Cervical Spine Segmental Loads from Frontal Impact using a Validated Finite Element Model

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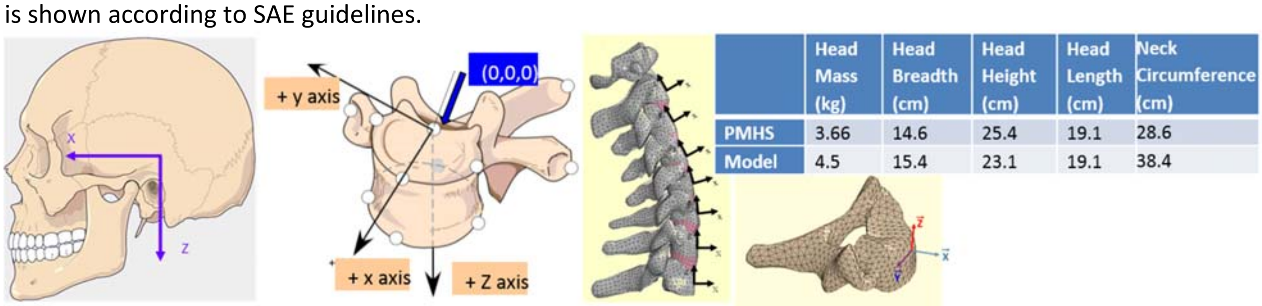
I. INTRODUCTION

Human volunteer and cadaver studies have been used to determine the kinematics and upper neck loads in impacts applicable to motor vehicle, aviation and military environments [1-2]. The upper neck loads calculated using head accelerations are used to characterise the head-neck biomechanics and neck injuries. The upper neck loads and neck injury criteria (N_{ij}) for the Hybrid III anthropomorphic test device are currently used in safety standards around the world [3]. Recent automotive and military field studies have shown that the neck injuries are generally confined to the lower cervical regions [4]. Investigations are needed, therefore, to determine neck loads along the different vertebral levels of the column, especially in the lower regions. The current study is focused on determining such neck segmental loads along the entire cervical spinal column under frontal acceleration, using experimental results and a validated finite element (FE) model of the human neck with muscles.

II. METHODS

The intact human cadaver experiments conducted at the Medical College of Wisconsin were used to determine the input and validation parameters for the three-dimensional Strasbourg University Finite Element Head Neck-Model (SUFEHN-M) [5]. Briefly, a triaxial accelerometer was attached to the mount fixed posteriorly to the T1 vertebra. A tetrahedron-shaped nine accelerometer package was attached to the head: the three linear accelerometers along three orthogonal axes were fixed to vertex, and two linear accelerometers were placed on the other vertices [6]. Using the physical properties of the head (centre of gravity (CG) and moment of inertia), the temporal linear accelerations were computed at the CG of the head, and this time-varying dataset served as the validation outputs for the SUFEHN-M. The spine accelerometer data were transformed to the T1 anatomical axis: origin at the superior vertebral body surface at its posterior middle region (Fig. 1). The system of reference is shown according to SAE guidelines.



	Head Mass (kg)	Head Breadth (cm)	Head Height (cm)	Head Length (cm)	Neck Circumference (cm)
PMHS	3.66	14.6	25.4	19.1	28.6
Model	4.5	15.4	23.1	19.1	38.4

Fig. 1. Anatomical coordinate system for the head (*left*), T1 (*second from left*) vertebra, local axes for the spinal column (*second from right*), and cervical vertebra (*right*).

The SUFEHN-M included geometries of all cervical vertebrae from the base of the skull/occiput to T1, intervertebral discs from C2-T1, major ligaments, including the unique ligamentous structures of the upper cervical encompassing the occipital-atlantal-axial complex, disc annulus and nucleus from C2 to T1, and all major muscles, i.e. posterior, anterior and lateral aspects [7]. The model was initially validated with human volunteer experimental data from the Naval BioDynamics Laboratory (NBDL, New Orleans, Louisiana, USA) for frontal impacts. The recorded accelerations from the sensors in the current series of experiments were transformed to the T1 anatomical axes (Fig. 1) and inputted to the SUFEHN-M. The head CG accelerations from the experiments were used as an additional validation dataset, thus adding to the robustness of the FE outputs, i.e. segmental neck loads. The maximum loads at all levels of the cervical spinal column, regardless of time of occurrence, from the C2-C3 to the C6-C7 segmental levels at the mid-height of the disc, were extracted along the local anatomical axes (Fig. 1), in the sagittal plane, to achieve the objectives of the study. This included the axial tensile force, flexion shear force and flexion moments at both low and high velocities.

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III. INITIAL FINDINGS

The intact human cadaver experiments were carried out at 6.9 m/s and 15.8 m/s velocities, low and high velocities. The FE model-predicted x-axis and z-axis head accelerations compared well across all timelines with the experimental at both velocities (Fig. 2). Figure 3 shows the calculated segmental loads on the cervical spinal column at different levels, describing the internal axial, shear and bending moment responses. The segmental loads decreased cranially, in general, for the axial tensile force, flexion shear force and flexion moments.

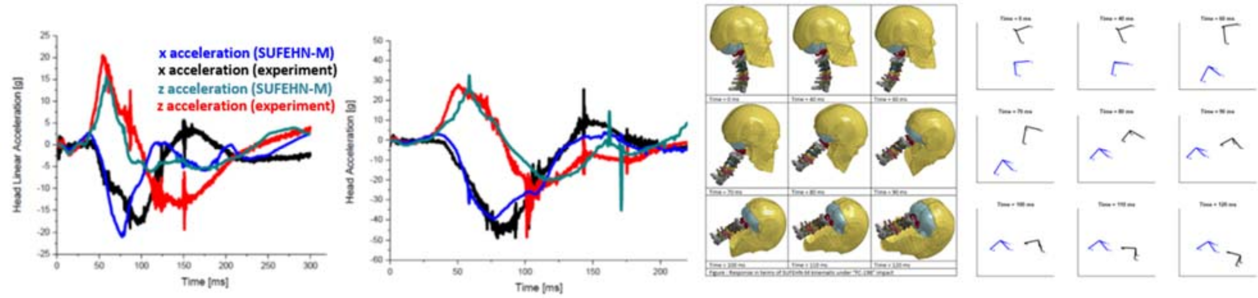

Fig. 2. Head acceleration plots comparing FE with experimental data (left) low and high velocities, and (right) kinematics.

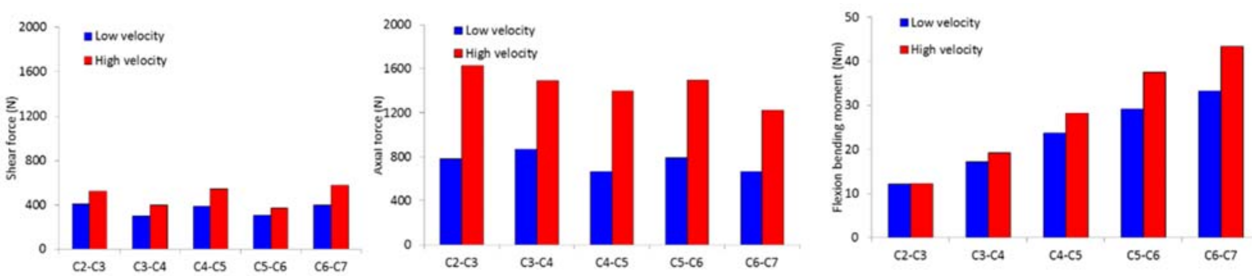

Fig. 3. Segmental loads (flexion shear, axial tension and flexion bending moments) on the spinal column.

IV. DISCUSSION

As stated in the Introduction, there is a need to quantify the segmental loads on the cervical spine, especially at the lower regions, from different perspectives: (a) survivors sustain injuries at the lower spine; (b) medical treatments, such as disc replacements, are mostly for lower spine disorders; (c) computational models can extract such loads because of recent developments in modeling; and (d) lower neck load cells are commonly used in modern test devices, such as the THOR dummy and manikins for military and aviation. Thus, the present hybrid approach of coupling experiments with FE modeling and using specimen-specific outputs in the form of T1 accelerations (input to FE) and head CG kinematics (validation of FE) is timely and addresses the intriguing question regarding the internal load distribution within the neck structures. The quantifications of these types of intrinsic responses (which are extremely difficult to obtain from experiments without compromising the integrity of the anatomical structure, thereby altering the load path and distribution), carried out using a comprehensive and thoroughly validated FEM, serve as milestones as FE models continue to become more accepted by international communities, and eventually become a standard tool to assess road/human safety. From this perspective, the present study has provided quantitative results in this pursuit.

V. ACKNOWLEDGMENTS

This work was supported in part by W81XWH-16-1-0010 and the VA Medical Center (NY employee). Any views expressed are those of the authors and are not necessarily representative of the funding organisations.

VI. REFERENCES

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