7075 Tu, 14:45-15:00 (P21)

Patient-specific simulation of dynamic stress distribution in the human knee

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We present a method for efficient, high-resolution, patient-specific simulation of the loads and stresses in a human knee joint during a gait cycle. Femur and tibia are modelled using first-order finite elements on a grid generated semi-automatically from a CT scan of the patient. We therefore obtain patient-specific information which can be very useful in operation and therapy planning. A new stabilized Newmark time scheme allows the time integration of Newton's equations of motion with arbitrarily large time steps. At each time step a large minimization problem has to be solved. Additional difficulty arises from the non-penetration condition imposed on the bones, which lead to inequality constaints for the minimization problem. A generalization of standard multigrid solvers, the so-called monotone multigrid solver, can solve such cntact problems with optimal efficiency. Knee ligaments are modelled as nonlinear Cosserat rods. These are physically correct one-dimensional objects and allow to capture bending and twisting phenomena. They are coupled to the three-dimensional bone-models using equality of mechanical work as the coupling condition. We show numerical results for test problems with analytically known solutions as well as real-world examples using the Visible-Human data set.

7630 Tu, 15:00-15:15 (P21)

Sagittal plane loading contributes to gender differences in sports-related non-contact ACL injuries: fact or fiction

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It is suggested that the gender disparity in ACL injury rates is governed by variable sagittal plane neuromuscular control (NMC) contributions to the injury mechanism. This commonly purported tenet is yet to be tested within a truly dynamic setting however, and hence, remains speculative at best. Here we utilize forward dynamic modeling to examine the potential for the sagittal plane knee loading mechanism to injure the ACL during simulated high-risk sports postures. The possibility for this mechanism to contribute to the increased number of non-contact ACL injuries in females was subsequently assessed. Subject-specific musculoskeletal model simulations of sidestep, jump-land and shuttle run movements were developed, optimized, and subsequently validated based on *in vivo* input data obtained from ten male and ten female athletes. Peak anterior drawer FD_{Ant} forces, comprising model generated external joint reaction forces (FR_{Ant}) and the sagittal force contributions of the quadriceps and hamstrings were extracted from each optimized system and submitted to a two-way mixed design ANOVA (gender and movement). Random NMC perturbations ($n = 5000$) were then applied to each model based on subject specific kinematic variations, and the number of ACL injuries recorded, based on a criterion of peak $FD_{\mathrm{Ant}} > 2000$ N. Differences were not found in peak FD_{Ant} between genders, but did exist across movements, with significantly ($p < 0.025$) lower values observed for jump-land models. Peak FD_{Ant} never exceeded 1100 N in any model, regardless of initial perturbation. This load ceiling likely stems from the relationship between knee flexion and patellar tendon orientation angle, in conjunction with the moment balance between the ground reaction and quadriceps forces associated with closed chain dynamic movements. The sagittal plane loading mechanism thus, does not appear in isolation capable of injuring the ACL, and hence, does not explain the increased incidence of sports related ACL injuries observed in females compared to males.

5992 Tu, 15:15-15:30 (P21)

Comparison of femoro-tibial contact forces measured in a telemetric implant to those predicted by mathematical modeling

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Mathematical modeling provides a cost effective and easy to reproduce alternative to telemetry in the determination of in-vivo joint forces. However, due to the complexity of the human body, modeling requires simplifying assumptions to generate a solution. Therefore a comparison between the data generated by a model to those obtained experimentally using telemetry becomes very important in order to validate the derived results. Therefore the objective of this study was to compare the in-vivo contact forces, theoretically derived from a 3D inverse dynamic mathematical model to that experimentally measured from a telemetric knee implant. In-vivo kinematic data obtained using fluoroscopy and 2D to 3D image registration was input to the model. The model represents the bones as rigid bodies, musculotendonous units as linear elements, ligaments as non-linear elastic element and incorporates friction and slip into the analysis in order to predict separate contact forces for the medial and the lateral condyle interfaces. The maximum telemetric force was around 3.84BW at 103° while the mathematical model predicted a value of 3.74BW at 91°, a difference of 1.6%. The greatest difference in the two values occurred at full extension where the model under predicted the telemetric data. This might be due to isometric contraction of the quadriceps, which the model failed to replicate since the subject is in a static position at full extension. Interestingly, the medial and lateral condylar forces were found to be similar in magnitude for the telemetric implant and the model. This might be the effect of ligament balancing during surgery since surgeons attempt to create a rectangular gap. In conclusion, this study demonstrated that our mathematical model produced similar results to those obtained from a telemetric tibia, validating the theoretical approach used in it.

6560 Tu, 16:00-16:15 (P23)

Validating a neuromusculoskeletal model of the elbow joint

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Replacing part of the skeletal system with a prosthetic joint is likely to have an impact on the activity of the neuromuscular system. This study examines this question by developing a neuromusculoskeletal (NMS) model of the elbow joint including four muscles (the biceps, brachialis, brachioradialis and triceps), feedback from muscle spindles and interaction with descending neural drives. Such a model would be a valuable tool in predicting the post-operative effects of joint replacement surgery on the neuromuscular system, including damage to surrounding mechanoreceptors. The system has been simulated, and validated through *in vivo* experiments.

To validate the model under isometric conditions, a series of experiments was conducted. Surface electromyography (EMG) was measured from the biceps, triceps and brachioradialis muscles of 12 subjects, during isometric contractions at six elbow angles. Maximum voluntary contraction (MVC) was estimated at each angle, followed by contractions at eight force levels from 10% to 80% MVC, for elbow flexion and extension. The RMS amplitude of the EMG signal (RMS-EMG) was taken to approximate muscle activation, and was used to drive the NMS model. Experimental and simulated data were compared.

Force-RMS-EMG relationships were examined for all angles. Maximum extension and flexion force varied with angle, peaking at 75° (0° – full extension), consistent with previous studies. However, RMS-EMG values during MVC were not significantly affected by angle. In addition, the relationship between RMS-EMG and normalised muscle force was similar across all angles. This suggests that modulation of neural activity in biceps, brachioradialis and triceps muscles with increasing force is independent of both elbow angle and the force–length properties of the muscle contractile elements.

The NMS model described above provides a good approximation of the behaviour of the NMS system of the elbow under dynamic and static conditions. The relationship between muscle activation and force output has been validated isometrically. Future work will involve dynamic validation. It will then be used to examine changes in neural control patterns in response to skeletal system changes.

6627 Tu, 16:15-16:30 (P23)

A computer model to evaluate radial head translation

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The elbow and forearm are critical to daily life. Earlier work in our laboratory quantified the frontal plane translation of the center of the radial head on the capitellum. A simple two-degree-of-freedom computer model of the elbow was created in MATLAB [Mathworks, Natick, MA] to simulate realistic pronation–supination (p/s) motion with the aim to compare translation measured experimentally to translation computed with the model.

The computer model ranged the p/s angle from 50° pronation to 50° supination in one-degree steps at an elbow flexion angle of 90°. The axis of p/s rotation was constant along a line from the center of the capitellum to the center of the ulnar head. The capitellum was modeled as a perfect sphere and the ulnar notch as a partial ellipsoid with radii equal to those averaged over four cadaveric elbows. The p/s rotation was performed with two different radial head geometries. An idealized head modeled the rim as an ellipse and the fovea as a partial sphere; an actual cadaveric head was measured and also used.

Previous work reported anterior/posterior (a/p) and medial–lateral (m/l) translations of the radial head center on the capitellum of 1.3 ± 1.2 mm and 0.7 ± 0.7,