Nonlinear Fibril Reinforcement and Fluid Pressurization in a Patient-specific Computational Model of the Knee Joint

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ABSTRACT

The human knee joint consists of articular cartilage and meniscus that are pressurized with an excess fluid pressure upon the application of compressive joint loading. This fluid pressure reaches its highest at the fastest compression and reduces with time when the loading remains unchanged. As a consequence of this loading mechanism, the cartilaginous tissues in the joint appear stiffer at a faster knee compression and softer at a slower compression. The implication of this behavior, however, has not been fully understood because past knee joint models generally employed elastic material laws and thus did not describe time-dependent and rate-dependent mechanical behaviors. We have developed a fibril-reinforced model of cartilage that highlights the interplay between the collagen fibril-reinforcement and fluid pressurization in the tissues [1] and is more or less similar to other sophisticated models published later [2,3]. We have then implemented the constitutive model in a patient-specific knee joint model using 3-Tesla MRI in order to determine the creep, relaxation and contact mechanics of the knee joint modulated by the fluid pressurization in the tissues [4]. This joint model was found to be able to predict the load support of the knee joint and load share between cartilages and menisci that cannot be described with an elastic model of the knee joint.

In order to further validate the joint model in predicting the in vivo mechanics of the human knee joint, we have recently obtained the MRI of the unloaded knee of a human subject and subsequently the dual fluoroscopic (DF) imaging [5] of the same knee under ¾ of her body weight. The DF images of bones and ground reactions were obtained as functions of time during ramp loading and creep. This combined modeling and experimental approach is expected to improve our understanding of knee joint mechanics. Our validated joint model may also be used with other newly developed image based approaches, such as interpreting in vivo cartilage deformation from MRI [6], in order to determine the in vivo stress and pressure distribution in the joint.

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