Development and Validation of Human Head-Neck Model for Simulating Soft Tissue Injury in Cervical Spine

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Abstract

Cervical spinal injuries are the most frequent result of road traffic crashes. Although most clinical symptoms are resolved within a short period of time, some cases will develop prolonged medical problems, placing soft tissue neck injuries among the most common causes of medical disability in car occupants world wide. It has been proposed that shear forces could cause stretch of the facet capsules, leading to neck pain. The current communication reports the development and validation of a Finite Element (FE) model of a detailed human cervical spine integrated with a human head model. The head-neck complex model was then used to predict facet strain responses in relation to the head-neck kinematics during simulated cadaver rear-end impact tests.

The geometry of cervical vertebrae was based on the CT scan of a cadaver. The FE mesh of the model was developed using a feature-based blocking mesh technique. The neck model consists of over 143,000 elements and 6 different material models to simulate cervical vertebrae, intervertebral disc annulus, nucleus and fibrous, facet capsules, ligaments and muscles. The neck model was then integrated with a detailed validated human head model (350,000-elements) at atlanto-occipital joints via cranio-vertebral ligaments and various membranes and muscles. The head-neck complex model was first validated against a series of inverted cadaveric drop tests. The model was further validated against head-neck kinematics during four low-speed rear-end impact cadaver tests. CORA 3.6 program was applied to objectively assess the correlation between the model predictions and experimental results.

For inverted head-neck drop test validation, the model predicted head resultant force, neck axial force and shear force agreed well with the experimental results at head/neck axis inclinations of -15°, 0°, $+15^o$. The corresponding CORA average scores were 0.69, 0.75 and 0.50 (1: perfect match), respectively. For rear-end impact test validation, the CORA correlation scores for the head linear and angular displacement time-history responses were 0.49 and 0.70, respectively. The model-predicted cervical spine incremental kinematics from C1-C5 showed similar trend and magnitudes to the experimental results using two cadavers. The model predicted high facet strain at the C4-C5 level. This may suggest high risk of facet strain-induced neck pain in the mid-cervical regions seen clinically. The model predicted 25% reduction in compressive strain at the facet joint due to the use of headrest which may result in decreases in capsular shear strain. The parametric studies on the effect of headrest material properties showed that softer foam resulted in increased head rotation than stiffer headrest. The detailed FE human head-neck model once fully validated it can be used a tool to help understand the biomechanical mechanism of soft tissue injury in rear-end collisions.