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Study on Pedestrian’s Head Injury in Accidents Using a Biomechanical Simulation Model

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Abstract: This study was aimed to the head injury of Chinese pedestrians in accidents. According to the results of multi-body dynamics (MBD) analysis on vehicle and pedestrian, the process of a vehicle-pedestrian crash accident was reconstructed and four kinds of analysis cases were obtained. Based on these data, the pedestrian’s injury of head skull, brain was analyzed utilizing a head bio-mechanical model of the 50th percentile Chinese male. Results show that during the collision of the same target, because the skull collision position is different, the skull damage also is different. The collision position located frontal and temporal bone have fracture risk. For head injury, as the collision position is different, there are different risk for contusion and laceration of brain and concussion of brain.

1 Introduction

Head injury is one of the most common injury types that lead to serious injury or death in traffic accidents. According to the statistics released by World Health Organization (WHO), the death of vulnerable road users accounts for 50% of all deaths in traffic accidents and that of pedestrians accounts for 22% in it [1]. Considering the mixed traffic conditions in China, the injury factor is larger to pedestrians. The statistics of WHO showed 689,996 Chinese pedestrians died in 2010, which accounted for 25% of all traffic deaths [2]. So it’s of great significance to study pedestrians’ injury in China.

2 Traffic accident reconstructions

For the multi-body dynamics analysis, a 50 percentile male dummy of pedestrian in Madymo software was utilized. Table 1 lists the basic parameters of the model [3]. According to available data in the literature, the pedestrian stride is set to 63.7 cm [4].

Table1 Pedestrian dummy basic parameters

parameter	value
Stand height	1.74m
Sit height	0.92m
Shoulder breadth	0.47m
Knee height	0.54m
weight	75.7kg

The vehicle model’s parameters, such as the geometry and stiffness, were defined using those in a Geely SUV model. The contact friction coefficient between the vehicle and pedestrian was set as 0.2, while those of the vehicle-ground and the pedestrian-ground were defined as 0.67 and 0.8 respectively. Base on the traffic accident data, the vehicle’s speed was set to 40 km/h. Figure 1 shows the MBD analysis of the vehicle and pedestrian.

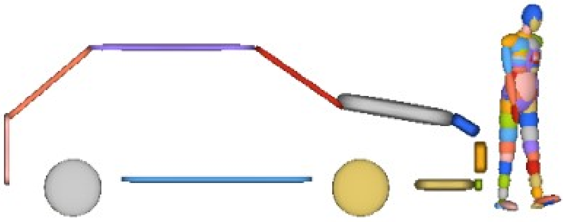
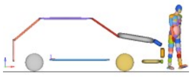
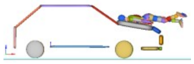
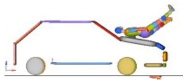
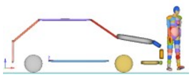
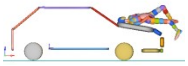
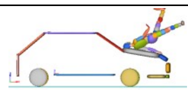
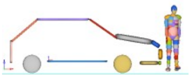
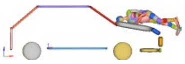
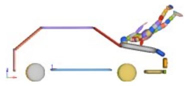
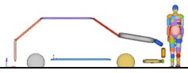
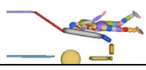
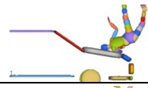
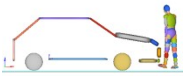
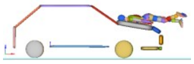
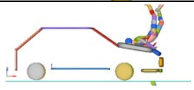
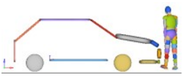
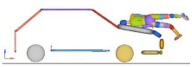
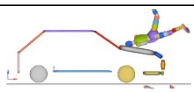
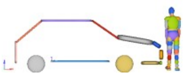
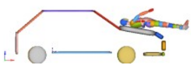
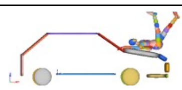
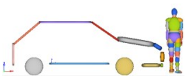
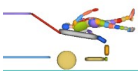
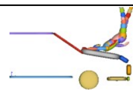


Figure 1 multi-body dynamics analysis model

The calculation of pedestrian’s movement was divided into 8 kinds of cases according to the crossing angle between the pedestrian and vehicle. Table 2 shows the simulation results in these cases. From table 2, it could be observed that different crossing angles between the vehicle and pedestrian lead to different collision positions of the pedestrian’s head. In the crossing angle of + 90° and 135°, the frontal bone contacted with the vehicle front end during the impact. In the crossing angle of 120 ° and -90 °, the parietal bone contact with the vehicle front end during the impact. In the crossing angle of 60 ° and 105 °, the occipital bone contact with the vehicle front end during the impact. In the crossing angle of 45 ° and 75 °, the temporal bone contact with the vehicle front end during the impact.

Table 2 Pedestrian movement in different crossing Angle

Crossing Angle	Pedestrian movement		
	0 s	0.2 s	0.4 s
45°			
60°			
75°			
+90°			
135°			
120°			
105°			
-90°			

3 Model development

3.1 Head model development

In this study, the head biomechanical model was developed by the South China University of Technology. Model geometry was derived from the computed tomography (CT) image data of a volunteer representing the 50th percentile Chinese male. It was created using reverse engineering in CAD and pre-processing technology in finite element method (FEM). The head model developed is shown in Figure 2[5]. It weights 4.08 Kg and contains details of the head, such as the scalp, skull, facial bone, falx, brain curtain, cerebellum sickle, pia mater, cerebrospinal fluid, brain, cerebellum and brain stem.

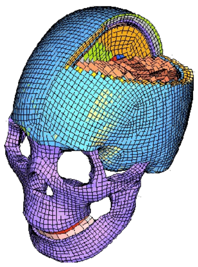


Figure 2. Biomechanical finite element model of the head

The geometric dimensions in the head model correlated with those of 50th percentile Chinese male [6]. The model was validated against the Post Mortem Human Subjects (PMHS) test by Nahum (1976) [7]. Figure 3 shows the simulation set-up based on the test conditions. In the simulation, an impactor of 5.59 kg impacted the forehead at s speed of 6.3m/s.

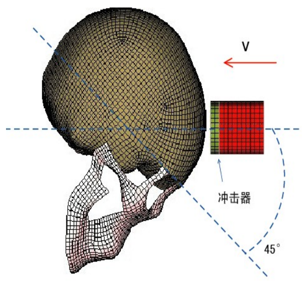
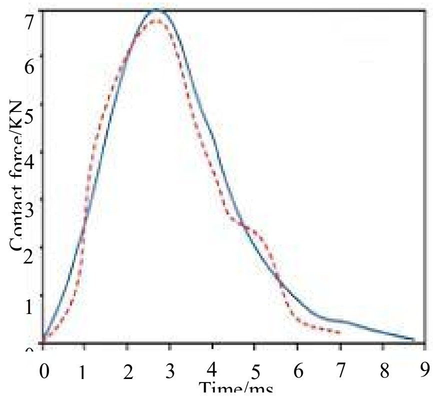
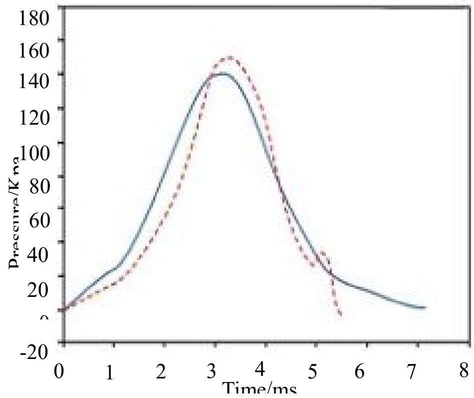


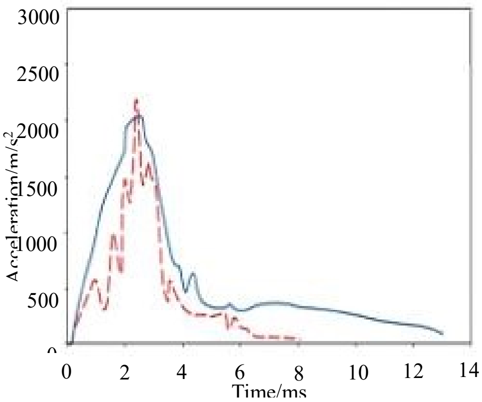
Figure 3. Simulation set-up against the test of Nahum

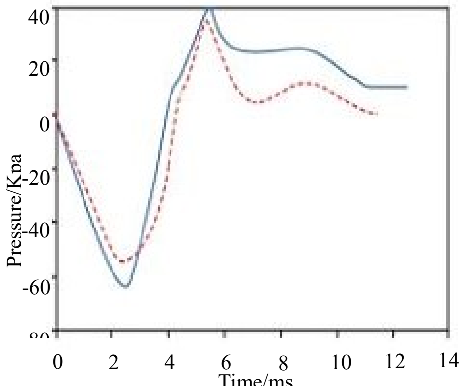
Figure 4 shows the comparison of the simulation and test results.(The solid line is the test curve, the dotted line is the simulation curve.) From the figures, it can be observed that the simulation curves agree well with those of the test, which indicates that the model developed can be used to accurately predict the head injury of real human body.





(a) head contact force curve of frontal impact test **(b) intracranial pressure curve of front impact position**





(c) Head acceleration curve of centroid **(d) Occipital cerebral fossa pressure curve**

Figure 4. Test of Nahum and simulation comparison

3.2 Vehicle Model development

Figure 5 shows the finite element (FE) model of the vehicle's front end. It contains about 1,107,982 nodes and 1,115,218 elements. The basic element size is 5×5mm.

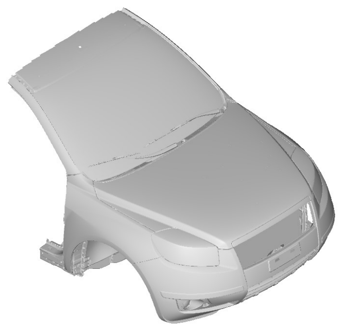


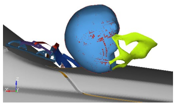
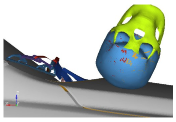
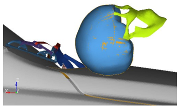
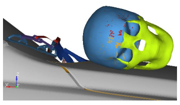
Figure 5. Finite element model of front-end vehicle

4 Injury Study on Pedestrian head

4.1 Analysis cases

With a launch angle of 65°, four cases of simulations were performed with different impact zones, as shown in table 3. The impact velocity was 40km/h and the model calculation time was 20 ms. The pedestrian's gait and its relative position with respect to the vehicle would result in the collision area of the head on vehicle hood. The four cases' analysis program below was made based on them.

Table 3. Analysis cases

Case	Schematic view	Collision zone
1		Frontal bone
2		Parietal bone
3		Occipital bone
4		Temporal bone

4.2 Skull injury analysis

The main types of skull injury are facial soft tissue injury, as well as the fractures of the facial bone and skull. Skull fractures include depressed fracture and linear fracture. The pedestrian's skull fracture has something to do with the impact point and contact area of skull. When the collision area is small, skull depressed fracture occurs due to the stress concentration, the energy absorption by the small collision area. When the collision area is large, the energy spreads easily on the head, and a wide linear fracture is generated at the position away from the point of impact [8]. The limits of the skull fracture tolerance in different parts are shown in table 4[9~10].

Table 4. Different parts of the skull fracture tolerance limits

Area	Contact force peak	Conclusions from
Frontal bone	3.6~9.0	Hodgson and Thomas.1968
Cheekbones	0.5~2.9	Nahum etc.1971
Temporal bone	5.0~12.5	Allsop etc.1991
Occipital bone	6.4	SAE.1980
Parietal bone	6.8~9.4	Chen Xingwu etc.2005
Maxillary bone	2.0~4.2	Nyquist etc.1986

Figure 6 shows the skull contact force - time curves in the four cases. It could be observed that the overall trends of the curves ser similar. Their peak values difference was small. But the curve of case 4 occurred a large shock near 5 ms. The reasons might be that the facial bone contacting with the vehicle hood absorbed parts of the collision energy. In case1, the maximum contact force was 5.9 kN, which indicated a risk of frontal bone fracture. In case 2, the maximum contact force was 5.8 KN, below the limit of parietal bone destruction. In case 3, the maximum contact force was also 5.8 kN, blow the limit of occipital bone destruction. In case 4, the maximum contact force was 5.9 kN. There was a risk of temporal bone fracture. From the analyses above, it can be concluded that different collision location in skull will lead to different injury. The collisions on the frontal bone and temporal bone have greater risks of fracture owing to their low tolerance limit.

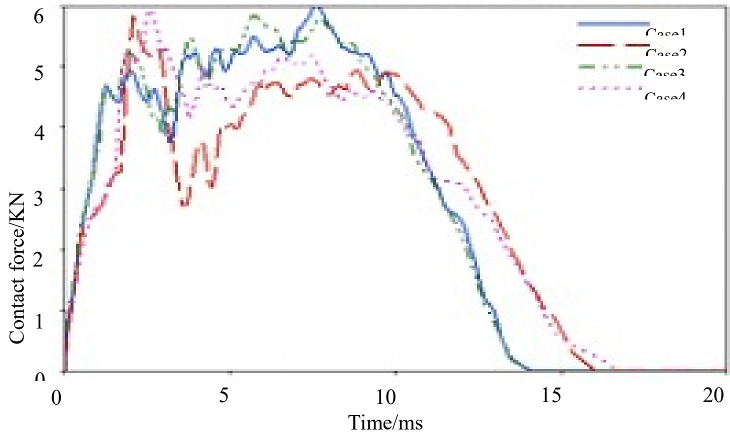


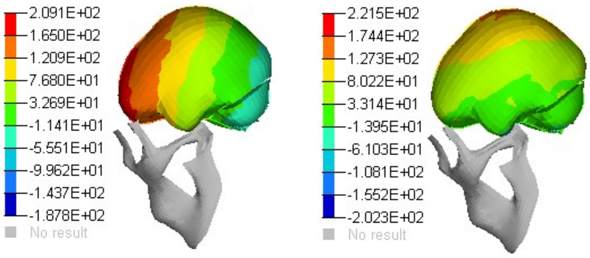
Figure 6. Skull contact force - time curve

4.3 Brain injury analysis

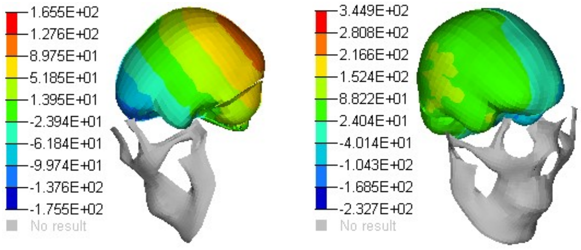
Brain injury can be divided into centralized brain injury and diffuse brain injury. Centralized brain injury includes the injuries, such as epidural hematoma, subdural hematoma, subarachnoid hemorrhage, intracerebral hematoma and brain contusion. Diffuse brain injury included brain concussion and diffuse axonal injury. Brain injury in a car accident was mainly caused by the dynamic loads. Head collision can result in the skull deformation and the stress wave transmitted within the brain. The inertial movement of the inner brain will cause positive pressure in the impact side and negative pressure in the other side, thereby forming a pressure gradient in the brain. Intracranial compression can lead to locally concentrated brain injury, such as the cerebral contusion [11]. Studies have shown that the translational acceleration in the head will cause concentrated brain injury, while the rotational acceleration will lead to diffuse brain injury [12~13].

4.3.1 Brain pressure analysis

Ward et al. noted that when the intracranial pressure went beyond 235 kPa and the tensile stress reached -186kPa, a serious brain injury would appeared. But the intracranial pressure between the 173-235kPa would only lead to moderate brain injury[14]. Figure 7 shows the intracranial press distribution in 4 cases. In case 1, the frontal bone impacted on the vehicle hood. A positive pressure appeared on the lateral frontal, while a negative one on the occipital. The maximum pressure in the frontal position was 209.1 kPa and the corresponding tensile stress was -187.8 kPa, which indicated a risk of brain contusion. In case 2, the parietal bone contacted with the vehicle front-end. The positive pressure on the collision side was 221.5 kPa, while the negative pressure on the contralateral side was 202.3 kPa. There was a risk of brain contusion at this time. The case3 Occipital bone collision with vehicle front-end, occipital lobe showed a positive pressure of 165.5kPa, the maximum pressure does not exceed the limits given literature, so brain contusion appears less likely. The case4 temporal bone collision with the vehicle front-end, the collision side of the right temporal lobe showed a positive pressure, collision contralateral left temporal lobe showed a negative pressure, but the maximum pressure does not appear in the collision and collision contralateral side, which appear in the lower part of the right temporal lobe, close to the irregular parts of the pressure value reaches 344.9kPa, there is a serious risk of cerebral contusion.

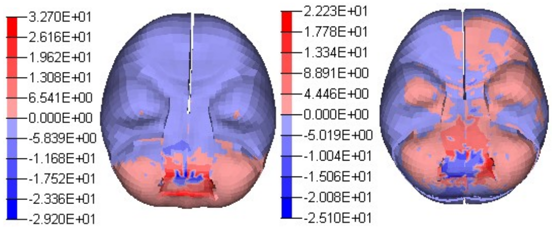


Case1 **Case2**

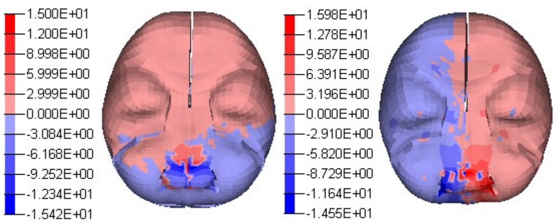


Case3 **Case4**

Figure 7. Intracranial pressure distribution /kPa



Case1 **case2**



Case3 **case4**

Figure 8. Schematic of intracranial stress /kPa

4.3.2 Brain stress analysis

Figure 8 shows the intracranial stress distribution in 4 cases. Willinger et al. pointed out that when the intracranial stress reached 15-20kPa, it would cause a slight concussion. When the intracranial stress exceeded 38kPa, it would lead to serious brain concussion. In case 1 and case 2, the intracranial maximum stress was 32.7kPa and 25.1kPa respectively. Both of them exceeded the injury tolerance limits, and there was a risk of serious concussion. In case 3 and case 4, the intracranial stresses stayed within the injury tolerance limits, which mean a injury of slight concussion.

5 Conclusions

(1) When skull different locations at the same target point collision, the frontal and temporal bone have greater fractures risk because there is a lower tolerance limits.

(2) At the same initial conditions, the temporal bone collision with the front of the vehicle there is a serious risk of cerebral contusion; frontal and parietal bone collision with the front of the vehicle there is a more serious concussion risk.

Acknowledgements

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