Repeatability of a Mechanical Surrogate Neck for Low Speed Impact Testing: A Preliminary Assessment

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I. INTRODUCTION

Over the last 30 years, helmets have become one of the leading technologies to protect humans from head and brain injury caused by impact [1]. In tandem with policy and regulation, helmets have been effective in reducing fatality due to head impact; however, milder brain injuries still persist. Because rotational kinematics are thought to be at least partially responsible for mild brain injuries, new helmet assessment methods focus on reducing abrupt head rotation, in addition to linear mechanics [2-3]. Ethical principles [4] would suggest that helmet testing on volunteers must be at a sub-injurious level therefore, helmet assessment relies upon accurate models of the human head and neck. Several head surrogates are accepted as accurate in their ability to characterise human mechanics during impact; however, available neck surrogates have been proposed to be too stiff, possibly leading to unrealistic head rotations [5]. The possible misrepresentation of rotational mechanics limits helmet testing and the ability to assess injurious head rotation. Thus, the objective of this work is to contribute a surrogate neck that can be tuned, with cable tensioning, to yield cases of repeatable mechanics during head impact. The work detailed in this abstract focuses on assessing the repeatability of the new model.

II. METHODS

The surrogate neck model was designed and manufactured to replicate the anatomical size of a 50th percentile male cervical neck. Laboratory pendulum impacts were conducted with a validated Hybrid III (Hy3) head model fixed to the surrogate neck. This work builds upon previous efforts where a prototype was developed and tested in quasi-static bending and low speed drop experiments against the Hy3 neck and cadaver literature data [6].

Mechanical Design

The internal mechanical structure, of the current prototype, was constructed using 6061-T6 aluminum and TangoBlack simulated rubber material (TangoBlack – FullCure®970, 3D Printers Canada, Vaughan, On) as vertebral bodies and intervertebral discs, respectively. Mechanical stability was achieved by three cables transited through the cervical levels. Cable tension was controlled by compression springs at the base of the cervical cables, which created a net compressive load across the column. The centre cable was adjusted to create 106 N of compression. The two lateral cables were adjusted to provide additional compression and create stability, allowing the neck to support a helmeted head. The mechanical structure was encased in silicone to approximate viscoelastic tissue surrounding the cervical column (Figure 1).

Experimental Testing

The base of the mechanical surrogate neck was fixed to a rigid support while a Hy3 headform, fit with a National Operating Committee on Standards for Athletic Equipment (NOCSAE) certified football helmet (Schutt F7, Size: Large), was fixed to the neck. Impacts were performed using an ISO headform (medium, mass = 2,511.7 g, CADEX Inc., St-Jean-sur-Richelieu, QC, Canada) that swung through an arc with 0.46 m change in height (3 m/s impact velocity), and around the ISO head was fit a NOCSAE certified helmet. Repeated impacts (n = 5) were conducted at three impact locations on the helmet (crown (CR), rear (RR), and facemask (FM)) and for two cable tension (CT) cases. Figure 2 presents images from a FM impact at six time stamps. The same pendulum impacts were performed with a Hy3 neck replacing the surrogate neck prototype.

Fig 1. Fully assembled surrogate neck.

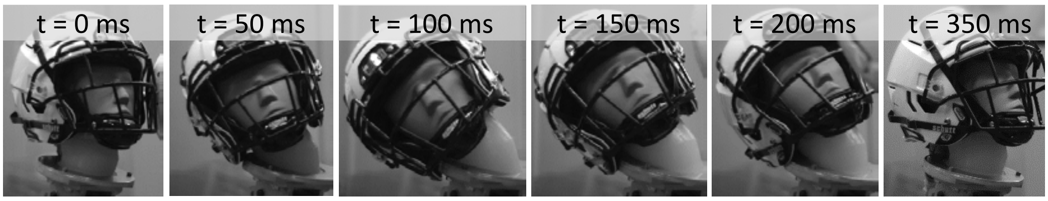

Fig 2. Still images from high speed video of a FM impact at six time stamps.

Two CT cases were created by adjusting the two lateral cable springs to create different compression loads over the neck, yielding a total compression force (from the three cable springs) of 224 N and 260 N for CT cases 1 and 2, respectively. The Hybrid III headform, with a nine uniaxial accelerometer array and a six axis upper neck load

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cell, was used to acquire head acceleration and neck force/moment data at a sampling frequency of 100 kHz and post processed with MATLAB R2017a (MathWorks ® Natick, MA) as per SAE J211 [7].

III. INITIAL FINDINGS

The analysis focused on the ensemble average of resultant data, for five repeats, of head linear acceleration (accel), angular velocity (vel), neck force, and neck moment at three impact locations (IL) and two CT cases. Table 1 presents the mean (μ) with corresponding standard deviation (σ) and percent coefficient of variation (CV) of peak resultant mechanics, where 1 g = 9.81 m/s^2. Figures 3 and 4 present the time series ensemble average resultant mechanics from a CR impact, a 100 ms time range (impact at 0 ms) was chosen for data presentation. Hy3 data was also shown in Figures 3 and 4 as a reference for visual comparison.

TABLE I

MEAN ± STANDARD DEVIATION AND PERCENT COEFFICIENT OF VARIATION FOR ENSEMBLE AVERAGE OF PEAK RESULTANT MECHANICS

	Linear Accel (g)		Angular Vel (rad/s)		Neck Force (N)		Neck Moment (Nm)	
IL-CT	*μ ± σ*	*CV*	*μ ± σ*	*CV*	*μ ± σ*	*CV*	*μ ± σ*	*CV*
CR-1	15.6 ± 0.9	5.8	9.7 ± 0.3	2.9	575.5 ± 20.2	3.5	9.2 ± 0.5	5.6
CR-2	15.7 ± 0.8	5.1	10.1 ± 0.3	2.8	604.1 ± 27.1	4.5	8.0 ± 0.4	4.7
RR-1	10.4 ± 0.8	7.9	12.9 ± 1.1	8.7	291.3 ± 20.2	6.9	2.0 ± 0.4	18.3
RR-2	10.5 ± 0.4	3.5	13.2 ± 0.5	3.7	219.6 ± 25.1	11.4	4.4 ± 0.5	11.1
FM-1	15.3 ± 0.9	5.9	10.8 ± 0.6	5.2	476.6 ± 170.9	35.9	8.3 ± 2.3	27.9
FM-2	15.3 ± 0.6	4.0	12.9 ± 0.4	3.2	324.2 ± 28.9	8.9	6.0 ± 0.9	14.9

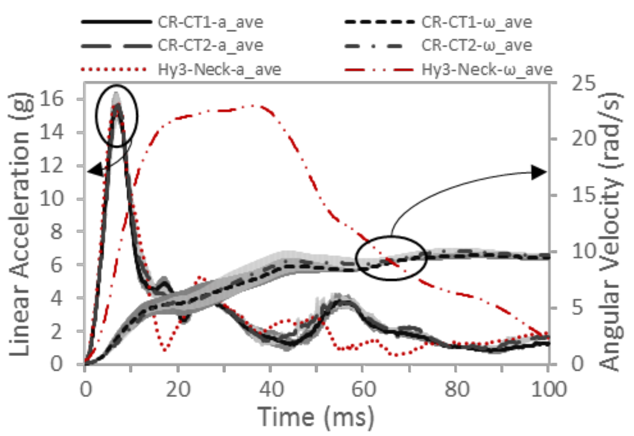

Fig. 3. Ensemble average of resultant linear accel and angular vel (CR impact, two CT cases). Greyed areas are ±1σ of the five repeats. Red curves are Hy3 data.

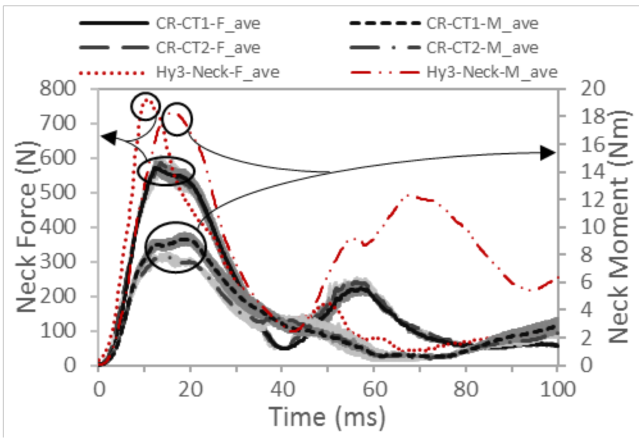

Fig. 4. Ensemble average of resultant neck force and neck moment (CR impact, two CT cases). Greyed areas are ±1σ of the five repeats. Red curves are Hy3 data.

IV. DISCUSSION

Repeatability was assessed using percent CV, defined by the ratio of standard deviation to the mean and categorised as acceptable, if CV ≤ 10%, and unacceptable, if CV > 10% [8]. For kinematics, all computed CV values were acceptable. However, for neck kinetics there were some CV values that exceeded the acceptable range. The unacceptable CV cases represent impact tests that were conducted last in our sequence of tests and the relatively large CV are believed to be due to failure of the most superior rubber disc. Future prototypes will be re-designed to prevent the noted mechanical failure mode. The differences in mechanics between the two CT cases were small, but in future work we plan to parameterise neck compression to further investigate whether kinematics/kinetics can be predictably altered by adjusting the net compression across the column. In Figures 3 and 4, mechanics measured in impact tests using the Hy3 neck were provided to allow the reader to compare these data to data measured using the new surrogate. Preliminary findings show repeatability of head kinematics and kinetics using the surrogate neck prototype.

V. REFERENCES

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