IN VIVO ANKLE LIGAMENT ELONGATION PATTERNS DURING GAIT

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INTRODUCTION

The ankle ligaments are critical in maintaining joint stability and congruity. Understanding in vivo elongation behavior and recruitment patterns of these ligaments in normal, healthy ankles may inform rehabilitation and surgical protocols, or improve designs of ankle replacements. Standard methods for quantifying foot bone kinematics, such as motion capture, cannot resolve individual bone trajectories accurately enough to estimate ligament elongation. Biplane fluoroscopy allows for accurate, direct quantification of in vivo foot bone motion [1]. The goal of this study is to develop methods for estimating in vivo ankle ligament elongation patterns during functional tasks, like gait and turning.

METHODS

Healthy, asymptomatic control subjects were enrolled in an on-going, IRB-approved investigation of in vivo motion capture skin-motion marker artifact. Data for three (n=3) subjects were analyzed for this study.

Subject-specific computed tomography (CT) scans (120kVp, slice thickness: 0.625 mm, in-plane resolution: 0.69-0.97 mm) were acquired of the distal tibia and foot at 20% bodyweight via a static foot loading frame. Foot and ankle bones (tibia, fibula, talus, and calcaneus) were segmented from the CT image volumes using Mimics software (v15, Materialise, Belgium). The edges and grayscale contrast of soft tissues in the CT images were enhanced in Mimics using image processing filters, and the bony origins and insertions of four ankle ligaments (calcaneofibular, anterior tibiotalar, posterior tibiotalar, tibiocalcaneal) were manually identified for each subject with the aid of osseous landmarks on the segmented surface models.

Subjects performed gait trials at self-selected speeds in a biplanar fluoroscopy system while stereo high-speed (1000Hz) image pairs of the foot and ankle were acquired. Concurrent motion capture (VICON, Oxford UK) tracked several markers on the foot; this was used to detect heel strike and toe off. Bone kinematics were calculated by matching subject-specific digitally reconstructed radiographs to the fluoroscopic image pairs in custom DRRACC bone tracking software [2]. DRRACC outputs the transformation matrices describing the motion of each bone in the lab coordinate system. These kinematic data were filtered with a 2nd-order Butterworth low-pass filter at 10Hz. Custom MATLAB (Mathworks, USA) software combined the ligament origin and insertion data and kinematic transformation matrices to estimate each ligament as a linear three-dimensional vector connecting the ligament origin and insertion. Ligament elongations were calculated relative to the CT-scan resting lengths as a function of the stance phase of the gait cycle.

RESULTS AND DISCUSSION

The elongation patterns of the tibiocalcaneal and calcaneofibular (Figure 1) and anterior and posterior tibiotalar (Figure 2) ligaments are shown as a function of gait cycle. Tibiocalcaneal ligaments stretched ~5-10% following heel strike and stayed elongated throughout stance phase (Figure 1). Posterior tibiotalar ligament length increased linearly following initial load acceptance, while the anterior tibiotalar ligament length decreased through stance (Figure 2). This elongation pattern is indicative of the ligament fiber recruitment that resists excessive tibial anterior translation relative to the talus, and resists ankle dorsiflexion during mid- to late-stance phase of gait. The predicted reciprocal behavior of the anterior and posterior tibiotalar ligaments is shown in Figure 2.

CONCLUSIONS

In vivo estimates of foot and ankle ligament behavior may be obtained through the combination of biplanar fluoroscopy and subject-specific volumetric imaging. These data may be used in computational models to estimate ligament stresses, or to quantify the success of reconstructive surgeries in restoring normal function.

REFERENCES


ACKNOWLEDGEMENTS

Funded by VA grant A1442-P