Morphological Similarities Between Chronic Ankle Instability and Cavus Foot Type Identified Using Weightbearing Computed Tomography and Statistical Shape Modeling

Elana Renae Lapins[1], Alayna Fendler[1], Scott LaTulip[2], Devon Nixon[1], Amy L. Lenz[1]
[1]University of Utah, Salt Lake City, UT [2]Ortho North Carolina, Raleigh, NC
elana.lapins@utah.edu

Disclosures: None

INTRODUCTION: Lateral ankle sprains (LASs) are one of the most common musculoskeletal injuries, and nearly 40% of first-time cases may progress to chronic ankle instability (CAI) [1]. CAI is characterized by recurrent sprains and ongoing functional impairments that persist beyond one year post-LAS, often impacting mobility and quality of life [2]. Although LASs are soft tissue injuries, their association with bony morphology has been mostly studied using two-dimensional radiographic assessments. Individuals with a cavus foot present with a raised arch, which can alter load distribution and increase stress on the lateral ankle structures. Many patients with CAI have a cavus foot shape. Using three-dimensional weightbearing computed tomography (WBCT) and statistical shape model (SSM), along with radiographic measurements to assess foot type, we examined the morphological relationship between cavus alignment and CAI. We hypothesized that individuals with CAI would exhibit foot posture characteristics consistent with a cavus foot type.

METHODS: In this retrospective study, 23 patients (13F/12M) with CAI requiring surgical repair were screened by two board-certified foot and ankle orthopaedic surgeons. Preoperative WBCT scans from these patients were analyzed along with 29 asymptomatic individuals with cavus feet (10F/19M) and 28 asymptomatic individuals with rectus feet (17F/11M). Rectus and cavus individuals were grouped based on Meary's angle (MA) values, where cavus was considered MA > 4° and rectus as -4° < MA < 4°. WBCT scans (n=80) were semi-automatically segmented using Bonelogic (*Paragon28*), then Mimics 24.0 (*Materialise*) and 3-Matic (*Materialise*) were used to audit, smooth, and decimate the segmentations. Bony segmentations were then used to create a 14-bone SSM in ShapeWorks (*SCI Institute*). Principal component analysis (PCA) assessed the modes of variation from the SSM, with parallel analysis applied to retain nonspurious modes, and a one-way ANOVA test determined any significant differences between patient groups for each PCA mode (α=0.05). Hotelling's T^2 test (α=0.05) was implemented to assess localized statistical differences between the mean shapes of each group in the SSM. In-house code calculated MA from the bony segmentations in MATLAB (*MathWorks*).

RESULTS: PCA mode 1 (Fig.1) demonstrated a foot type range from cavus to rectus. Significant differences were observed between the rectus and cavus groups, and between the rectus and CAI groups, whereas no significant differences were found between the CAI and cavus groups. Mode 3 revealed significant differences between rectus and cavus groups, characterized by posterior talar subluxation and altered first metatarsal and midfoot alignment. PCA mode 5 showed significant differences between the CAI and cavus groups, with the cavus group exhibiting a larger calcaneal pitch. MA values were significantly different between all groups, averaging 17.88° ± 9.43 in the cavus group, 10.83° ± 8.73 in the CAI group, and 0.17° ± 2.88 in the rectus group. Hotelling's T^2 analysis (Fig.2) indicated that differences between the rectus and cavus groups (80.23% of particles) and between the rectus and CAI groups (59.23% of particles) were predominantly driven by alignment. In contrast, the cavus versus CAI comparison showed only 2.61% of particles differing significantly in shape and alignment between mean group shapes.

DISCUSSION: These findings support the hypothesis that patients with CAI exhibit foot morphology similar to the cavus foot type, as shown by comparable MA values and minimal differences in PCA and Hotelling's T2 analyses between the CAI and cavus groups. The pattern suggests that the CAI group may represent a less severe or subtle form of cavus alignment. Cavus alignment increases stress on the lateral structures of the foot and ankle, which could contribute to a higher risk of developing CAI and the need for lateral ligament reconstruction, although further research is needed. Although varus alignment was not directly analyzed in this study, it remains an important factor in surgical planning, as failing to correct hindfoot varus during lateral ligament reconstruction has been associated with a 28% failure rate [3]. Additionally, subtalar joint alignment plays a key role in determining foot type and should also be evaluated. Overall, these findings highlight the importance of addressing underlying bony alignment when assessing CAI and planning surgical interventions. Limitations of this study include reliance on static WBCT imaging, which may not capture dynamic compensatory mechanisms, and the fact that WBCT scans were obtained in CAI patients whose preoperative planning specifically required it, potentially making this group unique and emphasizing the need to study bony morphology in larger populations. Future research with larger cohorts and functional assessments could help further clarify the relationship between cavus morphology, hindfoot alignment, and CAI risk.

CLINICAL RELEVANCE: Determining that patients with CAI share morphological characteristics with the cavus foot type highlights a potential structural predisposition for recurrent instability. This relationship can inform surgical planning, rehabilitation approaches, and prevention strategies that address underlying alignment rather than solely focusing on ligament repair.

REFERENCES: [1] Hertel & Corbett, *J Athl Train*. 2019[2] Gribble et al. *J Orthop Sports Phys Ther*. 2013[3] Bosman & Robinson, *Foot Ankle Clin*. 2013

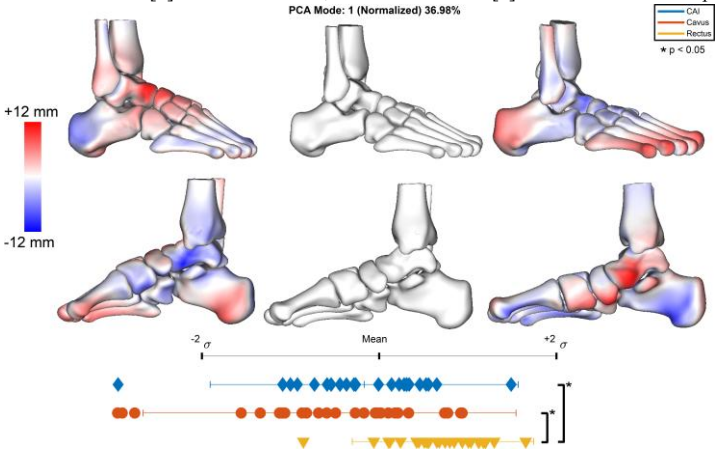

Fig 1: PCA Mode 1 Results. Red indicates shape differences away from the bone, representing an increase in feature size, while blue indicates shape differences toward the bone, representing a decrease.

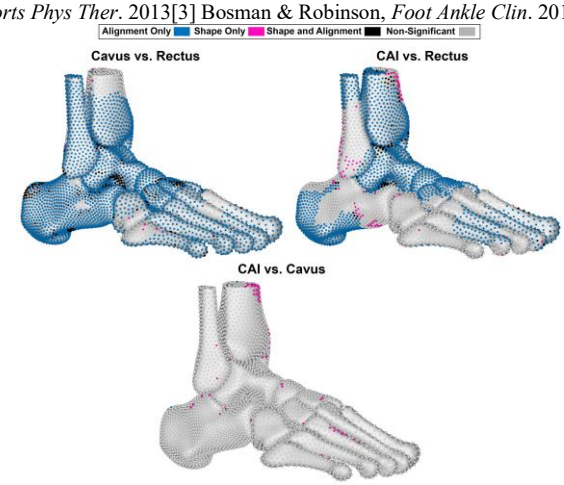

Fig 2: Hotelling's T^2 Results. Colored particles depict statistically significant differences. Grey particles are not significantly different between mean shapes.