Development of a Lower Extremity Finite Element Model to Study the Effects of Muscle Forces on Knee-Thigh-Hip Injury in Frontal Crashes

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ABSTRACT

Recent experimental and computational studies of knee-thigh-hip (KTH) tolerance and response to dynamic knee loading suggest that almost all AIS 2+ KTH injuries in frontal crashes should occur at the hip. This is in contrast to data in the CIREN and NASS databases, which indicate that approximately 40% of KTH injuries in frontal crashes are to the thigh (i.e., the femoral shaft). The hypothesized reason for this difference is that muscle tension is present in vehicle occupants, but was not present in the cadaver data used to characterize KTH tolerance and response. In particular, it is hypothesized that muscle tension will affect KTH injury pattern and the ability of the KTH to withstand externally applied load by increasing bending moments in the bowed shaft of the femur and by altering the coupling of soft tissue to the skeleton.

A finite element model (FEM) of lower extremities has been developed to help elucidate the effects of muscle tension on KTH injuries. This model was created by remeshing the MADYMO human lower-extremity FEM to include correct femur cross-sectional geometry, trabecular bone, cortical bone with directionally dependent mechanical properties and Tsai-Wu failure criteria, articular cartilage, and improved muscle geometry. The dynamic response of the model, including the coupling of soft tissue to skeletal mass, was validated by simulating biomechanical tests from the literature as well as tests of whole cadavers that were impacted using loading conditions similar to those produced in FMVSS 208 testing.

Simulations of knee-to-knee-bolster impacts conducted with and without levels of muscle activation reported in the literature for braking/bracing suggest that muscle tension affects the coupling of soft tissue to the skeleton, decreases the externally applied forces required to cause KTH fracture, and increases the likelihood of femoral shaft fracture by increasing bending moments in the femoral shaft while simultaneously reducing bending at the femoral neck. However, more accurate data on activation levels of muscles in the lower extremities during vehicle braking and bracing are needed before the effects of muscle tension on KTH injury can be sufficiently understood and quantified.