Biomechanics and Computational Modeling of the Impact Response of the Knee

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ABSTRACT

Anterior cruciate ligament (ACL) injury is the most common sports related injury in the US with an incidence of 1:3500. An estimated 500,000 knee ligament reconstruction surgeries are performed each year in the US. Almost 90% of those surgeries are primary ACL reconstructions (non-revision or multi-ligament injuries) and the number is projected to increase by 4-5% per year over the next 5 years. Replacement grafts have generally good short-term outcomes but problemmatic long-term outcomes. Computational modeling of the patient-specific biomechanical response of the entire knee during impact loading events is important for two reasons: to identify those at-risk of ACL injury and design preventative strategies, and to design a better graft for ACL replacement in the event of an injury.

This paper details my laboratory's efforts to characterize the biomechanical responses of the soft tissues of the knee and to implement them into a computational framework of the knee during impact (high-strain rate) loading scenarios associated with ACL injury. In the talk I will focus on the characterization of the ACL and the computational results. The ACL is non-linear, anisotropic, and viscoelastic. The tissue structures that make up the ACL also exhibit mechanical heterogeneity. The ACL is particularly challenging to experimentally characterize; in its anatomically relevant state, it is twisted and partially extended regardless of knee flexion angle. It consists of two bundles that are not simultaneously unloaded under any configuration, and an arduous approach to accurately characterize each bundle is described. Our experimental methods involve mechanically testing in uniaxial loading as well as anatomical positions using digital image correlation analysis to describe the strain fields arising from mechanical heterogeneity in each experimental condition. We have developed a non-linear viscoelastic mathematical model of the ACL bundles and implemented it into a finite element framework for computational analysis of the ACL during impact loading conditions. In our computational environment we can transition from the uniaxial loading state to the anatomically correct loading state and predict the strain fields in the ACL during an anterior tibial translation. This motion is relevant to ACL injury as the ACL tears when the tibia anteriorly translates excessively relative to the femur. Our computational model is able to predict the location of ACL tears in the proximal third of the tissue.