ACCURACY OF MEASURING IN-VIVO ANKLE KINEMATICS DURING LEVEL GAIT

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Summary

Biplane Video Radiography (BVR) is a highly accurate method for measuring in-vivo kinematics. This study assessed the accuracy of Magnetic Resonance Imaging (MRI)-BVR based tracking for measuring tibia, talus, and calcaneus movement compared with gold standard Radiostereometric Analysis (RSA). A volunteer with implanted tantalum beads underwent BVR during level gait. Bone poses were calculated from image registration and the absolute differences were compared against RSA. Results showed <1.1 mm translation and <1.4° rotation root mean square error, which is comparable to CT methods from literature. This approach allows the inclusion of soft tissue geometry for modelling.

Introduction

The ankle complex is a sophisticated structure comprising multiple joints, bones, ligaments, tendons, and muscles. Due to this anatomical complexity, it is challenging to accurately measure the internal joints of the ankle (tibiotalar and subtalar joints) using traditional marker-based motion capture. BVR is an imaging technique that allows direct measurement of individual bones using high-speed, dynamic X-rays during different activities of daily living. CT is typically combined with BVR to track direct bone movement, however, MRI provides an alternative approach with the ability to visualise soft tissues. Despite these advantages, the accuracy of MRI-based tracking remains unknown. The primary aim of this study was to quantify the accuracy of measuring the tibia, talus and calcaneus with a gold standard RSA method.

Methods

Ethical approval was granted by the Wales Research Ethics Committee, and written informed consent was obtained from one volunteer who had previously received tantalum bead implants: five in the distal tibia, four in the talus, and three in the calcaneus. Three-dimensional (3D) models of the tibia, calcaneus and talus were segmented (Simpleware Scan IP, Synopsis) from an MRI scan (Magnetom 3T Prisma, Siemens). The beads were segmented from a previous CT and co-registered with the MRI bone models to calculate their positions. BVR (125 FPS, 1.25 ms pulse width) was recorded during stance phase of gait. Bead positions were tracked and the 2D bead locations were used to digitally remove them from the X-ray images [1] allowing for blinded image registration. The tibia, calcaneus and talus were manually registered (DSX Suite, HAS Motion) and bone poses were calculated for each frame. The absolute bone position differences were calculated by comparing RSA bone positions versus the MRI derived bone positions (MATLAB, Mathworks) for all 6 degrees of freedom.

Results and Discussion

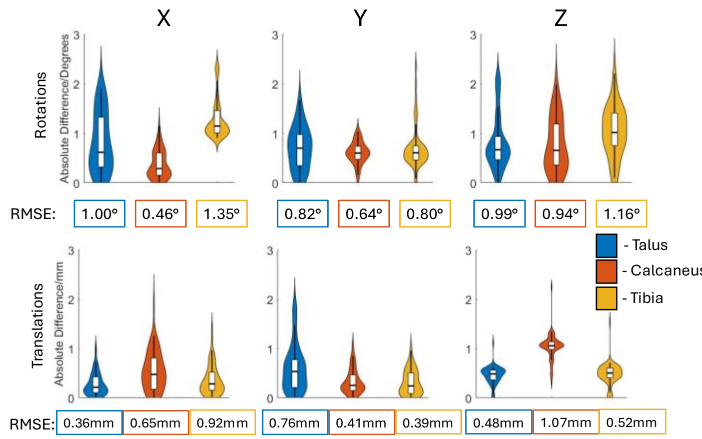

Figure 1: Violin plots showing the absolute difference between RSA derived bone positions versus MRI bone positions

The Root Mean Squared Error (RMSE) (Figure 1) between RSA and MRI derived bone models was found to be <1.1 mm for translations and <1.4 ° for rotations. The violin plots showed that certain frames for each bone had errors as high as 2.5°, highlighting the necessity of examining the full distribution of absolute differences rather than relying solely on single mean values. For context, optical motion capture has been reported to overestimate joint angles by up to 8.31° when evaluated against BVR [2]. CT-based studies have reported RMSEs between 0.5 mm and 0.8 mm for translation, and 1.4° to 1.7° for rotation [3], a comparable accuracy to the MRI-based approach presented here. Future work will expand validation to include CT, assess additional activities, and identify phases of the activity with the highest errors.

Conclusions

BVR combined with MRI can be used to accurately measure the ankle joint complex kinematics during gait. This approach is particularly beneficial for studies where CT is unsuitable due to radiation concerns, while also allowing for direct soft tissue integration into biomechanical analyses.

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References

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