Repositioning Study for a Motion Segment: effect of Initial Rotation

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I. INTRODUCTION

It has been demonstrated that there is a significant increase in the potential for neck injuries during automotive crashes with non-neutral head postures, such as a head-turned posture [1]. However, few attempts have been made using finite element (FE) human body models (HBMs) to assess the increased potential for neck injuries during vehicle collisions with non-neutral head postures. This is attributed to the limitations in the used models and lack of experimental data. One of the most important aspects of simulating crash scenarios and safety assessments for an occupant in a head-turned posture prior to a vehicle collision using finite element human body models is generating and retaining stresses and strains within the structures of the cervical spine because a head-turned posture naturally has stresses and strains within the neck [2]. Recent attempts have been made to generate and retain stresses and strains in the neck in non-neutral head postures prior to subsequent impact in order to demonstrate that if the initial stresses and strains are not retained, the response to subsequent loading, including the mode and progression of failure, is different [1-2]. The aim of this study is to demonstrate, using a segment of a neck model, that rotating a segment outside the neutral posture followed by subsequent loading with retained stresses and strains results in a different response and failure progression when compared to a segment that has been rotated outside the neutral posture followed by subsequent loading without initialising the stresses and strains that were generated during the initial rotation. The results from this study emphasise the importance of accounting for the initial stresses and strains in the neck in a non-neutral head posture prior to subsequent impact during safety evaluations and risk assessments of finite element human body models.

II. METHOD

An existing and validated detailed C4-C5 segment FE model from the Global Human Body Models (GHBMC) 50th percentile male was used for the current study. The segment model consists of adjacent C4-C5 vertebral bodies, with attaching Anterior Longitudinal Ligament, ALL, Posterior Longitudinal Ligament, PLL, Capsular Ligaments, CL, Interspinous Ligament, ISL, and Intervertebral Disc (3, 4). The ligaments were modelled as a series of non-linear, tension-only axial elements spaced at 1 mm intervals [3]. A schematic of the C4-C5 segment model used in this study is shown in Fig. 1. Two modes of loading, tension and flexion, were simulated for three load scenarios: non-rotational monotonic simulation; rotation-stress-free simulation; and rotation-retained-stresses simulation. The non-rotational monotonic simulation represents the validated cases for both tension and flexion loading conditions. In the rotation-stress-free simulation, the model was initially rotated 3 degrees prior to subsequent tension or flexion without retaining the stresses and strains generated within the model after the initial rotation. On the other hand, in the rotation-retained-stresses simulation, static stresses were generated and retained within the model prior to subsequent deformation. The loading conditions were applied until the model predicted failure, by ligament failure and disc avulsion. Figure 2 shows the different states of the model during the simulation, and the failed models for both tension and flexion.

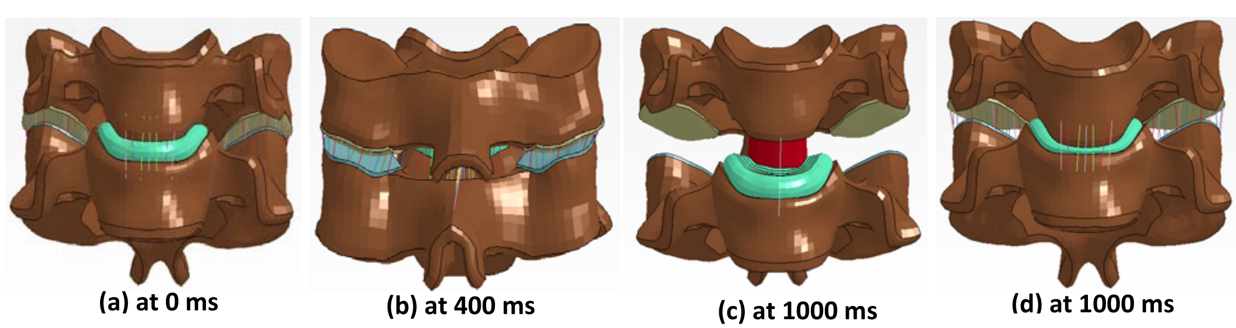

Fig. 1. (a) Anterior view of the C4-C5 segment used for the current study; (b) posterior view of the segment after initial rotation. Failed model after (c) tension and (d) flexion.

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III. INITIAL FINDINGS

In the current study, the results for the C45 segment model in tension under non-rotational monotonic simulation (Fig. 2(a)) were close to the experimental results reported by Barker *et al*. [5]. The failure force was close to the reported experimental value and within the failure corridors of the C45 segment. The response of the model and the progression of failure during deformation were a little different when the rotation-stress-free simulation was compared to the rotation-retained-stresses simulation. This is attributed to the fact that the initial stresses and strains generated within the model were not initialised in the rotation-stress-free simulation, even though they were both initially rotated 3 degrees prior to subsequent deformation. Nevertheless, they were both stiffer, with higher failure force, than the non-rotational monotonic loading. The results for the C45 segment model in flexion under non-rotational monotonic loading (Fig. 2(b)) fell within the failure corridors reported by the experiment from Nightingale *et al*. [6]. In flexion, the result for initially rotating the segment followed by subsequent flexion with retained stresses and strains was evident in the difference in response of the model to subsequent deformation when the stresses and strains were not initialised, as shown in Fig. 2(b). Furthermore, there was numerical instability because of excessive deformation of elements in the rotation-stress-free loading. The results from this study emphasise the importance of accounting for the initial stresses and strains in the neck in a non-neutral head posture prior to subsequent impact during safety evaluations and risk assessments of FE HBMs.

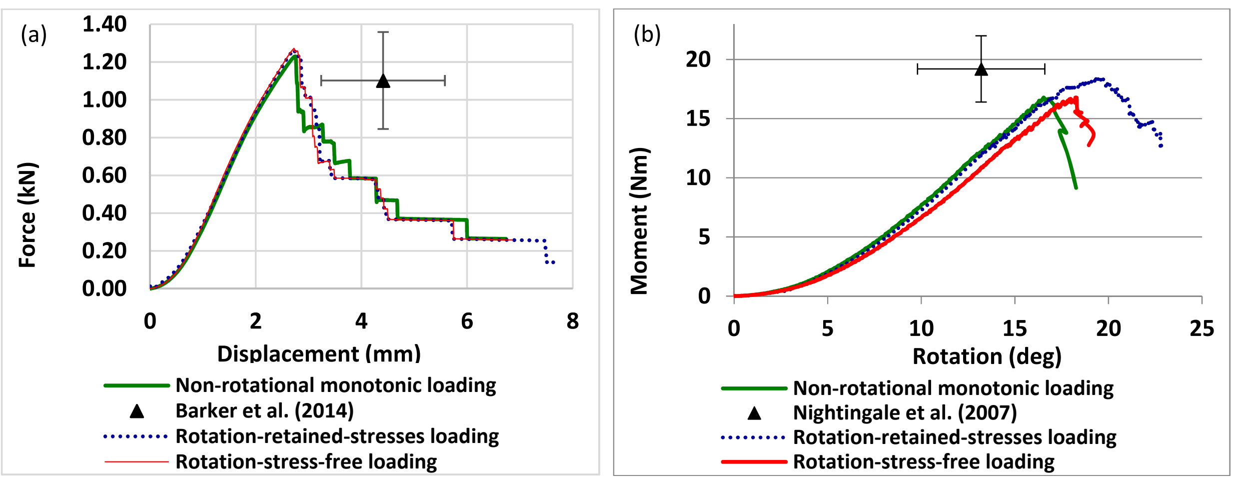

Fig. 2. Simulated results for C45 segment model in (a) tension and (b) flexion.

IV. DISCUSSION

The present study used an existing and validated detailed C4-C5 segment FE model from the Global Human Body Models (GHBMC) 50th percentile male to demonstrate the effect of retained initial stresses and strains prior to a subsequent deformation on the deformation response and progression of failure. Naturally, axial rotation of the head causes initial strain on the structures of the cervical spine, including soft tissues, and subsequent deformation results in additional soft tissue strains, which may lead to pain response in the cervical spine. In addition, to improve the biofidelity of HBMs during crash scenarios and safety assessments, it is important to generate and retain stresses in the model, or segments of the model, when the model or segment is not in standard positions or neutral positions. This is because, naturally, a raised arm, a turned head and other non-standard postures have stresses and strains, and not accounting for these stresses and strains may provide inaccurate injury predictions. The results from this study will serve as the starting point for incorporation into a full neck model and for the assessment of the increased potential for injury for an occupant in a non-neutral head posture during vehicle collisions.

V. REFERENCES

[1] Shateri, H. *et al.*, *TIPrev*, 2015.
[2] Boakye *et al.*, *IRCOBI*,2016.
[3] Cronin, D. S., *JMBBM*, 2014.
[4] Panzer, M. B. *et al.*, *JBiomech*, 2009.
[5] Barker *et al.*, *WCB*, 2014.
[6] Nightingale, R. W *et al.*, *JBiomech.*, 2007.