pathological conditions. These descriptions will provide a standard for objective evaluation of surgical therapies for these conditions.

Introduction: Optimal treatment of clubfoot and other pediatric foot disorders remains controversial. Previous kinematics studies have included techniques that are invasive or expose subjects to radiation. The ultimate goal of this study was to develop a method for quantifying the kinematic alterations of pediatric foot disorders and establish a basis against which the result of various surgical treatments may be compared. Towards this goal, the specific aim of the present in vivo study was to quantify the normal kinematics of the adult male hindfoot (preparatory to an analogous study of the normal pediatric hindfoot) through the use of magnetic resonance imaging and three-dimensional image analysis.

Methods: Five healthy male subjects (18-30 years of age) were recruited into this IRB-approved study. Subjects had no history of foot or ankle trauma and a physical examination of the right foot and ankle was performed to ensure normal motion. Each subject was placed in the supine position in the bore of a 1.5 tesla Siemens magnetic resonance imaging system. The right leg, ankle, and foot were secured in a positioning device allowing only dorsiflexion and plantar flexion motion of the ankle. A series of 64 magnetic resonance images (slice thickness 1.5 mm) were taken of the right foot and ankle in the sagittal plane (field of view=240 mm, matrix size 256×256) using a FLASH 3D protocol. A 10-cm coil was used to image the area from the distal end of the tibia to the proximal end of the third metatarsal. Images were then taken at successive 10° increments until a total of 25° of plantar flexion had been achieved. A 3D image analysis program was used to determine motion of the tarsal bones. The talus, calcaneus, navicular, and cuboid were segmented on each image slice. Interpolation, filtering, and thresholding techniques were used to create 3D volumes of these bones. The centroids of each of these bones were identified and the lines connecting these centroids were used to form triangles.

Results: Analysis of the data from 3 of these subjects has been completed as of this date. The average age, height, and weight of these 3 participants were 24.7±2.1 years, 69±0 inches, and 200±30 pounds. A total of 960 images (3 subjects×5 positions×64 slices) have been analyzed. Motion at the talonavicular, subtalar, and calcaneocuboid joints was of particular interest in this study. The changes in the interior angles of the triangle formed by the talus, cuboid, and calcaneus and those of the triangle formed by the talus, navicular, and calcaneus were observed as a function of foot position. Figure 1 shows magnitudes of the angles at these joints for dorsiflexion-plantar flexion motion.

Discussion: This in vivo study has established an engineering model of the normal adult male hindfoot by quantifying linear and angular changes between bones during dorsiflexion-plantar flexion. This study has also demonstrated the usefulness of MR imaging with three-dimensional analysis in evaluating these kinematic changes.


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Figure 1. Average angles between selected bones for the dorsiflexion (D) to plantar flexion (P) motion (n=3). Note: t-cu-ca is the angle formed by the cu with the t and ca, cu-t-ca by the t with the cu and ca, t-ca-cu by the cu with the t and cu, t-ca-cu by the n with the t and ca, n-t-ca by the t with the n and ca, n-ca-t by the cu with the n and t.