INTRODUCTION

Accurate knowledge of in-vivo ankle joint complex (AJC, including talocrural and subtalar joints) biomechanics is critical for understanding AJC disease states and for improvement of surgical treatments of the diseased joint. This study investigated 6 degree-of-freedom (DOF) in-vivo kinematics of the human AJC during the simulated stance phase of walking using a combined dual-orthogonal fluoroscopic and magnetic resonance (MR) imaging technique.

MATERIALS AND METHODS

Five healthy ankles of living subjects (age 32-43, 4 male and 1 female) were magnetic resonance (MR) imaged on a 1.5-T magnet (GE, Milwaukee, WI) using a surface coil and three-dimensional spoiled gradient-recalled (3D SPGR) sequence with the subject lying supine. Sagittal plane images at 1 mm intervals with a resolution of 512 x 512 pixels were acquired (Fig. 1A). A 3D anatomic model of each ankle, including the tibia, talus and calcaneus, was constructed from the MR images (Fig. 1B). The in-vivo ankle positions were then captured at three weightbearing positions (heel strike, mid-stance, toe off) during the simulated stance phase of walking using a dual-orthogonal fluoroscopic imaging technique [1] (Fig. 2). In-vivo AJC motion was then reproduced by manipulating the 3D AJC models in the virtual space until their projected contours matched the two sets of fluoroscopic images concurrently. The in-vivo kinematics of the AJC after injuries were obtained from the series of AJC models (Fig. 3).

The AJC motion was defined in two parts, the talocrural joint motion (relative motion of the talus with respect to the tibia) and subtalar joint motion (relative motion of the calcaneus with respect to the talus). Body-fixed coordinate system was built up for each bone (Fig. 1B). The ranges of motion of the talocrural and subtalar joints from heel strike to mid-stance, and from mid-stance to toe off were presented.

A repeated measure ANOVA was used to compare the motion of the talocrural and subtalar joints. The statistically significant difference was defined as p<0.05.

RESULTS

Heel Strike to Mid-stance

As shown in Table 1, motion of the talocrural joint showed 3.8° ± 8.2° of internal rotation, 9.1° ± 5.3° of plantarflexion and 0.1° ± 2.6° of inversion. The talus translated proximally by 0.1 ± 0.3mm, medially by 0.3 ± 0.8mm, and posteriorly by 0.2 ± 1.3mm. The motion of the subtalar joint during the same foot motion was 1.5° ± 9.9° of external rotation, 0.9° ± 1.2° of dorsiflexion and 1.7° ± 2.7° of eversion. Translation of the calcaneus with respect to the talus was 0.6 ± 0.7mm proximally, 0.5 ± 1.1mm laterally, and 0.2 ± 0.7mm posteriorly.

The plantarflexion motion of the talocrural joint was statistically significantly larger than that of the subtalar joint (p=0.021). The internal rotation and inversion-eversion angles of the two joints were statistically similar (p>0.05). All translations of the two joints were shown to be statistically similar (p>0.05). All translations of the two joints were shown to be statistically similar (p>0.05). All translations of the two joints were shown to be statistically similar (p>0.05). All translations of the two joints were shown to be statistically similar (p>0.05). All translations of the two joints were shown to be statistically similar (p>0.05).

Mid-stance to Toe Off

As shown in Table 1, motion of the talocrural joint showed 1.6° ± 5.9° of external rotation, 4.4° ± 13.2° of plantarflexion and 1.7° ± 2.7° of inversion. The talus translated proximally 0.0 ± 1.0mm, medially 0.0 ± 0.3mm, and anteriorly 0.3 ± 1.2mm. The motion of the subtalar joint during the same foot motion was 12.5° ± 8.3° of internal rotation, 8.5° ± 2.9° of plantarflexion, and 10.7° ± 3.8° of inversion. Translation of the calcaneus with respect to the talus demonstrated 1.5 ± 0.8mm of distal translation, 0.4 ± 3.4mm of lateral translation, and 2.1 ± 1.6mm of anterior translation.

The internal rotation and inversion motions of the subtalar joint were statistically significantly larger than those of the talocrural joint (p=0.046, 0.020, respectively). The dorsi/plantarflexion motions of the two joint were shown to be statistically similar (p>0.05). All translations of the two joints were shown to be statistically similar (p>0.05).

DISCUSSION

Strong kinematic coupling between the talocrural and subtalar joints was observed during in-vivo AJC activities. The talocrural joint demonstrated larger motion during the early part of stance phase while the subtalar joint contributes more motion during the later part of stance phase. The results add quantitative data to an in-vivo database of normals that can be used in clinical diagnosis, treatment and evaluation of the AJC after injuries.

REFERENCES

1. Li et al, J Biomech Eng, 2004

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