Segmental Motion Response Corridors of Female Cervical Spines from G_x accelerative loading

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I. INTRODUCTION

Computational models are used to determine the human body response and to predict injury in crash environments [1]. Similar to crash test dummies, human body models (HBMs), while developed for a specific loading condition/scenario, are often used to investigate responses for boundary conditions in other applications. Critical to model development is validation, and a typical source is human cadaver experiments under various impact loading modes [2-4]. Corridors expressed as the mean ± one standard deviation are used as validation targets to evaluate the accuracy of predicted responses from computational models. [5]. From an inertial loading perspective (e.g., rear impact in the automotive field, often termed G_{+x} accelerative loading in the military), corridors of segmental motions have been reported. One study grouped both male and female spines and normalized the output based on mid-size male anthropometry to calculate a response corridor [3]. It is known that women are more susceptible to injury and the segmental ranges of motions of the cervical spine are significantly different between males and females in rear impacts [6]. Therefore, a sex-specific response is necessary to obtain fundamental data that can be used for model validations. The objective of the present study is to develop segmental motion corridors from female spines subjected to rear impact loading using Post-Mortem Human Subject (PMHS) experiments that may serve as a female-focused model dataset.

II. METHODS

Previously conducted PMHS experiments were reanalyzed in this study [3]. Head-neck complexes with intact skin and musculature were isolated and fixed in polymethylmethacrylate at the proximal end. The anterior angulation of T1 was set at 25 degrees to simulate the normal driver posture and confirmed using lateral x-rays. A small incision was made on the right side of the specimen, and retroreflective targets were inserted into the lateral masses and vertebral bodies of the C2-C7 vertebrae. The specimens were attached to the base of a mini-sled, and a pendulum applied a 2.6 m/s rear impact pulse at the proximal end. A schematic of the test setup is shown in Fig. 1. Kinematics were measured using a high-speed video at 1,000 frames/sec. At each level, the orientation of the vertebrae was determined by calculating the vector between the posterior (lateral mass) and the anterior (vertebral body) markers. Sagittal plane (flexion/extension) inter-segmental angles were obtained by calculating the angle between the vectors at the C2-C3 to C6-C7 levels. The resulting segmental angles for each specimen were then aligned at time-zero (pendulum impact to the base of the mini-sled). The mean and standard deviations were calculated on a point-by-point basis at each time step. The boundaries of the corridor were defined by the mean +/- one standard deviation. Angles are reported using the SAE sign convention where extension is a positive angle, and negative is a flexion angle.

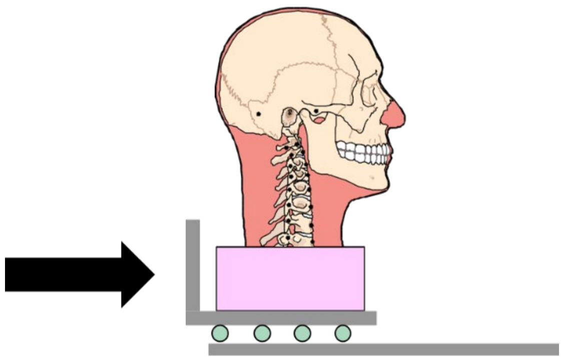

Figure 1: Schematic of the test setup [3]

III. INITIAL FINDINGS

Five specimens from the previous study were analyzed. The mean age, stature, and total body mass were 55±17 years, 167±5 cm, and 51±17 kg. The magnitude and morphology of the segmental ranges of motions were level-

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specific and mode-specific, i.e., upper levels were in the flexion phase while the lower segments were in the extension phase. The applied g-time pulse and temporal responses for the C2-C3, C3-C4, C4-C5, C5-C6, and C6-C7 spinal segments in the sagittal plane are shown in Fig. 2 and Fig. 3.

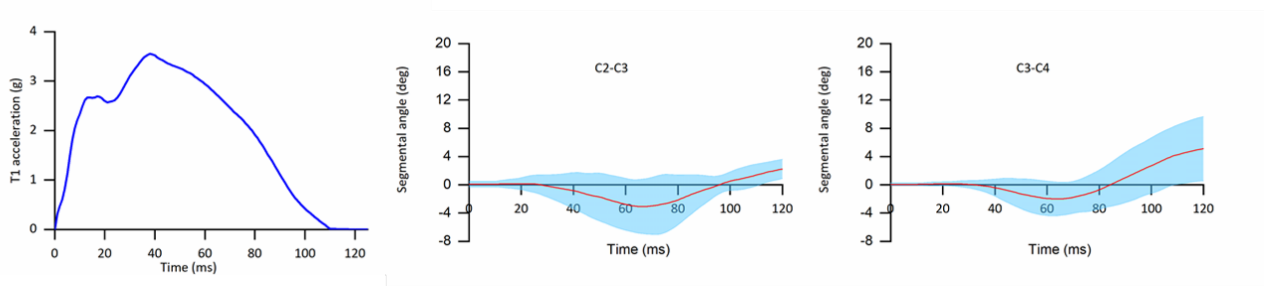

Figure 2: Left: acceleration pulse. Middle: Segmental motion at C2-C3. Right: Segmental motion at C3-C4 level

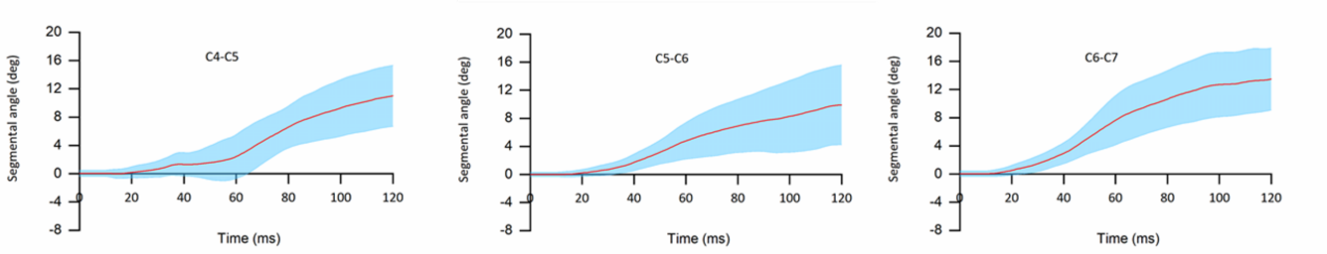

Figure 3: Left: Segmental motion at C4-C5. Middle: Segmental motion at C5-C6. Right: C6-C7 segmental motion

IV. DISCUSSION

While the methodology and development of corridors have been used before, the temporal corridors derived in the present study are a valuable dataset for the female cervical spine in rear impacts. Although the fundamental constituents are the same between male and female necks, their structural anatomy and head mass are different, and other studies have shown the responses under this loading mode are also significantly ($p<0.05$) different at the segmental level [7]. Female-specific corridors are therefore needed and developed in this study to validate female-specific computational models. It should be noted that the female-specific models continue to evolve. For example, the Virtual Vehicle-safety Assessment (ViVA) open-source HBM aims to address gender diversity and develop an anatomically detailed cervical spine model to generate biofidelic responses in rear impact. This and other female-specific models of the cervical spine may use the present corridors for validation. It is also possible for existing models to use the current female-specific corridors to reevaluate their biofidelity [1]. The small sample size may be a limitation, and from this perspective, it would be necessary to conduct additional head-neck complex experiments that may change the corridors. These studies are under consideration.

V. ACKNOWLEDGMENTS

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VI. REFERENCES

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