Outcomes

Computational models can serve as end-point technologies to realize routine use of simulation for biomechanics research, medical training and patient care. In this project, virtual knees (computational models including raw and derivative data) have been provided as potentially enabling technologies for modeling and simulation. These have been developed and disseminated through the Open Knee(s) initiative, https://simtk.org/projects/openknee. The activity started with an early model of the tibiofemoral joint, which is now referred as Open Knee(s) – Generation 1. The model included bones as rigid bodies; cartilage, menisci and ligaments as nonlinear elastic materials. Contact between articulating surfaces were modeled as frictionless. This virtual knee has the capacity to predict joint movements under given external loads and provides a full field estimation of tissue stresses and strains using finite element analysis. The model was publicly disseminated as is, supported by a user’s guide and followed by scholarly work related to the development of the model, its evaluation against joint mechanics data from literature, and promotion of its reuse. This model was the first and for a long time, the only, finite element representation of the natural knee that was publicly available for download. At the time of writing of this report, it has been downloaded almost 1,000 times. Users indicated their intentions for downloading this model as for research, for training, to use as reference to other models, to evaluate, to examine ligament function, to explore cartilage mechanics, for analysis of meniscal injury, for instrumentation design, for impact biomechanics, to use tissue geometries, among many others. Scholarly work by us and by others depended on this virtual knee; more than 35 publications used the whole model or parts of it. Topics of these studies, and therefore model use cases, were numerous: cruciate ligament deficiency, performance of anterior cruciate ligament grafts, evaluation of novel contact algorithms, tissue stress-strain during exercise, meniscus mechanics, meniscal implants, unicompartmental knee arthroplasty, geometric uncertainty, to name a few. This experience demonstrated the variety of user behavior and motivated diversification in the dissemination of virtual knees.

Our efforts to build and disseminate virtual knees expanded with Open Knee(s) – Generation 2, where the overall goal has been to provide computational knee models for a small but diverse sample population of knee specimens: 4 male and 4 female donors, age: 25 to 71 years, height: 1.52 to 1.83 m; weight: 45.3 to 77.5 kg, and body mass index: 18.9 to 23.1. Comprehensive imaging and joint testing were performed primarily driven by development, calibration, and benchmarking of models in a specimen-specific manner. Anatomical representations of tissue structures were generated, and virtual knees have been assembled to support simulations using finite element analysis. All these modeling content have been made available as part of the Open Knee(s) initiative. Our dissemination strategy for virtual knees have always relied on succinct principles: free as in free beer and free as in free speech. The former principle gives anyone the access to the models free of charge. The latter permits any modifications by the end-user, reuse for any purpose (academic or commercial), and redistribution without any restrictions. This approach have ensured accessibility to and transparency of virtual knees, the data that they relied on, and the processes that were used to build them. Other investigators’ utilization of Open Knee(s) resources is a testament to the success of free and open source model sharing and its place in the ecosystem of computational biomechanics.