Development and Validation of a Surrogate Mechanical Neck Prototype for Use in Helmet Certification Applications

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Introduction

Research on diffuse brain injury suggests angular head motion is a principal contributor to tissue damage [1]. Currently, helmet certification methods consist of a guided linear drop of a magnesium headform, fixed to a rigid neck, onto an anvil [2]. This method does not allow for angular head-motion. This has sparked debate in standards organizations on improvement/change of helmet certification methods.

Objective

The objective of this study is to develop a prototype mechanical neck that is conceptually different than necks applied in automotive research. This study will compare kinematic and kinetic results of the prototype to previously published cadaveric data [3]–[5], and to low-speed impacts of the HybridIII dummy neck. Additionally, this study will compare vertebral motion in quasi-static bending to similar cadaveric tests [6], [7].

Methodology

The prototype neck has length matching the average male, with cervical vertebra constructed from aluminum, separated by 3D printed discs. Posterior elements are approximated in aluminum and achieve mechanical coupling between vertebral levels. Neck stability is offered by steel cables, one that transits the center of each disc and two which transit posterior elements. The neck assembly is encased in silicone.

The prototype is attached to a HybridIII headform, instrumented with built-in accelerometer array and six-axis upper neck load cell. Impact speeds in drop tests range from 1.5 m/s – 5.0 m/s, and impact locations include forehead, rear, and side.

Quasi-static testing uses a six degree of freedom robotic platform. One end of the neck is fixed, and the opposing end is fastened to a six-axis load cell on the platform. Flexion and extension bending loads of 1.5 Nm and 2.0 Nm are applied. Markers are adhered to metal rods threaded into the vertebral bodies for post-hoc motion tracking.

Results

Figure 1 compares the variability in center of gravity (COG) linear acceleration of the un-helmeted HybridIII headform when using the prototype neck in 1.5 m/s and 3.0 m/s forehead impacts. Over 75 prototype trials, the maximum inter-test difference in resultant linear head acceleration was 31.4%. Figure 2 illustrates exemplar upper neck load cell kinetics from a 3.0 m/s impact. Over 75 prototype trials, the maximum inter-test difference in resultant neck force and moment were 43.9% and 31.1%, respectively. Figure 3 shows exemplar data that contrasts head kinematics and neck kinetics between two impact scenarios: first when the prototype neck was fit to an un-helmeted HybridIII head and second when a HybridIII neck was fit to an un-helmeted HybridIII head. Predictably, head kinematics between the two cases were similar (25% difference based on peak magnitudes) while the relatively more compliant prototype neck had 86.6% lower forces and 72.8% lower moments. Our presentation will include an expanded data-set, comparison to available cadaveric data, and associated statistical analysis.

Discussion and Conclusions

This preliminary data suggests the prototype neck is repeatable and is a more mechanically compliant neck than the HybridIII. With continued development, the prototype could be a repeatable tool for use in headgear assessment that offers neck kinetics resembling those from appropriate cadaver data.

References

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[3] Advani et al, "Human Head Impact Response - Experimental Data and Analytical Simulations," West Virginia University, Morgantown, WV, 26506.

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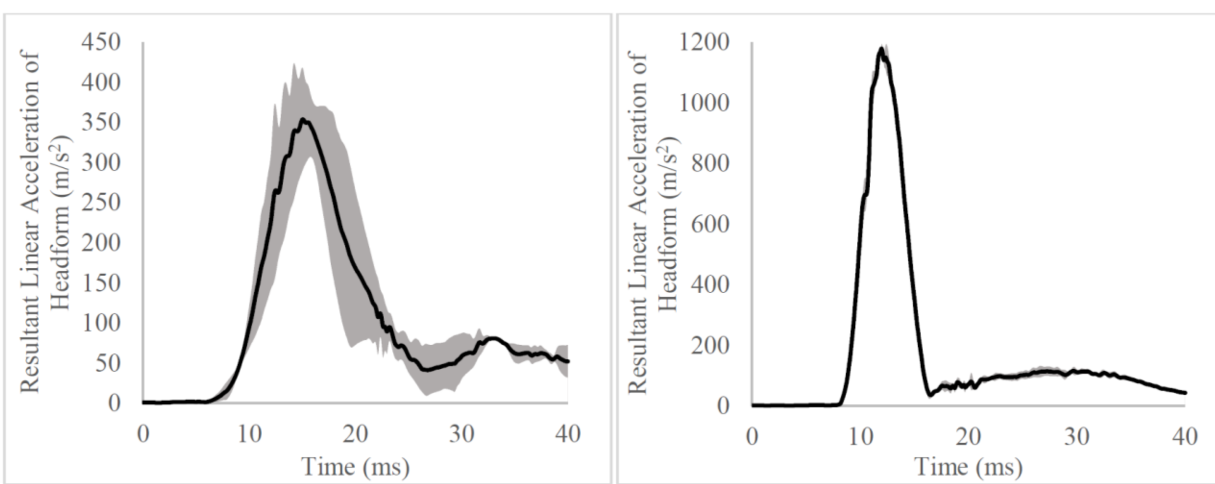
[5] Yoganandan et al, "Lateral Neck Injury Assessments in PMHS Tests," in Proc. AAAM Annual Conference, 2011, pp. 169-179.

[6] Camacho et al, "Experimental Flexibility Measurements for the Development of a Computational Head-Neck Model Validated for Near-Vertex Head Impact," Duke University, Durham, NC, 1997.

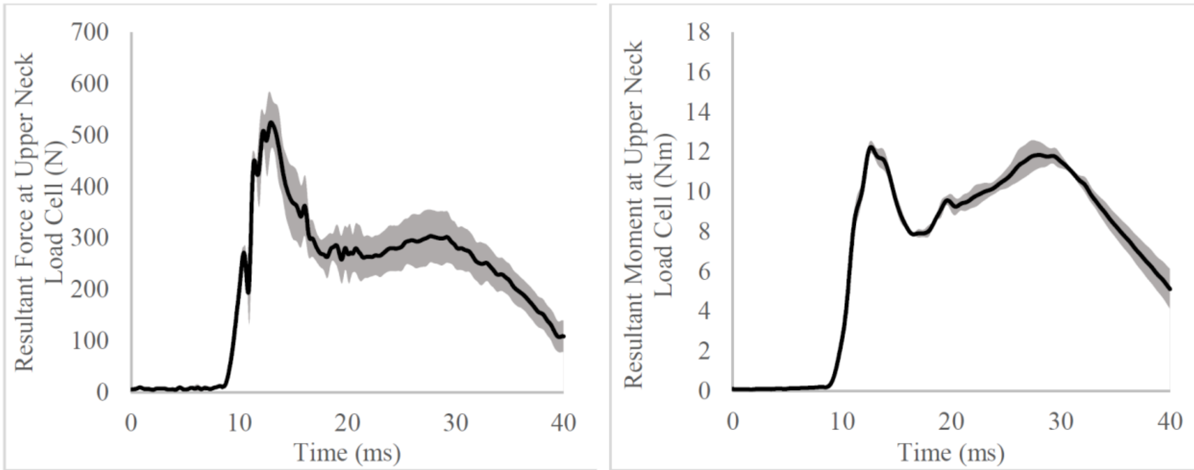
[7] Pintar et al. "Experimental flexion/extension data corridors for validation of finite element models of the young, normal cervical spine." Journal of Biomechanics, vol. 39, pp. 375-380, 2006.

Figures



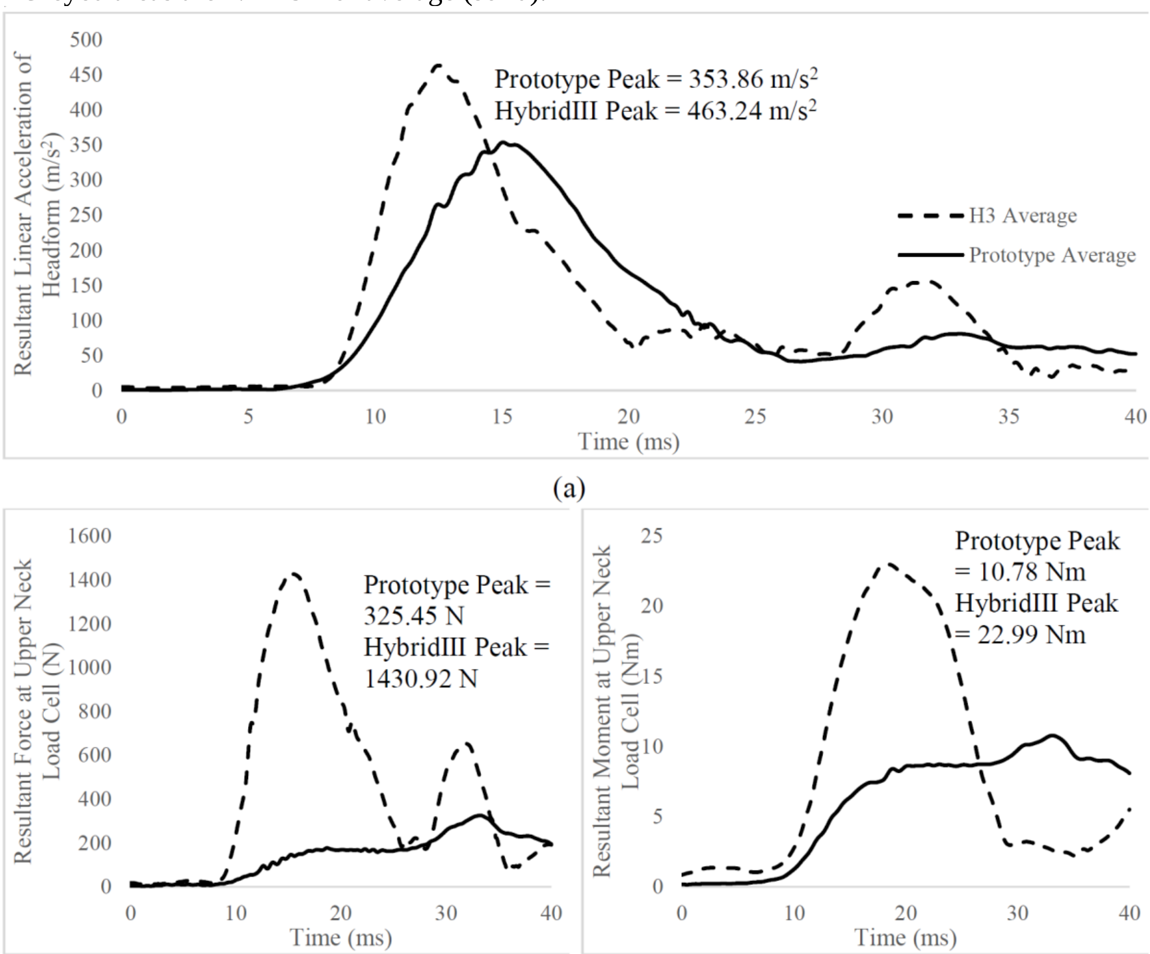
(a) (b)

Figure 1: Resultant COG linear acceleration (HybridIII head attached to prototype neck) (a) 1.5 m/s forehead impact, (b) 3.0 m/s forehead impact. Greyed areas are +/- 1 SD of average (solid).



(a) (b)

Figure 2: Exemplar kinetics: (a) resultant upper neck forces, (b) resultant upper neck moments. Greyed areas are +/- 1 SD of average (solid).



(b) (c)

Figure 3: Exemplar comparison of HybridIII neck model and prototype neck model in 1.5 m/s forehead

impact, (a) resultant COG linear acceleration of headform, (b) resultant upper neck forces, (c) resultant upper neck moments.