Neck Injury Risk in Out-of-Position Rear Impact Scenarios Using a Reference Geometry-Based Head Repositioning

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Introduction: Rear-end vehicle collisions can lead to whiplash associated disorders, which are generally non-fatal but cause a variety of prolonged head and neck pain responses (Haldorsen et al., 2003). Head position significantly affects the risk of these injuries during vehicle crashes (Jakobsson, 2004; Shateri & Cronin, 2015), with axial rotation accounting for the most frequent non-neutral position during travel time (Reed et al., 2020). Rear impact tests of the cervical spine have been reported for a 28° axial rotation (Ivancic et al., 2006). Given the limited experimental data for out-of-position scenarios, computational human body models (HBMs) can inform on the potential for tissue-level response and injury risk. Although previous analyses have considered head repositioning methods such as external rotation boundary conditions, studies have been limited in achieving a static head and neck position with biofidelic intervertebral movements.

Objectives: The objectives of the current study were to implement a novel head repositioning method using reference geometry to pre-stretch the muscles, and simulate out-of-position rear impact scenarios to assess tissue level response and the potential for neck injury.

Methodology: The head and neck model was extracted from the Global Human Body Models Consortium M50-O v6.0, a detailed HBM representing a 50th percentile male (Barker & Cronin, 2021). An axial rotation of 28° was achieved through a novel initial stress methodology by pre-stressing the muscle. The repositioning method was verified by comparing intervertebral kinematics with experimental data for axial rotation.

The out-of-position head and neck model was evaluated in rear impact scenarios by applying experimental T1 vertebra boundary conditions at 4g, 7g, and 10g severities (Deng et al., 2000; Ono et al., 2006). Head kinematics, muscle strains, and ligament displacements were obtained and compared with neutral position impacts.

Data to be Included: A summary of repositioning and impact phases (Figure A1 in Appendix A) and a comparison of muscle and ligament distractions for neutral and head-rotated impact cases (Figures B1 and B2 in Appendix B) will be included.

Results and Conclusion: Implementing a novel reference geometry-based repositioning method allowed the head to reach the target axial position of 28°, and the resulting intervertebral rotations were consistent with the experimental ranges of motion (Ivancic, 2013). The out-of-position rear impacts generated muscle maximum principal strains (95th percentile) up to 185% greater than in the neutral position. The trapezius and oblique capitis inferior muscles demonstrated the highest strains, with the trapezius exceeding physiological limits (Hasselman et al., 1995; Morrow et al., 2010). The maximum displacements of the capsular ligaments (CLs) averaged 56% higher in the non-neutral position, experiencing the most significant increases between the C3 and C6 vertebrae. In addition, CLs connecting C0 and C1 entered the traumatic region (Mattucci & Cronin, 2015) for the non-neutral position impacts, increasing the risk of pain response. The proposed repositioning method using stress initialization represented the intervertebral kinematics, resulting in a biofidelic injury assessment in out-of-position rear impacts. Future studies will expand the injury evaluation to nerve roots and investigate the influence of muscle co-contraction in these impacts.

References

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Appendix A

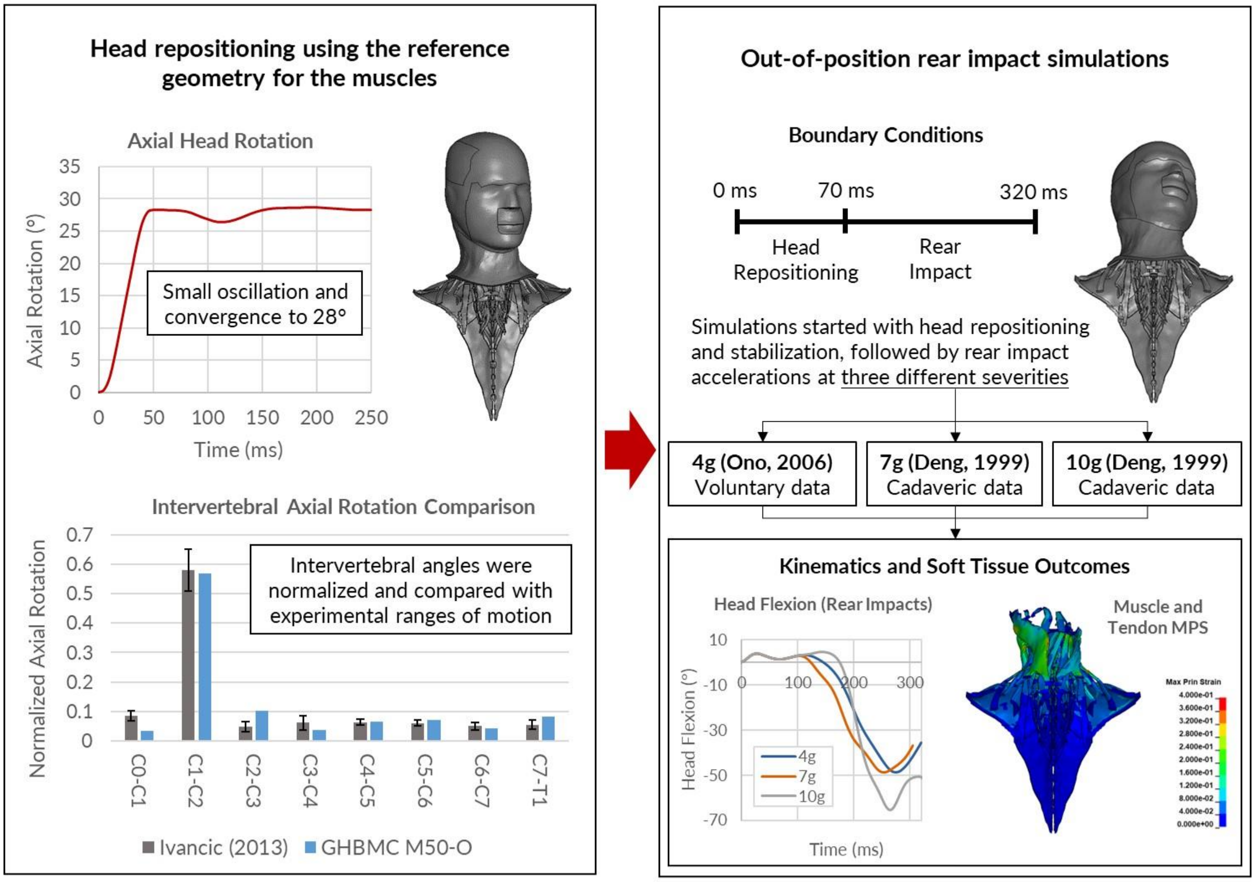

Figure A1: Results of the reference geometry-based repositioning and assessment of the out-of-position rear impact simulations.

Appendix B

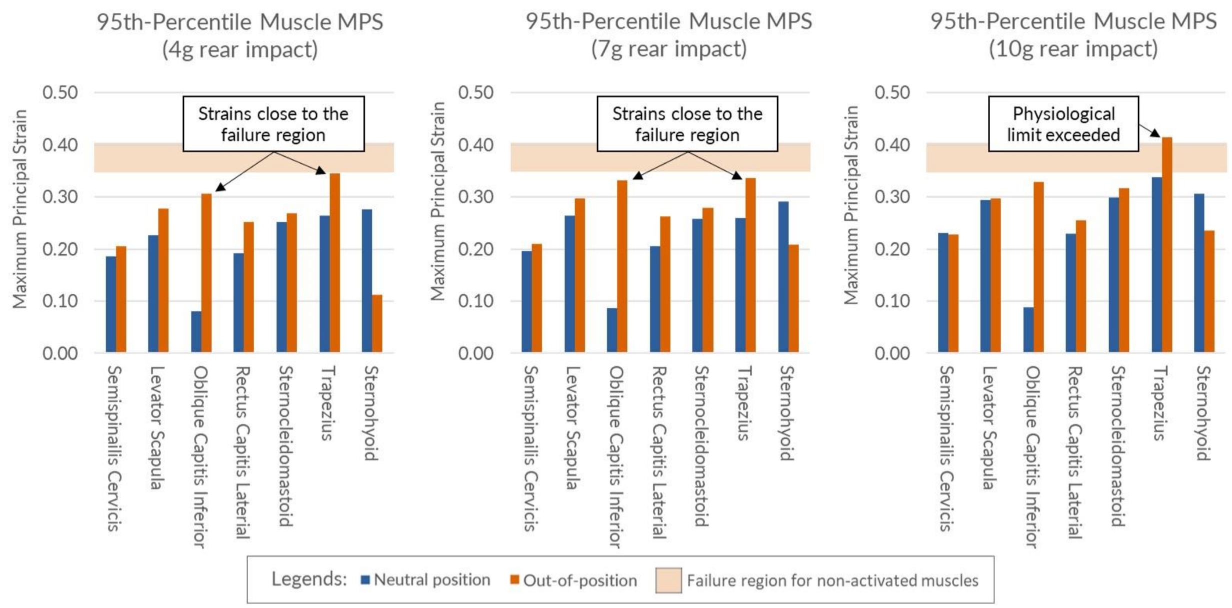

Figure B1: 95th percentile MPS for the muscles with the highest strain values and comparison with failure regions for the three rear impact severities.

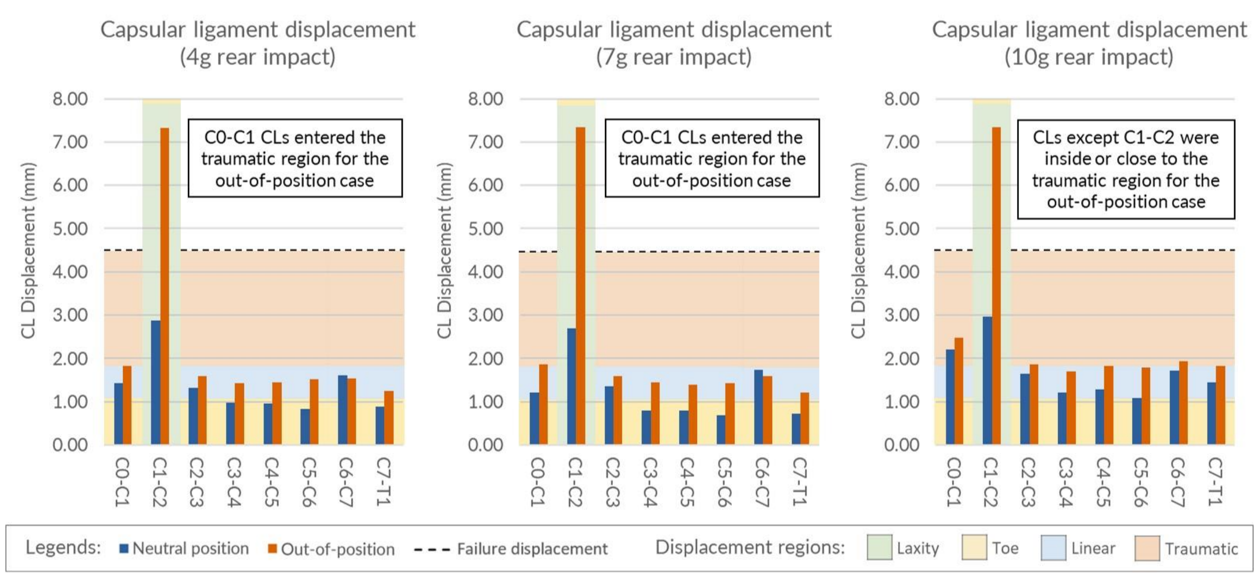

Figure B2: Maximum displacement for the capsular ligaments between C0 and T1 and comparison with characteristic regions for the three rear impact severities.