Trigonometry Of The Hand And Wrist Under Full Body Weight Loading Using Functional Upper Extremity Load-bearing CT Imaging

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Introduction
The effect of full body weight loading of the upper extremity on the kinematic relationship between the bones of the hand and wrist is not well understood, which presents challenges in diagnosing and treating injuries. However, the use of weight bearing CT (WBCT) on the foot and ankle has improved our understanding of injuries that are not easily identified using other forms of imaging. Injuries to the hand and wrist account for 3% to 9% of all injuries in athletes and are one of the most expensive injury types. Currently, there are no studies evaluating full body weight loading of the upper extremity using functional CT imaging methods. Other studies are limited in that only one particular bone or joint was evaluated, minimal loading was applied to the upper extremity, and 3D simulations used to represent full body weight loading were not validated against patient or cadaver data, thus demonstrating the need for functional upper extremity loading CT (FUEL CT) and imaging under full body weight loading conditions. We believe the impact that weight bearing CT has had on the understanding of foot and ankle pathology can be translated to the upper extremity using our FUEL CT method. In order to support the use of FUEL CT, we must first identify and describe the trigonometric relationships between bones of the hand and wrist under full body weight loading.

Methods
After approval by the University of Iowa Investigational Review Board (IRB ID #: 202201189), informed consent was obtained from past or present competitive gymnasts for analysis of handstands using a WBCT scanner (HiRise; CurveBeam). Age, sex, height, weight, previous injuries, current wrist pain rating, dominant writing hand, and cartwheel hand dominance were documented for each participant. A neutral, unloaded image was obtained for each participant. Then, participants performed a handstand (with standardized hand placement) inside the WBCT scanner. Finally, two parallel handlebars were attached to the scanning platform and participants performed a handstand-like action in the parallettes position. Images were converted to NIfTI files for analysis using the Disior Bonelogic® Hand and Wrist module (Bonelogic Hand and Wrist, version 2.0, Disior Ltd). The software identified bony anatomic landmarks and computed 2D radiographic measurements. Each measurement's calculation methods were defined. Representative 3D models were created based on the CT images. Measurements in the Handstand and Parallettes position were compared with those in the neutral position. Wilcoxon signed rank test and paired t-tests were used to analyze results.

Results
Fourteen participants were consented and imaged; however, four participants were excluded because at least one of their images had significant motion artifact and were unable to be analyzed. Radiolunate Angle, Capitolunate Angle, Scapholunate Angle, Lunotriquetral Angle, Radiotriquetral Angle, Radiotrapezoidal Angle, Radiotrapezial Angle, and Radiometacarpal III Angle all tilted dorsally in both the Handstand and Parallettes conditions compared to Neutral (all $p<0.05$). Carpal Height Ratio, Ulnar Translation Ratio, Radioscaphoidal Joint Minimum Gap (mm), Radiolunate Joint Minimum Gap (mm), Scaphotrapezial Joint Minimum Gap (mm), Lunocapitate Joint Minimum Gap (mm), and Carpometacarpal I Joint Minimum Gap (mm) were smaller in the Handstand and Parallettes conditions compared to Neutral (all $p<0.05$). In the Parallettes condition, Radial Inclination (°) had a volar tilt, Radial Height (mm) was larger, and Ulnar Variance (mm) shifted distally compared to Neutral (all $p<0.05$). In the Handstand condition, Scaphotrapezoidal Joint Minimum Gap (mm) was smaller compared to Neutral ($p<0.05$).

Discussion
We demonstrated, both trigonometrically and visually with 3D models, the ways in which the relationship between bones of the hand and wrist change during loading conditions. This study supports that FUEL CT may be a better tool to measure hand and wrist parameters compared to traditional imaging. We have laid the foundation for future FUEL CT research of the upper extremity, and the development of a dedicated FUEL CT device may be warranted. The research is limited due to a small sample size, so more participants need to be recruited in future studies to further validate our findings. Future research could include applications to everyday activities, such as falling onto an outstretched hand or pushing yourself up from the sitting position using the arms of a chair. Future analysis of this data could include stratification based on age, sex, height, prior injury, and wrist pain to see if any of these factors have bearing on the hand and wrist measurements.

Significance/Clinical Relevance
We believe the knowledge gained from using FUEL CT for the hand and wrist during full body loading will improve our ability to both diagnose and treat injuries of the hand and wrist. Demonstrating the changes that occur within the hand and wrist in full body loading conditions, can be used as a foundational tool for clinical use and further research. Harnessing the power of functional load-bearing CT imaging, we can describe the trigonometric shifts and structural 3D changes in the hand bony anatomy. Understanding positional changes may lead to a better grasp of the requirements of the hand while under use. Therefore, this study might serve to improve injury assessment and treatment strategies, shaping the development of imaging tools and protocols.