Hard Tissue Failure of an Aged Lower Cervical Spine Segment Model in Compression Loading with Anterior-Posterior Eccentricity

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Abstract

Background:
A high proportion of vehicle-related traumatic spinal cord injuries SCI are associated with rollover crash scenarios where the cervical spine can be subjected to axial compression loading producing soft and hard tissue damage, leading to SCI. Computational human body models (HBMs) can provide an understanding of these complex impact scenarios; however, it is first necessary to assess the model response and injury at the segment level.

Problem Statement:

Accurate material properties and tissue level failure criteria are critical for HBM. A set of aged cortical and trabecular bone properties, corresponding to the age of the experimental test samples, is proposed to simulate hard tissue response and fracture.

Objective:

The goal of the study was to assess the failure response of a detailed finite element model of a lower cervical spine segment (C5-C6-C7) extracted from the GHBMC 50th percentile male HBM. A set of proposed aged cortical and trabecular bone constitutive properties identified from the literature were assessed using experimental data for three compression loading cases: centric, posterior eccentricity, and anterior eccentricity.

Methodology:

Boundary conditions were applied at the superior C5 endplate for the centric compression case using prescribed displacements from the experiments with a Haversine velocity profile (8-15mm over 16ms). For both eccentricity cases, it was necessary to model the complete test setup to produce the eccentric loading and corresponding flexion or extension motion. Failure values and fracture patterns were assessed with the experimental results and X-ray images.

Data to be Included:

Results of the proposed aged anisotropic and the original average isotropic constitutive models loaded in centric, posterior-eccentricity, and anterior eccentricity compression cases, including a sensitivity analysis, will be presented. Comparisons with the experimental values [Carter, 2002] and X-ray images will be quantified.

Summary of Results:

The aged anisotropic model was in better agreement with the measured failure force and moment, compared to the isotropic model. In the centric compression case, the anisotropic model predicted a failure force (3.22 kN) and displacement (2.64 mm) that were 1.3% and 9% lower than the average experimental values, respectively. Whereas the isotropic model predicted a failure force (4.04 kN) and displacement (2.99 mm) that were 23.7% and 3.4% higher. In the posterior eccentricity case, the anisotropic model predicted a failure force (2.75 kN) that was 21% lower and a failure moment (51 Nm) that was 7% higher than the average values; whereas the isotropic model predicted a failure force (4.29 kN) and moment (118.89 Nm) that were 23% and 149% higher, respectively. An exception was the anterior eccentricity case, possibly due to the majority of the specimens being female and the pre-flexed state occurring from the weight of test apparatus. The fracture patterns in the aged anisotropic model were in better agreement with the experimental data than the isotropic model.

Conclusions:

This demonstrates the importance of hard tissue anisotropy and including age effects corresponding to the measured experimental data. Importantly, these models provide additional insight on fracture initiation and progression, which is challenging to measure in dynamic experiments.