MODELING AND COMPUTER SIMULATION IN SPORTS BIOMECHANICS: APPLICATION TO THE PREVENTION OF KNEE LIGAMENT INJURIES

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INTRODUCTION: Mathematical models of musculoskeletal dynamics have become important tools in sport biomechanics. Inverse dynamic analysis is now routinely applied to obtain estimates of internal forces in the human body, using external force and motion data collected during sport movements. Forward dynamic analysis can generate new, hypothetical movements via computer simulation, and thus explore the effect of movement technique, equipment, and muscle properties on sport performance. Forward dynamic computational models also offer a unique opportunity to study sport injuries without exposing human subjects to unacceptable risks. This keynote presentation will present methods for forward dynamic musculoskeletal modeling, and their application towards our long-term goal of preventing anterior cruciate ligament (ACL) injuries in sport.

METHODS: The mathematical methods of musculoskeletal modeling are now well established. Muscle models generate muscle force as a function of activation and length change, and passive forces in soft tissue and ground contact are represented by force-deformation equations. Once all forces are known, accelerations can be solved from equations of motion, which are obtained using methods from multibody dynamics. Movement is simulated by submitting the full set of equations to an ordinary differential equation (ODE) solver, which integrates accelerations to generate skeleton motion. Models can vary in their level of detail, and it is important that a model contains those mechanisms that are relevant to the scientific or clinical problem, without excessive complexity that makes predictions less reliable. Validation is needed to ensure that these requirements are met. It is often necessary to perform experiments on several individual models, representing biological variation, and obtain general conclusions via statistical methods.

RESULTS AND DISCUSSION: A musculoskeletal model was developed to simulate cutting movements and predict knee joint loading (McLean et al., 2003). Twenty instances of the model were obtained using movement and anthropometry data from ten male and ten female basketball players, and random changes in neuromuscular control were introduced to generate injuries (McLean et al., 2004). It was found that the anterior tibial force did not exceed 900 N in any neuromuscular perturbation in any subject. It was concluded that sagittal plane loads could not injure the ACL, which fails at about 2000 N. However, we found that the valgus moment acting on the knee was often high enough to cause ACL injury, and that this happened more frequently in the female models. These findings were subsequently replicated for other sport movements; supporting the evolving hypothesis that valgus load is responsible for the high incidence of ACL injuries in women. Further work is needed to better understand how ACL strain is generated by 3-D forces and moments at the knee, and how hazardous loading states can be prevented through neuromuscular training. Musculoskeletal modeling and simulation continue to be important tools in these studies.

REFERENCES:

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