Assessing Operator Reliability in Biplanar Videoradiography Knee Kinematics Tracking

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Summary

Biplanar videoradiography (BVR) enables precise *in vivo* bone motion tracking but is prone to inter-operator variability. We introduce a training method for operators to track knee movement in Slicer-Autoscoper. Two operators were trained to track the tibia and femur accurately during an unblinded training phase. Their accuracy was confirmed with a blinded evaluation phase. The patella was challenging to track due to the x-ray views. This approach enables multiple operators to track a single dataset without introducing bias.

Introduction

BVR is a powerful tool for measuring *in vivo* bone motion with high spatial and temporal resolution. While knee joint tracking accuracy has been reported, most studies use a single operator, and it is unclear whether they are blinded to the ground truth. We previously developed a training approach for tracking the ankle complex [1] that consisted of a trainee learning to track with unblinded ground truth kinematics derived from implanted tantalum beads. Once the trainee can track the training data with sufficient accuracy, they are tested using a separate trial blinded to the ground truth kinematics. [1,2]. This study aimed to implement a similar training protocol for the knee joint complex. A robust and open-access training approach may improve tracking quality across the field and reduce inter-operator variation, enabling faster processing times and multi-centre BVR studies.

Methods

A fresh-frozen cadaver knee was implanted with 6 tantalum beads in the femur, 5 in the tibia, and 4 in the patella. A CT scan captured bone volumes, and the cadaver was attached to an Oxford Rig for a controlled knee bend in a BVR volume. We developed an open-source approach to remove the beads from BVR images to avoid aiding the semi-manual tracking process. The training was structured in two phases. In the first phase, operators tracked knee motion in a trial while receiving automated feedback on translational and rotational errors. They continued until tracking errors were within the thresholds of 1 mm and 2° on every frame. Once proficient, operators moved to the second phase, tracking an entire trial without feedback. Accuracy was evaluated by comparing performance to bead-based kinematics [1]. Tracking accuracy was deemed acceptable if errors were within 1 mm and 2°. Two operators completed the training. Root mean square differences (RMSEs) quantified error.

Results and Discussion

Both operators consistently tracked the femur and tibia within the error thresholds throughout the feedback and blinded trials. The femur and tibia errors ranged between 0.19° and 0.99° with a mean of 0.50° across both operators (Figure 1A). However, tracking the patella remained challenging in both trials. Neither operator achieved the predefined threshold, with patella RMSE values significantly higher than those for the femur and tibia (range:1.8-7.1°, mean: 0.50, Figure 1B).

Poor patella tracking likely results from the biplanar camera configuration, with one camera positioned sagittally and the other posteriorly—a common setup in knee kinematics analysis during treadmill studies. While effective for femoral and tibial motion, this arrangement obstructed the patella. An oblique view may improve patella tracking without compromising the tibia and femur.

Conclusions

These findings highlight the importance of operator training and camera placement for accurate bone tracking, particularly with complex three-dimensional motion and overlapping structures. We plan to make the approach open access to enable multi-operator BVR studies.

References

[1] Welte et al. (2022). JOVE, 183: e63535., [2] Miranda et al. (2013) J Biomech, 46: 567-573, [3] Skelobslab (2023) GithHub, RemoveBeads

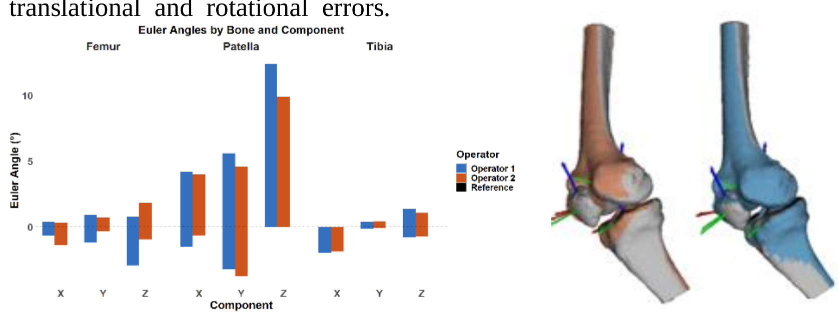

Figure 1 A) Euler angles of the patella, tibia, and femur in the X, Y, and Z planes, referenced to the beaded coordinate system, for Operators 1 (blue) and 2 (orange) during the lunge cycle. B) Reference bone (white) compared to tracking by Operator 1 (blue) and Operator 2 (orange).