Pediatric Foot and Ankle 3D Measurements from Weightbearing Computed Tomography

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INTRODUCTION: Current standard of care assessment of pediatric foot and ankle bony alignment utilizes conventional two-dimensional (2-D) weightbearing radiographs to quantify normal and abnormal alignment in developing feet [1,2]. However, little research has been conducted on utilizing weightbearing computed tomography (WBCT) to quantify pediatric ankle alignment in three-dimensions (3D). Prior studies have demonstrated WBCT measurements to be more accurate and reliable than plain film radiographs [3]. Additionally, pediatric foot and ankle alignment measurements from conventional radiographs generally require manual measurement by orthopedic surgeons and clinical researchers [1,2]. MATLAB toolboxes, specifically the Automatic Anatomical Foot and Ankle Coordinate Toolbox (AAFACT) and 3D Foot and Ankle Radiology Measurements (3D FARM) toolbox, have been developed to automate foot and ankle alignment measurements from segmented WBCTs [4]. Pediatric foot deformities present additional challenges due to the presence of growth plates and morphologic changes that happen to the developing foot. This study presents a valuable use case of 3D FARM to WBCT-derived bone models of pediatric feet and ankles with various pathologies.

METHODS: A retrospective database of WBCT scans collected at the University of Utah's Orthopaedic Center was utilized to identify 40 pediatric WBCT scans of patients with various foot and ankle pathologies. These scans (age: 15.1 ± 2.7 years; 22 male, 18 female) were placed into one of six groups based on clinical and radiographic notes: pes rectus (n=8), pes cavus (n=3), pes planus (n=4), clubfoot (n=8), Charcot-Marie-Tooth (CMT) (n=12), and talar fracture (n=5). These WBCT scans were semi-automatically segmented to develop 14-bone 3D models via DISIOR (Bonelogic Foot and Ankle). The bones were then audited, smoothed and decimated through Mimics 24.0 (Materialise) and 3-Matic 16.0 (Materialise). Common radiographic foot and ankle measurements were then automatically calculated using 3D FARM, which utilized coordinate vectors derived from AAFACT. Eight measurements were calculated, including sagittal talocalcaneal angle (STA), axial talocalcaneal angle (ATA), calcaneal inclination angle (CIA), axial Meary's angle (MAa), sagittal Meary's angle (MAs), talonavicular angle (TnA), calcaneal-1st metatarsal angle (CMA), and tibiocalcaneal angle (TcA). For each group, mean values and standard deviations were calculated for each 3D FARM measurement. Literature ranges from conventional 2D radiographs were compiled for comparison. No literature values were available for pediatric talar fracture, and no studies were found that presented these measurements in CMT populations, therefore we used studies that looked at pediatric pes cavus and hindfoot varus [12].

RESULTS SECTION: In the pes rectus group, 3D FARM means for ATA, CIA, MAa, MAs, TnA and TcA were within literature ranges, but STA was not [1,2,5]. In the CMT group, 3D FARM means for STA, ATA, MAs, and CMA were within literature ranges, but CIA was not [2, 6-8]. In the pes cavus group, 3D FARM means for ATA, MAs, and CMA were within the literature ranges, but STA and CIA were not [2, 6-8]. In the pes planus group, 3D FARM means for CIA was within the literature range, but STA, ATA, and MAs were not [9]. Finally, in the clubfoot group, 3D FARM means for STA, ATA, and MAa were within the literature ranges, but TcA was not [7, 10, 11].

DISCUSSION: This study provides an application of 3D FARM to pediatric WBCT data across multiple pathologies. While several of our mean measurements aligned with reported literature ranges, others did not. Importantly, it is not always expected that measures from 2D radiographs are equivalent to those from 3D WBCTs. Therefore, these differences should not be entirely interpreted as inaccuracies of 3D FARM, but rather as informing our understanding that 3D measurements may reveal variation not captured on 2D radiographs. For example, many of the measurements involving the talus showed differences from the reported literature ranges. Morphological changes to the talar dome have been recognized in CMT and clubfoot populations, but these current measures from 2D images are unable to assess these changes. This highlights the vital role 3D imaging holds in understanding these deformities. Additionally, pediatric populations present unique anatomical and developmental considerations compared to adults which should highlight the need to tailor our measurement techniques to such variations. The small sample sizes in each group limit the generalizability of these findings, and results should be viewed as preliminary. Instead of aligning with accepted normative values, this work highlights areas where 3D-based measurements may diverge from 2D literature and identifies pathologies that warrant focused investigation. As the 3D FARM toolbox continues to be refined, expanding pediatric datasets are necessary for reporting accurate, clinically meaningful alignment assessments in each of these populations.

SIGNIFICANCE/CLINICAL RELEVANCE: This study presents a novel application of the 3D FARM software to pediatric WBCTs, enabling automated ankle alignment assessment across developing bones. Establishing accurate, pathology-specific normative datasets is essential to improve understanding of these conditions and thus inform more precise treatment planning and long-term management in pediatric patients.

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Table 1: 3D FARM measurements are reported as mean ± 1 standard deviation and literature (lit.) measurements are reported as a range. Shaded regions indicate measurements that fell within the literature ranges.

3D FARM Measurement	Rectus		CMT		Cavus		Planus		Clubfoot	
	3DFARM	Lit.	3DFARM	Lit.	3DFARM	Lit.	3DFARM	Lit.	3DFARM	Lit.
Sagittal Talocalcaneal Angle (STA)	17.9°± 2.7°	25° to 55°	14.4° ± 4.7°	< 20°	28.2° ± 4.2°	< 20 °	27.2° ± 12°	> 45°	17.6° ± 7.3°	< 25°
Axial Talocalcaneal Angle (ATA)	11.9° ± 2.3°	10° to 56°	8.96°± 4.6°	< 30°	13.5° ± 8.8°	< 30°	17.5° ± 16°	> 30°	3.79° ± 9.6°	< 15°
Calcaneal Inclination Angle (CIA)	15.6° ± 1.8°	5° to 32°	20.9° ± 3.6°	> 30°	24.3° ± 1.7°	> 30°	15.7° ± 3.2°	< 20°	14.6° ± 5.9°	X
Axial Meary's Angle (MAa)	-1.26° ± 5.5°	-10° to 30°	-27.8° ± 24°	X	-11.2° ± 28°	X	-3.56° ± 16°	X	-12.2° ± 33°	- 20° to 0°
Sagittal Meary's Angle (MAa)	13.9° ± 5.0°	0° to 20°	33.0° ± 14°	> 4°	26.7° ± 2.0°	> 4°	2.92° ± 15°	< - 4°	18.8° ± 22°	X
Talonavicular Angle (TnA)	10.2° ± 8.7°	5° to 39°	-13.1° ± 24°	X	11.5° ± 3.8°	X	14.9° ± 26°	X	3.27° ± 25°	X
Calcaneal-1st Metatarsal Angle (CMA)	147° ± 6.4°	X	127 °± 11°	90° to 150°	126° ± 0.32°	90° to 150°	153° ± 3.6°	X	146° ± 22°	X
Talocalcaneal Angle (TcA)	73.4° ± 3.0°	60° to 77°	73.7° ± 14°	X	73.9° ±0.87°	X	82.4° ± 6.5°	X	83° ± 10°	> 90°