Development of an Omnidirectional Neck for Evaluation of Sports and Automotive Protective Equipment

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MOTIVATION

There are an estimated 12.5 million people worldwide living with a spinal cord injury (SCI) [1,2]. The most common injury is to the cervical spine [3]. Incidence of traumatic brain injuries (TBI) is even more dramatic, with approximately 10 million occurring annually [4]. SCIs and TBIs are most often due to vehicle collisions, fall- and sport-related impacts [1,3].

Safety devices meant to protect the head and neck in the aforementioned scenarios are often evaluated with the use of an anthropometric test device (ATD). The Hybrid III neck is the most commonly used ATD neck as it is specified in automotive and helmet standards, however, it is only biofidelic (matches human kinetic and kinematic biomechanics with high fidelity) in high speed rear or frontal vehicle collisions [5,6,7,8]. There is no single surrogate appropriate for the multiplane loading that often occurs in real-world scenarios [9].

OBJECTIVES

Our long-term project objective is to create a biofidelic, omnidirectional, (i.e. having biofidelic responses in all directions) durable surrogate neck that can represent three preparedness levels; asleep, awake and not braced, and awake and braced. This research, a first step towards the overall objective, aims to produce a biofidelic sub-axial cervical functional spinal unit (FSU; two or more vertebrae and the intervertebral discs between them) with passive muscle properties, simulating a sleeping individual.

METHODS

Computer-generated 3D models of C3-C5, obtained from an anatomical drawing, were modified to include ligament anchor points. The initial vertebrae were considered to be ideal, meaning they were symmetrical and without deformities. The modified vertebrae were 3D-printed and an FSU was constructed by attaching and adhering synthetic ligaments and intervertebral discs, respectively. The FSU underwent axial rotation in our custom spine machine. The kinematic results were compared to previous cadaver tests in our lab to assess biofidelity.

Durability was addressed by CNC milling the modified C3 using 316 SST. Dimensions of the CNC-milled part were taken with an optoelectronic motion analysis system (Optotrak) and compared to dimensions of the original model, measured with SolidWorks (Fig 1), to assess accuracy.

A C3-C4 cadaver CT scan was used to create a realistic 3D vertebrae by segmenting C3, in contrast to the previous 'ideal' and thus unrealistic model. The segmented C3 was then 3D-printed and dimensions were taken using the aforementioned Optotrak method. Results were compared to the CT-generated model dimensions, obtained using SolidWorks as previously described, to assess accuracy.

RESULTS

Similar to the previous cadaver test results, the axial rotation versus torque results from the surrogate FSU had a sigmoidal curve, however, it took only 0.1 Nm for the surrogate FSU to reach 10 degrees of rotation (Fig 2) compared to 1.5 Nm for the cadaver. The CNC-milled and segmented parts were >90% dimensionally accurate.

CONCLUSIONS

Reproducing the kinetic and kinematic responses of sub-axial FSUs will aid in the construction of a biofidelic omnidirectional durable surrogate neck. The overall goal is to use the surrogate neck to evaluate, improve and optimize head and neck safety equipment for transportation, occupational and sports settings.

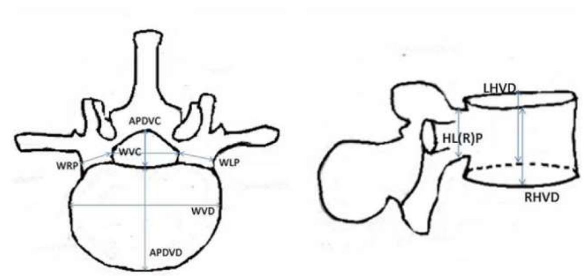

Figure 1 – Vertebral Dimensions Measured

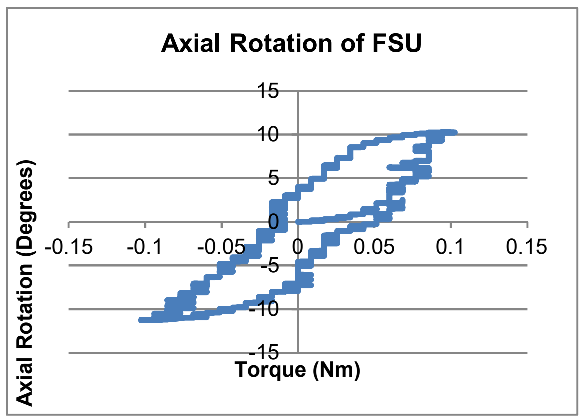

Figure 2 – Sigmoidal Axial Rotation Curve of C3-C5 3D-Printed FSU

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