Adult Head and Neck Dynamics: A Sensitivity Analysis Study during Frontal Impact

Courtney A. Cox, Alan T. Dibb, Barry S. Myers, Roger W. Nightingale, Cameron R. Bass

I. INTRODUCTION

Many computational head and neck models have been validated using a 15g frontal impact volunteer test performed at the Naval Biodynamics Laboratory (NBDL) [1-3]. However, few have conducted sensitivity analyses of model input parameters on their results. The objective of this study was to conduct full model sensitivity analyses of model parameters during the 15g frontal impact simulations.

II. METHODS

The significance of each model parameter of the current study was analysed through sensitivity analysis. Each parameter was varied plus and minus one standard deviation as reported in the literature. A subset of these parameters is given in Table 1.

TABLE I

Parameter	Min Scale Factor	Max Scale Factor	Source
Neck length	0.957	1.043	Gilad and Nissan 1986
Muscle max isometric stress	0.400	2.00	Winters and Stark 1988
Muscle attachment – x	-1.000	1.000	Chancey et al. 2003

Head centre of gravity (CG) location was varied relative to the occipital condyle joint. Intervertebral joint stiffness for the upper and lower cervical spines were varied jointly. The 22 muscle insertions, origins, and physiological cross sectional areas (PCSAs) were varied by their respective standard deviations. Muscle attachment locations were varied jointly in each of the three degrees of freedom, with the same percentage of their standard deviation in the same direction. Latin hypercube sampling was used to select the value of the variables and 50 simulations were run per variable [4-5]. With 31 model variables, a total of 1,550 simulations were run with additional simulations when boundary conditions were included.

Model development and activation states are detailed in [6]. Model boundary conditions for the NBDL simulations are given in [7]. Briefly, the horizontal acceleration and sagittal rotation kinematics from the first thoracic vertebrae (T1) were applied to the model. Simulations were run using LS-DYNA (LSTC, Livermore, CA).

III. INITIAL FINDINGS

The kinematic response of the adult model during 15g frontal impact was most sensitive to extensor muscle activation level. Increasing the extensor activation level significantly decreased the peak head translational and rotational displacements and accelerations. The other parameters with the greatest contribution to the overall response were the muscle maximum isometric stress, muscle anteroposterior attachment, and muscle activation dynamics. Increasing the muscle maximum isometric stress, posterior attachment of the muscles, and speed of activation significantly decreased the peak head translational and rotational displacements and accelerations. Other muscle modelling parameters with a significant effect on the model response were: superior-inferior attachment, PCSA, passive stiffness, and active force-length shape.

The intervertebral joint flexion and extension stiffness had a significant effect on the model kinematic response but were, at most, the sixth ranked parameters. Increasing the flexion stiffness significantly decreased the peak head z-direction displacement and neck rotations. Increasing the joint extension stiffness significantly decreased the peak head rotational acceleration and decreased the head lag time. The intervertebral joint

C.A. Cox is a PhD student in Biomedical Engineering in the Department of BME at Duke University in Durham, NC, USA (+1 919-660-8274, courtney.a.cox@duke.edu). A.T. Dibb is a PhD graduate, B. S. Myers is a Professor, and, R. W. Nightingale and C. R. Bass are Associate Research Professors in the Department of BME at Duke University, NC, USA.

tension, compression, and shear stiffness did not have a significant effect on the model kinematics.

The kinetic response of the adult model during 15g frontal impact was most sensitive to extensor muscle activation level. Increasing the extensor activation level increased the overall neck bending stiffness while decreasing the loads and moments within the osteoligamentous cervical spine. The loads of the C5-C6 spinal segment were most sensitive to the intervertebral joint flexion stiffness. Increasing the intervertebral joint flexion stiffness significantly increased the peak flexion moment while decreasing the peak compressive force. The peak flexion moments of C5-C6 were significantly decreased by increasing the muscle maximum isometric stress, PCSA, and posterior attachment. On the other hand, the peak compression forces sustained by C5-C6 were significantly increased by increasing the muscle maximum isometric stress, PCSA, posterior attachment, passive stiffness, and active force length shape factor.

The overall neck bending secant stiffness was only significantly sensitive to the model muscle parameters. Increasing the posterior attachment distance, PCSA, active force length shape factor, max isometric stress, and activation significantly increased the neck bending stiffness. The applied boundary conditions, model geometry, and intervertebral joint stiffness did not have a significant effect on the neck bending stiffness. The applied T1 boundary conditions and the inclusion of gravity in the simulation had a significant effect on loads sustained by the osteoligamentous spine. The inclusion of gravity significantly increased the peak C5-C6 flexion moment.

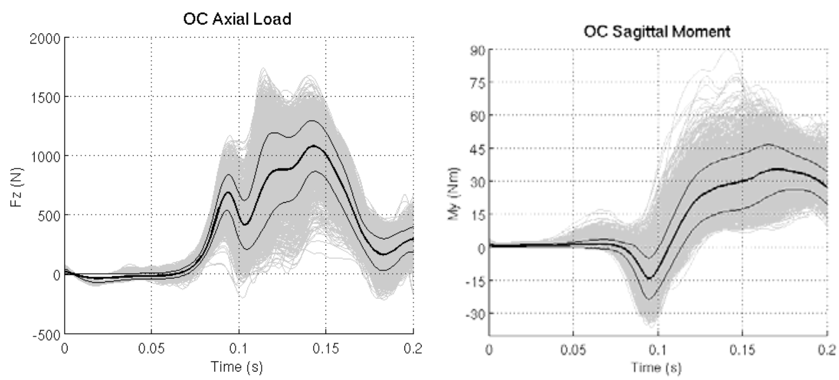

Fig. 1. Model OC neck axial force and sagittal moment during frontal impact sensitivity analysis. Plotted are simulations with the average ± SD.

IV. DISCUSSION

Muscle activations had the most significant effect on head and neck kinematics compared with head mass, neck length, or osteoligamentous stiffness. The second most significant model parameter was muscle maximum isometric stress, σ_{max}. Increasing σ_{max} decreased head and neck kinematics. The third most significant model parameter was muscle attachment location. While muscle activation level, reflex time, and σ_{max} altered muscle forces, attachment location altered the muscle loading line of action and effective moment arm length. These results indicate that muscle modelling should be of high priority in automotive modelling, as it significantly affects both the kinematic and kinetic response. Additionally, sensitivity analyses are necessary for head and neck modelling, as variances in parameters across literature values produce significantly different results in simulations.

V. REFERENCES

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