Major Activities

The budget period for this progress report was 06/01/2014 – 05/31/2015. In this budget year, major activities of the Open Knee(s) project focused on experimentation 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 (including those rescheduled from year 1) were to engage with the Advisory Board and the community, and to disseminate information.

Significant Results

Scheduling of activities has changed in this budget period. The focus was mainly on the acquisition of experimentation to collect anatomical and mechanical data for all the specimens rather than conducting experimentation and modeling and simulation one specimen at a time. As a result ,a total of six specimens were tested (five conforming to specimen specifications of Open Knee(s), one to fine tune experimentation workflow) (Table 1). Quantification of tibiofemoral joint mechanics indicated large variations in joint range of motion (Figure 1). Experimentation on patellofemoral joint provided the relationship between contact mechanics and quadriceps force and tibiofemoral flexion angle (Figure 2). Our observations indicated the specimen-specific nature of these associations. The data set obtained at the joint level indicates the need for building virtual knees authentic to the individual (anatomically and mechanically) not the average of the population mean. Multiple virtual knees can then be accumulated to build a virtual population for *in silico* explorations. In regard to experimentation, the group has submitted multiple abstracts to upcoming conferences, which are currently in review. In regard to infrastructure, *in situ* strain feature for FEBio, finite element analysis software, has been further developed and tested to generalize three-dimensional mapping within the tissue volume. The theory and sample applications have been presented in an international conference.

Table 1. Currently, seven knee specimens have been acquired for Open Knee(s). Donor characteristics span multiple age groups and genders. Joint level testing, including anatomical imaging and robotics experimentation to characterize joint mechanics, has been completed for six specimens. Specimen oks005 was not tested due to its health history. Different tissue types were dissected from all tested specimens and stored for upcoming experiments to characterize tissue mechanics. Dissemination of these comprehensive data is in pending.

Specimen Label	**oks001**	**oks002**	**oks003**	**oks004**	**oks005**	**oks006**	**oks007**
Donor Gender	Male	Female	Female	Female	Male	Female	Male
Donor Race	White	White	White	White	White	White	White
Donor Age (years)	71	67	25	46	22	71	71
Donor Height (meters)	1.83	1.55	1.73	1.58	1.75	1.52	1.70
Donor Weight (kilograms)	77.1	45.3	68.0	54.4	63.5	49.4	65.8
Donor BMI (kg/m^2)	23.1	18.9	22.8	21.0	20.7	21.3	22.7
Side	Right	Right	Left	Right	Right	Right	Right
Anatomical Imaging	Yes	Yes	Yes	Yes	N/A	Yes	Yes
Tibiofemoral Joint Testing	Yes	Yes	Yes	Yes	N/A	Yes	Yes
Patellofemoral Joint Testing	Yes	Yes	Yes	Yes	N/A	Yes	Yes
Tissue Dissection	Yes	Yes	Yes	Yes	N/A	Yes	Yes
Tissue Testing	Pending	Pending	Pending	Pending	N/A	Pending	Pending
Data Dissemination	Pending	Pending	Pending	Pending	N/A	Pending	Pending

Key Achievements

A major achievement of the project was the development of streamlined experimentation procedures, particularly for joint level data collection. In a span of four days, the team can i) prepare the specimen, ii) conduct magnetic resonance imaging for anatomical reconstruction, iii) execute robotics testing for detailed mechanical characterization of the tibiofemoral and patellofemoral joints, iv) dissect various tissue types (cartilage, menisci, ligaments, tendons, etc) to establish a specimen-specific tissue sample bank for prospective mechanical characterization, v) document experimentation in the project wiki, and vi) store data in an in-house data management system for organization, evaluation, and future dissemination. Proven by testing of six specimens (Table 1), this montage of heterogeneous experimentation procedures essentially provides a turn-key workflow for testing of musculoskeletal joints that can also be utilized for other joints. Such experimentation can be reproduced by third-party groups using publicly available detailed specifications.

From the perspective of collaboration with Simbios, National Center for Biomedical Computing at Stanford University, a key achievement was the implementation of a results retrieval interface for cloud computing. This interface supports simulation submission interface developed in the first year of the project and brings the cloud computing feature to a level usable by the broader community. Simple usability tests have already been conducted on a staging server. Public access will likely be available in the upcoming year ,after the launch of the new release of SimTk.org infrastructure.

FEBio has been significantly improved to facilitate simulations directed towards *in silico* explorations of joint movements and tissue deformations. Software feature to prescribe *in situ* strain in ligaments has been maturing and was generalized to incorporate different formulations and multidirectionality. A new feature now allows definitions of element, node, and surface sets which will facilitate customization of models and automation of model generation and post-processing. Similarly, another new feature provides the possibility to split and combine model files to accommodate user-friendly customization.

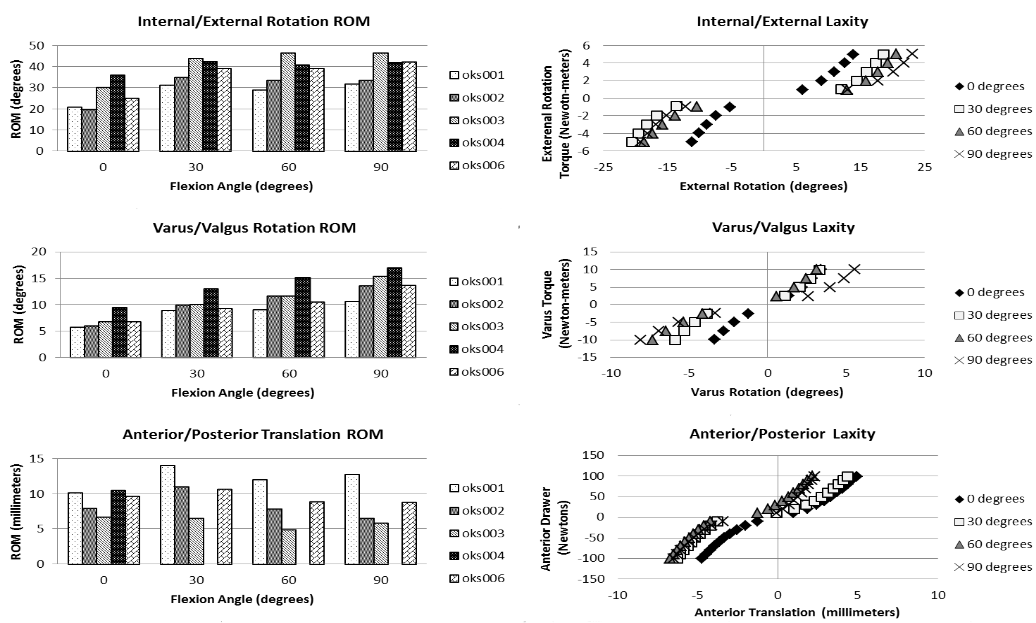

Figure 1. Robotics testing of the tibiofemoral joint has quantified specimen-specific laxity, i.e. motion range and stiffness characteristics of the joint under isolated loads of internal/external rotation, varus/valgus, and anterior posterior translation. Large variations in range of motion (ROM) can be seen on the left indicating the necessity to recognize specimen-specific anatomy and mechanical properties in virtual representations of the knee. Plots on the right provide insight into joint stiffness of oks006 at different flexion angles. Additional data are available illustrating the behavior of Open Knee(s) specimens under combined loading.

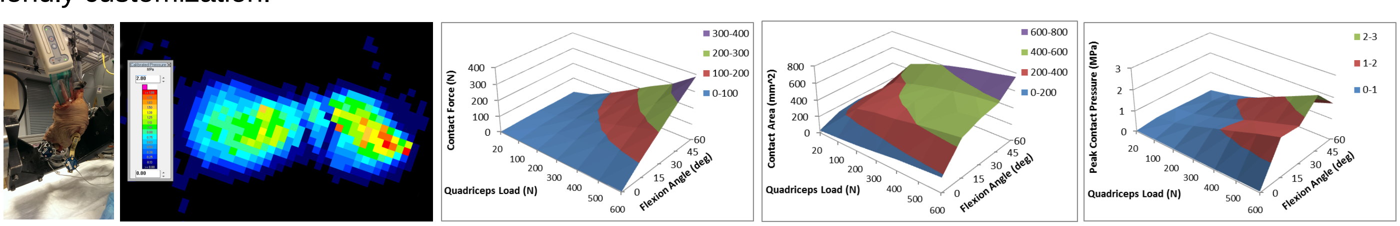

Figure 2. During patellofemoral joint testing contact pressures and patellofemoral kinematics have been measured as a function of quadriceps loading and tibiofemoral flexion angle. Contact stress distribution, contact force, contact area, and peak contact pressure are shown for oks007. This data will provide the opportunity to build knee models authentically representing specimen-specific patellofemoral joint mechanics.