Development of an Upper Cervical Spine Model for use in an Omnidirectional Surrogate Neck

Romani S and Cripton, P.A.

Background

Safety devices meant to protect the head and neck are often evaluated with the use of an anthropometric test device (ATD). ATDs are designed for a specific loading scenario and typically are biofidelic only in that application [1]. The Hybrid III neck is the most commonly used as it is specified in automotive and helmet standards, however, it is only biofidelic in high speed rear or frontal vehicle collisions [2]. There is no single surrogate appropriate for the multiplane loading that often occurs in real-world scenarios.

The long-term goal of this project is to create an omnidirectional ATD neck that is biofidelic in headfirst impacts, as well as in head impacts and inertial loading in the transverse plane by replicating the geometry and mechanical properties of key anatomical structures in the neck. Here we report on our approach to generating a surrogate of the anatomically complex upper cervical spine (C0-C2 vertebrae).

Methodology

Vertebrae models: We obtained CT scans from a 31year-old male with no cervical spine pathologies from Vancouver General Hospital through a collaboration with the UBC Dept. of Orthopaedics Spine Surgery Group. These were segmented using the Analyze software (Biomedical Imaging Resource, Mayo Clinic) and were then 3D printed in PLA.

Ligament stiffnesses: The transverse and alar ligaments were replicated in the model as they are believed to be the most deterministic to the kinematics of the region [3]. A nuchal ligament surrogate was implemented to restrict excessive flexion. Attachment points were based on anatomic landmarks. Candidate materials were tested in uniaxial tension at a quasi-static rate on an Instron materials testing machine and compared to the stiffness of cadaveric ligaments. We selected a cotton webbing for the surrogate ligament material.

For testing, a custom spine machine built in our lab was used to apply pure moments in flexion-extension, lateral bending and axial rotation to the specimen at quasi-static rates [4]. Markers were attached to each of the vertebrae, and their movements tracked using the Optotrak motion analysis system (Northern Digital, Waterloo, Canada). In this way, the applied moments and corresponding movements of the vertebrae can be recorded and evaluated. Range of motion, neutral zone and helical axis of motion were extracted from the resultant momentrotation plots and compared to the cadaveric literature.

Results and Discussion

The range of motion and neutral zone of the whole C0-C2 segment are plotted along with cadaveric data. The range of motion in flexion-extension, lateral bending and axial rotation are within range of the cadaveric results presented. Reproducing the kinetic and kinematic responses of surrogate spinal segments will aid in the construction of a biofidelic omnidirectional durable surrogate neck. Such a neck could be used to evaluate, improve and optimize head and neck safety equipment for transportation, occupational and sports settings.

Acknowledgements

We gratefully acknowledge Ms. Lani Reichl and Dr. Brian Kwon for assistance with ethics and obtaining the patients’ cervical spine CT scans.