

Asymmetry in the Presentation of Cavovarus Foot Deformity Associated with Charcot-Marie-Tooth Disease

Melissa R. Requist¹, Andrew C. Peterson¹, Bopha L. Chrea², Amy L. Lenz¹
¹University of Utah, Salt Lake City, UT, ²University of Iowa, Iowa City, IA
melissa.requist@hsc.utah.edu

Disclosures: Melissa R. Requist (N), Andrew C. Peterson (N), Bopha L. Chrea (N), Amy L. Lenz (N)

INTRODUCTION: Bilateral cavovarus foot deformity is strongly associated with the neurologic disease Charcot-Marie-Tooth (CMT) [1,2]. This cavovarus deformity has been characterized at the whole foot and individual bone level through several types of medical image analysis demonstrating hindfoot varus, forefoot valgus, midfoot adduction, and variation in the morphology of the talus, calcaneus, and several other bones throughout the foot and ankle [3-10]. Asymmetries in lower limb imaging markers and function have been previously reported in CMT, but the symmetry or asymmetry of bony foot structure is unknown [11-13]. This study used weight-bearing computed tomography (WBCT) to analyze differences in foot structure between paired limbs in individuals with CMT through statistical shape modeling (SSM) and radiographic measures.

METHODS: Bilateral WBCT scans of 31 individuals with CMT (average age 39.5 years, 13F/18M) as well as bilateral and unilateral WBCT scans of 33 limbs from 29 control individuals (average age 36.8 years, 10F/19M) were segmented to yield three-dimensional structures of 14 bones from the tibia through metatarsals. These reconstructions were used to automatically calculate radiographic measures used in existing studies on CMT: Meary's angle in the sagittal and axial planes, talonavicular angle (TNA), calcaneal inclination angle (CIA), hindfoot alignment angle (HAA), and first to second intermetatarsal angle (IMA) [3-7]. Parts were then smoothed and decimated. The tibia and fibula were consistently cropped 50mm proximal to the tibiotalar joint surface, left limbs were mirrored across the sagittal plane to appear as right limbs, and the feet were aligned with iterative closest point alignment. The aligned bony structures were used to generate a multi-domain statistical shape model consisting of all 97 limbs. This model was analyzed with principal component analysis (PCA) and differences in shape score between limbs were tested for modes that accounted for more than 5% of population variance. Following a Shapiro-Wilk test of normality, the absolute difference between limbs of shape score and radiographic measures were tested with either a one-sample t-test or Wilcoxon rank sum test with Holm adjustment for multiple comparisons. Tests were repeated with signed differences to compare left and right limbs. Radiographic measures were compared between CMT and control groups using the same statistics pipeline. All tests used significance $\alpha = 0.05$.

RESULTS: There were no differences between CMT and control groups in age or sex distribution. Radiographic measures demonstrated a significant difference between CMT and control groups in sagittal and axial Meary's angle, TNA, and IMA (Table 1). All radiographic measures tested demonstrated a statistically significant absolute difference between limbs. The first three PCA modes of the SSM each accounted for more than 5% of population variance. The first mode (Figure 1A) demonstrates a spectrum of mildly planovalgus to substantially cavovarus foot shape and showed a statistically significant absolute difference between limbs ($p < 0.001$) with an average difference in shape score of 40.7%. The second mode of variation (Figure 1B) demonstrates variation in arch height and similarly identified a significant absolute difference between limbs ($p < 0.001$) with an average difference in shape score of 21.7%. The third mode (Figure 1C) shows variation in hindfoot varus rotation and again demonstrated a significant absolute difference between limbs ($p < 0.001$) with an average difference in shape score of 59.5%. All modes and radiographic measures showed no significant difference between left and right limbs.

DISCUSSION: Both radiographic measures and statistical shape modeling demonstrate a significant absolute difference between paired limbs, which supports existing literature showing asymmetric functional deficits in individuals with CMT [12-14]. Additionally, as has been reported in previous literature, there is no consistency of the left or right limb having more severe morphologic differences [12]. For radiographic measures, the largest magnitude absolute differences were seen in Meary's angle and talonavicular angle, likely due to the centering of the cavovarus deformity at the midfoot [3-5,8,9]. In the SSM, the largest magnitude absolute difference was seen along the third mode of variation, representing high variability in hindfoot rotation. This is especially important for surgical planning of hindfoot reconstructions to reduce CMT-related cavovarus deformity as contralateral limbs may require substantially different surgical interventions. It also supports the use of bilateral data in studying this rare disease since limbs may be differentially impacted.

SIGNIFICANCE/CLINICAL RELEVANCE: The cavovarus deformity of CMT does not present symmetrically between limbs. This is relevant for treatment planning and patient education as it suggests that surgical and non-surgical treatments should be customized to the limb and that it may be inappropriate to assume equivalent deformity in contralateral limbs.

REFERENCES: [1] Nagai MK. J Pediatr Orthop. 2006. 26(4): 438-43. [2] Jani-Acsadi A. Pediatr Clin North Am. 2015. 62(3): 767-86. [3] Michalski M. Foot Ankle Int. 2022. 43(4): 576-81. [4] An T. Foot Ankle Int. 2022. 43(5): 676-82. [5] Michalski M. Foot Ankle Surg. 2024. 31(2): 143-47. [6] Bernasconi A. Foot Ankle Surg. 2021. 27(2): 186-195. [7] Song JH. Foot Ankle Int. 2024. 45(6): 601-11. [8] Peterson AC. Foot Ankle Int. 2025. 46(3): 268-74. [9] Requist MR. JBMR Plus. 2025. 9(6): ziaf058. [10] Requist MR. Foot Ankle Int. 2025 (in review). [11] Burns J. Clin Biomech (Bristol). 2012. 27(7): 744-47. [12] de Franca Costa IMP. Gait Posture. 2018. 62: 463-67. [13] Chung KW. Neuromuscul Disord. 2008. 18(8): 610-18.

Table 1: Radiographic measures and p-values for between group and between limb absolute difference tests

Measure	Control Average	CMT Average	P-value between groups	CMT Limbs Mean Absolute Difference	P-value between limbs
Meary's Sagittal	6.94°	14.54°	0.034*	9.06°	< 0.001*
Meary's Axial	6.00°	-10.07°	0.003*	8.79°	< 0.001*
TNA	26.16°	5.00°	< 0.001*	10.92°	< 0.001*
CIA	20.02°	20.19°	0.84	1.81°	< 0.001*
HAA	6.78°	8.36°	0.95	3.40°	< 0.001*
IMA	11.40°	9.33°	0.010*	0.68°	< 0.001*

