OPEN KNEE(S): FOUNDING DATA FOR NEXT GENERATION KNEE MODELS

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Introduction: Finite element analysis has been shown to enable a comprehensive understanding of healthy and pathological biomechanics of the tibiofemoral and patellofemoral joints and their substructures. The tool also facilitates development and evaluation of implants and surgical procedures. As imaging and mechanical testing technologies evolve, subject/specimen-specific models and evaluation of model performance against high fidelity joint mechanics data becomes achievable. Despite these advancements, comprehensive specimen-specific knee joint models, including individualized anatomy and tissue material properties, do not exist. Similarly, detailed computational knee models representing varying states of health and disease are scarce. Acquisition of specimen-specific anatomical and mechanical data specifically intended for model development at both joint and tissue scales is a logistically challenging task. Nonetheless, when collected and made publicly available, such data sets can establish reference information to build credible knee joint models for scientific explorations, and through customization, allow for the investigation of new interventions. The goal of this study is to present a workflow developed to collect heterogeneous data on cadaver knee specimens for development and evaluation of specimen-specific knee joint models from varying populations, aka Open Knee(s).

Materials and Methods: The project aims to develop six knee models, from young & elderly, healthy & osteoarthritic, and male & female donors. Before experimentation, motion analysis markers and registration markers are placed on the femur, tibia, and patella. Anatomical landmark locations and registration marker positions are measured relative to motion analysis markers. Magnetic resonance imaging (MRI) is performed to obtain anatomical geometries of the femur, tibia, and patella, including the bone, cartilage, menisci, cruciate and collateral ligaments, patellar ligament, and quadriceps tendon. Multiple image sequences are collected: (i) a general purpose setting including of both the tibiofemoral and patellofemoral joints and registration markers, (ii) a setting focusing on cartilage, (iii) axial, sagittal, and coronal image sets with settings focusing on ligaments, tendons, and menisci. Kinematics and kinetics of the tibiofemoral joint are characterized at 0°, 30°, 60°, and 90° of flexion using a robotics testing system: (i) laxity testing: internal rotation (±5 Nm), varus (±10 Nm), anterior translation (±100 N), and (ii) combined loading. Kinematics, kinetics, and contact pressures of the patellofemoral joint are characterized under quadriceps loads (up to 600 N in steps of 100 N) at 0°, 15°, 30°, 45°, and 60° of flexion. Tissue samples are collected from cartilage (medial & lateral femoral condyles and tibial plateau, trochlear groove, patella), meniscus (medial & lateral), ligaments (anterior & posterior cruciate, medial & lateral collateral, patellar), and quadriceps tendon. Cylindrical compression samples are acquired from cartilage and menisci. Planar dumbbell shaped tensile samples are acquired from ligaments, tendons, cartilage, and menisci. Multi-step stress-relaxation tests under confined and unconfined compression and under tension (for relevant sample types) allow characterization of tissue mechanical behavior. Additional methodological details can be found at http://wiki.simtk.org/openknee/Specifications.

Results and Discussion: Four knee specimens were tested thus far, one to evaluate the procedures and the remainder as part of the targeted Open Knee(s) specimens. Joint testing for each specimen was typically completed within four days: specimen thawing (day 1), preparation (day 2), imaging (day 3), mechanical testing (day 3: tibiofemoral joint, day 4: patellofemoral joint), and dissection for tissue testing (day 4, possibly day 5). Tissue samples were frozen for sample preparation. For one specimen, tissue testing was completed in approximately two weeks by incrementally thawing samples and immediately characterizing their stress-strain response. Thirty tests were performed on the collected tissues of a knee, each lasting 2-3 hours. Additional information on tested specimens can be found at Open Knee(s) wiki,e.g., http://wiki.simtk.org/openknee/oks001. Data organization, dissemination, and testing of additional knee specimens are underway.

Conclusions: This study illustrated that a comprehensive data collection scheme, specifically intended for development of high fidelity models, can be realized. This information will be used for open development of fully specimen-specific (anatomy and tissue properties) models of the knee joint complex for different populations and evaluated against their specimen-specific joint mechanics response.

Acknowledgements: This study was funded by NIGMS, NIH (R01GM104139, PI: Erdemir).Contributions of Shannon Donnola and Chris Flask for MRI are greatly appreciated. Open Knee(s) is an open development modeling project; specifications, models, and data can be accessed at http://wiki.simtk.org/openknee.