Statistical Shape Modeling Versus Radiographic Measurements to Describe Ankle Foot Orthosis Impact on Foot Position in Charcot-Marie-Tooth Disease

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Summary

Charcot-Marie-Tooth disease (CMT) commonly results in weakness and cavovarus foot deformity, which can be managed with ankle foot orthoses (AFOs). This study uses statistical shape modeling (SSM) and radiographic measurements from weight-bearing computed tomography (WBCT) to analyze differences in morphology between AFO and barefoot conditions in CMT. SSM and radiographic measures identified a small increase in cavovarus position with the AFO, but SSM additionally revealed correction of hindfoot varus that was not seen in radiographic measures.

Introduction

CMT is an inherited neuropathy associated with a cavovarus foot deformity [1]. AFOs are often used in the treatment of CMT, but foot position resulting from AFO use is poorly characterized [2]. SSM from WBCT can well-characterize pathologic foot and ankle morphology [3,4]. However, SSM is not as accessible as standard radiographic measurements, which can be calculated automatically from WBCT. The objective of this study is to use SSM and radiographic measures to describe foot structural differences in individuals with CMT between standing barefoot and wearing AFOs.

Methods

WBCT images of 27 limbs from 14 individuals with CMT (3 F, average age 49.6 (18-80)) were collected barefoot and with AFOs. Images were semi-automatically segmented and manually verified. 3D bone reconstructions were aligned with an iterative closest point algorithm. Radiographic measures were calculated based on mathematically identified coordinate systems. A 14-bone SSM was generated and analyzed with principal component analysis (PCA) to identify modes of shape variation. Differences in radiographic measures and differences in shape score along each mode between barefoot and AFO conditions were tested with a paired Wilcoxon rank sum test. For each PCA mode that showed significance, a multiple linear regression model from radiographic measures with a significant difference between conditions to shape scores along that mode.

Results and Discussion

Significant differences between conditions were seen along PCA modes 1, 2, and 4. Mode 1 demonstrated a more overall cavovarus position in the AFO condition. Contrarily, mode 2 showed a more neutral hindfoot with the AFO. Mode 4 demonstrated a higher arch with the AFO. Significantly lower talocalcaneal angle (TC), talonavicular angle (TN), and hindfoot alignment angle (HAA) were seen in the AFO condition along with significantly greater sagittal Meary's angle and Foot and Ankle Offset (FAO). Multiple linear regression between these 5 measures and shape scores showed strong correlation in mode 1 (R^2=0.93), but did not strongly relate to shape scores along modes 2 and 4 (R^2 = 0.17, 0.10).

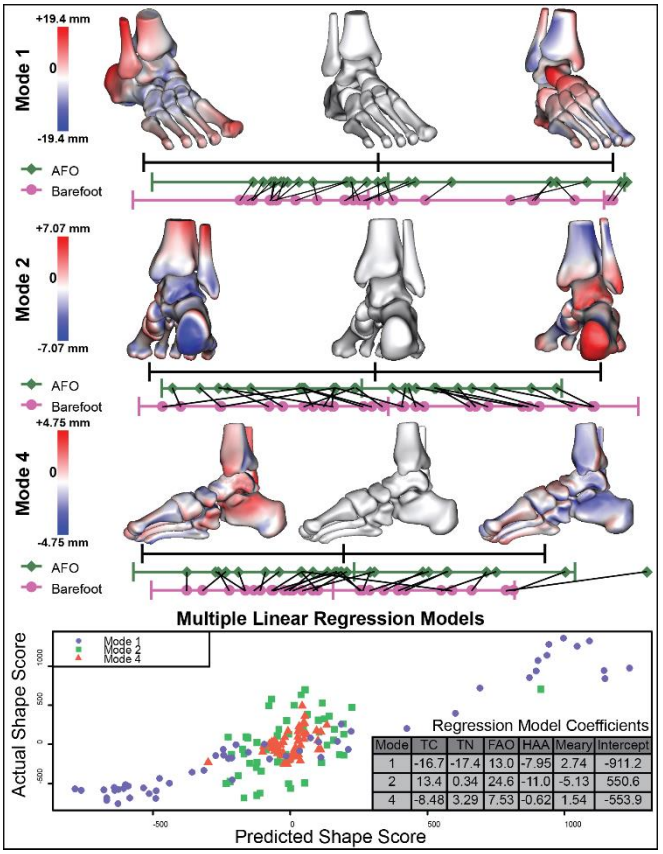

Figure 1: PCA modes 1, 2, and 4 and their shape score distributions as well as the predicted versus actual shape scores from linear regression models with coefficients given in the bottom right.

Conclusions

While radiographic measurements predicted the dominant mode of shape variation between AFO and barefoot conditions, they failed to identify the subtle differences in modes 2 and 4. Mode 2 is highly relevant, as it demonstrates AFO correction of hindfoot varus, but that is overshadowed by the increased arch height in radiographic measures.

References

[1] Jani-Ascadi. 2015. Pediatr Clin North Am. 62.3: 767-86. **[2]** Ounpuu. 2021. Gait Posture. 85: 198-204. **[3]** Lenz. 2023. Foot Ank Clin. 28.1: 63-76. **[4]** Peterson. 2024. Foot Ank Int.