OPEN KNEE: A PATHWAY TO COMMUNITY DRIVEN MODELING AND SIMULATION IN JOINT BIOMECHANICS

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INTRODUCTION

Computational modeling and simulation (M&S) in biomechanics is extending its reach from research environments towards translational applications. In particular to the knee joint, finite element (FE) analysis has significant utility to understand joint and tissue function, explore pathological conditions and injury mechanisms, and investigate surgical interventions and implant performance [1]. Unfortunately, while FE models of joints, in particular of the knee, are ubiquitous in literature [1], they are not necessarily available publicly for the community to reuse and further develop. Further, community driven modeling can provide the opportunity for crowd-sourced review, modification, and validation to address clinical and research problems in knee biomechanics. Therefore, the goals of this study are to provide an overview of our approach for open development of knee joint modeling as a potential framework to overcome potential challenges of implementing citizen science in joint biomechanics.

MATERIALS AND METHODS

Open Knee project was launched to provide an accessible model for FE analysis of the tibiofemoral joint [2]. The model incorporates femur and tibia (rigid bodies); femoral and tibial cartilage (nearly incompressible Neo-Hookean); medial and lateral menisci (Fung orthotropic hyperelastic with horn attachments as linear springs), and cruciate and collateral ligaments (transversely isotropic hyperelastic) [2]. Frictionless contact between articulating surfaces, cruciate ligaments, and if desired, collateral ligaments and bones, are defined. FEBio is utilized for simulations [3]; the model was tested for FEBio v1.3. Simulation scenarios include a fixed tibia, where flexion of femur is prescribed and all other degrees of freedom are free or kept under load control. An anatomical coordinate system describes knee kinematics [4]. A dynamic implicit time integration is used to obtain solutions.

The data, upon which Open Knee was based on, includes joint level anatomical and mechanical measurements [5]. A cadaver specimen, right knee from a 70 years old female donor, was tested. Anatomical reconstruction was based on magnetic resonance images. Joint kinematics-kinetics were measured during laxity testing and for combined loading scenarios in a robotics system. Gross measurements of anterior cruciate ligament deformations are also available.

Open Knee website (https://simtk.org/home/openknee) provides the infrastructure for open development. It is also used to disseminate data, models, scripts (for configuration and post-processing), results, and documents.

EXPLORATORY STUDIES

Various simulations were conducted using Open Knee to illustrate customization (menisectomy) and to evaluate predictive capacity of joint response (passive flexion) and tissue mechanics (anterior cruciate ligament). Disagreements were noted in predictions of proximal-distal translation at high flexion angles during passive flexion, and for anterior displacements and ligament deformations during anterior drawer. Despite its limitations, Open Knee enabled various other studies, e.g., multiscale simulations [6].

DISCUSSION

Open Knee has been provided as a first openly developed and disseminated FE representation of a joint, specifically that of the tibiofemoral joint. While the model can be utilized for different purposes to explore knee joint biomechanics, various limitations do exist. An extensive specimen-specific evaluation of joint level response has not been conducted, and previous studies illustrated the limitations of Open Knee's predictive capacity. In addition, many modeling components are missing, e.g., the patellofemoral joint and representation of *in situ* ligament strains. Driven by these limitations, more comprehensive experimentation is in progress, including accurate registration of high-resolution image data with robotics joint testing, and specimen-specific joint and tissue characterization. With the help of the community, future explorations may be possible through sensitivity analysis and by studies confirming the adequacy of predictive capacity and attempting to answer scientific and clinical questions.

Citizen science in joint biomechanics can be challenging. While many computational aspects can be conducted in a remote manner, experimentation requires facilities that impose geographical constraints. Nonetheless, the community can be involved to establish specifications of experiments and during the analysis of data. Another bottleneck is associated with the computational cost of simulations that may hinder community developers/users to test model features, assess performance and conduct scientific studies. It may be necessary to establish a web-based framework to publicly access high performance computing to conduct simulations on the cloud. The use of free and open source simulation software has utmost importance to allow anyone to conduct analysis. Last but not least, contributions may need to be incentivized through a support system. Development of such a comprehensive platform will promote public development and dissemination of knee models representative of healthy and pathologic conditions.

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