

# Accuracy and Precision of Model-based Bone Tracking for a Dynamic Hop Landing Activity

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**INTRODUCTION:** Biplane videoradiography is commonly used to quantify 3D skeletal joint motion using either gold-standard marker-based tracking or the more clinically applicable model-based tracking. While model-based tracking depends only on the bone shape, it is more sensitive to biplane system geometry and bone-soft tissue image contrast. Our previous work demonstrated that the systematic errors of marker- vs. model-based bone tracking of individual cadaveric bone specimens are less than 0.25°/mm.<sup>1</sup> This information was critical to custom software development, but the uncertainty in 3D reconstruction of the kinematic position of relative bone movement as a function of in vivo biplane system geometry and realistic bone-soft tissue image contrast was not fully captured.<sup>1</sup> Given our interest in quantifying dynamic hop landing kinematics in patients following anterior cruciate ligament (ACL) surgery, we sought to quantify the accuracy, precision, and bias of model-based tibiofemoral kinematics relative to gold-standard marker-based tracking for a simulated hop landing task for a biplane system configuration used for in vivo motion capture.

**METHODS:** A male cadaveric knee specimen was used. Fourteen 0.80mm diameter tantalum beads were implanted: 6 in the distal femur and 8 in the proximal tibia. Computed tomography (CT) scans were taken, and femur and tibia models were generated using commercial software (Mimics; Materialise). To quantify precision of relative tibiofemoral bone motion, the specimen was frozen such that any non-zero joint motion was attributable to tracking errors. Three trials simulating a hop landing were recorded at 250 frames/second as the specimen was moved through the calibrated biplane system field of view. The average source to image distance for the biplane setup was ~185 cm, and the angle between the two x-ray image intensifier pairs was ~55°. X-rays were taken with a voltage of 76 kV and a current of 160 mA. Marker-based tracking was completed by digitizing and tracking the displacement of the beads in the x-ray videos using open-source software (XMALab; Brown University).<sup>2</sup> X-ray videos and model partial volumes were then processed to remove the spatial information associated with the beads using custom-written software.<sup>3</sup> Model-based tracking was then conducted using open source 2D-3D registration software (Autoscopec; Brown University).<sup>4</sup> Analyses were performed for each trial using the first 38 frames where both the femur and tibia were visible in the field of view. All tracking data were filtered using a 4<sup>th</sup>-order Butterworth filter. 3D knee motion was expressed as 6 degree of freedom (DOF) kinematics. For each DOF, the mean ( $\pm$  SD) absolute difference between marker- and model-based kinematics was used to describe tracking accuracy. Bland-Altman tests were used to quantify bias and precision.

**RESULTS:** The mean absolute differences in flexion/extension (FE), ab/adduction (AA), and internal/external (IE) rotation were 0.19 $\pm$ 0.24°, 0.36 $\pm$ 0.20°, and 0.64 $\pm$ 0.55°, respectively. Translational differences in medial/lateral (ML), anterior/posterior (AP), and inferior/superior (IS) directions were 1.62 $\pm$ 0.34mm, 0.20 $\pm$ 0.26mm, and 0.14 $\pm$ 0.09 mm, respectively. Bland-Altman analyses revealed biases of -0.07°, 0.24°, and 0.58° in FE, AA, and IE rotation respectively. Biases in the ML, AP, and IS translational DOFs were -1.60mm, 0.19mm, and -0.12mm, respectively. The Bland-Altman analysis also revealed limits of agreement (1.96xSD) of 0.59°, 0.66°, 1.2° for FE, AA, and IE rotation, respectively. Limits of agreement for ML, AP, and IS translation were 0.66mm, 0.51mm, and 0.23mm, respectively.

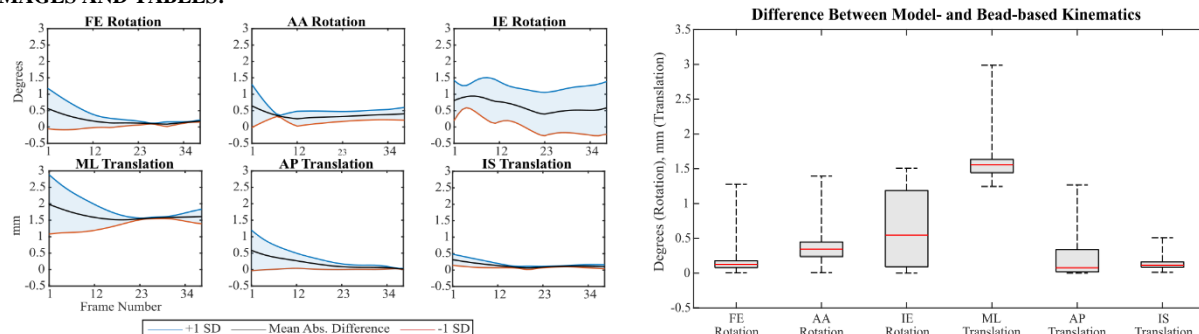
**DISCUSSION:** The accuracy, precision, and bias of 3D joint kinematics obtained from our hop landing biplane videography system configuration showed good agreement with previous measures based on idealized conditions, with the exception of some dependency on DOF of interest.<sup>1</sup> Of note, ML translation was the least accurate DOF (Fig 2) and is likely the result of ML translations occurring in the plane normal to the image intensifier (i.e., out-of-plane motion). This result was not unexpected given the geometry of our system was optimized to capture in-plane AP translation, in which model-based tracking was 8x more accurate compared to ML translation. We have previously reported that ACL reconstructed patients land with their tibia anteriorly translated by up to 7.5mm during a hop-landing compared to matched uninjured patients;<sup>5</sup> the magnitude of this difference is more than an order of magnitude greater than the level of imprecision quantified in the AP DOF here, giving us high confidence that our biplane videoradiography configuration and post-processing approach is sensitive to likely clinically meaningful long-term functional changes in this patient population of interest.

**SIGNIFICANCE/CLINICAL RELEVANCE:** The accuracy, precision, and bias of the biplane videoradiography configuration we have optimized to capture dynamic hop landing is sufficient to quantify what we believe are clinically relevant differences in 3D knee kinematics of ACL reconstruction patients, although caution should be used in interpreting dynamic medial/lateral tibial position.

**REFERENCES:** 1. Miranda, D. et al. J Biomech (133), 2011. 2. Knörlein, B. et al. J Exp Biol (219), 2016. 3. [https://bitbucket.org/xromm/xromm\\_autoscopec/tools/src/master/](https://bitbucket.org/xromm/xromm_autoscopec/tools/src/master/) 4. Akhbari, B. et al. J Biomech (92), 2019. 5. Beveridge, JE. Et al. Trans ORS, 2020.

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## IMAGES AND TABLES:



**Figure 1 (left).** Mean absolute difference between marker-based and model-based tracking by frame for each DOF. **Figure 2 (right).** Absolute difference between marker-based and model-based tracking by DOF.