INTRODUCTION:
Flatfoot deformity (pes planus) involves not only loss of the medial longitudinal arch of the foot, but is also characterized by forefoot abduction and hindfoot dorsiflexion. Many cases, especially those that are severe or longstanding, are associated with Achilles tendon contracture. In recent years, much research has been devoted to creating and testing physiological flatfoot models in cadavers. We are unaware of a model that has examined the effects of Achilles tendon contracture (equinus deformity) on the flatfoot. One goal of this study was to determine if Achilles tendon overpull in a cadaveric flatfoot model is associated with increased pes planus severity.

Most current cadaveric models rely on substantial sectioning of ligaments and/or tendons, which simulates complete rupture, to create the flatfoot deformity. MRI data has shown that complete soft tissue ruptures do not usually occur in pes planus feet. A custom-designed acrylic foot-loading frame was used to apply compressive forces to the tibia and fibula and tensile forces to the tendons. Physiological muscle forces for midstance (30% gait cycle) were calculated using physiological cross-sectional area, EMG measurements, specific tension, and pennation angle. Forces were scaled to 25% of normal due to loading constraints. A 7° wedge was also used to dorsiflex the foot to simulate the midstance. The Fastrak® electromagnetic motion analysis system was used to measure the 3D movements, specific tension, and pennation angle. Forces were scaled to 25% of normal due to loading constraints. A 7° wedge was also used to dorsiflex the foot to simulate the midstance. The Fastrak® electromagnetic motion analysis system was used to measure the 3D movements, specific tension, and pennation angle. Forces were scaled to 25% of normal due to loading constraints. A 7° wedge was also used to dorsiflex the foot to simulate the midstance. The Fastrak® electromagnetic motion analysis system was used to measure the 3D movements, specific tension, and pennation angle. Forces were scaled to 25% of normal due to loading constraints. A 7° wedge was also used to dorsiflex the foot to simulate the midstance.

Three-dimensional bone orientations were acquired in the following conditions: normal bone orientations were taken in three conditions: normal vs. flatfoot, or Achilles force, i.e., normal vs. Achilles overpull. Normal bone orientations were taken in three conditions: normal vs. flatfoot, or Achilles force, i.e., normal vs. Achilles overpull. About half of Achilles tendon overpull resulted in talar plantar flexion (2.17 ± 1.25°, p=0.0001), first metatarsal-to-talus dorsiflexion (2.38 ± 1.19°, p=0.0015), navicular-to-talus dorsiflexion (1.23 ± 1.12°, p=0.0055) and abduction (0.96 ± 0.87°, p=0.028) and first metatarsal-to-calcaneus abduction (0.96 ± 0.59°, p=0.0045). There was a small trend toward calcaneal eversion (0.66 ± 0.49°), but it did not reach statistical significance (p=0.2).

METHODS:
Ten fresh-frozen human cadaver feet (76 ± 13 years; range, 56 to 88 years; eight female, two male) with no gross or radiographic evidence of previous surgery or deformity were used for this IRB-approved study. The tibialis posterior, peroneus longus, peroneus brevis, flexor digitorum longus, flexor hallucis longus and Achilles tendons were preserved during dissection and fitted with plastic tendon clamps. A custom-designed acrylic foot-loading frame was used to apply compressive forces to the tibia and fibula and tensile forces to the tendons. Physiological muscle forces for midstance (30% gait cycle) were calculated using physiological cross-sectional area, EMG measurements, specific tension, and pennation angle. Forces were scaled to 25% of normal due to loading constraints. A 7° wedge was also used to dorsiflex the foot to simulate the midstance. The Fastrak® electromagnetic motion analysis system was used to measure the 3D measurement and track the movements of the tibia, calcaneus, first metatarsal, navicular, cuboid, medial cuneiform, and talus with motion sensors secured via carbon fiber bone rods (4.0-4.6 mm diameter) in each bone. Normal bone orientations were taken in three conditions: unloaded, normal tendon loads, and 50% Achilles overpull. A flatfoot model was created by attenuating ligaments involved in flatfoot deformity followed by cyclic axial loading an average of 17,600 cycles (range 14,000-20,000) at 2 Hz with a maximum force of 600 N. During cyclic loading, the tendons continued to be loaded in tension, except the tibialis posterior tendon, which was unloaded to simulate PTT dysfunction. Flatfoot 3D bone orientations were acquired in the unloaded, normal tendon loads, and Achilles overpull conditions, and all data were normalized to the normal foot unloaded condition.

RESULTS:
Changes seen between normal feet and the created flat feet were consistent with those seen in pes planus deformity (Figure 2). (Data are presented, as the difference between condition, either foot type, i.e. normal vs. flatfoot, or Achilles force, i.e., normal vs. overpull.) The first metatarsal dorsiﬂexed 4.89° ± 3.59° (p<0.0001) and ab ducted 3.98° ± 3.30° (p<0.0001) relative to the talus. The navicular dorsiﬂexed 1.47° ± 2.07° (p=0.012), everted 2.98° ± 1.74° (p<0.0001), and abducted 3.02° ± 2.20° (p<0.0001) relative to the talus. The calcaneus everted 4.01° ± 2.66° (p<0.0001) and abducted 1.78° ± 1.90° (p=0.0004) relative to the tibia. The talus planar ﬂexed 2.00° ± 2.37° (p=0.0002) and abducted 4.35° ± 2.95° (p<0.0001). Achilles tendon overpull resulted in talar plantar ﬂexion (2.17 ± 1.25°, p=0.0001), first metatarsal-to-talus dorsiflexion (2.38 ± 1.19°, p=0.0015), navicular-to-talus dorsiflexion (1.23 ± 1.12°, p=0.0055) and abduction (0.96 ± 0.87°, p=0.028) and first metatarsal-to-calcaneus abduction (0.96 ± 0.59°, p=0.0045). There was a small trend toward calcaneal eversion (0.66 ± 0.49°), but it did not reach statistical significance (p=0.2).

DISCUSSION:
The cadaver model developed for this study resulted in significant changes in 3D bone position that are consistent with those of a physiologic pes planus deformity. Calcaneal eversion, talonavicular joint abduction, forefoot dorsiflexion, forefoot abduction, talar adduction, and talar plantar ﬂexion are all common features of flatfoot and were all seen in the current model.

Overloading the Achilles tendon in the flatfoot model resulted in significant changes in the sagittal plane, including talar plantar ﬂexion, ﬁrst metatarsal-to-talus dorsiflexion, and navicular-to-talus dorsiflexion, that are consistent with ﬂattening of the longitudinal arch. Navicular-to-talus and ﬁrst metatarsal-to-calcaneus abduction show that Achilles tendon overpull also increases forefoot abduction in this model. However, no significant hindfoot eversion was seen in the Achilles tendon overpull condition compared to normal tendon loads.

In conclusion, this study indicates that ligament attenuation followed by cyclic axial loading with tendons loaded can create a cadaveric flatfoot model that is consistent with the in vivo deformity. This study also indicates that the Achilles tendon contracture seen in many patients with ﬂat feet may contribute to the severity of the deformity, particularly in longitudinal arch depression and forefoot abduction.

ACKNOWLEDGEMENT:
This work was supported in part by the Medical Student Research and Training Program at the Univ. of Washington, and the Dept. of Veterans Affairs, Rehabilitation R&D Service grant number A2661C.

REFERENCES: