

Constitutive Modeling of Cortical and Trabecular Bone Applied to Compression Loading and Failure of a Lower Cervical Spine Segment Model

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Abstract

Background:

Automotive collisions are the most common etiology for cervical spine injuries [Myers 1995, Carter 2002] with approximately 44% being traumatic injuries (AIS 3+) and the lower cervical spine being frequently injured [Yoganandan, 1989]. In a crash scenario, the neck may be subjected to axial compression loading [Carter 2002, Yoganandan 1989] leading to anterior wedge compression fractures, tear drop fractures or burst fractures [Argenson 1997].

Objective:

The aim of this study was to investigate constitutive models to predict hard tissue response and failure in finite element human body models. The constitutive models for trabecular and cortical bone were implemented in a lower cervical spine C5-C6-C7 model for comparison to experimental data [Carter 2002].

Problem Statement:

Many cervical spine models utilize symmetric elastic-plastic material models [Marwan 2009, Garo 2011, DeWit 2012]. Cortical and trabecular bone exhibit asymmetric, anisotropic and rate dependent properties. Specifically, the mechanical properties of trabecular bones are density dependent and hence, vary significantly between different anatomic regions.

Methodology:

Material property data for both cortical and trabecular tissues was compiled from the literature [McElhaney 1996, Reilly 1975, Yang 1999, Wolfram 2010, Liu 2012]. It was taken into consideration that the material properties for trabecular tissues were from experimental data that utilized vertebral specimens as trabecular bone properties vary significantly between anatomic regions. The available constitutive models in a commercial finite element code (LS-DYNA) were reviewed and candidate models were identified based on the key properties of the bones. Single element simulations were then performed to evaluate the constitutive models and compare

to the experimental data. The best performing models that described cortical and trabecular bone response, respectively, were implemented in the lower cervical spine model.

Data to be Included:

Results of the investigated constitutive models using single element uniaxial test simulations with comparison to experimental stress-strain values for cortical bones [Hansen 2008] and trabecular bones [Liu 2012] are presented. Evaluation of failure forces and displacements, and fracture patterns in the C5-C6-C7 model will be discussed.

Summary of results:

The single element simulation studies showed that the results of the asymmetric plasticity constitutive model for cortical bone and an anisotropic crushable foam model for trabecular bone were in good agreement with the experimental stress-strain curves. Elastic models with failure could exhibit instability, while standard plasticity models did not capture the material asymmetry in tension and compression. The lower cervical spine failure study with the implemented constitutive models showed that the failure force and displacement were in good agreement with experimental results. Also, the qualitative evaluation showed good agreement with clinical studies based on the location of elements eroded and burst fracture locations reported in the literature.

Conclusions:

Hard tissue response and failure is challenging to model due to the complex properties of bone tissue. Based on the available constitutive models and material properties from literature, key properties including asymmetry for cortical bone and anisotropy for trabecular bone were identified as important for modeling the response and fracture of cervical spine hard tissues.