Verification of Rib Fracture Prediction in Frontal Collision with Human Body Models Representing Specific Ages

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I. INTRODUCTION

It is reported that drivers at the age of 65 or older involved in fatal crashes increased by 8% from 2006 to 2015, while total number decreased by 16% [1]. It is estimated that drivers in the same age range will increase up to 50 million by 2020 in the United States [2]. Frontal collision occupies much of collision direction distribution and occupants may experience thoracic injuries associated with rib fractures, which are generally related to severe injury, especially for the elderly [3]. In order to improve restraint systems to reduce thoracic injury to the elderly, prediction of rib fractures using whole-body simulations is an effective measure. The goal of this study was to verify rib fracture prediction in frontal collisions using modified versions of the Global Human Body Models Consortium (GHBMC) human body model representing specific ages.

II. METHODS

Rib fracture predictions were performed with modified versions of the GHBMC 50th percentile male model. Based on a previous study, the representative age for the adult and the elderly model was set at 35 and 75 years old, respectively [4]. The Young's modulus of the rib cortical bone was set based on the literature [5]. The ultimate effective plastic strain of the rib cortical bone and the effective plastic strain of the rib trabecular bone were respectively set at 2.4% and 13% for the adult and 0.9% and 7.8% for the elderly [6-7]. The Young's modulus of the costal cartilage was set at 24.8 MPa and 19.7 MPa for the adult and elderly models, respectively [8]. The cortical bone thickness was determined by the aging function from a previous study [4]. Since a previous study showed that the effect of the geometrical change of the rib cage with aging is small [9], the rib cage geometry was not modified. Those modifications to the material property were validated against published frontal pendulum impact tests [10] and frontal sled tests [11]. In the pendulum tests, a pendulum with the diameter of 152 mm and the mass of 22 kg hit the centre of the thorax at the height of the 4th rib at 7.2 m/s. The frontal sled test model is depicted in Fig. 1. The delta-V was set at 40 km/h. A seatbelt without load limiter and a rigid knee bolster were installed. The kinematics at the Head, T1, T8, L2 and the Pelvis were evaluated by the procedure proposed by [12]. The fracture locations for each of the adult and the elderly models were compared against a specific test with the subject closest to the age represented by the models.

In order to further verify the simulation models against real accidents, the number of rib fractures for the elderly and adult with respect to delta-V was compared. The Crash Injury Research and Engineering Network (CIREN) database was filtered by choosing the cases that closely match the frontal sled test configurations and 50th percentile male anthropometry represented by the models. Data were restricted to the principle direction of force (PDOF) between 11 and 1 o'clock, mid-size sedan, front seat occupants with a shoulder and lap seatbelt and occupant height and weight between 170 and 180 cm and 73 and 84 kg, respectively. Delta-V was divided into 15-24, 25-34, 35-44 and 45-54 km/h group and defined as 20, 30, 40 and 50 km/h group, respectively. Representative CIREN data for the number of fractured ribs were extracted per each delta-V group and compared with the simulation results.

III. INITIAL FINDINGS

Fig. 2 compares the number of fractured ribs between the PMHS tests pendulum tests and the simulation with respect to age, indicating that the increasing trend is well represented by the model. The results of the evaluation of the kinematics showed that all the results fell within Good rating, except for T1 X-direction which rating was moderate. The comparison of the rib fracture locations shown in Fig. 3 revealed that the predicted rib fractures captured a generic increasing trend of number of fractured ribs. Fig. 4 shows the comparison of the

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number of fractured ribs with respect to delta-V between the CIREN data and the simulation for the adult and elderly, respectively. The CIREN data shows that the number of fractured ribs was represented by the model with a similar increasing trend as the age or delta-V increases.

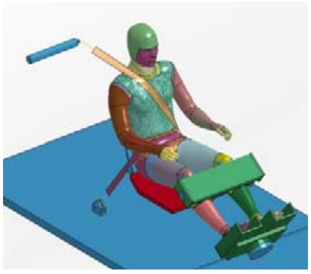

Fig. 1. Sled test configuration.

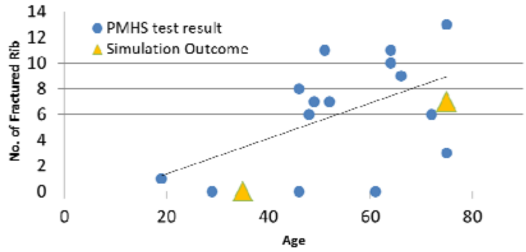

Fig. 2. Number of fractured rib on chest pendulum test.

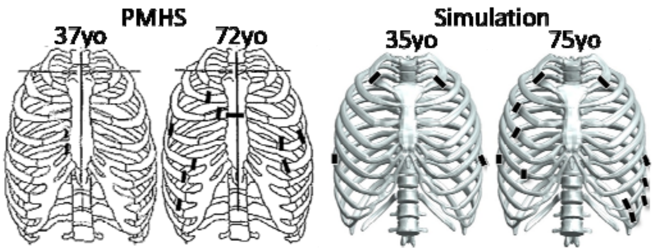

Fig. 3. Rib fracture location of PMHS test (Left) and Simulation (Right) for the adult and elderly.

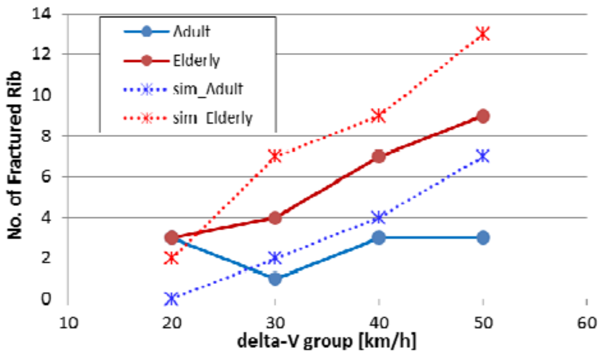

Fig. 4. Comparison of the number of fractured ribs between CIREN data and the simulation.

IV. DISCUSSION

The results of this study indicate that the frontal impact simulation using modified GHBMC models can be used to estimate the number of fractured ribs in real accident cases. One of the reasons why predicted number of fractured ribs overestimated the CIREN data may be differences in seat-belt and crash type. The frontal impact simulation incorporated a seat-belt without a load limiter, while vehicles in the CIREN data were fitted with a seat-belt with a load limiter. A seat-belt without a load limiter increases load on the thorax and number of fractured ribs. Although the simulation in this study simulates full frontal rigid barrier crashes, the CIREN data includes other frontal crash type such as centre pole crash, which acceleration is lower than full frontal crashes. This results in increased severity in the simulations relative to the CIREN data. As only one case for each of the delta-V was identified that meets the selection criteria used in this study, a more complete comparison needs to be done with an increased number of cases from in-depth accident data.

V. REFERENCES

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