Differences in Three-Dimensional Foot Alignment Between Patients with Progressive Collapsing Foot Deformity and Asymptomatic Controls in Female.

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INTRODUCTION: In recent years, computed tomography (CT) has become a common tool in diagnosing and evaluating progressive collapsing foot deformity (PCFD). PCFD is a complex clinical presentation of combined deformities thought to be driven by the medial longitudinal arch, however detailed evaluation of the morphology and alignment contributions to the deformity from the hindfoot through the metatarsals is not well documented. Simulated weight-bearing CT (SW-CT) can be used to mimic a weight-bearing stance, preserving important joint relationships. While SW-CT provides three-dimensional (3D) information, most often in clinical practice these images are evaluated using the same or similar two-dimensional (2D) measurements used for plain film X-rays. Statistical Shape Modeling (SSM) provides 3D evaluation of population-wise anatomical variation as well as group-wise shape differences of anatomies reconstructed from volumetric imaging data without the influence of human bias. Recent advancements in SSM have made it possible to evaluate multiple domains at once, providing the ability to study the variation in the alignment of a human joint [1]. Herein, we developed a multi-domain SSM (MD SSM) of SW-CT image data to investigate variation in the 3D foot alignment between female individuals presenting with PCFD as compared to asymptomatic controls.

METHODS: In this retrospective comparative study, 23 female patients presenting with PCFD (age: 65.1 ± 7.1) and 23 female asymptomatic individuals (age: 46.7 ± 19.2) underwent SW-CT (0.625 mm slice thickness, 512/512 matrix). For each participant, SW-CT images were auto-segmented to create 3D models of distal tibia, distal fibula, talus, calcaneus, navicular, cuboid, all cuneiforms, and all metatarsal bones (Disior 2.1, Bonelogic), then manually segmented to finalized models (Mimics 22.0, Materialise). An MD SSM was performed with all 16 bones across all 46 individuals to generate statistical shapes using Shapeworks 6.4. Correspondence particles from the SSM were evaluated via principal component analysis (PCA). Significant PCA modes were identified using parallel analysis in MATLAB (R2023a, MathWorks). Statistical analysis was performed in MATLAB. First, a Shapiro-Wilks normality test was conducted followed by the appropriate Mann-Whitney t-test (for normal) or Wilcoxon rank sum test (for not normal) to compare PCA component scores between groups within that mode. Across modes, a Holm-Sidak correction was implemented to reduce the probability of type 1 error. For all statistical measures and comparisons an alpha value of 0.05 was used ($p < 0.05$) (Figure 1).

Figure 1: Computational workflow for this study

RESULTS: The first mode of variation from the MD SSM was the only mode with PCA component score significant differences, describing 53.0% of the variation. Notable interactions of each joint were identified along with changes in 3D foot alignment. Compared to the control group, in PCFD patients, the anterior and intermediate surfaces of the subtalar joint tended to detach when the talus was plantar flexed and internally rotated. Similarly, the navicular, cuboidal, and each cuneiform bone moved medially downward with internal rotation, and the Chopart joint was dorsiflexed and abducted, with deformity progressing in the same direction as the subtalar joint. On the other hand, Lisfranc's joint was abducted and dorsiflexed while being valgus, and the deformity progressed in the opposite direction of the subtalar joint and Chopart joint (Figure 2).

DISCUSSION: We conducted a study using MD SSM to analyze the 3D foot alignment from the tibia to the metatarsals in both female individuals presenting with PCFD and asymptomatic controls. Our findings suggest that the deformity progresses in the same direction from the subtalar joint to the Chopart joint, but Lisfranc's joint undergoes compensatory deformity progression. It would be very difficult to capture these variations using 2D measurements. The application of an MD SSM from SW-CT to evaluate alignment deformities in patients with PCFD represents a new and novel approach to understand the pathophysiology of this condition.

CLINICAL RELEVANCE: This research can assist in understanding the pathophysiology of PCFD and determining appropriate surgical approaches.

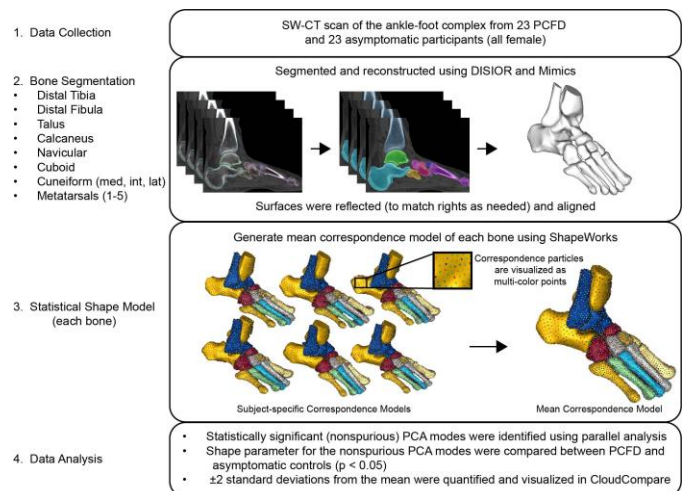**REFERENCES:** [1] Agrawal P, et al. Shape Med Imaging 2020.

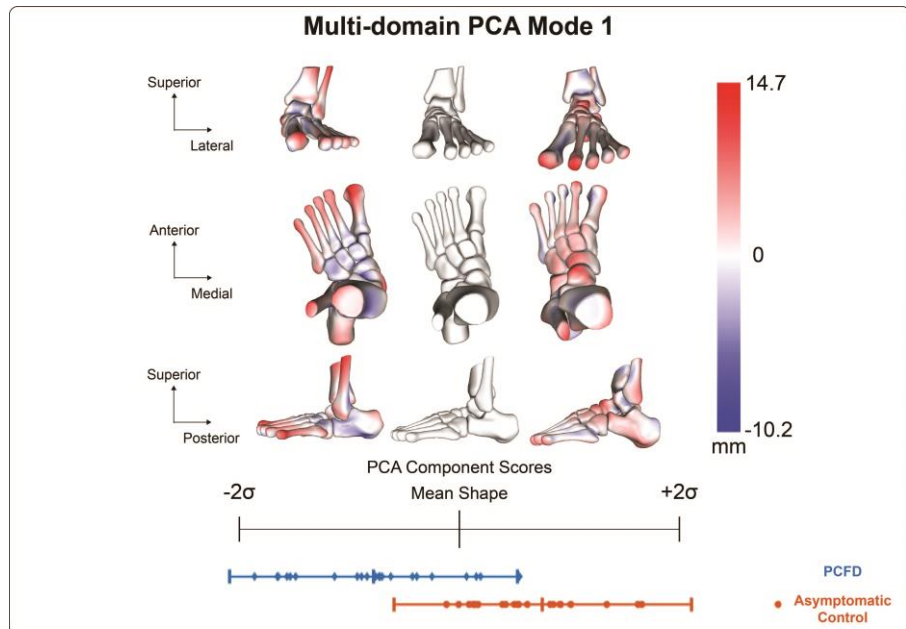

Figure 2: Quantitative visual description of significant PCA modes. Bone shape variations (mean and ±2 standard deviations) and P-values for each mode represent a group-wise comparison of the PCA component scores for the indicated mode. Arrows indicate focal locations of morphological differences/changes acorss the mode.