KINEMATIC-DRIVEN, SUBJECT-SPECIFIC FINITE ELEMENT MODEL OF THE HUMAN KNEE

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Summary

A finite element (FE) model (FEBio) of a healthy tibiofemoral (TF) joint was driven by 6 degree of freedom (DOF) biplane videoradiography (BVR) kinematics of stance phase of gait to investigate cartilage stress and contact pressure. Contact pressure maps were created using elastic foundation theory for comparison. The model produced maximum TF cartilage contact pressure (16.27 MPa) and stress (12 MPa) consistent with reported values from literature. The elastic foundation model showed lower pressure (8.39 MPa) likely due to using a different material model. These initial findings indicate that kinematics-driven modelling shows potential but requires further validation.

Introduction

FE modelling is a valuable tool for investigating internal tissue mechanics in the TF joint. While most knee FE models use estimated muscle or contact forces, kinematically-driven models are limited by the availability of accurate input data and validation. BVR enables calculation of accurate in-vivo 6 DOF kinematics [1], allowing for direct measurement-based inputs. Some kinetic-kinematic FE models have used BVR inputs to model TF joint loading [2,3], prescribing only 5 DOFs and allowing the 6th to settle under forces, but none have prescribed all 6 DOFs. This study explored the feasibility of BVR kinematics-driven modelling of the TF joint.

Methods

Ethical approval was granted by the Wales Research Ethics Committee, and written informed consent was obtained from one healthy volunteer (M, 53). BVR (60 FPS, 1.25 ms pulse width) was recorded during stance phase of gait. Bone poses were derived for each frame via image registration and converted to define tibial motion relative to the femur.

The femur, tibia, articular cartilage, and meniscus were segmented (Simpleware Scan IP, Synopsis) from an MRI scan (Magnetom 3T Prisma, Siemens). Meniscal horns and ligament (ACL, PCL, MCL, LCL) attachment regions were also segmented for defining spring attachments. The FE model was set up in FEBio (Figure 1), with bones modelled as rigid bodies, cartilage as Neo-Hookean, menisci as Mooney-Rivlin, meniscal horns as linear springs, and ligaments as non-linear springs. The geometries were separated to eliminate segmentation overlaps and aligned to the pose of the first frame. The model was then kinematically driven using BVR-derived kinematics.

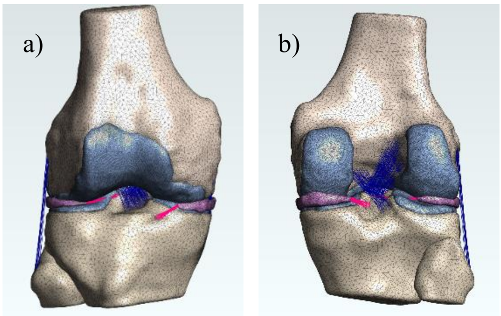

Figure 1: FE Model viewed from the anterior (a) and posterior (b).

For comparison, contact pressure maps were created from the BVR kinematics using the cartilage surface meshes and elastic foundation theory [4].

Results and Discussion

The model successfully ran with all 6 DOFs prescribed, capturing 17–76% of the stance phase due to the knee's motion relative to the BVR capture volume. Peak pressure and stress occurred at the first loading peak (20–25% stance) [5], within the captured range. Maximum TF cartilage contact pressure (16.27 MPa) aligned with reported values (~20 MPa) [5,6]. The elastic foundation model showed lower pressure (8.39 MPa), likely due to the difference in the material models and parameters used. Maximum cartilage stress (12 MPa) fell between previously reported values [5,7]. Further work is needed to assess the variability of these parameters in literature and how they relate to differences in model outputs.

Conclusions

A model, driven by 6 DOF BVR kinematics, was successfully developed, producing maximum cartilage contact pressure and stress values of similar magnitude to literature [5,6]. These results are promising; however, further work is needed to evaluate the suitability of kinematics-driven modelling for determining internal cartilage mechanics.

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References

[1] Setliff & Anderst (2024). *J Othrop Res*, **42**:915-922
[2] Carey et al. (2014). *J Biomech Eng*, **136**:0410041-8.
[3] Gu & Pandy (2020). *J Biomech Eng*, **142**:0710011-10.
[4] Bei & Fregly (2004). *Med Eng Phys*, **26**:777-7.
[5] Mononen et al. (2015). *Comput Methods Biomech Biomed Engin*. **18**:141-152.
[6] Thambyah (2007). *The Knee*, **14**:336-8.
[7] Vidal et al. (2007). *MMB VII*, 55-66