INTRODUCTION

The pes planus or flatfoot deformity is the most common foot pathology (Gould, et al. 1980). It is often associated with posterior tibialis tendon insufficiency (PTTI) (Mann 1999; Niki, et al. 2001). A number of studies have generated cadaveric flatfoot models, but most consider only midstance. We are unaware of a study that has characterized all of the stance phase of the gait cycle, used inputs from flatfoot subjects and simulated both translational and rotational motion. Our purpose was to create a six-degree of freedom (DOF) cadaveric flatfoot model with PTTI that quantified bony motion and ground reaction forces (GRF) during the entire stance phase of gait.

METHODS

Previously, gait kinematics and GRFs were recorded from ten flatfoot subjects using a Vicon® twelve-camera motion analysis system. A single fresh frozen cadaver lower limb was acquired for study. Proximal to the ankle, soft tissue was dissected away leaving intact the extrinsic tendons, tibia and fibula. Retro-reflective markers were placed on the tibia, calcaneus, talus, navicular, medial cuneiform and first metatarsal. The foot was mounted in the Robotic Gait Simulator (RGS), a dynamic gait simulator consisting of a parallel axis robot (R-2000), force plate, dedicated motion analysis system and tendon actuators (Figure 1, Aubin et al. 2008). The RGS moves the “ground” relative to a cadaveric foot. Physiologic extrinsic tendon forces were applied, the gait kinematics (rotations) were prescribed and translations were adjusted to match the vertical GRF. Cadaveric bony motion and GRFs were recorded at 10 discrete (static) instances between 0 and 90% of stance phase. The foot was then conditioned flat using surgical ligament attenuation and cyclic loading (Blackman et al. in review). Each foot was tested again in the RGS without loading the posterior tibialis to simulate PTTI. The normal and flatfoot conditions were compared.

RESULTS

The RGS was able to recreate the kinematics and kinetics of the in vivo flatfoot subjects by prescribing the correct angular rotation of the “ground” with respect to the foot and generating the correct vertical GRF (data not shown). The cadaveric foot demonstrated collapse of the medial arch as indicated by plantar flexion of the talus relative to the tibia and dorsiflexion of the following: the first metatarsal with respect to the talus (Figure 2), the medial cuneiform with
respect to the navicular and the navicular with respect to the talus. Forefoot abduction was seen by the first metatarsal with respect to the talus (Figure 3). Unexpectedly, the calcaneus inverted slightly rather than everted relative to the tibia (Figure 4).

DISCUSSION

With the exception of the calcaneus, the cadaveric flatfoot model demonstrated changes consistent with a flatfoot deformity resulting from PTTI. The common bony motion changes expected with a flatfoot are collapse of the medial arch, plantar flexion of the talus, abduction of forefoot and eversion of the calcaneus (Johnson and Strom 1989; Mann 1999). The RGS was able to generate the correct kinematics and kinetics in six DOF based on in vivo pes planus subjects and estimated extrinsic muscle forces for 10 discrete (static) points during the stance phase of gait. The cadaveric flatfoot model with PTTI showed changes consistent with the acquired flexible flatfoot pathology including collapse of the medial arch and abduction of the forefoot. Whereas other cadaveric models only considered midstance or a few positions within the stance phase, this simulation has the potential to evaluate both non-invasive treatments and surgical treatments throughout the entire stance phase of gait perhaps eliciting unknown advantages or disadvantages of these treatments at other points in the gait cycle. Future work will include dynamic simulation of gait.

REFERENCES


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