# Joint Measurement Analysis of Progressive Collapsing Foot Deformity

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INTRODUCTION: Progressive collapsing foot deformity (PCFD) is primarily characterized by peritalar subluxation [1]. Clinical evaluation of Stage I (flexible) versus Stage II (rigid) deformity is largely based on the definition for the deformity to be corrected manually, or by performing a heel rise activity [1]. The complexity of intra-articular relationships of PCFD requires further investigation to improve our clinical understanding. Foot and ankle joint morphology has historically been analyzed with two-dimensional measurements from conventional radiographs, which fail to illustrate the three-dimensional (3D) complexity of the joints, including their relationship with one another. However, with the emerging clinical use of weightbearing computed tomography (WBCT), high-resolution volumetric data enables accurate 3D analyses of deformity and subluxation which can be quantified as joint measures within these complex joints. The objective of this study was to analyze the subchondral bone joint space distance of the talocrural, subtalar, and talonavicular joints, using WBCT scans to assess individuals with flexible and rigid PCFD compared to asymptomatic controls.

METHODS: In this study 20 patients presenting with flexible PCFD (age: 44.7 ± 16.8 years; 9 females), 20 patients presenting with rigid PCFD (age: 66.0 ± 14.7 years; 12 females), and 27 asymptomatic control patients (age: 50.0 ± 7.3 years; 20 females) underwent WBCT scans (Planmed Verity; 0.4 x 0.4 x 0.4 mm voxels) with IRB approval. For each participant, WBCT images were semi-automatically segmented to create 3D models of the calcaneus, cuboid, fibula, navicular, talus, and tibia (DISIOR 2.1), then manually verified to final quality (Mimics 22.0, Materialise). A multi-domain statistical shape model (SSM) was performed with all six bones across all 67 participants using ShapeWorks 6.4.1 (University of Utah). Correspondence particles from SSM were used as inputs into a Joint Measurement Analysis toolbox (University of Utah) [2] to determine joint distances of the following joints: talofibular, tibiotalar, subtalar, calcaneocuboid, and talonavicular. Distance measurements at each particle were tested for normality using a Shapiro-Wilk test, and then compared between groups using a one-way ANOVA or Kruskal-Wallis test based on their homoscedasticity to determine statistically significant joint measurements.

RESULTS: When observing differences in the subtalar joint between the control group and flexible PCFD there is joint narrowing in the anterior-medial (ant-med) facet, with regions of statistically different joint distance values along the lateral border of the facet (Figure 1). Comparing the control group to rigid PCFD there is greater joint distance in the anterior aspect of the ant-med facet, with joint narrowing in the sinus tarsi region of the subtalar joint. Differences between flexible PCFD and rigid PCFD for the subtalar joint are subtle, only showing significance in the sinus tarsi region of the joint. Rigid PCFD versus controls show increased regions of statistical significance as well as notable narrowing in the inferior-lateral region of the calcaneocuboid joint (Figure 1). Joint distance trends can be seen in the talus across multiple articulations. Controls versus flexible PCFD show large regions of statistical significance for tibiotalar and talonavicular interactions. Meanwhile, flexible versus rigid PCFD shows little to no statistical significance, with mild narrowing in the medial face of the tibiotalar joint. Rigid PCFD versus controls shows increased regions of significance in joint distance values, as well as a medial shift of the talonavicular region of articulation shown as shift in coverage region (Figure 2).

DISCUSSION: These findings highlight the complexity and difficulty of describing and quantifying PCFD. Flexible versus rigid PCFD was clearly distinguished in the selection criteria, but upon joint analysis appears to be more similar than not. Clinical markers such as sinus tarsi impingement seem to be a distinct indicator between the two stages of PCFD. Gapping present in the anterior-medial facet of the subtalar joint in the rigid PCFD cohort in a static pose leads us to believe the peritalar subluxation must have downstream effects. Future work includes dynamic joint analysis from biplane fluoroscopy kinematics to better understand the role morphology and alignment plays in PCFD. Our study highlights the complexity of the foot and ankle, the value in robust 3D joint analyses to clinically evaluate PCFD, and the necessity to further investigate PCFD function and morphology.

CLINICAL RELEVANCE: The ability to quantify 3D joint relationships across multiple joints and morphologically different populations, such as PCFD, allows for robust and comprehensive analyses that can influence new approaches to clinically evaluate and treat complex foot and ankle morphologies.

REFERENCES:[1] Myerson, MS., et al, Foot Ankle Int. 2020, [2] Lisonbee, R. (2023). JMA Toolbox (Version 1.0.0)

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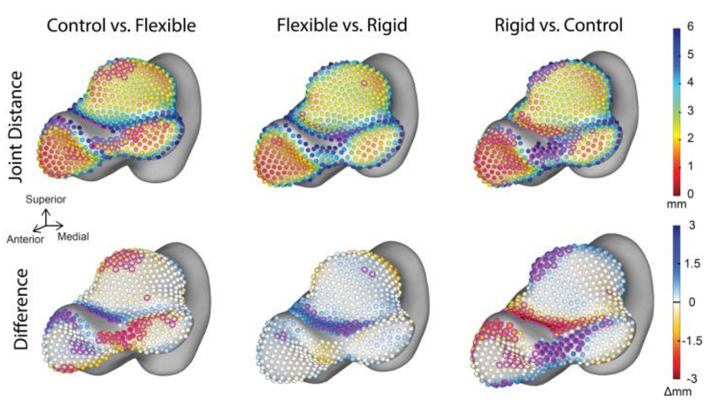


**Figure 1:** Joint distance (mm) results for calcaneus (subtalar and calcaneocuboid) in top row. Second row shows difference between groups. The joint space for the first group listed in the column heading is visualized on the bone. The pink circles around particles represent the statistical difference between the two listed groups.

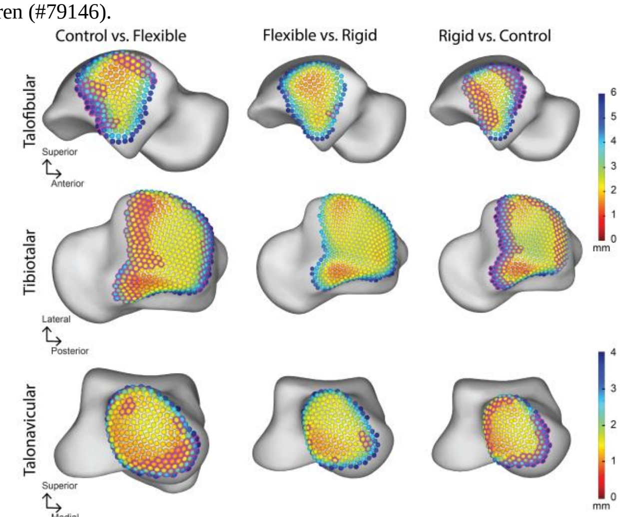


**Figure 2:** Joint distance (mm) results for talus (talofibular, tibiotalar, and talonavicular). The joint space for the first group listed in the column heading is visualized on the bone. The pink circles around particles represent the statistical difference between the two listed groups.