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Head injury of CHARM-70 FE model and a comparative study with Hybrid III

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Abstract:

***Background*:** The risk of head injury is very high in car collision, while the elderly account for the highest proportion of people with brain injury. The traumatic injury mechanism and injury model of human head in cadaver experiment has been more exhaustive, but the establishment and validation on human FE model with high biological fidelity is not effective enough, which makes it limited to study head injury using human FE model.

Objective: To better understand the injury mechanism of frontal head in the CHARM-70 and compared with Hybrid III.

***Method and Material*:** The structure composition, head injury and dynamic mechanical responses of CHARM-70 FE model in frontal impact are studied and compared with Hybrid III dummy head collision experiment.

***Results* and *Conclusions*:** The results shows that impact speed have great effect on Hybrid III dummy injury. CHARM-70 head FE model gains depressed injury of external skull plate, coup and contrecoup lesions of brain, has good biological fidelity for well simulation of injury mechanism in collision process, and get higher dynamic mechanical response compared to Hybrid III head FE model as well.

Keywords: CHARM-70, Hybrid Ⅲ, Injury mechanism, Biological fidelity

1 Introduction

In the worldwide, traumatic brain is the main cause of death and disability in people, which costs more than 8 billion dollars annual. While in the U.S, there are more than two million traumatic brain injury patients each year, of which the main pathogenic factors are falls, motor vehicle accidents and athletic sports [1]. Traumatic brain injury will be the third leading cause of death and disability by 2020 according to the WTO [2]. Skull and brain injuries constitute for head injury characterized by fracture of skull, contusion and laceration of brain, coup and contrecoup lesions of brain, epidural hematoma, cerebral concussion and diffuse axonal injury in traffic accidents.

In view of the importance of head injury research, many researchers have been devoted to related research. A rigid impact bar with diameter of 20mm and length of 230mm was used by Allosp [3] to impact on the heads of Hybrid III dummy and corpses for simulating the effect of steering wheel edge on head in frontal-impact vehicle collision, which concluded that the average stiffness of the forehead, zygomatic bone and maxilla was 1000 N/m, 150 N/m, 120 N/m, respectively. Loyd et al. [4] studied the head impact response of adult cadaver and Hybrid III dummy, which showed that the acceleration and HIC values increases with age. More detailed studies focused on head internal injuries were studied for better understand the mechanism of head traumatic injury. Two groups of cadaver head collision experiments were performed by Nahum et al. [5], which showed that the intracranial pressure was linearly related to the acceleration at the center of gravity (CG) of the head. Hardy et al. [6] studied the brain motion in head impact experiment with low degree of injury, which found that the displacement of brain and skull were similar in low-speed impact. Besides, the kinematics of DAI (diffuse axonal injury) in the subhuman primate was determined by Thibault [7] by utilizing animal studies, physical model experiments, and analytical model simulation.

Nowadays, traumatic injury mechanism and injury forms of human head in cadaver experiment have been more exhaustive, but the establishment and validation on human FE model with high biological fidelity is not effective enough, which makes it limited to study head injury using human FE model. Meanwhile, elderly people aged 75 and older are the most likely to be treated in hospital because of traumatic brain injury [8].In view of these, the structure composition, head injury and dynamic mechanical responses of CHARM-70 FE model in frontal impact are studied and compared with Hybrid III.

2 Method and Material

To study the injury mechanism of the elderly in vehicle collision, a 50th percent elderly female FE model named CHARM-70 was established and verified by Wayne State University (WSU) in cooperation with the TOYOTA Security Research Center (CSRC). The detailed anatomical structure of CHARM-70 head FE model is shown in Fig. 1. Compared with CHARM-70, the structure of Hybrid III head model is rougher, and has no detailed anatomical structure of human brain tissue.

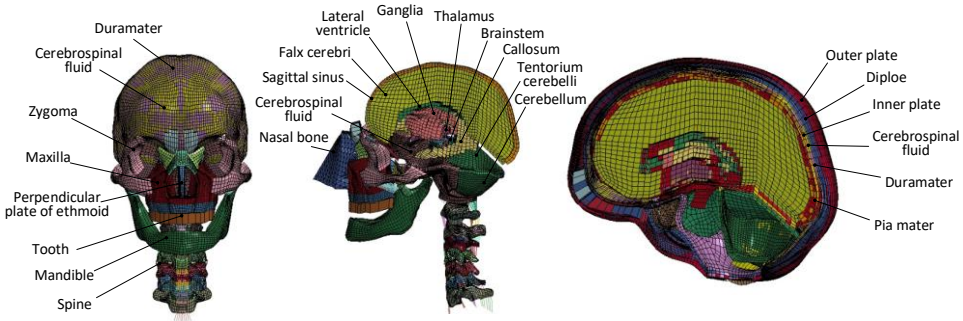

Fig. 1 Anatomical structure of CHARM-70 head model

2.1 Simulation experiment of CHARM-70 head model

For the sake of simulating the injury to occupant by the edge of steering wheel in collision process, refer to cadaver frontal impact test from Allsop [3], rigid cylindrical hollow impact bars with diameter of 20mm and length of 230mm are created in CHARM-70 head simulation experiment, of which the centerline are adjusted to align with the point 20mm above the supraorbital ridge and through its CG, for impacting at a low constant speed (3.45m/s) and a high constant speed(4.9m/s) , respectively. The velocity is determined by the mean speed of Hybrid III dummy head impact test and the simulation experiment device is shown in Fig. 2.

2.2 Simulation experiment of Hybrid III head model

In order to compare with the dummy experiment, the same angle of neck are set up and an cylindrical impact block with mass of 14 kg, diameter of 100mm and thickness of 30 mm are developed to impact at frontal head of Hybrid III head FE model at 3.45m/s and 4.9m/s, respectively. The experimental setup is shown in Fig. 3.

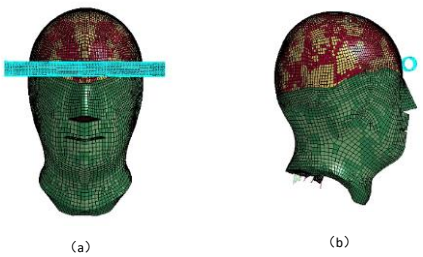

Fig.2 CHARM-70 head model simulation device

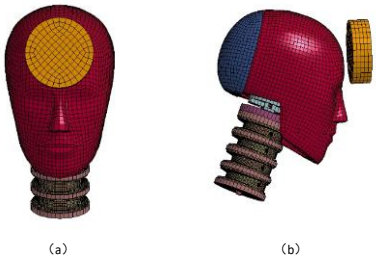

Fig.3 Hybrid III head model simulation device

2.3 Head impact test of Hybrid III dummy

As shown in Fig. 4, head impact experiments are carried out in order to study the mechanical response of 50th percent male Hybrid III dummy. The neck of dummy is fixed on the rail of the linear air bearing table, and the worktable is adjusted to make the head and the impact block at the same horizontal line. Air pressure is adjusted by the air valve to obtain the different speed of impact blocks. The mass of the cylindrical impact block is 14 kg, which is wrapped with a layer of elastic material.

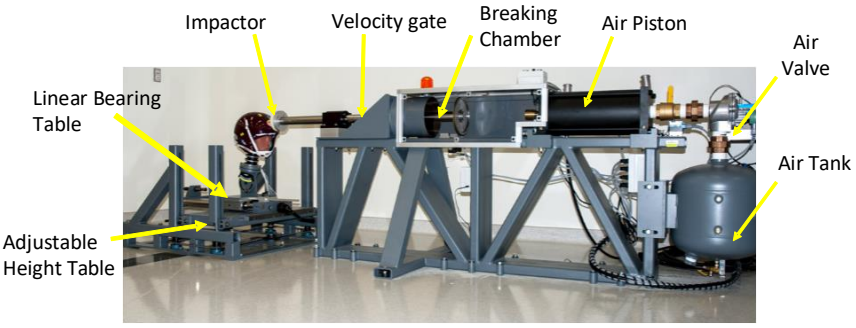

Fig. 4 Head impact test device of Hybrid III dummy

3 Results

3.1 Simulation experiment of CHARM-70 head model

The force versus displacement curves shown in Fig. 5 clarifies that the force increases nonlinearly with the displacement at different speeds before the force reaches the peak value. The impact stiffness curves of CHARM-70 head FE model are shown in Fig. 6. Under low and high speed loading, two curves are both increasing linearly and similar to each other, with the peak values of 3.12 KN/mm and 3.13KN/mm, respectively.

The skull fracture of CHARM-70 head model in collision is shown in Fig. 7. Under the impact, the comminuted depressed fracture occurs near the contact area, but there is no significant difference in shape of fracture caused by high speed and low speed.

According to Theodore [9], contrecoup brain trauma occurs in the settings of closed head injury, where the force of an impact moves the intracranial contents away from the original site of the blow. The strain nephogram at the anterior, left and posterior parts of the brain is shown in Fig. 8. The main strain position is transferred to the posterior part of the brain. Owing to that the back side of head model are restraint, the occipital lobe of the brain is slowed down by the blocking of the occipital bone. And, the brain and inner surface of the rugged skull are relatively moved and are compressed by the occipital bone, resulting in contusion of the brain and contrecoup brain trauma.

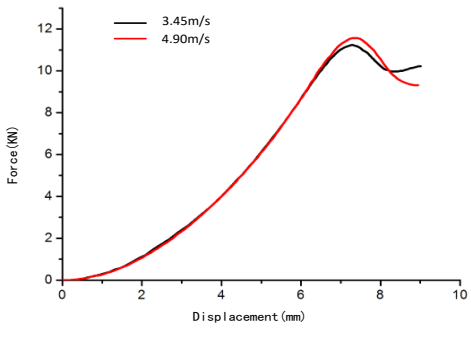

Fig. 5 Force vs. displacement for CHARM-70

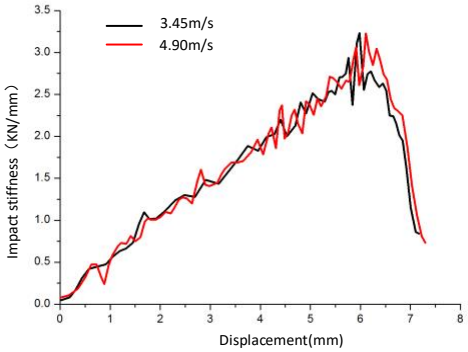

Fig. 6 Impact stiffness for CHARM-70

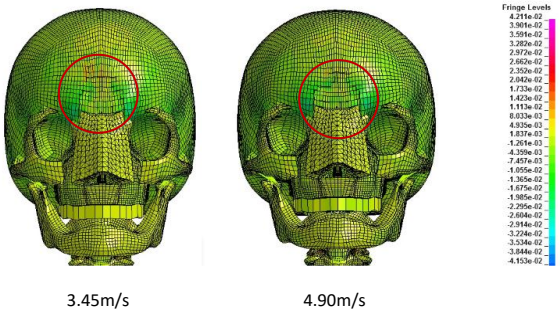

Fig. 7 Stress nephogram of skull for CHARM-70

3.2 Simulation experiment of Hybrid III head model

The acceleration of head CG of Hybrid III at different speeds is filtered and arranged as shown in Fig. 9. Among them, the black and red color curve represent the acceleration history at the speed of 3.45m/s, 4.9m/s, respectively, of which the peak value are 0.639 mm/ms2 (65.14g) and 0.784 mm/ms2 (79.92g), lower than corresponding response of the dummy. The force-displacement curves of head are shown in Fig. 10, of which the peak force under low and high speed are 7.75KN and 9.97KN respectively.

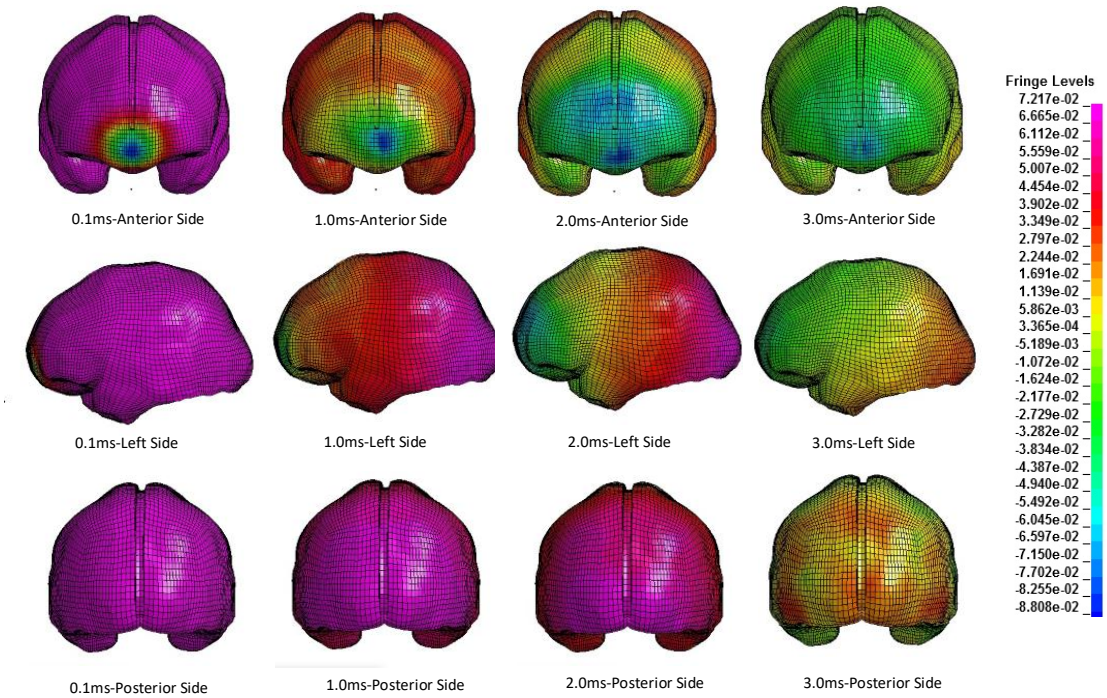

Fig. 8 Brain strain nephogram for CHARM-70

3.3 Head impact test of Hybrid III dummy

In Hybrid III dummy experiment, the data measured in the impact direction is summarized as shown in Tab. 1. The comparison of dummy test data at low and high speed impact is shown in Fig. 11 which can be analyzed that when the speed increased by 1.45 m/s, the SI and HIC15 increased by 96.93% and 101.1%, respectively. It can be considered that

the impact velocity has an important effect on head injury.

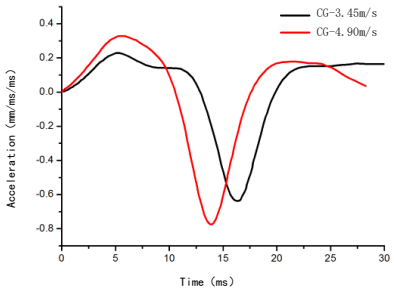

Fig. 9 Acceleration response at CG of Hybrid III head

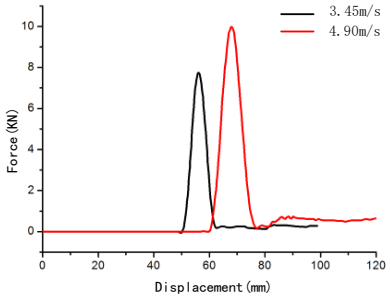

Fig. 10 Force-displacement of Hybrid III head

Tab. 1 Head impact test of Hybrid III dummy

Test number	Velocity (m/s)	Acceleration (g)	Average Acceleration	Standard Deviation	Impact Force (KN)	SI	Average SI	HIC15
1	3.49	87.98				61.86		
2	3.46	74.81	77.94	8.90	41.8	55.33	57.67	91.48
3	3.44	71.02				55.83		
4	4.89	88.67				112.92		
5	4.91	84.51	102.25	27.20	45.77	110.30	113.57	184.03
6	4.84	133.56				117.50		

4 Discussion and conclusion

Because of the undetailed structure, this injury research is only focused on the aspects of force, acceleration etc. in the impact test of Hybrid III dummy. While the detailed anatomical structure of CHARM-70 is convenient for more in-depth and intuitive prediction of human injury, and the results show that the model can accurately simulate the injury response and mechanism of human head under frontal impact.

In the experiment of Allosp [3], the foreheads of corpses were impacted by an rigid impact rod dropping from the position of 460-915 mm high, of which the velocity reached about 3 m/s to 4.23 m/s before impact occurred, which was little less than the impact speed of this experimental setup. That is one of the reasons why the impact response of CHARM-70 head FE model is stronger than that of cadaver experiment.

In the head impact experiment of Hybrid III dummy, it is found that the high speed impact will bring more serious damage than the low speed, and the speed has a great impact on the dummy damage, but no more enough controlled experiments with different speeds are set up to explore the quantitative relationship between the damage value and velocity. While the Hybrid III head FE model can simulate the injury response or of Hybrid III dummy more accurately, and the peak value of acceleration at low and high speed are 65.14g and 79.92g respectively, which is lower than the acceleration response value of dummy impact test.

Compared with the human head, The CHARM-70 model has good biological fidelity and contains the head anatomical structure comprehensively, which can simulate the human head injury mechanism well in the collision process, but the distinguishment of ventricles is not clear and the modeling of brain detail parts is rough. In this simulation, the main injury types are comminuted depressed fracture of skull, coup and contrecoup lesions of brain, which can well simulated by CHARM-70 head model when impacted in the frontal head. But, because of the limitations of this model, it is difficult to simulate the lubrication and buffering effect of cerebrospinal fluid when contusion of brain occurs.

As shown in Fig. 12, compared with Hybrid III simulation experiment, the CHARM-70 head model has greater stiffness and force response, which is mainly due to its systematic structure that can reflect the contribution of various

component during impact.

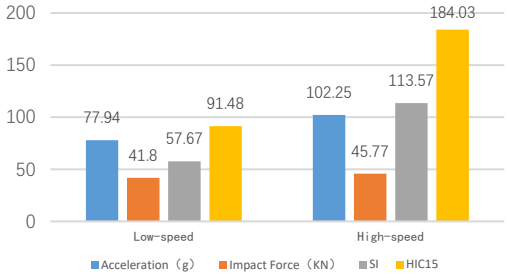

Fig. 11 Comparison for Hybrid III dummy

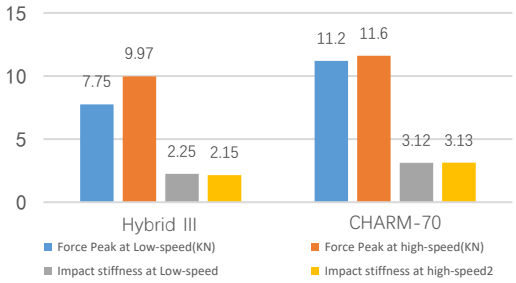

Fig. 12 Comparison of Hybrid III FE and CHAM-70

This study can provide a reference for improving the CHARM-70 finite element model and the fidelity of the model. The injury versus with velocity of the CHARM-70 FE model still lacks quantitative basis, so it is necessary to carry out more homogeneous and higher density simulation experiment with regard to speed control.

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