Do Non-Weight Bearing Computed Tomography Scans Accurately Represent Weight Bearing Metatarsal Orientation?

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Summary

Non-weight bearing (non-WB) computed tomography (CT) scans are commonly utilized to estimate metatarsal orientations for musculoskeletal models, however, they may not adequately represent bone orientation due to weight bearing (WB). We obtained CT images of the 1st and 2nd metatarsals of six participants during WB and non-WB conditions. Both metatarsals were significantly more dorsiflexed in the sagittal plane (p=0.004) and more internally rotated in the transverse plane (p<0.001) during WB compared to non-WB. Further, non-WB orientations strongly predicted their WB counterparts through linear relationships. This work arms researchers with a method of correcting non-WB CT data to create more accurate musculoskeletal models.

Introduction

Precise estimates of metatarsal orientation are essential in the determination of *in vivo* bone loads, as prior research has illustrated the large effect of sagittal metatarsal angle on peak bone strain and fatigue failure risk [1]. The majority of prior research has obtained metatarsal orientations in a non-weight bearing (non-WB) position [1,2], which may introduce errors as foot bones likely shift in weight bearing (WB). The purpose of this research was to characterize the relationship between metatarsal orientation during WB and non-WB conditions.

Methods

Six participants (4 male; 2 female) received two scans in a HiRise WB CT scanner (CurveBeam AI, USA). For non-WB scans, participants stood on their left foot while their right foot rested on the baseplate. For WB scans, participants stood on their right foot only and used armrests for balance. The 1st and 2nd metatarsals were manually segmented from the CT scans using Mimics (v25.0; Materialise, Belgium). Anatomical coordinate systems were created for each metatarsal in Matlab (v2024; MathWorks, USA) using an iterative closest point algorithm [3], and three-dimensional metatarsal orientations were calculated relative to a global reference using cardan angles in a sagittal-transverse-coronal sequence.

Results and Discussion

Paired t-tests were used to investigate differences in metatarsal orientation in the sagittal and transverse planes. The 1st (p=0.002) and 2nd (p=0.004) metatarsals were significantly more plantarflexed and more internally rotated (p<0.001) in non-WB versus WB.

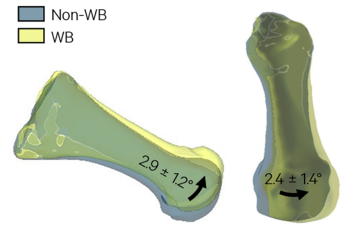

Figure 1: Representative participant sagittal (left) and transverse (right) 1st metatarsal orientation during non-WB and WB.

Statistically significant first-degree polynomial relationships were observed between non-WB and WB sagittal metatarsal orientations for the 1st (p=0.007) and 2nd (p=0.004) metatarsals (Figure 1a), with r^2 values of 0.87 and 0.91, respectively. The 1st and 2nd metatarsals were grouped for the transverse orientation as they displayed a similar relationship, which illustrated an r^2 of 0.96.

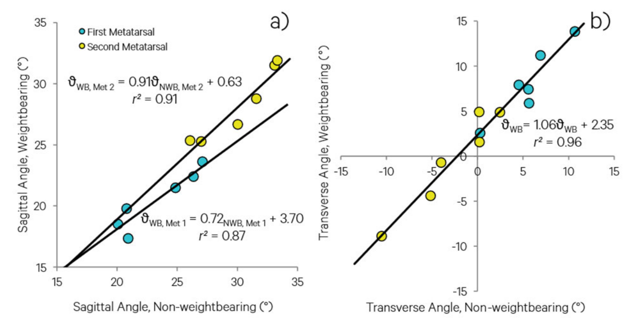

Figure 1: Sagittal (a) and transverse (b) metatarsal orientation during non-WB and WB. Positive angles indicate plantarflexion and internal rotation, respectively.

Conclusions

While metatarsal orientation was indeed significantly altered in WB, the novel relationships we have developed will allow future studies utilizing non-WB imaging methods to more accurately model metatarsal orientations, leading to more refined musculoskeletal models and estimations of bone strain and failure.

Acknowledgments

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References

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