Comparison of Optical Motion Capture and Biplane Video X-ray In-Vivo Tibiofemoral Joint Rotations

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INTRODUCTION: Optical Motion Capture (OMC) is the current research gold standard approach for investigating tibiofemoral (TF) joint rotations in-vivo, but it suffers from two main errors: misplacement of skin-mounted markers and soft tissue artefact. OMC is generally considered to be accurate in the sagittal plane (flexion) but has insufficient accuracy in the other planes [1]. Biplane Video X-ray (BVX) is an alternative in-vivo imaging modality which has been proven to have a high degree of accuracy in all planes [2]; however, BVX is less widely available, and involves ionising radiation so may not be suitable for some clinical applications. Comparison between OMC and BVX derived knee rotations has previously been investigated to describe the accuracy of marker-based kinematics and improve the interpretation of results for a range of activities [3], but not for a weightbearing, dynamic lunge. This study aimed to explore the accuracy of OMC derived TF rotations by comparing with kinematics acquired using BVX for a lunge, to understand the errors associated with OMC-derived knee rotations during an activity involving natural joint loading and a large degree of flexion.

METHODS: 5 healthy volunteers (3M/2F, mean age 47.8, mean BMI 23) were recruited as part of this exploratory study. Ethical approval for the study was obtained from the Wales Research and Ethics Committee. Written informed consent was obtained prior to every data collection session. MRI scans were performed (Magnetom 3T Prisma, Siemens) and segmented (Simpleware Scan IP, Synopsis) to obtain 3D models of the femur and tibia. Anatomical coordinate systems (ACS) were defined for each 3D bone model using automated algorithms [4]. BVX (60 FPS 1.25ms) and OMC were collected simultaneously whilst each participant performed a dynamic, weightbearing lunge. Image registration was performed (DSX Suite, C-Motion Inc.) to calculate the object transform between the global coordinate system (GCS) and ACS for each bone by matching the 3D bone models to the two X-ray views at each frame. The BVX TF rotations were calculated using a custom MATLAB script (MathWorks) and a digital adaptive low-pass Butterworth filter was applied (cut-off frequency range 5-10 Hz). OMC data was tracked (Qualysis Track Manager), anatomical coordinate systems defined using marker positions in a neutral standing position [5], kinematics were calculated and filtered using a digital low-pass Butterworth filter (Visual3D, C-Motion Inc.). The three TF joint rotations were calculated using the Joint Coordinate System approach [6] then compared using a Bland-Altman analysis [7].

RESULTS SECTION: Figure 1 contains three Bland-Altman plots plotting the difference between the OMC and BVX calculated rotations – flexion-extension (FE), abduction-adduction (AA) and internal-external rotation (IE) – at the same points during the lunge activity for each healthy volunteer (represented by different colours).

DISCUSSION: The Bland-Altman plots in Figure 1 show that the mean difference between the OMC and BVX rotations calculated in for FE and IE were positive, agreeing with previous studies that found joint angles tended to be overestimated when using skin markers [8]. The offsets may indicate an error in marker placement, with the range of differences for each participant likely being due to skin motion artefact.

Whereas the limits of agreement (±1.96SD) in FE were relatively small in comparison to the range of motion in that plane, AA and IE rotation limits of agreement were much larger compared to the range of motion. Therefore, OMC is best suited for calculating flexion compared to calculating the other TF rotations. These results highlight the need for caution when using marker-based kinematics to inform computational models, as they can be very sensitive to small changes in joint kinematics. Future work will focus on investigating how these errors in OMC data effect musculoskeletal modelling outputs, including calculated inverse kinematics.

SIGNIFICANCE/CLINICAL RELEVANCE: (1-2 sentences): Understanding the accuracy of OMC data will inform future musculoskeletal modelling pipelines, whose optimisation algorithms are sensitive to subtle changes in kinematics. Knowledge of the limitations of input data is important to understand the model outputs when quantifying changes due to disease or interventions.

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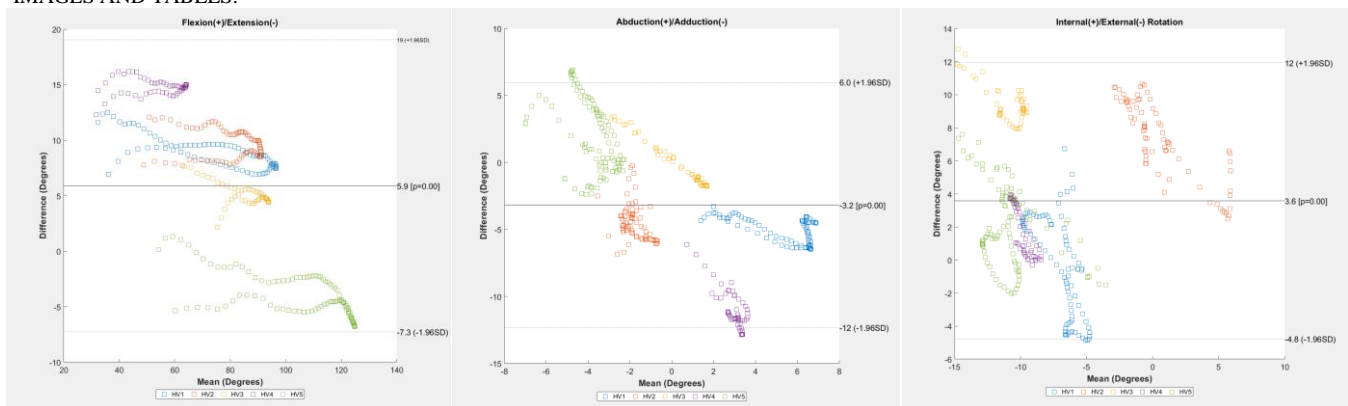
IMAGES AND TABLES:

Figure 1 – Bland-Altman plots showing the mean and difference between OMC and BVX calculated tibiofemoral rotations, where each square represents a point during the lunge of each participant. The solid line represents the mean difference of all data points, with the dashed lines showing ±1.96 standard deviations from the mean.