Relative Elongation of the Ankle Deltoid Ligament During Running

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Disclosures: Plakseychuk (N), Olawin (N), Kuhn (N), Gale (N), Anderst (N), Cain (N)

INTRODUCTION: Ankle sprains are a common and often serious injury, with over 3 million ankle sprains presented to Emergency Departments in the US between 2002 and 2006[1]. Medial ankle sprains, especially those involving the deltoid ligament, are often underreported. An MRI study found that 49% of athlete ankle sprains had a deltoid ligament injury component[2]. Previous cadaver studies have primarily focused on biomechanical strain properties or tears of individual components of the deltoid ligament[3-4]. Takao et al noted that Tibionavicular tension peaked in plantar flexion in contrast to the Tibiocalcaneal tension, which peaked in dorsiflexion[3]. However, the *in vivo* elongation of the deltoid ligament during physiologic loading remains poorly understood. The aim of this study was to characterize the timing and amount of peak relative elongation of the deltoid ligament during running in healthy individuals. We hypothesized that the posterior components of the deltoid ligament (Tibiocalcaneal and Posterior Tibiotalar) would achieve peak relative elongation during dorsiflexion in the heel strike to midstance phase, the spring ligament would achieve peak elongation during midstance, and the anterior components of the deltoid ligament (Tibionavicular and Anterior Tibiotalar) would achieve peak elongation during the toe off phase of stance.

METHODS: Inclusion criteria were healthy individuals between the ages of 21-45 with a BMI of 18-30kg/m^2. Exclusion criteria were prior patient-reported lower extremity injury, high amounts of radiation exposure, or osteoporosis. Synchronized biplane radiographs (150 images/second, 90kV, 50mA, 2ms pulse width) and conventional motion capture (100 Hz, 12-camera Vicon Vantage) were collected during 1 static and 2 overground running trials for each ankle. Bone motion was tracked using a validated technique[5] that matched subject-specific digitally reconstructed tibia, talus, calcaneus, and navicular models (obtained from CT scans) to the biplane radiographs. Markers were placed on the 3D bone models by an orthopaedic surgical resident following previously reported anatomical ligament footprint locations[6]. The Anterior Tibiotalar, Posterior Tibiotalar, Tibiocalcaneal, Tibionavicular, and Spring Ligament were all modeled to represent the deltoid ligament (Figure 1). Multiple points were used to model the origin and insertion of ligaments with fan-shaped insertions, and the average deformation of each ligament component was calculated. The relative deformation of each ligament comprising the deltoid ligament was calculated during the stance phase of running, with the static standing length serving as the reference length. Averages of the two running trials were graphed and the timing of peak relative elongation was qualitatively analyzed, while amount of peak elongation was quantified by means and standard deviations.

RESULTS: Bilateral data from five healthy volunteers (4M, 1F, mean age 30 years) who consented to participate in this IRB approved study are included in this analysis. A total of 20 running trials were included in this analysis of 10 ankles. The average running speed was 2.6 m/s. All runners were heel strike runners. Posterior Tibiotalar had the greatest relative peak deformation (Table 1). The peak relative elongation of the Posterior Tibiotalar and Tibiocalcaneal ligaments tended to occur during the midstance, 51% and 58% stance, respectively (Figure 2). Peak relative elongation for the Anterior Tibiotalar and Tibionavicular tended to occur during the toe off phase of gait (>80% stance). The Tibionavicular had an additional smaller peak between heel strike and midstance (13-35% stance). The spring ligament did not have a consistent discernable peak relative elongation among the ankles. The Posterior Tibiotalar and Talonavicular ligament relative elongations appeared to mirror each other.

DISCUSSION: These *in vivo* data under physiological load demonstrate deltoid ligament elongation corresponds closely to tibiotalar plantarflexion and dorsiflexion. The findings suggest that the Tibiocalcaneal and Posterior Tibiotalar would be most susceptible to injury during their peak relative elongation in midstance while the Tibionavicular and Anterior Tibiotalar would be most susceptible to injury during ankle plantarflexion. These results apply only to straight ahead running in relatively healthy young adults with no history of chronic ankle instability or other pathology.

SIGNIFICANCE/CLINICAL RELEVANCE: Understanding the native behavior of ankle ligaments under physiologic load may improve conservative treatments and surgical interventions to better restore native function and help identify persistent abnormal *in vivo* kinematics after treatment.

REFERENCES: 1) Waterman et al. (2010) JBJS Am. 2) Roemer et al. (2014) AJSM. 3) Takao et al. (2020) BMC Musculoskeletal Disorders. 4) Brady et al. (2023) AJSM. 5) Pitcairn et al. (2020) Journal of Biomechanics 6) Campbell et al. (2014) JBJS.

Table 1: Static standing, peak dynamic length, and peak elongation while running for each component of the deltoid ligament. All values are mean ± SD.

Ligament	Anterior Tibiotalar (AT)	Posterior Tibiotalar (PT)	Tibiocalcaneal (TC)	Tibionavicular (TN)	Spring Ligament (SL)
Static length (mm)	13.7±0.9	20.6±1.2	32.8±2.7	35.1±4.3	27.4±4.3
Maximum dynamic length (mm)	13.9±1.2	23.4±2.1	34.0±3.0	36.2±5.0	28.0±3.2
Peak relative elongation (%)	2.2±5.4	13.5±4.1	3.5±3.8	3.5±8.3	3.5±7.1

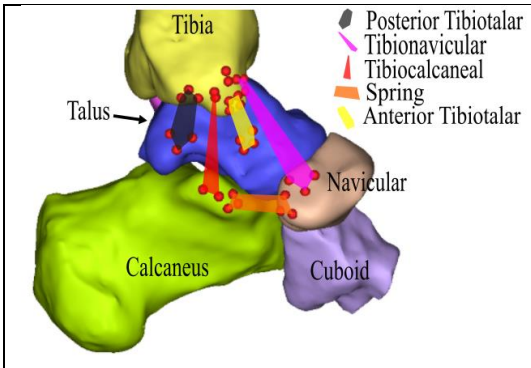

Figure 1: 3D ankle bones with markers representing deltoid ligament origins and insertions.

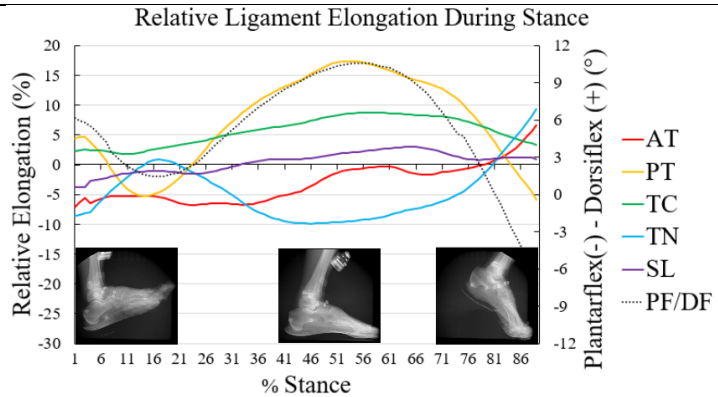

Figure 2: Relative length changes of ankle deltoid ligaments from a representative individual: Anterior Tibiotalar (AT), Posterior Tibiotalar (PT), Tibiocalcaneal (TC), and Tibionavicular (TN), with ankle plantarflexion/dorsiflexion (PF/DF) shown on the right vertical axis. Radiographic depiction of corresponding portions of the gait cycle