Comparison of a Biofidelic Finite Element Model to an ATD Finite Element Model for Assessing Knee-Thigh-Hip Injuries

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Introduction: Motor vehicle crashes account for a significant portion of annual medical costs in the U.S. Although increased use of safety restraints such as seatbelts and airbags have decreased the frequency and severity with which life threatening injuries occur, these restraints do little to protect the knee-thigh-hip (KTH) region. Though injuries to the KTH do not generally result in death, it has been shown that injuries to this region often result in chronic disability and high psychosocial cost [1].

Traditionally, injuries to the KTH region have been studied using cadaveric test specimens in laboratory settings. Recent improvements to computer simulation technology have allowed researchers to develop numerical models that can be used to study injury. This paper presents the development and validation of a biofidelic numerical model that can be used to study injuries to the KTH region. The model was developed for use with the LS-DYNA finite element code. The biofidelic model's ability to predict injury to the KTH region was compared to the ability of an FE model of an anthropomorphic test dummy (ATD) that is frequently used by LS-DYNA users.

Method: The starting point for this research was a finite element (FE) model of the lower extremities developed by Lawrence Livermore National Laboratories. This model depicted the pelvis, femur, knee, ankle, foot, and a few ligaments to provide stability to the joints. Several improvements were made to this model, including re-meshing the geometry of the skeletal structure to include cortical bone, developing new orthotropic material properties of the bones, and adding discrete elements to the knee and hip joint to represent ligaments. Additionally, muscles were modeled using discrete elements which included a "Hill's" material model [2]. In addition to this, soft tissue overlaying the KTH region was modeled with Kelvin-Maxwell properties to allow some of the femur force to be transferred into the flesh.

The completed model was validated at both the component and full scale level against physical experiments conducted by Dr. Rupp at the University of Michigan [3]. The individual component validations included the femoral head, the pelvis, and the femoral condyles and were primarily used to validate the material properties of the bones. In addition, the model was validated against the results of a full scale sled test, where the model was positioned to a typical seated driving position and accelerated into a knee bolster that was represented by a piece of foam. In all validation simulations, the model performed acceptably well compared to the results of the physical tests [2].

A FE model of the Hybrid III ATD provided by Livermore Software Technology Corporation (LSTC) was also simulated under the same sled impact conditions as the FE KTH model. The Rigid Hybrid III dummy model developed by LSTC was used in this project, as it appears to be the most readily available model [4]. Figure 1 shows the positioned KTH model and Hybrid III dummy prior to the impact sled simulation.

Figure 1. FE KTH (left) and FE Hybrid III (right) Models Positioned for Sled Test

Risk of injury to the KTH complex is generally evaluated by measuring the maximum femur axial force during impact [5]. Thus, the maximum femur axial force obtained in the FE KTH was validated based on the axial force from the physical test and, compared to the axial force predicted by the FE Hybrid III.

Results: Figure 2 shows the time histories for the femur axial forces recorded for the different models and the test.

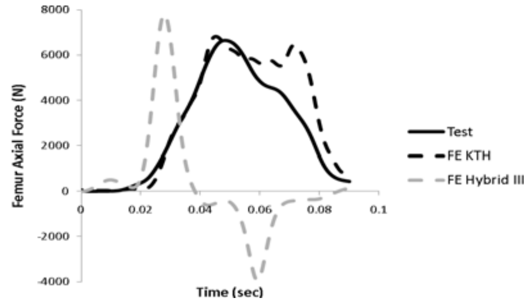

Figure 2. Comparison of Femur Axial Force Time Histories

As shown in the plot, there is good agreement between the FE KTH model and the physical experiment results, particularly at times leading up to the maximum femur axial force. Although the peak femur force from the FE Hybrid III model was comparable to the one recorded in the test, its slope appears too steep compared to the test's results because of the rigid materials used to model the thighs of the Hybrid. Results show the FE KTH model being an improvement of the lower extremity representation compared to the FE Hybrid III.

Conclusions and Future Work: This project has shown that the FE KTH model accurately replicates results obtained from a cadaver sled test. This FE model offers a more accurate way of studying lower extremity response to frontal impact when compared to the FE Hybrid III model.

Future work will consist of further validation of the KTH model, particularly with respect to anterior-posterior translation of the tibia relative to the femur. This will allow the KTH model to be used in studying injuries to ligaments in the knee such as the anterior cruciate ligament (ACL). Also, the KTH model will be simulated in a frontal collision of a full car FE model. This will provide researchers with a biofidelic representation of occupant response in an actual vehicle collision.

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