The Curvature of the Posterior Facet of the Talus Correlates with Subtalar Inversion-Eversion Range of Motion During the Stance Phase of Gait

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INTRODUCTION: Ankle and subtalar instabilities share similar injury mechanisms and symptoms, often causing misdiagnosis. Neglecting subtalar instability can lead to treatment failure and chronic ankle issues [1]. Subtalar instability, first described by Rubin in 1962, is challenging to diagnose accurately due to limitations in clinical measures [2]. Recent advancements in high-resolution medical imaging and biplane fluoroscopy have made it possible to measure *in vivo* kinematics of the subtalar joint more precisely. Biomechanical testing on cadavers has indicated that the morphology of articulating bones, such as the talus and calcaneus, plays a role in joint stability and kinematics [3,4]. However, there is a lack of *in vivo* data to confirm that kinematics are related to morphology under physiologic loading. Understanding this relationship between morphology and kinematics is crucial for identifying risks of subtalar instability and this knowledge could also be applied to improve the design of total talus replacements. Thus, the purpose of this study was to investigate the association between bony morphology and kinematics in the subtalar joint during walking. Our hypothesis was that bone shape would be associated with subtalar inversion-eversion and internal-external rotation range of motion (ROM) during the stance phase of gait.

METHODS: Written informed consent was obtained from 20 participants in this IRB approved study. Participants had no previous significant ankle injury or surgery. Participants walked on a raised laboratory walkway while synchronized biplane radiographs were collected (100 frames/s, 1 ms pulse width), and ground reaction forces were recorded. CT scans of the distal tibia, talus, and calcaneus (0.68 x 0.68 x 1.25 mm) of each participant were segmented to create three-dimensional subject-specific bone models using Mimics software (Materialise, Leuven, Belgium). Digitally reconstructed radiographs, created from the subject-specific segmented bone tissue, were matched to the biplane radiographs with submillimeter accuracy using a previously validated volumetric model-based tracking method [9]. Anatomical coordinate systems for each bone were defined independently for both ankles and hindfeet of each participant [5]. Joint kinematics were calculated [10] and averaged over two walking trials for each foot, and subtalar joint range of motion (ROM) during the stance phase was determined. The bone shapes and modes of variation of the talus and calcaneus were characterized using ShapeWorks software (ShapeWorks, University of Utah) [6]. Principal component analysis (PCA) was used to reduce the high-dimensional shape data to a smaller set of linearly uncorrelated components, or 'modes'. Each mode of variation was associated with specific morphologic features, as identified by an orthopaedic surgeon specializing in foot and ankle. Pearson correlation was used to assess the relationship between subtalar range of motion and the PCA component score for each mode of shape variation in the talus and calcaneus. Given a sample size of 40, 80% power, and a significance level of 0.05, the study was powered to detect medium size associations ($r = 0.41$). All data were analyzed with SPSS software version 27.0 (IBM-SPSS, New York, USA).

RESULTS: The study included 40 ankle and hindfeet from 20 participants (10 male, 10 female) with an average age of 30.8 ± 6.3 years. The average BMI was 24.1 ± 3.1 kg/m², and walking speed was 1.3 ± 0.2 m/s. Talus and calcaneus morphology were analyzed using seven and five principal components, respectively, that explained over 70% of the variance in each bone shape. Talus morphology modes of variation included talar dome height, talar neck length, posterior process length, medial process length, and curvature of the posterior facet. Calcaneus morphology modes of variation included curvature of the upper and lower portion of the posterior part, steepness of the middle facet, medial wall curvature, calcaneal sulcus depth, and lateral wall curvature. A shallower posterior facet of the talus (Mode 5) was associated with greater subtalar inversion-eversion ROM ($r = -0.42$, 95% CI [-0.65, -0.13], $P = .006$) (Figures 1, 2). No correlations were found between calcaneus morphology and subtalar joint range of motion.

DISCUSSION: The results suggests that a shallow posterior facet of the talus might contribute to greater inversion-eversion motion in the subtalar joint during the stance phase of gait. This finding provides novel quantitative data to link bone morphology and kinematics in the hindfoot. This link between bone morphology and kinematics suggests a potential mechanical origin for chronic ankle instability, as previous qualitative observations indicate that patients with chronic ankle instability tend to have flatter talar joint surfaces [7]. Additionally, posterior facet shape may be an important consideration in designing total talar replacements to replicate *in vivo* subtalar inversion-eversion. These results are limited to individuals with healthy ankles during overground walking; additional data is needed to confirm these relationships in other activities and in individuals with symptomatic pathology such as chronic ankle instability.

SIGNIFICANCE: Knowing how bone morphology can affect kinematics may help in identifying individuals who are more susceptible to subtalar instability. This knowledge may also be used to improve surgical techniques for subtalar instability or to improve total talar replacement implant design.

REFERENCES: [1] Pereira BS, et al., OJSM, 2021. [2] Rubin G, et al., Am J Orthop, 1962. [3] Imhauser CW, et al., J Biomech, 2008. [4] Kleipool RP, et al., KSSTA, 2010. [5] Brown JA, et al., J Biomech. 2020. [6] Cates J, et al., Inf Process Med Imaging, 2007. [7] Tümer N, et al., J Orthop Res, 2019. [8] Liu T, et al., Med Biol Eng Comput. 2022. [9] Pitcairn, et al. J. Biomech., 2020. [10] Grood and Suntay, J. Biomech. Eng., 1983.

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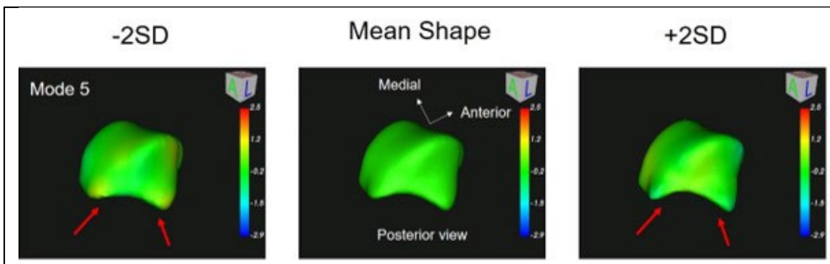

Figure 1. *Talus PCA mode 5 obtained from ShapeWorks. The fifth mode of variation was the curvature of the posterior facet, shown by the mean shape (middle) and shapes ± 2 standard deviations from the mean.*

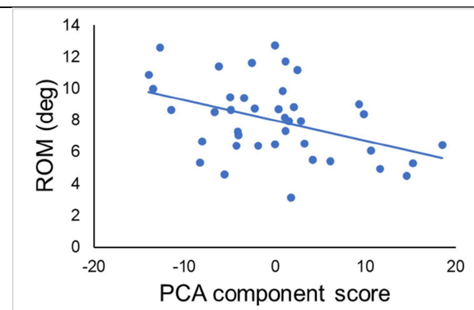

Figure 2. *Correlation between talar morphology (PCA mode 5 score) and subtalar inversion-eversion ROM during the stance phase of gait.*