Prediction of Pedestrian Head Injury Risk by Real World Accident Reconstruction

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Abstract: The objective of the present work is to investigate the head-brain injury risks of pedestrian in car to pedestrian accidents and compare it with the existing head injury criteria. Seven pedestrian cases were selected for reconstruction from existing database of accidents in Changsha. Accident reconstructions initially were performed using multi-body system (MBS) pedestrian and car models, From these simulations head impact conditions, like head relative velocity, position and orientation were determined and used as the initial conditions in the simulations of the same event with finite element (FE) head and car models. A logistic regression model was used to examine AIS3+ brain injury risk in relation to the values of injury related parameters calculated from the reconstructions considering kinetic and physical parameters. The results showed that head injury criteria using kinetic parameters such as HIC and HIP can effectively predict injury risk of a pedestrian's head. However these parameters are weak to predict detailed brain injuries. The coup/contrecoup pressure, Von Mises and shear stress are important predictors of brain injury risk.
Keywords: Head injury criteria, accident reconstruction, injury prediction, pedestrian safety, logistic regression

1. Introduction

Pedestrians are the most vulnerable road users. Recently in China, approximately a quarter of traffic accident deaths are pedestrians [1]. Head injuries are most common in passenger car to adult pedestrian accidents. They always result in large social and economic loss. Therefore, preventing and minimizing head injuries become a critical issue and the most important is to understand the mechanisms of these injuries. Biomechanical research works have been carried out all over the world but the injury mechanisms and the tolerances of brain remain controversial (Yang et al. 2007) [2].

Common head injuries in vehicle to pedestrian collision are skull fracture, laceration, cerebral injuries including, contusion, concussion, intracranial hematoma and diffuse axonal injury (DAI). Main causes of head injuries are the concentrated impact force, the loads distribution in viscous material of the brain, and the inertial loading to the head/brain (Yang, 2005) [3]. The skull fracture depends mainly on the impact velocity and location on the head and the properties of contact area on the vehicle. When the impact force exceeds the tolerance level, cranial bone fracture will occur. Subsequently, linear and angular accelerations of head are generated. These accelerations result in the relative movement between the skull and the brain. The brain injuries can be caused by high strain and strain rate due to this movement.

During the past decades, various head injury criteria have been developed to predict head injuries. The Wayne State University Tolerance Curve (WSUTC) has been used since the early 1960's. This criterion expresses the relationship between the linear acceleration of impacted head and head injury (Lissner et al.1960) [4]. Based on WSUTC, the National Highway Traffic Safety Administration (NHTSA) proposed the Head Injury Criterion (HIC) in 1972. HIC is widely used in industrial and research fields for risk prediction. However, HIC is only an empiric criterion considering the linear acceleration but the impact direction and the angular acceleration are neglected. Consequently, Newman (1986) [5] proposed the GAMBIT that concerns the influences of both linear and angular accelerations. Considering the impact direction, Newman (2000) [6] proposed a new criterion called Head Impact Power (HIP). As WSUTC, HIC, GAMBIT and HIP are based on the kinetic parameters of head, the criteria based on physical parameters were proposed recently such as criteria based on FE model SIMon [7].

The purpose of present study is to investigate head impact conditions of pedestrian accidents and to analyze prediction of head injury risk.

2. Method and material

Since 2006 on site accident investigation database from Changsha is developing by the Vehicle and Traffic Safety (VTS) research group of Hunan University. This database includes detailed accident information as measures registered from the accident scenes, interview of people involved in accident and witnesses. Also information about injuries collected from the emergency hospitals is included.

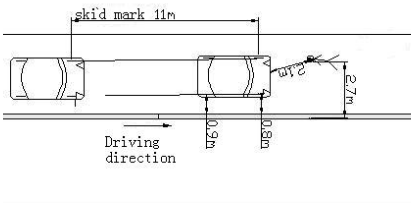
In the current study seven detailed passenger car to adult pedestrian cases were selected out from this database to reconstruct head impact conditions and injury mechanisms. Reconstructions were conducted using MBS models in order to determine head impact conditions, than were applied as initial conditions in an FE head model developed at Hunan University (HUHM-1). Then the existing head injury criteria calculated from MBS and FE HUHM-1 reconstructions were analyzed using logical regression method.

2.1 Accident data

The selection of accidents was done according to the following requirements:

1) The accident should be caused by passenger car,
2) The pedestrian should be adult,
3) The injury should be AIS 1+,
4) The documentation should include detailed sketch of the accidents report as showed in Fig. 1a,
5) The accidents should include detailed description of injuries, and on the car clear impact marks causing these injuries (Fig. 1b).

The data from selected cases for reconstruction are summarized in Table 1.



a

b

Figure 1 (a) Sketch of the accident scene and, (b) Photo of damages to the involved vehicle.

Table 1 Cases selected for reconstruction

Case Number	Age	Height	Weight	Car	Speed (km/h)	Scenarios	Injury Description
Case 1	50	1.74	72	VW Jetta	27.0	Side impact Standing	Right temporal contusion (AIS 4); Right temporal cephalophyma (AIS 4); Right temporal epidural hematoma (AIS 4)
Case 2	20	1.72	60	Hondar Accord	22.0	Side impact Running (Fig. 2c)	Scalp haematoma (AIS 1)
Case 3	26	1.62	49	VW Jetta	30.2	Side impact Walking (Fig. 2a)	Right side subarachnoid hemorrhage (AIS 3); Cerebral concussion (AIS 2); Scalp haematoma (AIS 1)
Case 4	48	1.73	72	Mazda6	43.6	Rear impact Standing (Fig. 2b)	Coronal linear fracture (AIS 2); Subarachnoid hemorrhage (AIS 3)
Case 5	61	1.55	46	VW Jetta	33.4	Side impact Walking	Cerebral concussion (AIS 2)
Case 6	74	1.50	58	Lin Shuai	57.6	Side impact Walking	Right temporal contusion (AIS 4); Subarachnoid hemorrhage (AIS 3); Basilar fracture (AIS 2); Scalp laceration (AIS 2)
Case 7	17	1.71	81	VW Jetta	28.6	Side impact Standing	Cerebral concussion (AIS 2)

2.2 Accident Reconstruct

Both multi-body system (MBS) and finite element (FE) models are used for accident reconstructions. MBS reconstructions are conducted using the MADYMO program, in order to reproduce the pedestrian kinematics associated with the collision. HIC, GAMBIT, HIP are calculated from the MBS reconstruction results and maximum angular velocity and acceleration are used for analyze the critical strain curve [3] for brain injuries.

The head impact conditions derived from the MBS reconstructions are used as input data for FE reconstructions, using both an FE head model and an FE car model. SIMon criteria, Coup/contrecoup pressures, Von Mises and shear stress are calculated from FE reconstructions.

2.2.1 MBS reconstruction models

The existing model of pedestrian [8] is used in the study. The model consists of 24 ellipsoids that represent the head, neck, chest, abdomen, hip, upper and lower extremities; these are connected by 18 joints. In each reconstruction, the pedestrian model is scaled according to the real height and weight of the victim (as in Table 1) using "gebod" code of MADYMO. Also the joint properties and contact stiffness of the body segments are scaled from a validated 50th percentile adult pedestrian model, based upon the same data. The models of cars involved in accidents are developed according to their real 3D dimensions. The mechanical properties of the car models are defined based on stiffness properties acquired from Euro NCAP sub-system tests [9].

The initial speed of the car is calculated using both skid marks and throw out distance. The initial posture and orientation of the pedestrian model are also adjusted according to information from accidents as shown in Fig. 2. The initial velocity is selected from the simulation matching impact marks and the interview with peoples involved in accident and witnesses. It is ranged from 0 to 3 m/s to represent standing, walking, rapidly-walking and running pedestrians, accordingly. Different friction coefficients are set based on the weather condition and the road material.

Throw out distance and wrap around distance from the accident data and reconstruction are compared to validate the simulation results. When the error between the simulation and the accident case is less than 20% the reconstruction results are accepted.

a b c

Figure 2 MBS car-pedestrian impact model examples: (a)normal walking, (b)standing and working, (c) running

2.2.2 FE reconstruction model

The validated FE HUHM-1 is used in current study (Fig.3) [10, 11]. The whole model contains 6 components, 9890 nodes, 6487 solid elements and 7007 shell elements. The effective mass is 4.4 kg. The HUHM-1 model is not scaled to the actual size of the pedestrian involved in an accident because of the lack of exact head 3D dimensions in the accident database and also such scaling is assumed not be influencing the results of current study.

In present study, an FE windshield model is developed using a pre-validated method (Sun et al., 2005) [12]. The model contains two coincident layers to simulate the glass and the PVB layer, respectively. The glass layer is modeled with shell elements that fail when they reach a maximum stress. The PVB layer is modeled with membrane elements, using a hyper-elastic material.

The bonnet model is developed based on the 3D dimension of the car involved in accident. The material characteristics are defined using these from validated Neon 7.0 model [13].

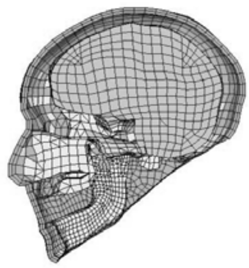
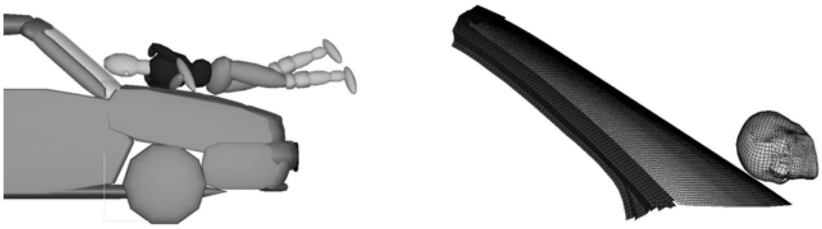


Figure 3 HUHM-1 model

The initial impact conditions of FE reconstruction (Fig. 4b) as initial head linear velocity, angular velocity, orientation and position, as well as the velocity and position of the car, were defined according to the corresponding values derived from MBS reconstruction (Fig 4a). The accuracy of FE reconstruction is validated based on the comparison of damage pattern of windscreen and bonnet observed in reconstruction to these from real car involved in accident.



a b

Figure 4 (a) The pedestrian kinematics at the moment of the head impact to the windshield, (b) The FE reconstruction of head injuries.

2.3 Considered Head injury criteria

2.3.1 HIC (Head Injury Criterion)

HIC considers the head as a one mass structure. It is computed using the following formula:

$$HIC = \max_{(t_1,t_2)}\left\{(t_2-t_1)\left[\frac{1}{t_2-t_1}\int_{t_1}^{t_2} a(t)dt\right]^{2.5}\right\} \qquad \text{Eq. 1}$$

where: a (m/s^{-2}) is the resultant linear acceleration measured at the Center Of Gravity (COG) of the head,t_1 and t_2 (ms) are chosen in order to maximize the HIC value.

2.3.2 GAMBIT (Generalized Acceleration Model for Brain Injury Threshold)

GAMBIT expresses the maximum linear and angular accelerations of the COG of head as factors of head injuries:

$$G(t) = \frac{a_m}{250} + \frac{\alpha_m}{10000} \le 1 \quad HIC = \max_{(t_1,t_2)}\left\{(t_2-t_1)\left[\frac{1}{t_2-t_1}\int_{t_1}^{t_2} a(t)dt\right]^{2.5}\right\} \qquad \text{Eq. 2}$$

where a_m (g) is the maximum linear acceleration of head, while α_m (rad/s^2) is the maximum angular acceleration.

2.3.3 HIP (Head Impact Power)

HIO consider the head is also a one-mass structure. Head impact direction is deliberated:

$$HIP = \underbrace{C_1 a_x \int a_x dt + C_2 a_y \int a_y dt + C_3 a_z \int a_z dt}_{Linear-contribution} + \underbrace{C_4 \alpha_x \int \alpha_x dt + C_5 \alpha_y \int \alpha_y dt + C_6 \alpha_z \int \alpha_z dt}_{Angular-contribution} \qquad \text{Eq. 3}$$

where Ci coefficients are set as the mass or appropriate moments of inertia for the human head; a_x, a_y and a_z (m/s^{-2}) are the components of linear acceleration along the three axes of the local coordinate system of the dummy head; α_x, α_y and α_z (rad/s^{-2}) are the components of angular acceleration around the three axes of the same system.

2.3.4 SIMon Criteria

Cumulative strain damage measure (CSDM) is supposed to be correlated with neurological injury occurrences such as diffuse axonal injuries (DAI). It measures the cumulative portion of the brain tissue experiencing tensile strains over a predefined critical level. Several such critical levels are proposed in the software and in current study a level of 15% is chosen as it seems to show the best correlation with injuries after scaled animal test simulations [7].

Dilatation damage measure (DDM) is also supposed to be a correlated with contusions. It involves localized regions where mechanical pressure exceeds negative value that is large enough to produce tissue damage. Several such critical levels are proposed in the software and in present study a level of -100 kPa is chosen as it seems to show the best correlation with injuries after scaled animal test simulations [7].

Another SIMon criterion is the relative motion damage measure (RMDM) that is supposed to correlate with acute subdural haematoma (SDH). It is based on the brain motion computation relative to the interior surface of the cranium. However RMDM was not analyzed in this study because the brain and skull FE model using shared nods.

2.3.5 Other criteria

A critical strain curve expressed in terms of the peak angular acceleration and change in angular velocity is used as a threshold corridor of brain injuries (Marguiles and Thibault, 1992; summarized by Yang 2005) [3]. It was suggested that the bridging vein could be ruptured when the head angular acceleration exceeds 4500 rad/s2 and the change of the angular velocity is above 50 rad/s.

As head FE models are widely used recently, the physical parameters such as coup/contrecoup pressure, Von Mises and shear stress could be used to predict head injuries by reconstruction (Yao et al. 2007) [14]. Therefore we decided also to use these criteria and make analysis of prediction for brain injury risk.

2.4 Statistical methods

A logistic regression model was used to examine AIS3+ brain injury risk p(x) relative to the calculated injury criteria (HIC, GAMBIT and HIP) and physical parameters (SIMon criteria, coup/contrecoup pressure, Von Mises and shear stress):

$$p(x) = \frac{1}{1+e^{\alpha-\beta x}} \qquad \text{(Eq. 4)}$$

where p is the probability of injury for the given value x of the injury predictor candidate. The α and β parameters are determined using maximum likelihood method to maximize the function's fit to the data. Goodness-of-fit of the statistical model was examined by means of chi-squared X^2. The probability value p is associated with X^2. The relationship between injury and predictor variables is statistically significant when the probability value is at the level of $p \leq 0.05$. The α, β and their associated standard errors σ ($\alpha \pm \sigma$, $\beta \pm \sigma$) were calculated by fitting the logistic regression model by maximum likelihood. When $x = \alpha/\beta$, $p(x)$ has a bending point with a maximum or minimum value for the slope and $p(x)$ = 50% level. So the value of α/β gives the median of the distribution of MAIS3+ over values of x. A bootstrap method was used to calculate the standard error σ of α/β ($\alpha/\beta \pm \sigma$) for each injury parameter using MATLAB program (Zoubir and Boashash, 1998) [15]. Total 1000 bootstrap samples were generated for each case.

3. Results

3.1 MBS reconstruction results

After several runs of each case we could finally reconstruct each accident according to requirements for current study as summarized in Table 2 and 3. For all cases the errors between the simulation and the accident are less than 20%, so the seven cases are well reconstructed.

Figure 5 showed all the impact points of head on the car. The AIS 3+ injuries were found mainly around the edges of windshield and near the A pillar. These parts are much stiffer than the other area on the windshield.

Table 2 Comparisons of throw out distance (m)

	case 1	case 2	case 3	case 4	case 5	case 6	case 7
Accident	5.9	2.4	7.5	8.2	10.6	11.0	6.3
Reconstruction	5.4	2.7	7.9	8.0	10.9	11.3	5.8

Table 3 Comparisons of wrap around distance (m)

	case 1	case 2	case 3	case 4	case 5	case 6	case 7
Accident	2.05	2.3	1.92	2.04	1.66	1.96	1.82
Reconstruction	2.1	2.24	1.94	2	1.65	1.93	1.85

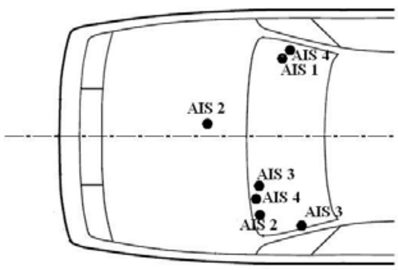


Figure 5 Head impact point and AIS code on car

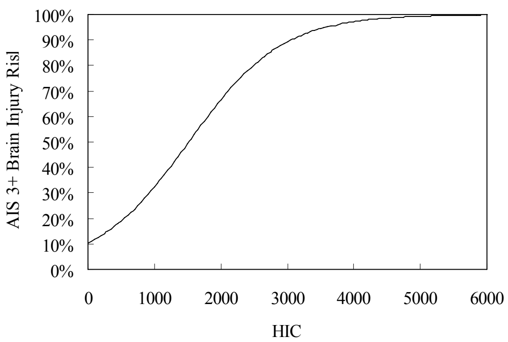
Results regarding the injury related parameters calculated from MBS reconstructions of all cases are presented in Table 4. Brain injuries occurred when HIC is greater than the level of 463.3 and HIP is greater than the level of 26.7 while such level is not found in GAMIT.

Table 4 MBS reconstruction results

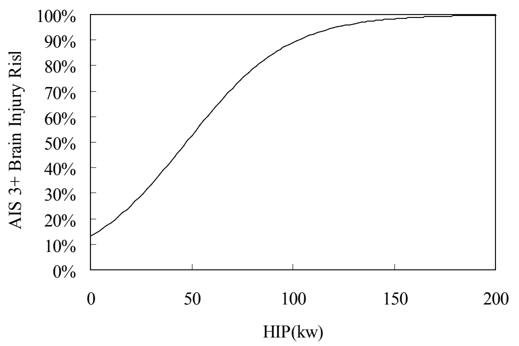
Case Number	HIC	GAMBIT	HIP (kW)	Maximum Angular velocity (rad/s)	Maximum Angular acceleration (rad/s^2)	Maximum AIS (MAIS)
Case 1	1345.6	3.48	36.5	42.5	25686	4
Case 2	463.3	2.02	26.7	31.8	15300	1
Case 3	1500.1	3.53	48.2	57.1	28000	3
Case 4	2407.2	1.87	69.6	90.6	11794	3
Case 5	2081.3	1.84	64.4	39.6	9352	2
Case 6	5691.0	5.48	137.1	71.2	43874	4
Case 7	1281.2	4.02	42.5	50	30400	2

The correlation between head injury criteria, calculated from MBS reconstruction, and AIS3+ brain injury examined using a logistic regression model, is shown in Fig. 6 a,b,c. As the *p* value of HIC, GAMBIT and HIP are 0.140, 0.298 and 0.223, respectively, HIC exhibits the stronger correlation with AIS3+ brain injuries than other two criteria, however the *p* value still greater than 0.05. The values of α, β and α/β with their standard errors are presented in Table 5.

The angular velocity and acceleration of head calculated from each case is presented in Figure 6d in order to analyze the critical strain level of brain criterion. Based on the MBS reconstruction results, all the cases including brain injury are within the area exceeded the 5% strain level.



(a)



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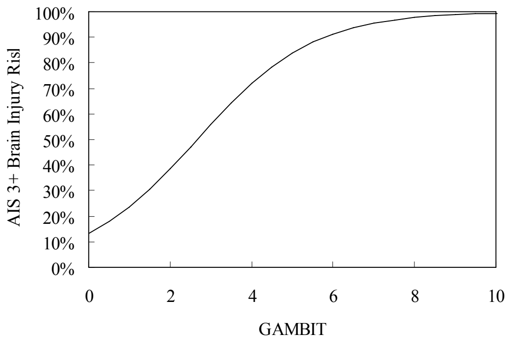

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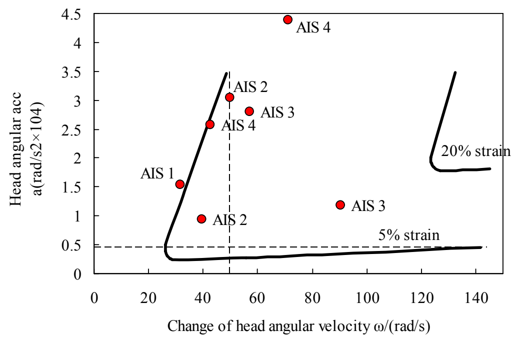

(d)

Figure 6 Logistic regression curves for (a)HIC, (b)HIP, (C)GAMBIT versus AIS3+ brain injury risk (d)threshold corridor for angular velocity and acceleration

Table 5 Logistic regression coefficients and statistics for probability of AIS3+ brain injury (MBS results)

	$\alpha\pm\sigma$	$\beta\pm\sigma$	X^2	p	$\alpha/\beta\pm\sigma$
HIC	2.169±2.495	0.0014±0.0015	2.175	0.140	1549.3±833.5
GAMBIT	1.878±2.349	0.7048±0.7433	1.085	0.298	2.7±2.9
HIP (kw)	1.885±2.361	0.0398±0.0447	1.488	0.223	47.4±28.6

3.2 FE reconstruction results

Figure 7 shows an example of FE reconstruction results that the fracture patterns on photo of a windshield after an accident and that from simulation are comparable.

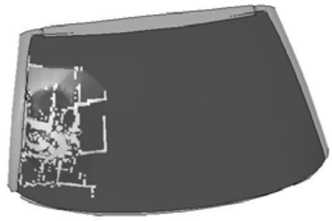

Figure 7 Fracture pattern of a windshield during an accident photo and a simulation.

Physical parameters including coup pressure, contrecoup pressure, Von Mises and shear stress calculated from FE reconstruction are shown in Table 6. Brain injuries occurred when coup pressure >122 kPa, contrecoup pressure < -140 kPa, Von Mises > 13.7 kPa and shear stress > 7.9 kPa.

Table 7 shows all the coefficients of logistic regression for probability of AIS3+ brain injury based on results from FE reconstructions. Concerned the *p* value, physical parameters exhibit the stronger correlation with AIS3+ brain injuries than the criteria based on kinetic parameters. Coup and contrecoup pressures exhibit the strongest correlation with AIS3+ brain injuries because their *p* values are less than 0.05.

Figure 9 shows the SIMon criteria results, including CSDM and DDM, calculated from FE reconstruction results.

Table 6 FE reconstruction results

Case Number	Coup Pressure (kPa)	Contrecoup Pressure (kPa)	Von Mises (kPa)	Shear Stress (kPa)	CSDM	DDM	Maximum AIS (MAIS)
Case 1	353	-271	26.9	15.5	2.0%	11.0%	4
Case 2	122	-140	13.7	7.9	5.6%	2.0%	1
Case 3	188	-195	15.7	9.0	3.1%	1.1%	3
Case 4	289	-262	33.3	19.2	13.3%	13.0%	3
Case 5	139	-181	16.3	9.4	1.6%	2.7%	2
Case 6	245	-236	25.6	14.8	12.2%	12.5%	4
Case 7	201	-197	22.1	12.8	2.0%	9.2%	2

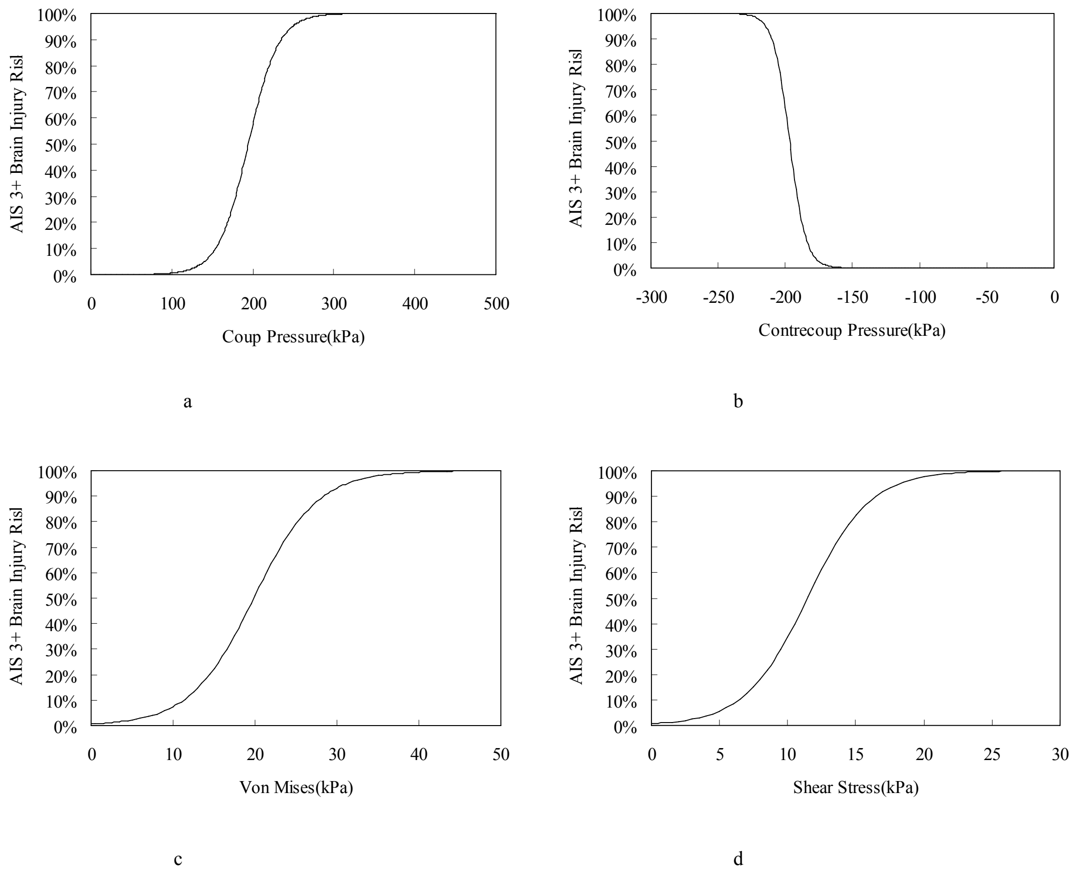

Fig. 8 Logistic regression curves for (a) coup pressure; (b) contrecoup pressure; (c) Von Mises and (d) shear stress, versus AIS3+ brain injury risk.

Table 7 Logistic regression coefficients and statistics for probability of AIS3+ brain injury (FE results)

	α±σ	β±σ	X2	p	α/β±σ
Coup Pressure (kPa)	10.6±9.1	0.054±0.047	5.749	0.017	195.5±25.8
Contrecoup Pressure (kPa)	32.6±48.5	-0.166±0.250	6.290	0.012	-196.8±14.6
Von Mises (kPa)	5.2±3.9	0.257±0.187	2.964	0.085	20.1±8.3
Shear Stress (kPa)	5.0±3.8	0.436±0.318	2.901	0.089	11.4±5.1

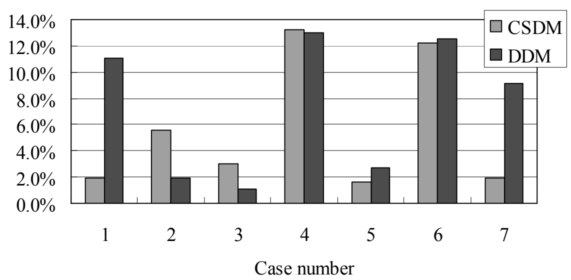

Fig. 9 SIMon criterion results (CSDM, DDM)

4. Discussion

Head injury mechanisms are complex especially for brain. Up to now, the brain injury mechanisms and tolerances remain controversial. However, existing head injury criteria could be used to predict injury types and risks. In current study we analyzed the prediction of different head injury criteria and discussed the 50 percentiles threshold of serious head injuries (AIS3+).

The correlations of all the criterion parameters with AIS3+ brain injury risk were examined using the logistic regression model, as shown in Fig. 7 and 8. For each injury related parameter, there is a critical value for *x*, where *P(x)* is 50% and where the injury risk shows a maximum increase.

MBS reconstruction results showed that when HIC value reached 1549.3 (Tab. 5), the pedestrian was likely to suffer AIS 3+ head injury with 50% probability. Based on EEVC WG17, 1998 [16] HIC value 1000 is used as the tolerance level representing 20% probability of head injury, while in the current study the probability of AIS 3+ when HIC =1000 was 32% (Fig. 6a). HIC exhibited a strong correlation with head injuries but the severity of brain injuries were not well predicted via HIC. For example, the AIS code was 4 while HIC was 1345.6 in case 1, but in case 5, HIC excess 2000 while the AIS code was only 2 (Tab. 4).

Newman [5] indicated that when *G(t)* value reached 1, slight head injury probably occurred. Table 5 showed the critical values of 50% probability of AIS 3+ head injury was 2.7. Also this information can be used as additional criterion of GAMBIT.

Newman proposed that when HIP reached 12.8 kW [6], cerebral concussion (AIS = 2) would be generated with 50% probability. In his study, SDH was likely to happen with 50% probability when HIP reached 50 kW. In present study, the critical value for HIP was 47.4 kW (Tab. 7). Cerebral concussion occurred in case 3, 5, 7 while the HIP was 48.2, 64.4, 42.5 kW, respectively (Tab. 5). All these values exceeded the proposed tolerance of 12.8 kW. Daniel et al. (2007) [17] proposed a HIP tolerance of 48 kW for severe head injuries. These values are closer to these of current study. Due to detailed formulation considering both linear and angular acceleration and impact direction calculated from MBS reconstructions, then HIP presented a good prediction probability studying case of head injuries.

Threshold corridors of head injuries concerning of the peak angular acceleration and change in angular velocity also showed good probability for predicting brain injuries, as showed in Figure 7d.

As the former criteria are based on the kinetic parameters, physical parameters such as stress and pressure in present study exhibited stronger correlation to brain injuries (Table 7). In this study, the critical value of coup pressure is 195.5±25.8 kPa and the critical value of contrecoup pressure is -196.8±14.6 kPa (Table 7). Ward et al. (1980) [18] proposed based on the experimental study a coup pressure tolerance of 235 kPa and contrecoup pressure tolerance of -186 kPa for serious brain injuries. Later Baumgartner (2001) based on FE model proposed pressure level of 200 kPa as an indicator of brain contusion, oedema and haematoma [7]. Also Yao et al.(2007) [14] suggested a coup pressure tolerance of 256±76kPa and a contrecoup pressure tolerance of -152±25 kPa for AIS 3+ brain injury. The critical values of these two pressure parameters between all these studies are comparable within a standard error. The differences may occur due to various FE head models.

In present study, the critical value of Von Mises is 20.1±8.3kPa and the critical value of shear stress is 11.4±5.1 kPa (Table 7). Currently Yao et al (2007) [14] proposed a Von Mises tolerance of 14.8±4.5 kPa and a shear stress tolerance of 7.9±1.6 kPa for AIS 3+ brain injury. Based on the reconstruction results of head to head collisions in professional American football games Zhang et al. (2004) [19] proposed a shear stress of 7.8 kPa as the tolerance level for a 50% probability to sustain a mild brain injury . The results from present study are at higher level than other reports but comparable within a standard error.

Eppinger et al. (2001) [20] proposed that slight DAI was likely to happen when CSDM reached 5.5% while serious DAI might occur when CSDM reached 22.7%. Cerebral concussion is considered to be the slight injury form of DAI. In present study, cerebral concussion is registered in case 3, 5, 7 while the CSDM are 3.1%, 1.6%, 2.0%, respectively. The results show weak correlation between CSDM and cerebral concussion.

In the present study DDM is used to predict contusions. Contusions were registered in case 1 and 7 while the DDM were 11.0% and 12.5%. Takhounts et al.(2003)[8] proposed that 50% probability of contusions was correspond to a DDM of 7.2%. Comparing results from our study with previous results the DDM showed better capability to predict cerebral injuries than CSDM. It was also confirmed by Daniel et al. (2007) [17] who pointed that CSDM showed bad correlation with DAI due to the simple geometry and fewer elements of head model. In order to get the relationship between CSDM and DAI, detailed and accurate FE head model is needed.

In current study, only 7 accident reconstructions were carried out due to the limited number of accident cases that are suitable for reconstructions. To improve the precision of calculated results, more accident reconstructions are needed.

5. Conclusion

MBS pedestrian and car models were effective in reproduction of the overall kinematics of a pedestrian in vehicle collisions. The head impact conditions at the moment of head impact against the bonnet and windshield can be calculated with accident reconstructions and used as input for injury reconstructions using head FE models.

Head injury criteria using kinetic parameters such as HIC and HIP can effectively predict head injury risk but still weak to predict detailed brain injuries. Physical parameters from FE reconstruction including coup/contrecoup pressure, Von Mises and shear stress are important predictors of brain injury risk. The critical values of these parameters, correlated to AIS3+ brain injuries with 50% probability, are 195.5 kPa, -196.8 kPa, 20.1 kPa, 11.4 kPa, respectively.

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