Improving the Prediction Accuracy of Head Rotation Behaviour in THUMS and Investigation of Influence on Brain Injury Risk in Frontal Collision

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I. INTRODUCTION

In recent years, the evaluation of not only skull fractures and severe brain injuries but also mild brain injuries such as concussions in frontal collisions has gained attention. Although this type of injury is unlikely to result in fatal harm, it has the potential to cause long-term aftereffects and is thus associated with significant societal impact. For the evaluation of brain injury, indicators such as Diffuse Axonal Multi-Axis General Evaluation (DAMAGE) and brain strain have been proposed [1], and utilising the Human Body Model (HBM), which represents the human body's anatomical structure, is effective. It is known that brain injury is significantly influenced by the angular acceleration of the head, therefore the prediction accuracy of head rotational motion in HBMs is important. In this study, the head and neck model of the Total Human Body Model for Safety (THUMS) Version 7 was modified, and its prediction accuracy for head rotational motion was validated against human head motion in sled tests. Furthermore, the influence of the model modifications on brain injury indicators in a frontal collision was investigated.

II. METHODS

In a first step, the modelling of the atlantooccipital joint, which affects the forward bending behaviour of the head, was improved. As shown in Fig. 1, the joint capsule of the atlantooccipital joint, which was omitted in THUMS v7, was added, and the gap between the occipital bone and the C1 vertebra was reduced. Additionally, the thickness of the joint capsule for the entire spine was changed from 1 mm to 2 mm, based on [2]. Next, to verify the prediction accuracy of the modified model, a simulation of the volunteer sled experiments [3] was conducted, as shown in Fig. 2. A forced acceleration was applied to pull the area below the T1 vertebra of THUMS backward, and the resulting head centre of gravity acceleration, rotation angle and DAMAGE were compared with the test results. Next, a sled simulation of a 50 km/h frontal collision, as shown in Fig. 3, was conducted using a small prototype SUV sled model. The interior parts were assumed to be deformable, while the windshield and floor panel were assumed to be rigid. The seat-belt retractor model simulated the functions of a pretensioner and a load limiter. The deployment of the driver airbag (DAB) and knee airbag (KAB) was also simulated. Using both the original THUMS Version 7 and the improved model, the acceleration of the head's centre of gravity, DAMAGE, and the brain injury risk calculated from the 95th percentile of the maximum principal strain (MPS) in the white and gray matter of the brain were compared.

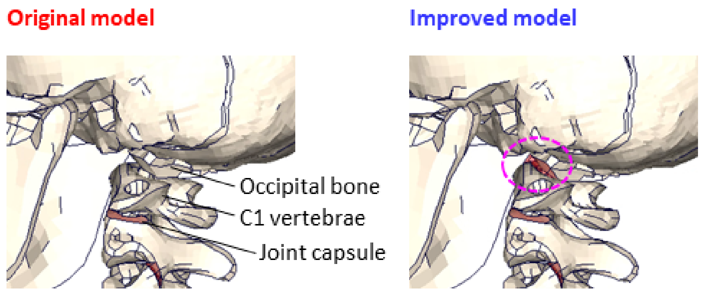

Fig. 1. Atlantooccipital joint model

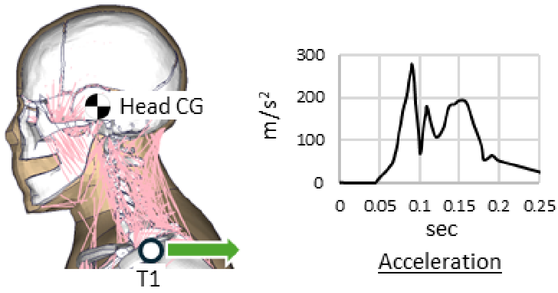

Fig. 2. Head forward bending simulation model

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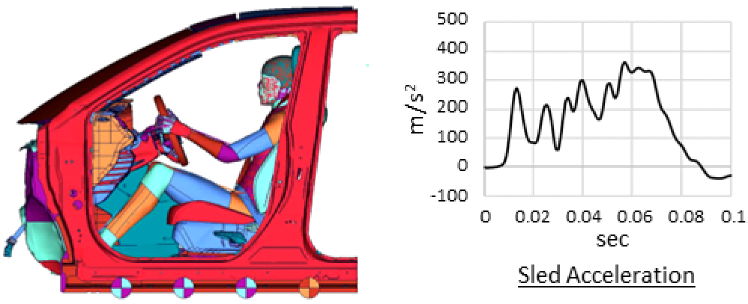

Fig. 3. Vehicle frontal collision sled simulation model

III. INITIAL FINDINGS

In the head forward bending simulation, the torso is pulled backward, then the neck is flexed until the chin contacts the chest. As shown in Fig. 4, the rise timing of the head acceleration in the improved model was earlier than in the original model and is closer to the test results. Additionally, the level of the first peak decreased and was within the corridor of the test results. Furthermore, the peak of the head rotation angle was also closer to the test results, and DAMAGE was within the corridor of the test results. In the vehicle frontal collision sled simulation, the angular acceleration in the forward bending direction increases at the timing of contact between the head and the DAB. As shown in Fig. 5, the angular acceleration of the improved model decreased compared to the original model, and DAMAGE was reduced by 13%. Furthermore, the brain injury risk calculated from brain strain (MPS95) decreased by 28%, from 0.39 to 0.28, for AIS2+ and by 42%, from 0.08 to 0.05, for AIS4+.

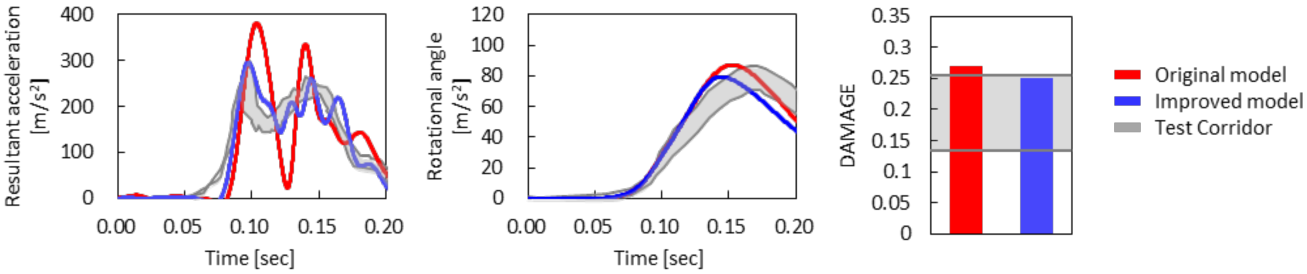

Fig. 4. Time history of head acceleration and rotation angle, and DAMAGE in head forward bending simulation

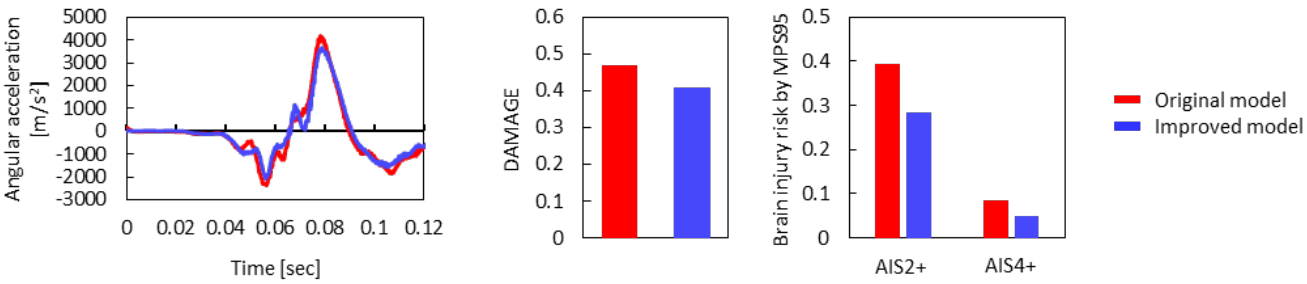

Fig. 5. Frontal bending angular acceleration, DAMAGE and brain injury risk in vehicle frontal collision sled simulation

IV. DISCUSSION

It was observed that the THUMS head kinematics response of acceleration and rotational angle in the frontal sled condition improved and became closer to the corridor derived from human subjects when a joint capsule was added to the atlantooccipital joint. Additionally, the DAMAGE and brain strain in a frontal collision were lower than those in the original model. These brain injury indicators are highly sensitive to the angular acceleration of the head, highlighting the importance of accurately modelling of the connection between the head and the cervical spine. This study indicated the necessity of verifying the head rotation behaviour of HBMs in future brain injury evaluations through virtual testing.

V. REFERENCES

[1] ISO/TC22/SC36, 2021 [2] Little J.S. et al., NIH 2005 [3] Ewing C.L. et al., SAE 1968, 1973