Major Activities

The budget period for this progress report was 09/15/2013 – 05/31/2014. In this abridged budget year (8.5 months), major activities of the Open Knee(s) project first focused on organizational aspects, including establishing interactions between collaborating teams at the Cleveland Clinic, University of Utah, and Stanford University, and forming and informing the Advisory Board of clinicians and modeling and simulation experts. The team updated the web based collaboration site, worked on a web based computation interface, and on the implementation of new features for finite element analysis software. Development of detailed specifications has been emphasized to allow structured and collaborative work as knee specimens will be tested and modeled.

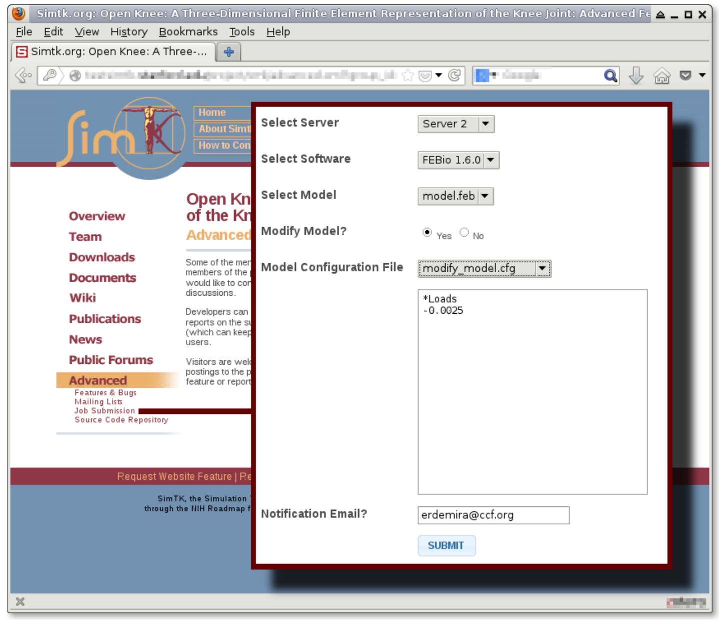

Figure 1. A job submission feature, currently implemented on a staging server, provides the capacity for cloud computing. Selection of the compute server, software and the model, and the capacity to change the model are possible. Notifications are e-mailed during job execution.

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 (1) development of a web collaboration infrastructure, (2) development of a web computation infrastructure, (3) simulation software improvements, (4) development of specifications to establish standard operation procedures for experimentation, modeling & simulation, and (5) testing of the first specimen. In addition, activities were planned to engage the Advisory Board, the community, and to disseminate information.

Significant Results

The project site at https://simtk.org/home/openknee provides the web collaboration infrastructure. All information (including work in progress) is publicly accessible at the site. The community has been invited through multiple channels to contribute, e.g. by providing write access to wiki pages for reviews and comments, and by public forums. The start page of the wiki (http://wiki.simtk.org/openknee) provides an entry point to various sections of the project for desired utility, as a user or as a developer.

A cloud computing prototype has been developed in a staging server (Figure 1). The platform currently allows solution of a test problem. Upcoming activities aim for resolving security issues related to user authentication and authorization and implementation of a results retrieval interface.

Implementation of new features to FEBio, finite element analysis software for biomechanics, has started to accommodate anticipated needs for knee joint simulations. In particular, capability to prescribe *in situ* strain distribution in ligaments has been developed and tested (Figure 2). This capacity allows accurate representation of ligament mechanics. The feature will be available to public in the upcoming version of FEBio.

A plethora of specifications providing standard operating procedures to collect appropriate experimental data has been developed and disseminated. Mature ones include specifications for specimen acquisition and joint level mechanical testing. Detailed descriptions of procedures for anatomical imaging (Figure 3), specimen and tissue sample preparation, and tissue testing have evolved significantly. Modeling specifications are in progress. All these documents are publicly available in the wiki page as they are developed; a list can be found at http://wiki.simtk.org/openknee/Specifications. These documents not only provide our know how to the biomechanics community (to let them conduct their own musculoskeletal research) but also allow clear descriptions of needs, requirements, and operations for collaborative work.

Key Achievements

Apart from some of the early results mentioned above, public delivery of specifications outlining experimental procedures and modeling and simulation approaches is worth emphasizing as a key activity and potentially as a key achievement. All these specifications are designed to explain the desired outcome of the procedure, the prerequisite infrastructure and activities, and the necessary inputs to the process. The overall goal is that not only team members but any interested member of the community will be able to conduct the activity based on these descriptions. This will provide guidance to the community when contributing to model development and simulation activities. Along with the roadmap (http://wiki.simtk.org/openknee/Roadmap), these specifications will establish a reference (essentially white papers) for building models of musculoskeletal joints to simulate joint movement and tissue deformations. Providing such detail is not necessarily possible in scholarly publishing. Therefore, these documents will likely enhance the reproducibility of the work conducted through the Open Knee(s) project. Some of these specifications are already completed and recommendations from the public were requested through various channels. For example, after completing specimen specifications, three knee specimens were acquired as Open Knee(s) candidates (healthy elderly male, healthy elderly female, healthy young female). Some specifications are under development, with multiple iterations being conducted to finalize the specifics of operations, e.g. for anatomical imaging.

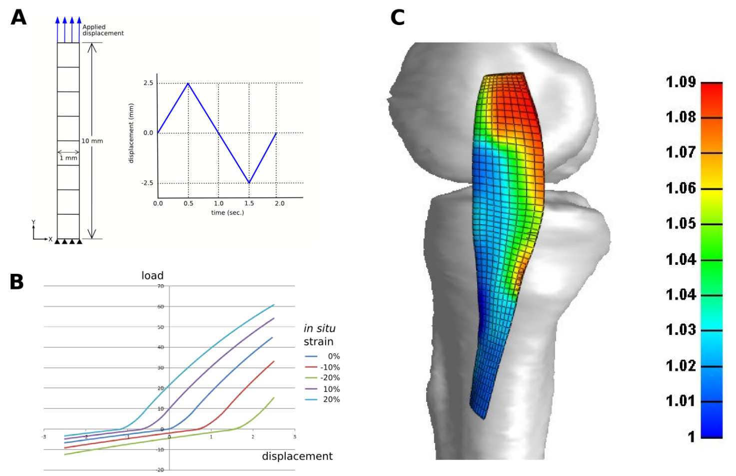

Figure 2. A. A test problem was devised to evaluate the implementation of *in situ* strain feature in FEBio. B. With different *in situ* strains, zero load displacement of the ligament changes as expected. C. The feature allows prescription of an *in situ* strain map on the three-dimensional reference geometry, e.g. for the medical collateral ligament.

An unmet goal for this year was the testing of the first specimen as proposed in the grant application. Despite the abridged term, the team was prepared to conduct anatomical imaging, robotics testing, and tissue experimentation in the final month of the budget year. Unfortunately, mechanical problems in the robotics testing system resulted in the delay of joint level testing. Due to specimen-specific data acquisition, both for anatomical reconstruction and for tissue properties, the whole experimentation sequence needed to be postponed until equipment repairs can be conducted. These tests are expected to be completed within the first quarter of the upcoming budget year.

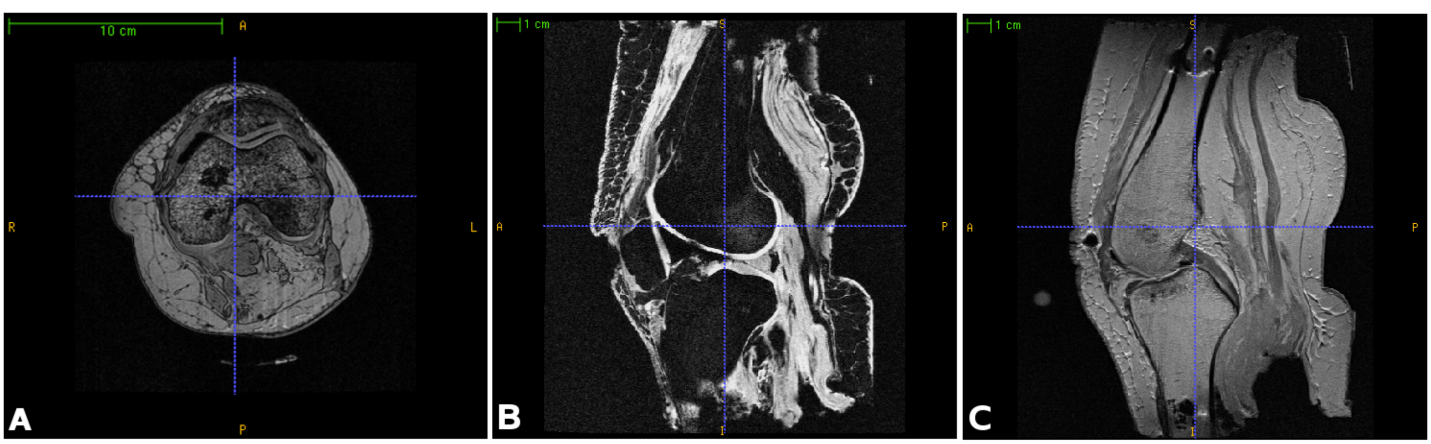

Figure 3. With different imaging settings, it will be possible to adequately reconstruct tissue geometry. A. An axial slice from a general purpose 3D T1-weighted imaging without fat supression (0.5 mm x 0.5 mm x 0.5 mm). B. A sagittal slice from a 3D T1-weighted imaging with fat supression for cartilage reconstruction (0.35 mm x 0.35 mm x 0.70 mm). C. Sagittal plane 2D proton density type imaging for ligament reconstruction (0.5 mm x 0.5 mm x 2.8 mm), i.e., clear delineation of the posterior cruciate ligament is apparent.