Tibiotalar and Subtalar Kinematic Analysis of Asymptomatic Flatfoot during Heel Rise

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Disclosures: None

INTRODUCTION: Patients with flat feet experience altered foot and ankle biomechanics through medial arch collapse, hindfoot valgus, and forefoot abduction [1]. However, individuals with asymptomatic flatfoot (AFF) experience these biomechanical differences without experiencing the pain or discomfort. This makes them a valuable group to study, as they can help provide insights into presymptomatic stages of flatfoot. The subtalar joint contributes to shock absorption and adaptability, while the tibiotalar joint provides dorsiflexion–plantarflexion needed for propulsion. Abnormal function in either joint can reduce stability, efficiency, and range of motion (ROM) during heel rise. Standard static 2D radiographs and marker-based motion capture are unable to capture these changes in form and function relationships; instead, weightbearing computed tomography (WBCT) and biplane fluoroscopy provide 3D and dynamic assessments using dynamic stereo X-ray (DSX) [2]. This study evaluates subtalar and tibiotalar joint kinematics during heel rise in individuals with AFF versus rectus-aligned controls.

METHODS: Participants included six healthy controls, four male, two female, and five individuals with AFF, four male, one female. Patients first underwent WBCT scanning to capture 3D anatomical models of the tibia, talus, and calcaneus under physiological loading. Segmented bone geometries were reconstructed and standardized across subjects [3]. Anatomical coordinate systems were then assigned to each bone using the AAFACT MATLAB toolbox [4]. Following CT acquisition, patients performed heel-rise trials while being imaged with a biplane fluoroscopy system. This technique records dual-plane radiographic video at high speed, which, when registered with WBCT bone models through DSX tracking, provides sub-millimeter 3D kinematic reconstructions [2]. Start and end points of heel rise were identified by visually locating heel-off and heel-down, with 10 additional frames included before and after each event to capture residual motion. Pose data were exported as object transform files and processed using an in-house MATLAB toolbox to calculate joint angles and ROM for both the subtalar and tibiotalar regions in all three planes. Data were time-normalized to consistent trial lengths, interpolated across subjects, and averaged within each group. Statistical parametric mapping (SPM) was then applied to identify regions where significant differences in joint angles were present between groups. An alpha of 0.05 was used to show significant differences, while an alpha of 0.32, which is not standard, was used to show kinematic trends in data.

RESULTS SECTION: For the subtalar joint, ROM was similar across groups with no statistically significant differences. AFF subjects showed slightly higher sagittal motion (5.47° ± 1.78° vs. 3.80° ± 0.62°, $p = 0.0589$). When looking at the kinematic joint angles there were no significant differences; however, the AFF group was trending more everted near peak heel rise. At the tibiotalar joint, sagittal ROM was significantly reduced in the AFF group (31.37° ± 5.28° vs. 40.07° ± 5.09°, $p = 0.0214$) compared to controls, while coronal and transverse ROM were not significantly different.

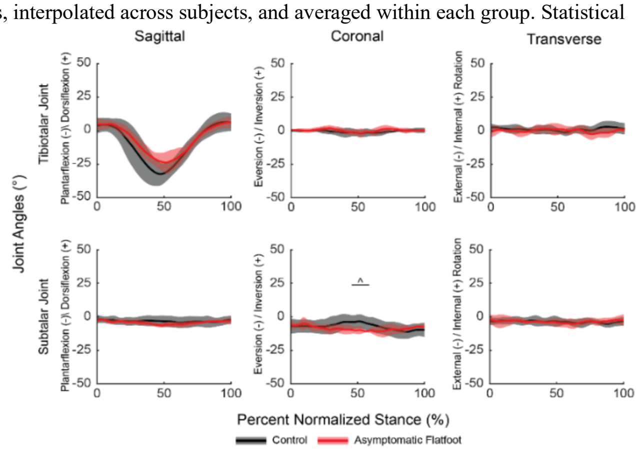

Figure 1. Kinematic plot points for tibiotalar and subtalar joint angles vs percent normalized stance. A carrot (^) represents significant differences with an alpha of 0.32.

DISCUSSION: The kinematic patterns of the subtalar and tibiotalar joints were largely consistent between groups across the full heel-rise cycle, indicating that overall joint angle trajectories were preserved. These results indicate that subtalar ROM remains largely preserved in flatfoot, whereas tibiotalar sagittal motion is restricted, reflecting reduced dorsiflexion–plantarflexion excursion. This suggests that, although ROM differs between groups, the preservation of subtalar and tibiotalar joint angle trajectories, despite reduced sagittal tibiotalar motion in flatfoot subjects, indicates compensatory strategies that allow kinematic similarity even under restricted mobility. This limited tibiotalar ROM could affect the subtalar increased eversion at peak heel rise. Such findings align with the idea that AFF may initially present as a reduction in available motion rather than major deviations in movement patterns. Over time, this constrained motion could reduce efficiency during propulsion and increase susceptibility to further joint degeneration.

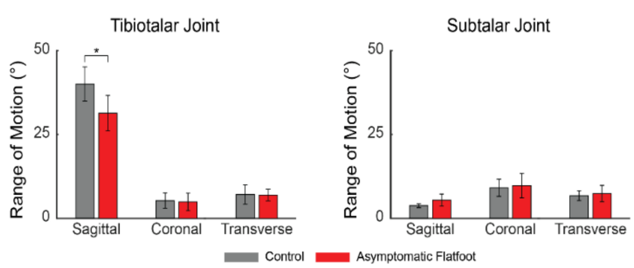

Figure 2. Range of motion in different medical planes comparing subject groups for tibiotalar and subtalar joint spaces. An asterisk (*) represents significant differences with an alpha of 0.05.

SIGNIFICANCE/CLINICAL RELEVANCE: Reduced sagittal tibiotalar range of motion may serve as an early marker of flatfoot impairment. Even when overall kinematics are preserved, limited dorsiflexion–plantarflexion can signal emerging dysfunction before overt deformity develops. Screening for ankle mobility could help identify individuals at risk and support timely interventions—such as strengthening, orthotics, or mobility training—to preserve joint function and reduce long-term degeneration.

REFERENCES: [1] Kodithuwakku Arachchige et al., 2019, Clin Biomech, [2] Perez et al., 2024, Med Eng Phys, The Foot, [3] Lisonbee et al., 2025, [4] Peterson et al., 2023, *Front Bioeng Biotechnol*

ACKNOWLEDGEMENTS: Funding was provided by Shriners Hospitals for Children (#79135).