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A Computational Framework to Predict Subject-Specific Knee Kinematics from Static MRI

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Background

❑ Estimating the kinematics and load sharing of the knee is critical to understanding the mechanical causes of knee disorders and osteoarthritis.

❑ The kinematics of the tibiofemoral joint are controlled by a combination of soft tissue constraints and articular contact.

❑ Existing musculoskeletal models rarely account for subject-specific articulating geometry or 6 DOF tibiofemoral kinematics.

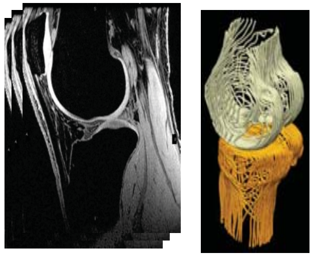
❑ Finite element (FE) models derived from magnetic resonance imaging (MRI) offer a promising method to account for subject-specific geometry [2].

❑ Knee soft tissue constraints can be tuned to reproduce experimental data from knee laxity tests [1]. However, it is not known if this approach reproduces 6 DOF joint kinematics along gait cycle.

Research goal:

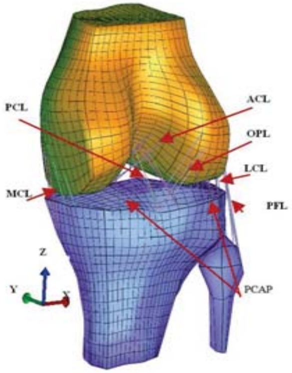
To determine whether a FE model developed from a static MRI can predict 6 DOF kinematics at the knee joint.

Method



(A) Extraction of Joint Geometry

- ❖ Data Source: Sagittal plane MRIs of the knee from one healthy subject
- ❖ Outer surfaces of bones including their cartilage layers were segmented
- ❖ Point-clouds were meshed in CMISS environment
- ❖ Femur: 4913 Nodes and 4096 hexahedral elements
- ❖ Tibia-fibula: 4946 Nodes and 4124 hexahedral Elements

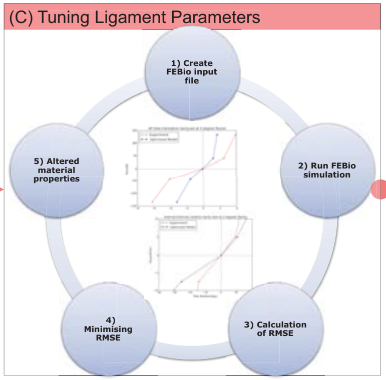


(B) Tibiofemoral Joint Model

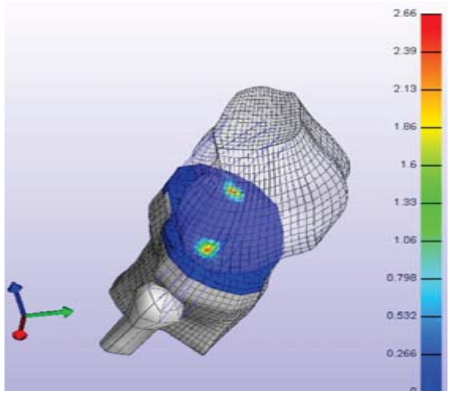
- ❖ Materials: Bones and ligaments as rigid bodies and non-linear elastic springs respectively.
- ❖ Boundary Conditions: Femur constrained at 6DOF and tibia-fibula unconstrained at certain flexion angles
- ❖ Contact: Frictionless sliding contact defined between tibial plateau and femoral condyles

- ❖ Simulations via FEBio (University of Utah) thru SciPy algorithm
- ❖ Alteration of stiffness and slack lengths of the ligaments thru a bounded optimisation algorithm
- ❖ Resulted force-displacement and torque-angle profiles compared to the cadaveric experiment [2].

(C) Tuning Ligament Parameters



- ❖ Tibiofemoral contact areas and pressures at 30º of knee flexion, where joint only constrained by the soft tissue.



(D) Contact Simulations, 0-90º knee flexion

Results and Discussion

Following calibration the model was capable of reproducing the anterior-posterior force displacement curves and internal-external torque-angle pattern [3] (rms = 1.32 and 1.26). Model predictions of knee kinematics were within the envelope of passive knee joint motions [fig.1].

The model was developed from an unloaded static MRI from one male subject. It remains to be seen whether these simulations will adequately represent the loaded knee kinematics.

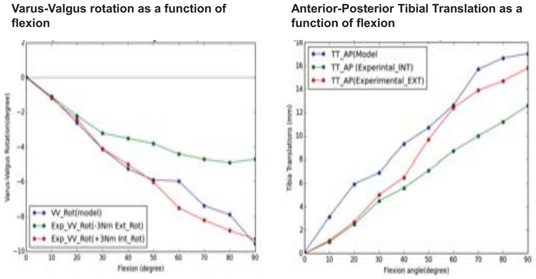


Fig. 1 Comparison of predicted kinematics to cadaveric experiments

Next Steps

Validating the predicted kinematics to weight-bearing MRIs, adding menisci and patellofemoral joint to the model, and estimating knee kinematics and contact pressure are the next steps.

References

[1] Baldwin et al., Computer Methods in Biomechanics and Biomedical Engineering, 2009. **12**(6): p. 651-659.
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[3] Blankevoort et al., *Journal of biomechanics* 24.11 (1991): 1019-1031.

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