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DEVELOPMENT AND VALIDATION OF SUBJECT-SPECIFIC MOVING-AXIS KNEE MODEL USING MRI AND EOS IMAGING DURING QUASI-STATIC MOVEMENTS

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INTRODUCTION

Musculoskeletal (MS) models are used by the scientific community to gain insight on how external forces and movements influence the human body internally. This allows researchers to quantify muscle, ligament, and joint contact forces without the use of invasive methods. Despite the complex knee structure, the knee is often idealized as a hinge joint. However, many studies have revealed tibial-rotation trends with respect to knee flexion [1]. A handful of researchers have already incorporated secondary kinematics into MS modeling [2-4] but only rarely on a subject-specific basis. The level of knee joint complexity that is required for a MS model to mimic reality and accurately simulate human movements is up for debate especially when the model is applied for critical applications. This stresses the importance of thorough validation by quantifying uncertainty and errors in the computational model when compared to ground truth data. The EOS bi-plane x-ray system (EOS Imaging SA, Paris, France) is a valid alternative to the reference standard, computed tomography (CT), for lower-limb torsion measurements while also substantially decreasing patient radiation exposure [5]. The aim of this project was to validate the predicted secondary knee joint kinematics of a novel, subject-specific moving-axis knee models during a knee bend under loaded conditions using EOS technology.

METHODS

Various magnetic resonance imaging (MRI) acquisitions were acquired from five adult males to enable subject-specific (SS) MS model development of each. Manual segmentation was performed on full lower limb MRI (femur, tibia, patella, and talus bones) with Mimics (Materialise, Belgium) and these surfaces were used to obtain SS joint centers though analytical shape fitting methods [4]. Segmented articular cartilage surfaces from two detailed knee MRI scans at roughly 0 and 90 degrees flexion were used to define novel tibiofemoral (TF) and patellofemoral (PF) moving-axis (MA) joints using AnyBody Modeling System v6.0 (Anybody Technology A/S, Aalborg, Denmark). The model applies a linear interpolation scheme (Figure 1, top) between the extension (EFC) and flexion facet centers (FFC) of the medial and lateral contact surface of the tibiofemoral and patellofemoral joints estimated from the two MRI scans at 0 and 90 degrees of flexion to estimate the secondary joint kinematics [6].

To validate the SS knee models, EOS Imaging technology was employed to capture secondary knee joint kinematics of each subject during a quasi-static lunge. The 2D bone contours were segmented from the frontal and lateral x-rays of the femur, tibia, and patella structures. Custom MATLAB code was used to register the 3D STL to the bi-planar contours to determine the bone position in the EOS scanner (Figure 1, bottom).

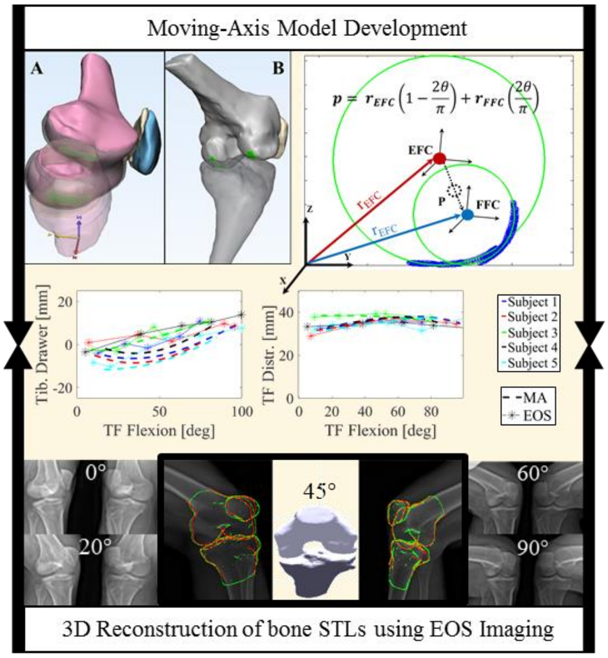

Figure 1: MA model and EOS reconstruction workflow to obtain clinical translations [7]. θ: TF flexion angle.

RESULTS AND DISCUSSION

EOS reconstructions were considered "gold standard" when determining how well the MA knee model mimic reality. Root mean square errors of TF anterior drawer (5.58 ± 1,91mm) and joint distraction (2.28 ± 1.16mm) indicate acceptable agreement. Other clinical translations such as tibial internal rotation, adduction/abduction, and lateral tibia dislocation also provide reasonable comparisons with EOS outputs.

CONCLUSIONS

We developed a new approach to modeling the TF and PF joints in MS modeling. Initial results indicate that a linear model based off two passive MRI scans can accurately represent secondary kinematics of a loaded knee joint. In addition, this study provides groundwork necessary to further validate knee models of varying complexity.

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