ABSTRACT

Objective. To develop a detailed three-dimensional geometrically and biomechanically accurate finite element model of the human lower cervical spine, and to further investigate the biomechanical responses of the simulated ligamentous and articulating facets injured human cervical spine.

Study design. The study comprised the development of a finite element model of human lower cervical spine and validation by direct comparison of the model prediction against published data under axial compressive, flexion and extension loading configurations. The effects of ligamentous and facets injuries in the overall movement response of the spinal motion segment under sagittal moments were then studied by varying the necessary parameters of the validated model.

Background. The complex shapes of the vertebrae, the overlaying facets, intervertebral disc and the attaching ligaments have made modeling a laborious task. Attempts to quantify the clinical stability of cervical spine due to ligamentous and facets damage in vitro also limited due to the insufficient study samples to perform a statistical analysis. Race-, age- and occupational-related the normative values for geometry and biomechanical properties were not specifically available. Accordingly, the pathological alteration in the tissues and facets could only be best performed ex vivo using numerical simulation to quantify the subjective manner.

Methods. Based on the digitized geometrical data of the dried cadaveric cervical spine, protocols for the creation of surface profile and generation of “watertight” solid volume that truly preserves the topography of the original vertebrae for the reconstruction of finite element model were developed. Based on published data available, the cortical shell, cancellous bone, the ligaments and intervertebral disc were incorporated to complete the modeling of the lower cervical spinal motion segment. The model was analyzed under sagittal moments and axial compressive loading, and the predicted results were compared against published experimental data and existing finite element models. A parametric study was performed to analyze the moment deflection of simulated injured segments (segment without ligaments, and segment with both ligaments and facets).

Results. The protocols used in the generation of vertebral finite element mesh and the use of published data for the modeling of lower cervical spinal motion segment have reliably developed. The model was able to predict the force-displacement response that agreed well with published data. Furthermore, the model was able to predict the non-linear force displacement response of the human lower cervical spine function unit. Results from the parametric study on the roles of ligaments and facets shows that ligaments or facets are crucial to maintain the stability movement of the normal cervical spine under flexion or extension, respectively.

Conclusions. Based on the digitizing technique of extracting the geometric data of the surface profile of the vertebrae and the incorporation of associated tissues based on published data, a geometrical and biomechanical accurate model of lower cervical spine was developed. The surface and solid volume development protocols permit the fine tuning of the model for detailed
quantitative assessment of the prevalence of pathological changes in ligaments and facets in cervical spine. The predicted response of injured spine will provide additional information for the clinical assessment of cervical spinal stability and the design and analysis of spinal implant device. This validated finite element model will be served to explore the effect of potentially detrimental influences of injury to vertebrae, ligaments, disc and facets in individual cases.

**Keywords:** Cervical spine, Biomechanics, Digitizer, Ligaments, Facets, Injuries, Implant