Neck Response of Young and Aged Small Stature Female Human Body Models in Rear Impact

M. A. Corrales, D. S. Cronin

I. INTRODUCTION

Elderly persons have been identified as a population with a higher incidence of injury than their younger counterparts [1]. In addition, females are reported to be at higher risk of sustaining higher severity injuries compared to males in similar crash conditions [2] and the risk of sustaining whiplash-associated disorders (WADs), associated with soft tissue injuries in the cervical spine (CS), is significantly higher than that of males [3]. According to vehicle crash statistics, soft tissue injury occurs most frequently in rear impacts [4]. In anthropometric test devices (ATDs), used to test safety systems, gross kinematics, e.g., head kinematics, are assessed to comply with safety standards; however, soft tissue response cannot be monitored. In this study, a modern human body model (HBM) was used to assess the effect of the postural changes occurring with age on head kinematics and soft tissue metrics in a rear impact scenario.

II. METHODS

The head and neck complex was extracted (Figure 1a) from the 24-year-old (YO) subject-specific Global Human Body Model Consortium (GHBMC) small stature female model (F05 v5.0). The cervical spine curvature and size of the young F05 model ($F05_{24YO}$) agreed with the average posture predicted by the Cervical Spine posture Predictor (CSP) [5] and a full-body posture predictor [6] for the same age, weight, and stature range. The CSP was then used to define the aged posture of the aged F05 model ($F05_{75YO}$) [5]. A morphing software [7] was used to re-posture and morph the $F05_{24YO}$ to account for the increase in lordosis (superior Bezier angle from 9.1° to 14.8° and inferior Bezier angle from 4.3° to 11.8°) [5] and capsular facet angle (form 119.3° to 132.3° on average) [8] associated with age, resulting in the $F05_{75YO}$ model (Figure 1b). The mesh quality of the $F05_{75YO}$ model was within the GHBMC mesh quality standards. Both the $F05_{24YO}$ and $F05_{75YO}$ models were evaluated in a 7 g rear impact [9] by applying translational and rotational displacement pulses to the first thoracic vertebra (Figure 1c). The head kinematics and the capsular ligament (CL) elongation were monitored (Figure 1d). The cross-correlation method (CORA, pdb, Germany) was used to compare the head kinematics (linear and rotational acceleration and displacement in the X and Z directions) of the models where a rating of 1 means strong similarity and 0 means no similarity.

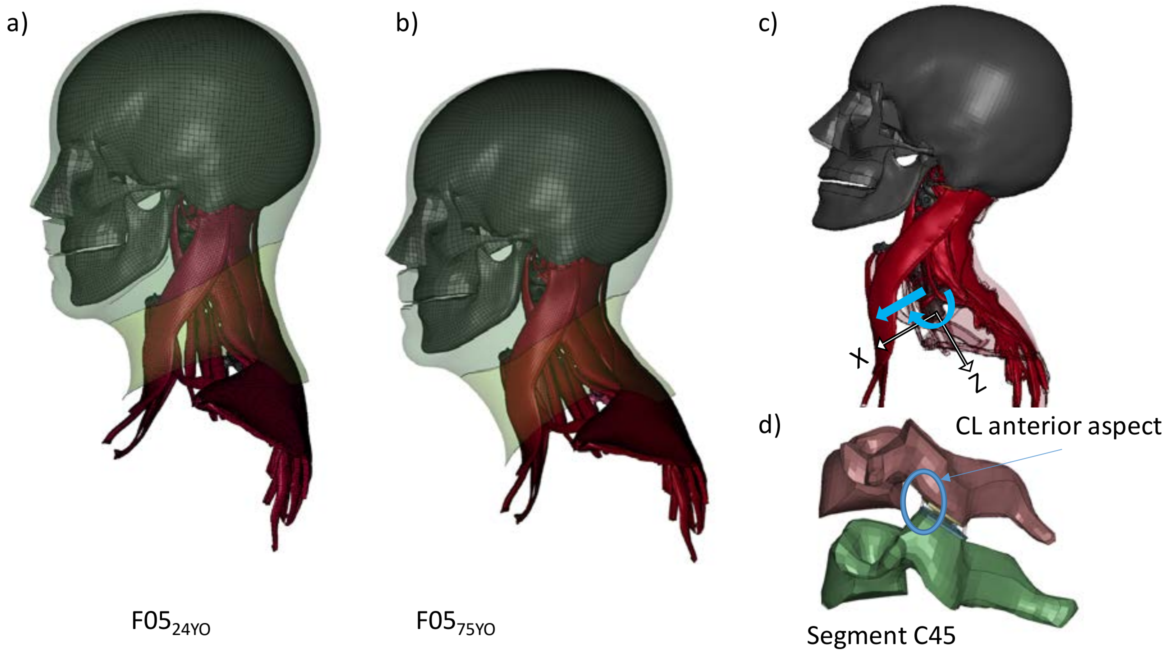

Fig. 1. a) Young posture $F05_{24YO}$ female model, b) repostured model to an aged $F05_{75YO}$ posture, c) $F05_{75YO}$ model in a 7g rear impact at 135 ms and d) C45 motion segment and the location of the CL distraction measurement.

M. A. Corrales is a MASc student, and D. S. Cronin (e-mail: duane.cronin@uwaterloo.ca; tel: +1-519-888-4567 x.32682) is a Professor, both in the Department of Mechanical and Mechatronics Engineering, University of Waterloo, Canada.

III. INITIAL FINDINGS

The CORA ratings demonstrated a strong similarity between the $F05_{24YO}$ and $F05_{75YO}$ head kinematics with an average rating of 0.96. The lowest rating was obtained in the linear acceleration along the Z-axis with a rating of 0.86 and the highest was the linear acceleration along the X-axis with a rating of 0.99. The CL distraction predicted by the $F05_{75YO}$ model was higher at 4 of 5 motion segment levels (1.75 more CL distraction on average) compared to the $F05_{24YO}$ model. In the C23 segment, the $F05_{24YO}$ model predicted 0.84 more CL distraction than that of the $F05_{75YO}$. The segment with the highest difference of CL distraction between models was the C34 segment, where the $F05_{75YO}$ model predicted double (1.96 times) the CL distraction than that of the $F05_{24YO}$ model.

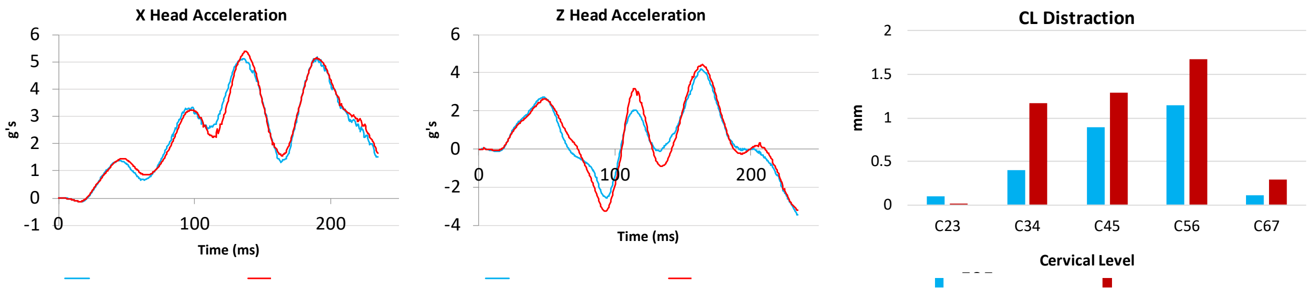

Fig. 2. Head kinematics of the $F05_{75YO}$ (red) and $F05_{24YO}$ (blue) and the CL distraction for each segment level.

IV. DISCUSSION

With respect to the $F05_{24YO}$ model, the increased CL distraction observed in the $F05_{75YO}$ was primarily attributed to the change in the facet angle. The facet angle increases with age in a way that the facets become more parallel to the transverse plane, this leads to a normal orientation with respect to the facet surface of the elements representing the CL in the model. A normal to the capsular facet orientation of the CL elements allows to capture distraction in shear and tension loadings as soon as the load is applied. Secondly, the increased CL distraction was attributed to the shorter ligaments in the aged model (-23% on average), which was a consequence of the increased lordosis associated with the ageing process. The similarity in head kinematics agreed with previous studies showing that the head kinematics were somewhat insensitive to local geometrical changes in the neck. Therefore, global metrics, e.g., head kinematics, could be insufficient in order to quantify the effects of the ageing process in modern HBMs. The response of the uniaxial elements representing the CL in the model was found to be sensitive to the facet joint angle. The effect of the ageing process could be further amplified if changes in material properties associated with age are considered in the model. In this study, the curvature of an average 75 YO small stature female was analyzed; however, the variability of spinal curvature also increases substantially with age. Studying postures close to the bounds of the subject distributions could have an effect on head kinematics and the soft tissue response. Future studies will consider age-related changes in material properties and a comparison of the effects of ageing between a male model and a female model.

V. ACKNOWLEDGMENTS

The authors would like to acknowledge the Global Human Body Models Consortium for the use of the HBM and financial support, Compute Canada for computational resources, the Natural Sciences and Engineering Research Council, Canada, the Consejo Nacional de Ciencia y Tecnología, Mexico, and the Fundación Mexicana para la Educación, la Tecnología y la Ciencia, Mexico for the financial support.

VI. REFERENCES

[1] Kahane J, NHTSA, 2013 [April 2020].
[2] Bose, D., et al., Am J public Health, 2011.
[3] Jakobsson, L., et al., Traffic Inj Prev, 2004.
[4] Stigson, H., et al., Traffic Inj Prev, 2015.
[5] Reed, M. P., et al., UMTRI, 2017 [April 2020].
[6] Park, J., et al., Ergonomics, 2016.
[7] Beillas, P., et al., IRCOBI, 2015.
[8] Parenteau, C. S., et al., Traffic Inj Prev, 2014.
[9] Deng, B., et al., Stapp Car Crash, 2000.