Effect of Posture on Neck Response During Head-first Impact Evaluated using a Numerical Full-body Model

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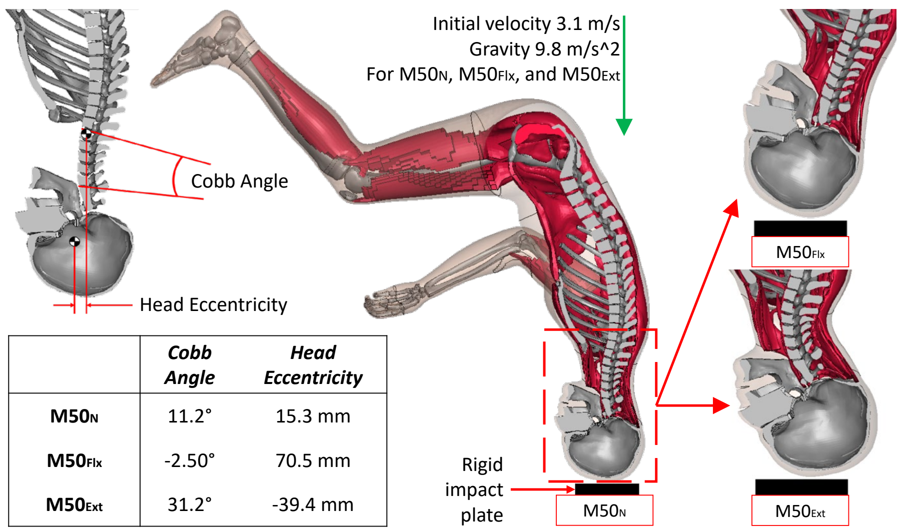
I. INTRODUCTION

Automotive rollovers are one of the leading causes of automotive-related cervical spine fractures in adults [1-2]. Roof-to-head contact and spinal compression due to torso momentum are the suspected causes of injurious neck loading in rollovers [3-4]. To study rollovers, head-first impact (HFI) experiments and computational studies have been carried out. Full-body cadaveric HFI experiments have reported a high sensitivity of injury to posture [5]. A recent study [6] assessed the kinematics of a computational human body model (HBM) in a controlled rollover experiment against post-mortem human subject (PMHS) experiments and measured the effect of the pre-roll posture on body kinematics under rollover, but did not model HFI directly. A finite element (FE) HFI study [7] varied the impactor velocity, displacement, and direction for a human body model in a single posture. At present, no study has quantified the effect of varying the pre-HFI posture on kinematics and vertebral fracture using detailed HBMs. In this study, HFI was simulated using the Global Human Body Models Consortium 50th percentile male detailed HBM (GHBMC M50-O, Version 6.0) [8] in three postures. GHBMC M50-O, Version 5.0 head and neck were assessed against experimental HFI loading [9], and enhancements to the upper cervical spine validated in flexion, extension and axial rotation [10] were included in GHBMC M50-O, Version 6.0.

II. METHODS

HFI was simulated with a vertical drop onto a rigid plate (Fig. 1), with three different head and neck postures, in a full-body model: (a) neutral ($M50_N$); (b) flexed head and neck ($M50_{Flx}$); and (c) extended head and neck ($M50_{Ext}$). An impact velocity of 3.1 m/s was used, corresponding to the velocity used in experiments [11], and the reported onset of injury in diving reconstructions [12]. To directly assess the effect of posture, no muscular pre-stresses were added to the models.



	Cobb Angle	*Head Eccentricity*
$M50_N$	11.2°	15.3 mm
$M50_{Flx}$	-2.50°	70.5 mm
$M50_{Ext}$	31.2°	-39.4 mm

Fig. 1. Diagram of kinematic measures (top left) showing positive Cobb angle (the mid-sagittal angle between the C2 and C7 lower endplates) and positive head eccentricity (anterior-posterior position of the head CG relative to the C7 vertebral body), body position at the start of $M50_N$ (centre), $M50_{Flx}$ (top right) and $M50_{Ext}$ (bottom right) simulations, and their tabulated kinematic measures (bottom left).

III. INITIAL FINDINGS

The three head and neck postures resulted in three initial Cobb angles and head eccentricities (head centre of gravity (CG) position relative to C7 CG) (Fig. 1). Initial impact of the head on the plate resulted in a head force of approximately 16 kN, while the force at C7 was approximately 2.5 kN in all cases. The neck was compressed between the head and the downward moving torso, leading to bending of the spine in extension. Due to the plate being rigid, the head rebounded (Fig. 2c) and lost contact with the plate, moving 18.6 mm anterior to C7 for $M50_{Flx}$, <1 mm anterior to C7 for $M50_N$, and 20.3 mm posterior of C7 for $M50_{Ext}$ (Fig. 2b).

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Between the first and second head impacts, the neck of $M50_{Flx}$ re-straightened from a maximum 12° Cobb angle to 2.3°, while both $M50_N$ and $M50_{Ext}$ increased Cobb angle by ~30° (Fig. 2a) due to the motion of the head relative to the spine. Increased extension of the $M50_N$ and $M50_{Ext}$ models resulted in contact between the transverse process of C2 and the C3 facets at ~17 ms, leading to element erosion (Fig. 2d), and the prediction of fracture initiation in the models. This same contact and element erosion occurred at 30 ms for $M50_{Flx}$ due to the flexed model delaying that contact.

IV. DISCUSSION

Modifying the neck posture affected the head translation direction during HFI, resulting in different amounts of curvature in the cervical spine during the impact. Although the head rebound led to loss of contact and therefore force at the impact plate, a lower relatively constant force occurred at the C7 level owing to compliance in the torso from increased kyphosis in the thoracic spine. The model predicted transverse process fracture at C2, which is reported to be the fourth most common cervical spine fracture [13], occurring most commonly in C2 and C7. Notably, the flexed model reported injury to occur at a much later time compared to the $M50_N$ and $M50_{Ext}$, suggesting an important contribution of initial posture to response and injury outcome. These simulations were limited by their lack of muscular pre-tension at the start of the simulations, since only the effect of neck posture was studied. As such, future work should study the effect of neck muscle co-contraction on impact to a full head and neck in various postures.

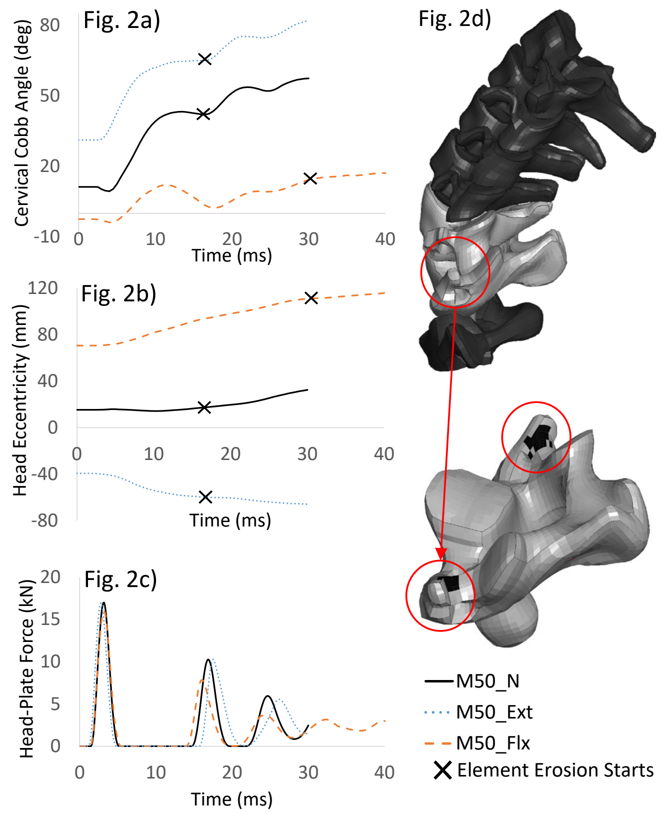

Fig. 2. a) cervical Cobb angle, with positive values denoting neck flexion; b) head eccentricity, with positive values denoting anterior head motion relative to C7; c) head-plate contact force; d) a rendering of the contact between a C3 facet and C2 transverse process (circled), and the erosion seen in C2 in all three cases with the eroded elements (black) circled.

V. ACKNOWLEDGEMENTS

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VI. REFERENCES

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