Major Activities

The budget period for this progress report was 06/01/2015 – 05/31/2016. In this budget year, major activities of the Open Knee(s) project focused on dissemination of data, additional experimentation, and development of models at the Cleveland Clinic site, continued development of collaboration and computing infrastructure with the Stanford University team, and enhancements of simulation software features through collaborations with the University of Utah team.

Specific Objectives

Overall goals of the project are (1) to provide an open, freely available, and collaborative development, testing, simulation and dissemination platform for *in silico* exploration of the biomechanics of healthy and diseased knees and (2) to develop *in silico* biomechanical models of healthy and diseased knee joints of different genders and ages, supported by specimen-specific joint and tissue level experimental mechanics.

Relevant to these goals, specific objectives planned for this budget year were continued experimentation and modeling & simulation of multiple knees. Additional activities were to engage with the Advisory Board and the community, and to disseminate information.

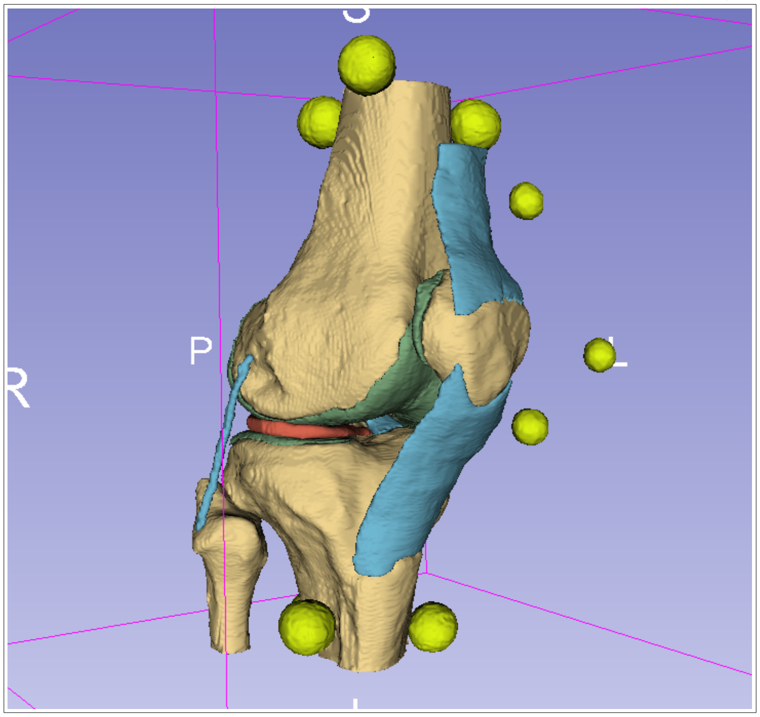

Figure 1. Reconstructed tissue volume (for Open Knee(s) Generation 2 – Specimen 1). The outcome is the result of the image segmentation specifications developed and documented at Open Knee(s) project web site.

Significant Results

In this project period, more specimens were acquired and tested to obtain anatomical and mechanical data to characterize additional knee joints. At this moment, a total of eight specimens underwent magnetic resonance imaging and tibiofemoral and patellofemoral joint testing. All data were disseminated and available at the project site. Data collection procedures have been presented in scientific conferences. For characterization of tissue mechanical properties, significant effort was put on detailed documentation of testing specifications, in particular development and execution of a protocol evaluation plan to understand uncertainties associated with testing.

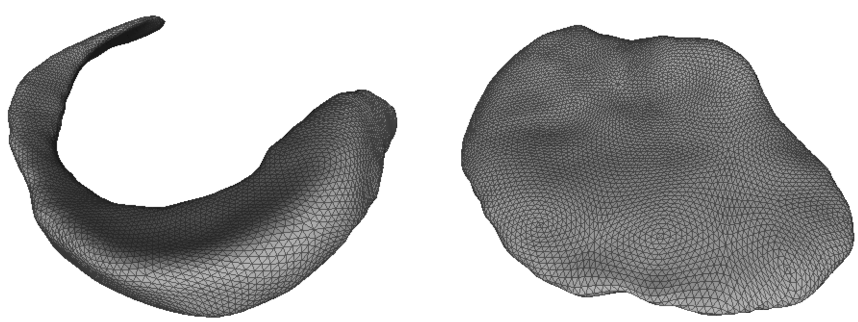

Figure 2. Lateral meniscus and tibial cartilage surface geometries (for Open Knee(s) Generation 2 – Specimen 1) obtained by smoothing and resampling. The process follows image segmentation and conforms the geometry generation specifications developed and documented at the Open Knee(s) project web site.

For development of models, specifications for image segmentation and geometry generation were finalized. Magnetic resonance images from Open Knee(s) Generation 2 – Specimen 1 were segmented to reconstruct individual tissue volumes (Figure 1) and surface geometries, smoothed and resampled at various levels of refinement (Figure 2), were generated. With the help of these specifications and their outcome, generation of knee meshes (at varying densities) will be possible.

The team has also started programming in Python to process raw data by generating derivative data, which would be more suitable to feed into computational models. The scripts were designed and developed for extraction of joint kinematics-kinetics data from robotics testing files, to compare joint kinematics-kinetics data collected under the same loading conditions, to calculate transformation matrices to relate image and joint testing coordinate systems, for automated processing of contact pressure data to report contact metrics, to evaluate tissue mechanical properties and experimentation settings, to record geometric properties of tissue samples, etc.

Additional development of Open Knee(s) – Generation 1 model continued. An unsupervised model update, simulation, and post-processing workflow was implemented to conduct large number of simulations on a high performance computing cluster. This workflow was used to identify the role of model parameters and simulation settings on convergence characteristics. The role of additional tissue constraints were also evaluated, i.e. those of the menisci, to enhance the predictive capacity of the Open Knee(s) – Generation 1 model. This model was also used to test the in situ strain feature of FEBio (Figure 3) as part of a scientific publication, which was submitted and recently got accepted.

Key Achievements

A key achievement of the project during the report period included publication of the Open Knee(s) – Generation 1 model in a clinically oriented journal – Journal for Knee Surgery. Another major accomplishment was the completion of investigation and implementation of in situ strain feature, which was recently accepted for scholarly publication. It is also worth mentioning the implementation of a new FEBio feature to define kinematic joints. This feature will facilitate modeling modeling and simulation of musculoskeletal joints.

Dissemination of anatomical imaging and joint mechanics level data to allow development and evaluation of knee joint models was a significant milestone. At this moment, the Open Knee(s) project provides comprehensive data for eight knees that will serve for specimen-specific modeling and simulation by anyone. Additional details of dissemination and its impact were noted in the “Resource Sharing” document.

An important achievement of the project was the implementation of an internship program for Summer 2015, which resulted in the recruitment of 4 students (3 undergraduates and 1 high school) as interns. Students' projects were designed to allow experiences relevant to different stages of modeling and simulation lifecycle while contributing to the Open Knee(s) roadmap. Each student had a programming project, which resulted in implementations of data processing and analysis procedures in Python. Students were also assigned to image segmentation tasks. This activity provided an understanding of a common model development task and informed development of specifications to facilitate the process for Open Knee(s). A third type of project, to which all students were assigned, was the modification of an existing model, in this case Open Knee(s) – Generation 1 model, and conduct simulations to understand the influence of added components on joint and tissue mechanics. The outcome of this work helped inform needed updates on the existing knee joint model to constrain the movements of the menisci. The study done by one of these students was selected and presented for the Research Experiences for Undergraduates Symposium held in Arlington, VA during October 25-26, 2015.

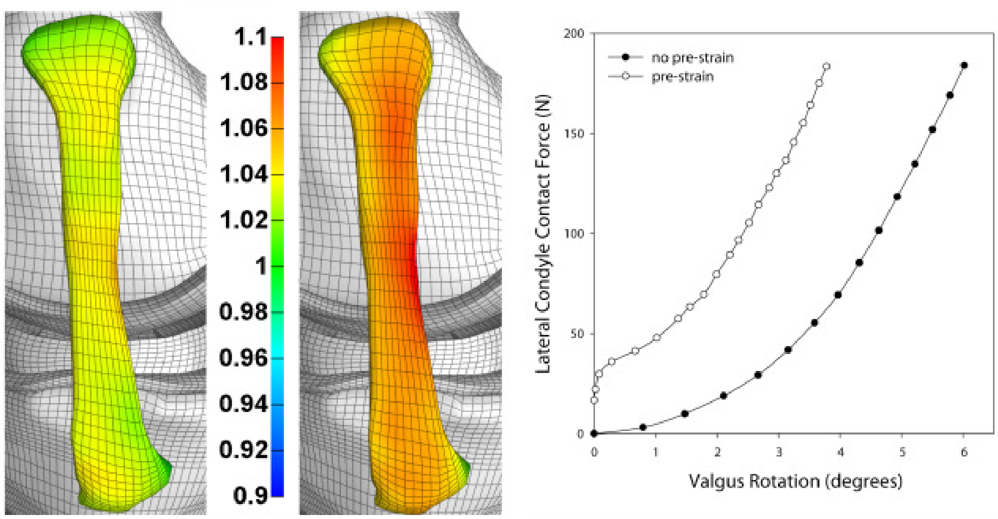

Figure 3. FEBio development team implemented the in situ strain feature on Open Knee(s) – Generation 1 model. Fiber stretches in the medial collateral ligament (with and without pre-strain at ~3° valgus) were illustrated along with the change in lateral contact force due to application of pre-strain. Simulations were conducted at 0° flexion for increasing levels of valgus torque.