Lateral Impact Validation Study Using a Probabilistic Statistical Shape Finite Element Model of the Head and Neck

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INTRODUCTION

- Injury prediction and mitigation are common overarching goals of modern biomechanical research.
- Unlike traditional mechanical systems, biological systems are difficult and costly to test resulting in a need for robust and accurate numerical simulations.
- Typically models are created from generalized anatomical geometry or subject specific geometry taken from single subject imaging data.
- Individual models fail to account for the variability of vertebral spinal segment orientation, geometry, and material properties present in a given population.
- Statistical shape models capture the variability of the biological structures by projecting a high dimensional representation of the structure onto a lower dimensional subspace of possible shapes constructed from a population of training shapes.
- The purpose of this study is to validate the response of a parametric, probabilistic, cervical spine finite element model as part of a hierarchical V&V methodology using lateral impact experimental data.

METHODS

- 5 cervical spine CT scans were semi-automatically segmented to extract vertebra surfaces (Seg3D, The Center for Integrative Biomedical Computing, University of Utah, Salt Lake City, UT).
- Triangulated surfaces were generated for each vertebrae and smoothed to remove stair stepping effect (MATLAB R2010b, The Mathworks, Inc. Natick, MA).
- Vertebral surfaces were registered to each other on a level by level basis and vertices were repositioned using a coherence point drift algorithm such that all vertices were positioned at the same anatomical location on all vertebral surfaces.
- Due to node to node correspondence all vertices coordinates can be averaged resulting in an average surface model that was then volumetrically meshed.
- This volumetric mesh then warped to each surface mesh resulting in corresponding volumetric meshes for all subjects which are then averaged into a statistical shape model (SSM).
- Intervertebral discs are modeled as transversely isotropic viscoelastic, ligaments are modeled as nonlinear discrete elements, and muscles are discrete elements with a hill type muscle model.
- An average head and upper cervical spine model were connected to the SSM to complete the head and neck complex.
- Model boundary conditions were modeled to match lateral sled impact experiments conducted at MCW with 1, 2, and 3 m/s impact velocities.
- A 100 Latin hypercube sample (LHS) probabilistic analysis was performed to determine the mean and variation for the kinematic response of the model.

METHODS (continued)

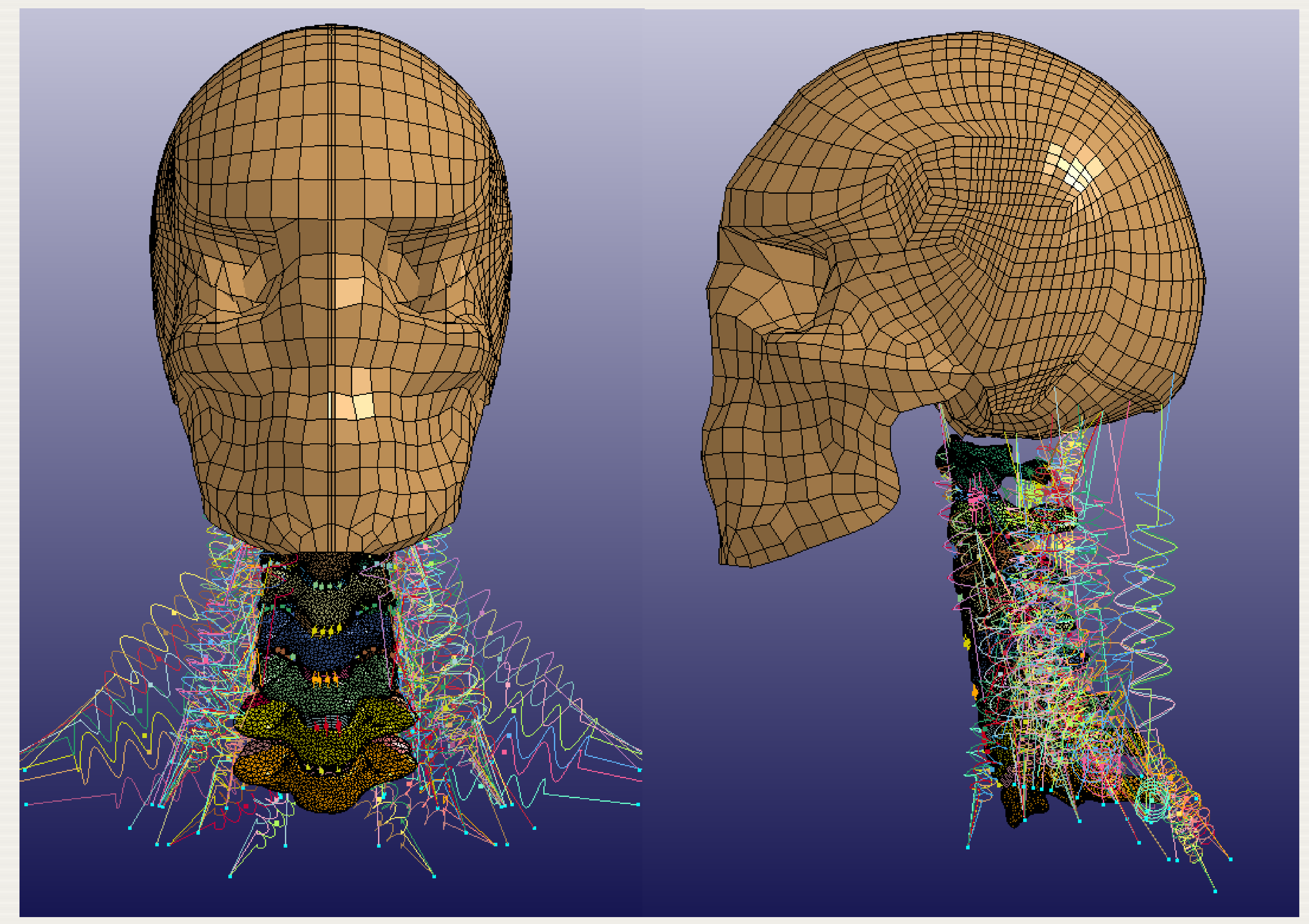

Figure 1: Average Head and Neck Finite Element Model

RESULTS

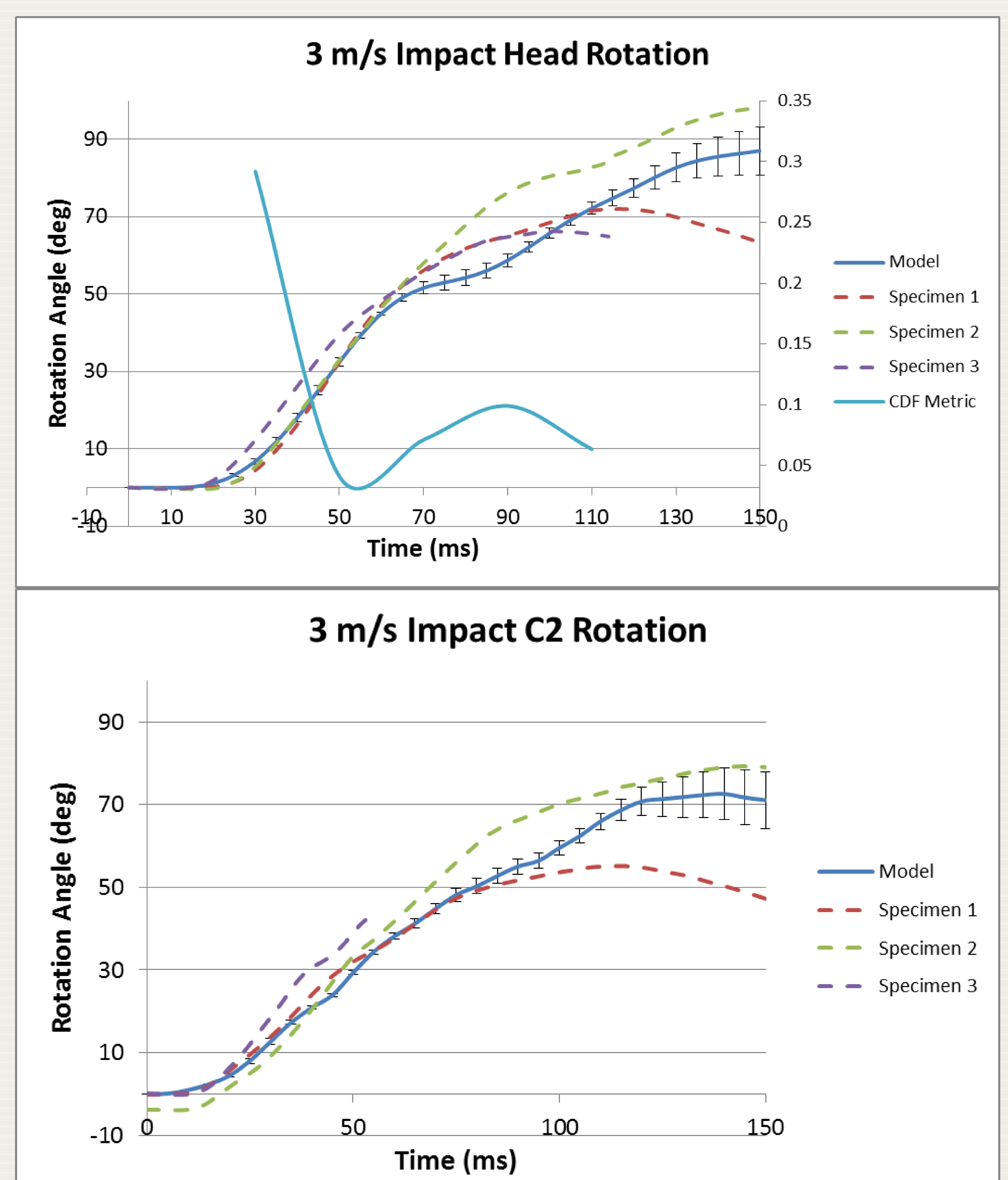

Figure 2: Average model head and C2 rotations with one standard deviation error bars for 3 m/s impact.

RESULTS (continued)

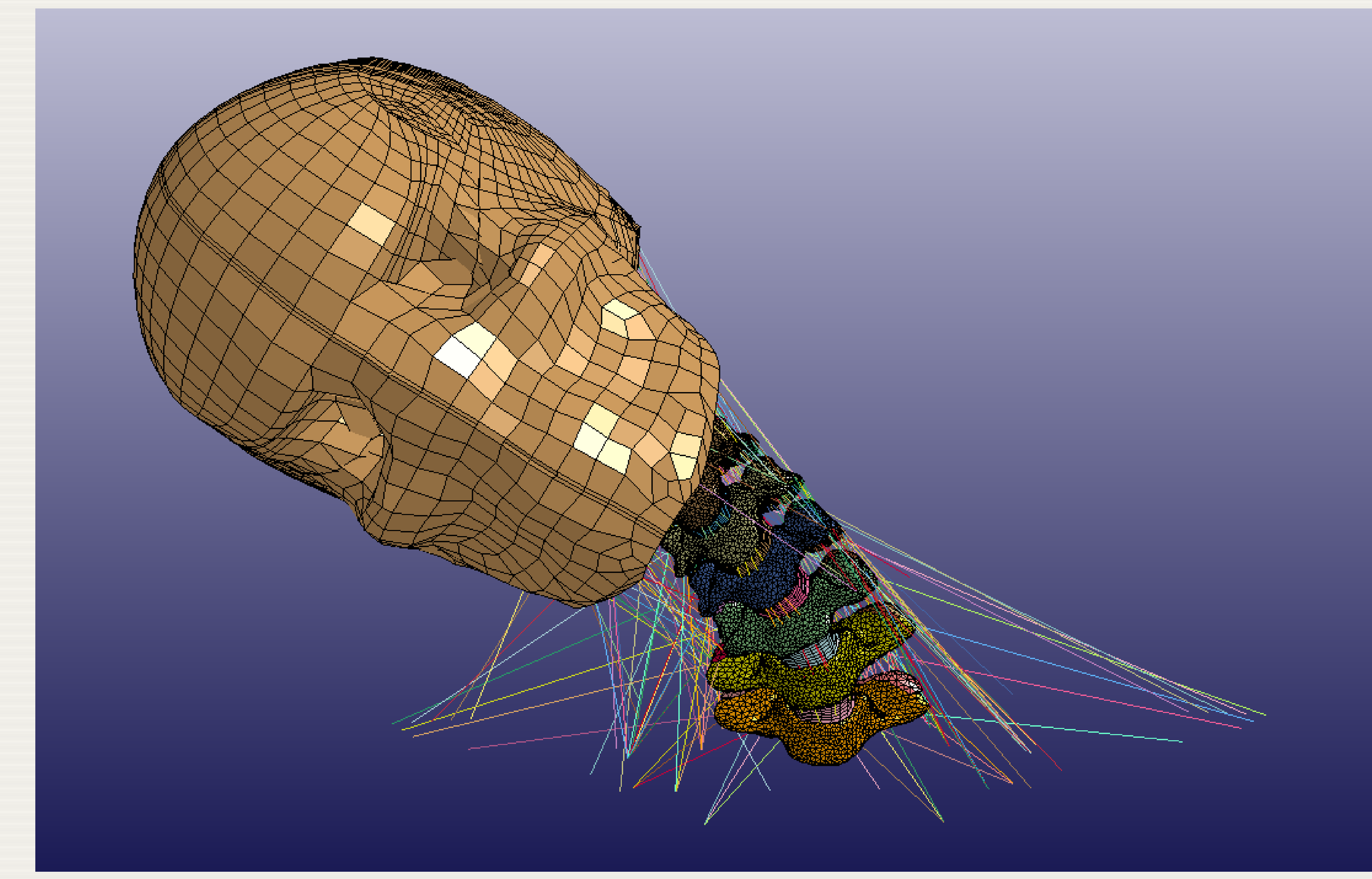

Figure 3: Facet contact limiting rotation at extreme end of loading.

DISCUSSION

- Model responses fit the experimental data very well for the initial rise of the kinematic curves. This is where previous V&V work has focused and these results confirm previous findings.
- A quantitative metric that compares the experimental and model CDFs also showed a good fit for our model. However, dropped markers limited the use of this metric.
- At the extreme end of the range the model fits the mean of the experimental results but does not fully capture the experimental variance.
- Limited number of experimental subjects limits full understanding of physiologic variance under these loading conditions.
- Possible explanation for lack of variance is due to the methodology utilized for modeling the facet joints.
- The gap between facet cartilage interfaces is arbitrarily set when the cartilage elements are generated and therefore held constant across all subjects.
- Future work will include this gap distance as a random variable in the probabilistic analysis to investigate its effect on the response.

Conclusion

- As a part of a rigorous hierarchical V&V methodology this study has shown that our SSM of the head and neck accurately represent the kinematic response to a lateral impact acceleration.
- This study has also highlighted areas for further investigation to enhance the models ability to model not only the mean response but the variance as well.

ACKNOWLEDGEMENTS

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