DEVELOPMENT OF A MUSCULOSKELETAL CERVICAL SPINE MODEL FOR THE USE IN THE BIOMECHANICAL ANALYSIS OF AXIAL IMPACTS

*Silvestros, P., *Preatoni, E., **Gill, H.S., **Gheduzzi, S., **Hernandez, B.A., ***Holsgrove, T.P. and * Cazzola, D.
*University of Bath, Bath, United Kingdom

Introduction

Head collisions in sport can result in catastrophic injuries to the cervical spine [1]. Musculoskeletal (MSK) modelling can help analyse the relationship between players' motion, external loading and internal stresses that lead to injury. However, sport specific MSK models are lacking. In automotive research, the intervertebral disk behaviour (IVD) has been represented as viscoelastic bushing elements, whose parameters are often estimated in quasi-static conditions [2] that may lack validity in dynamic impacts. The aim of this study was to develop and validate a cervical spine musculoskeletal model for use in axial impacts.

Materials and Methods

A drop test rig [3] was used to replicate sub-catastrophic axial head impacts. A load of 80 N from 0.5 m was applied to the cranial aspect of five C2-C6 porcine spinal specimens mounted in the neutral position. The 3D motion of C2-C6 vertebras (4 kHz) and the cranial and caudal axial loads (1 MHz) were measure. Specimen-specific musculoskeletal models were created in NMSBuilder from µCT scans (0.1 mm voxel resolution) of the specimens. Each MSK model included four intervertebral joints with six degrees of freedom linear viscoelastic bushing elements used to represent intervertebral disc behaviour. Axial and shear viscoelastic properties of the C2-C3 to C5-C6 joints were estimated through an optimisation algorithm (Genetic Algorithm, MATLAB) that minimised tracking errors between measured and simulated spinal kinematics. The simulated kinematics were obtained by running forward dynamic simulations driven by the experimental load in OpenSim 3.3. A five-fold cross-validation was performed across the parameter sets.

Results

Median optimised bushing parameter values are presented in Table 1. Average cross-validation tracking errors were 0.518 mm. Residual values for the 3D motion capture system were 0.150 mm.

Table 1. Median stiffness (k) and damping (b) values for compression and shear motion of each joint of the best validation run (ε=0.448 mm). Values from de Bruijn [2] that were used to initialise the model bushing elements are also presented.

Joint	Compression		Shear	
	k (MN/m)	b (kNs/m)	k (kN/m)	b (kNs/m)
C2-C3	26.0	3.1	80.6	0.6
C3-C4	25.0	5.5	69.0	1.5
C4-C5	24.4	2.2	75.5	1.4
C5-C6	2.7	2.2	77.8	1.4
de Bruijn	1.1	1.0	63.0	1.0

Discussion

The estimated axial stiffness bushing values increased by one order of magnitude for the C2-C3 to C4-C5 joints from the initialised values. The remaining stiffness and damping bushing values remained mostly within the order of magnitude of the initialised values. Increased axial stiffness values specifically for the three most cranial joints could be related to the high impulsive impacts (600-1000 N/ms). In addition the significantly higher relative increase of axial stiffness compared to axial damping values (20-fold vs 2-fold respectively) is in line with the theorised poroelastic behaviour of IVD under higher axial loading rates [4,5]. For the C5-C6 joint the smaller increase of axial stiffness could be due to the spine's higher region of lordosis which would lead to larger shear loading of this joint under axial cranial load. Similarly shear stiffness and damping values remained close to initialised values.

Conclusion

This study provides for the first time the estimated viscoelastic intervertebral joint values of a multi-jointed porcine cervical spine via an integrated *in vitro* experimental and *in silico* musculoskeletal modelling approach. The respective joint stiffness and damping values can be used for future investigations of axial impacts under similar loading conditions.

References

1. Brown J.C., et al., (2013). *BMJ Open*, 3(2)
2. de Bruijn E., et al., (2016). *Multibody Syst Dyn*, 36(4)
3. Holsgrove T.P., et al., (2015). *Spine*, 15(8)
4. Costi J.J., et al., (2008). *Spine, 33(16)*
5. Race D.A, et al., (2000). *Spine*, 25(6)

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Affiliations

* Pavlos Silvestros, Department for Health, University of Bath, Applied Biomechanics Suite, BA2 7AY, Bath, UK. Email: p.silvestros@bath.ac.uk
**Centre for Orthopaedic Biomechanics, Department of Mechanical Engineering, University of Bath, BA2 7AY, Bath, UK.
*** Collage of Engineering, Mathematics and Physical Sciences, University of Exeter, EX4 4QF, Exeter, UK.