A Study on Head and Chest Injuries in Car-Pedestrian Collisions

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Abstract: In vehicle-pedestrian collisions, the front shape and the structure stiffness affect the pedestrian kinematics and injury risk. There are some studies that investigated the pedestrian injury risk in a collision of bonnet-type car, sport utility vehicle (SUV) and one-box vehicle. In the minicar-to-pedestrian collision, the kinematic of the pedestrian and the injury mechanism of each human body have not been discussed yet. In the current study, the kinematic behavior and the injury risk of the pedestrian struck by the three different type of vehicle (medium car, one-box type vehicle and minicar) was compared using a human finite element model (THUMS). It was shown that the kinematic behavior were different for three types of vehicles, which led to different velocity time histories of the head and chest. The injury risk to the head and chest were also affected by the stiffness of the contact area. For the medium car, the head injury risk was high because the head made contact with stiff cowl area at a high velocity. For the one box type vehicle, the chest injury risk was high since a large shear force was applied to the chest from the stiff lower windscreen frame. In the minicar collision, the upper thorax and scapula were at a high fracture risk due to hit by the cowl which with a high stiffness.

Keywords: pedestrian protection; minicar; finite element analysis

1. Introduction

Pedestrian fatalities comprised a considerable percentage of total traffic fatalities in highly motorized country: 12% in USA (NHTSA 2009) and 35% in Japan (Transportation Authority Police, 2009) [1-2]. Additionally, from the analysis accident data in Japan, the ratio for a pedestrian killed during a traffic accident is high than the occupants (32.6%) in 2009, and more than 77% of the pedestrian fatalities are elderly people (60 years old or more). Head and chest were the main injury body region where led to death.

There are many researches on vehicle-pedestrian collisions that have shown that the vehicle shape and the structure stiffness can influence pedestrian kinematics and injury risk to each body based on cadaver and dummy experiment, and pedestrian FE models [3-6]. From the FE simulation of vehicle-pedestrian collision by Han et al. [6], the pedestrian kinematic behavior and injury mode were different from the front shape of the vehicles (bonnet type car, one-box type vehicle and SUV). The head was at a high risk when hit by the bonnet type car whereas the chest of the pedestrian was at a high injury risk when struck by the one-box type vehicle. However, for the minicar collision, the kinematic of the pedestrian and injury mode of the head and chest have not been studied in detail though it is expected that the number of minicar will increase due to environment demand for light weight vehicles.

The purpose of this study is to understand the injury process in minicar-pedestrian collisions compared to other types of vehicles. In this study, a minicar FE model was developed, and using human FE model (THUMS), the pedestrian kinematics and injury mode of the head and chest in the minicar collision were compared to that in other two types of vehicles (medium car and one box type vehicle). The result would be beneficial for understanding the injury mechanism of the pedestrian impacted by vehicles with different shapes.

2. Method

2.1 The FE Models

The FE models of medium car, minicar and one-box type vehicle were used. The dimension of the front shape of the minicar was measured from the real one; and the shape of each part, such as the bumper, grille, bonnets, cowl, windscreen and A- and B-pillar was measured and assembled into the FE model. The material properties of bumper, inner and outer bonnet, cowl and A-pillar were determined from specimen tensional tests results. The number of nodes and elements of front part of the

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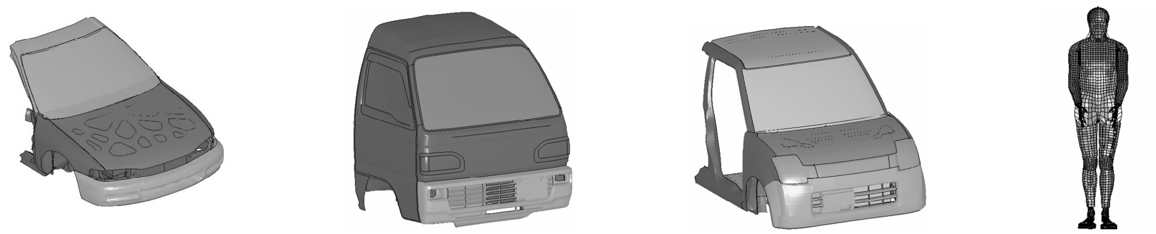
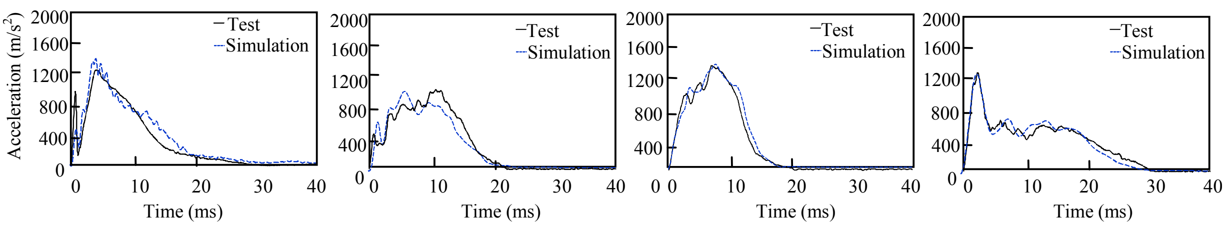
minicar FE model were 166,538 and 176,238, respectively. The one-box vehicle FE model was developed and validated by Nishimoto et al[5].

The NCAC Honda Accord car FE model was used as a medium car. The frontal structures forward of the A-pillar of the car were used from the original models and the element of the structures were modified for pedestrian impact simulations. The mass and inertia of the removed parts were added to make the reduced models have the same mass and inertia as the original full car models. The number of nodes and elements for the medium car is 83,024 and 100,048, respectively.



(a) Medium car (b) One-box type vehicle (c) Minicar (d) THUMS model

Figure 1. FE models for simulations



(a) Roof edge-A5-a (b) Bonnet leftside-C3-b (c) Bonnet leftside-C3-d (d) Bonnet rightside-C1-a

Figure 2. Headform impact test validation

The THUMS pedestrian FE model (version 1.4, height 175 cm, weight 77 kg) was used [7-8]. Based on the pedestrian accident analysis [9], elderly people ranging from 60 to 69 years old are involved frequently. The average height and weight of the Japanese elderly people (60-69 years old) are around 165 cm and 65 kg, respectively. Accordingly, the THUMS pedestrian model was scaled to 165 cm and 65 kg, to represent the Japanese population at risk.

In order to validate the minicar FE model, headform impact test results were used. The headform impactors (adult 4.5 kg, child 3.5 kg) were impacted on various locations of the frontal structures of the minicar. The impact velocity was 35 km/h. The impact angle was 65 degree (from the horizontal plane) in the bonnet top area and was 40 degree in the windscreen area. The accelerations of the headform impactor were compared with the experimental results (see Figure 2). The results show that the FE simulations agree with the experimental results.

2.2 Simulation Set-Up

The pedestrian model was initially positioned at the vehicle centerline. The pedestrian model was set to be in a walking posture facing laterally with the left leg forward and right leg backward. Both left and right arms were positioned forward. The vehicles impacted the left side of the pedestrian model at a traveling velocity of 40 km/h. The friction coefficient between the human body and vehicle was set as 0.65, and that between the shoes and ground was set as 0.7.

3. Results and Analysis

3.1 Kinematic Behaviour

The overall human body kinematics is dependent on many factors such as vehicle frontal shape, vehicle impact velocity, pedestrian initial posture and pedestrian anthropometry. For the pedestrian FE model hit by the medium car, the upper body of the pedestrian rotated around the femur. The chest and head made contact with the bonnet top and cowl area, respectively. The head contact time and the wrap around distance (WAD) was 109 ms and 1.76 m (see Figure 3).

For the pedestrian model struck by the one-box type vehicle, the entire body of the pedestrian was impacted by the vehicle within relatively short time duration without obviously rotation of the pedestrian (Figure 4). The chest made contact with the windscreen lower frame with stiff structure. The head made contact with the windscreen at 46 ms with a WAD of 1.67 m.

Figure 5 shows the kinematic behaviour of the minicar. For the minicar collision, the tibia and thigh are hit almost at the same time by the bumper and grille. The ground clearance of the bonnet leading edge was high for this minicar. As a result, the upper body rotated around the pelvis and the rotation radius of the upper body rotation was small compared to the medium car. The left shoulder joint was impacted against the cowl. The head was hit by the windscreen at 94 ms, and the WAD of the head was 1.77 m.

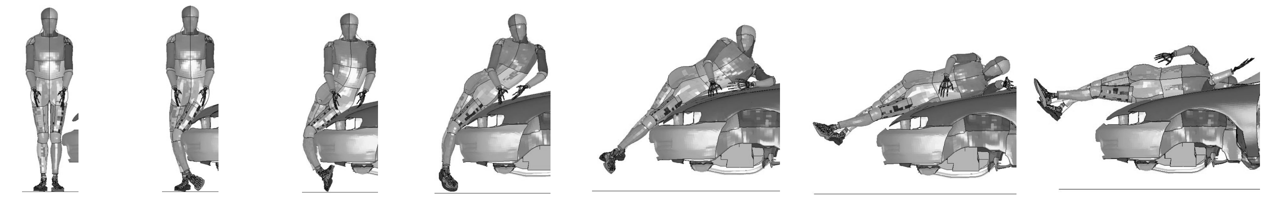


Figure 3. Kinematic behaviour of pedestrian in medium car collision

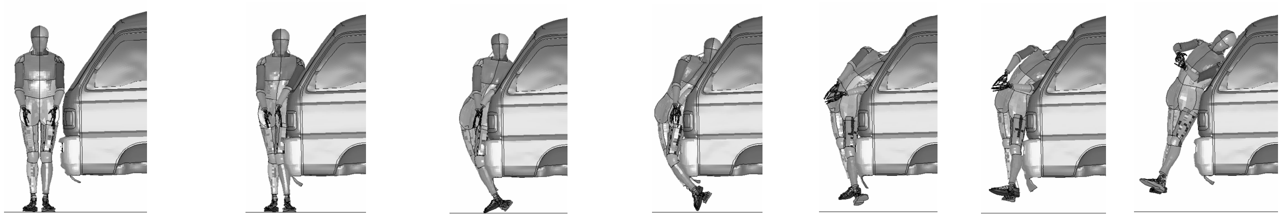


Figure 4. Kinematic behaviour of pedestrian in one box type vehicle collision

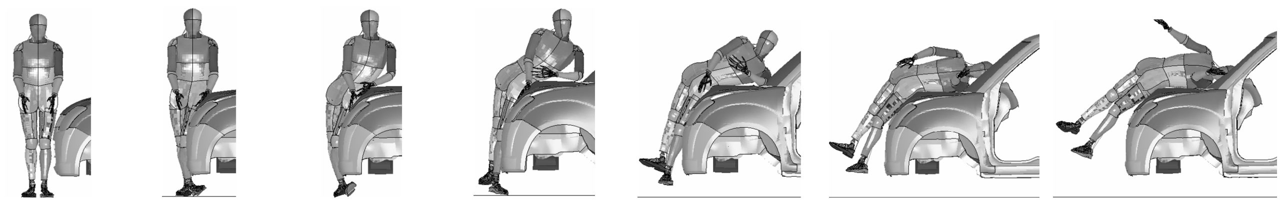


Figure 5. Kinematic behaviour of pedestrian in minicar collision

3.2 Head Impact Conditions

The head impact conditions were examined in terms of head impact velocity, impact angle and contact time. Figure 6 shows the head resultant velocity relative to the vehicle. In the case of the medium car, the head contacted the cowl top at a high velocity of 12.5 m/s with impact angle of 62.2 degree. The velocity was higher than the initial vehicle velocity because of the rotation behavior of the head. In the one-box type vehicle collision, the pedestrian rotation was small. The head velocity decreased after initial impact, and the contact velocity was 9.1 m/s and impact angle was 9.1 degree. In the minicar collision, the head velocity curve was similar with the medium car collision, and the head impact velocity and angle were 10.4 m/s and 54.4 degree respectively.

3.3 Head Injury Parameters

The injury parameters of the head are presented in Table 1. For the medium car, the head injury values are high compared to the other two cases. The reason for the difference was high head impact velocity and the stiff structure where the head made contact in the medium car –pedestrian collision. The HIC was 935, which was comparable with 1000.

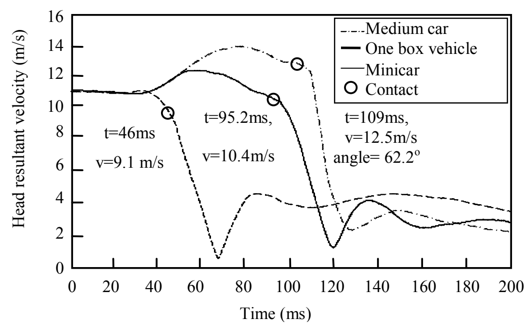


Figure 6. Head resultant velocity relative to vehicle

Table 1. calculated head injury parameters

	3-ms Acceleration (G)	HIC_{15}	Angular Velocity (rad/s)	Angular acceleration (rad/s^2)
Medium car	104	935	61	7504
One-box type vehicle	50	338	42.8	4161
Minicar	55.9	344	57	2063

In the collision with the one-box type vehicle, the chest impacted directly with the front panel in a vehicle's longitudinal direction. Since the time between lower extremity contact and chest impact was short, the pedestrian was not accelerated enough in the vehicle's direction, and the velocity of the chest relative to the vehicle was still high (9.6 m/s) compared to an initial collision velocity (11.1 m/s). The chest velocity relative to the vehicle decrease consistently until 60 ms.

For the minicar, the upper body of the pedestrian rotated around the pelvis, and the chest impacted the bonnet top. Because the radius of the rotation of the upper body was small, the velocity of the chest decreased consistently. The chest contact velocity was low (5.2 m/s).

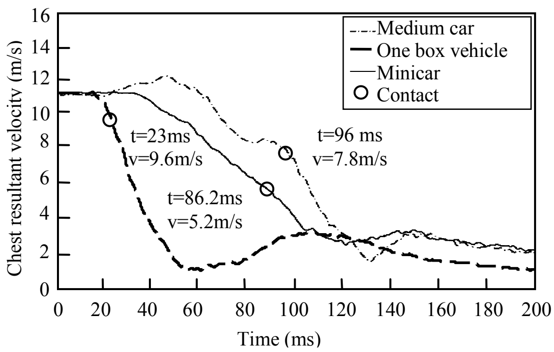
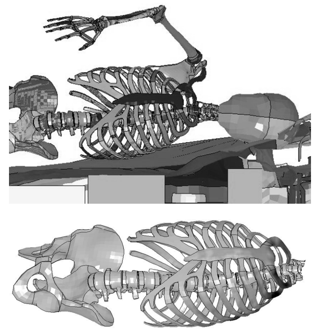


Figure 7. Chest resultant velocity

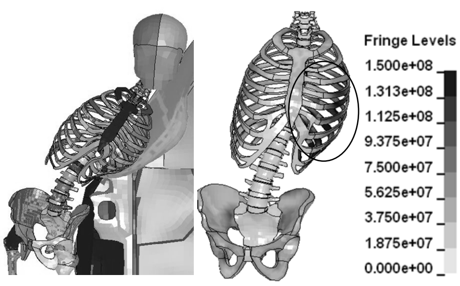
The chest deformation and von Mises stress of the ribcage were presented in Figure 8. In the case of the medium car (see Figure 8a), since the stiffness of the bonnet panel was distributed, the bonnet deformed uniformly and absorbed the impact energy efficiently in the impact with the pedestrian chest. Although the bonnet panel deflected significantly, the clearance of the bonnet top from the engine was 110 mm which was large enough to prevent the bottom out of the bonnet by the engine top. Therefore, the thorax deformation was small. As the force was transmitted from shoulder joint during the impact, there were relatively high stresses around the clavicle and 1st rib.

Figure 8b shows the deformation and the stress distributions of pedestrian rib cage in the one-box vehicle collision. Due to the high stiffness of the windscreen lower frame and lower stiffness of the windscreen, the upper thorax moved into the windscreen but the lower thorax was contact to the frame. As a result, a shear loading was applied to the thorax and local deformation was occurred in the lower rib cage area. Then, a high stress was observed in the lower ribs, whereas the stresses in the ribs which made contact with the windscreen were small.

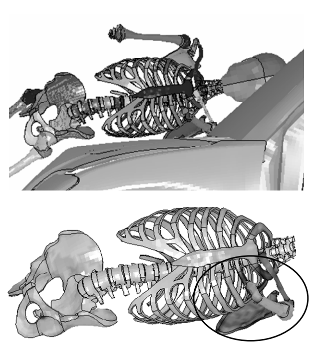
In the minicar collision, the stiffness of the bonnet was also distributed, and the deformation of the lower thorax was small. The left shoulder joint impacted the cowl area with a relatively high stiffness. The force transmitted from the shoulder joint and scapula bone, therefore, a high stress distribution was observed at the 1st rib and 2nd rib (see Figure 8c). However, in the case of the pedestrian with 1.75 m height, the shoulder joint and the pelvis will contact with the windscreen and the bonnet-top, respectively, which can make a "bridge". As a result, the chest will not contact with the cowl area and the ribcage deformation will be small.



(a) Medium car



(b) One-box type vehicle



(c) Minicar

Figure 8. Chest deflection and von Mises stress

4. Discussions

The pedestrian kinematic behavior depends on the vehicle shape. The pedestrian is wrapped around the vehicle front surface in the medium car and the minicar collisions, whereas the pedestrian is projected forward from the vehicle in the one-box type vehicle collision. The kinematic behavior affects the impact velocity and the loading of the head and the chest. For the medium car and the minicar collision, the chest impact velocity was lower than the one-box type vehicle collision, since the time duration is longer and the chest velocity relative to the car already decreased. For the medium car collision, the head rotated during a relatively long duration, and its high vertical component velocity increased, which led to a high impact velocity against the car.

The head injury risk depends on the head impact velocity and the local stiffness of the structures where the head made contact. Although the head impact velocity was high in the one-box type vehicle and the minicar collision, the lower HIC was observed. The main reason will be the lower stiffness of the windscreen. The head injury risk is high when the head impact against the A-pillar at a relative high impactor velocity. From the study (Kikuchi et al. 2006 and Kerrigan et al. 2009), it is indicated that the HIC is also influenced by the neck force that was applied to the head during car to pedestrian collisions. Therefore, the effect of neck force on the head acceleration should be examined as a factor to investigate the head injury risk in the future study.

In addition to the vehicle shape and structure stiffness, the chest injury risk also depends on the area where the body makes contact. The structure affects the deformation and impact loading of the chest. The stiff windscreen frame and soft windscreen of the one-box type vehicle applied shear loading on the thorax, which led to a high local stress distribution on the lower ribcage.

In this research, the FE simulation of minicar-to-pedestrian collision was conducted. Since the bonnet leading edge of this minicar was high, the pedestrian upper body rotated around the pelvis. As a result, the chest and the head impact velocity against the car was low. The head injury risk was low since the head impacted less-stiff windscreen and the head impact velocity was small. In this minicar, the shoulder joint made contact with the cowl, which transferred a great force to the chest. It is probable that the injury risk to the chest will be low if the shoulder joint will make contact with windscreen. Consequently, it is likely that a high bonnet leading edge and large windscreen area could be one of the design directions of the minicar to reduce adult pedestrian injury risks.

5. Conclusions

The pedestrian kinematic behavior and injury risk was examined for three types of cars (medium car, one-box type vehicle and minicar). It was found that the vehicle shape affected the overall kinematic behavior of the pedestrian. The frontal shape affected the impact velocity, impact location and the contact time of the head and chest.

The FE simulations showed that a high HIC value was observed in the medium car collision, which was caused by the high head acceleration and the stiff contact location at the cowl. A shear loading on the rib cage and the rib fracture risk was high in the one-box type vehicle impact due to the high local stiffness where the rib cage made contact to. In the minicar-to-pedestrian collision, the injury risk of the head was low, however, the upper rib cage fracture can occur when the chest impact to the cowl area with relatively high stiffness.

Acknowledgement

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