PEDESTRIAN-VEHICLE ACCIDENT: ANALYSIS OF 4 FULL SCALE TESTS WITH PMHS

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ABSTRACT

In industrialized nations, more than 25% of road traffic fatalities concern pedestrians. In some large urban areas, pedestrians account for as much as 40 to 50 percent of traffic casualties. To investigate pedestrian impact requirements for regulation in Europe, four full-scale pedestrian impact experiments were performed on embalmed PMHS. Two impacts were conducted in a standard condition with the PMHS laterally at the center line of the vehicle with the struck-side limb positioned anteriorly. The 2 other tests were a reconstruction of two real accidents and the PMHS were hit by the vehicle front laterally from ¾ right. Each PMHS was instrumented to measure the acceleration at points along the lower limb, the pelvis, the head. Pedestrian height being an important factor in the type of injuries sustained, the vehicle profile in relation to pedestrian height was recorded. After each test, a necropsy of each PMHS revealed the injuries to the tested PMHS. The distribution of vehicle contact areas and throw distance were noted. Because the head and lower limbs are the most commonly injured body parts for adult pedestrians, with head injury being the main cause of fatality, the analysis was focussed on these two body parts. The kinematics response of the pedestrian surrogates head was measured using precisely located targets. In particular, head velocity and head impact angle on the windscreen have at the instant of the impact been evaluated. The results provide complementary data for future pedestrian test methods and biofidelity assessment of a pedestrian dummy.

INTRODUCTION

Pedestrian crashes constitute the most frequent cause of traffic-related fatalities worldwide. On Europe roads, around 6 000 pedestrians are killed every year [3]. This translates in a death rate for the EU for 2002 of 15.7 killed pedestrians per 1 Million inhabitants. In Australia this figure is 12.3, in the USA 16.4 and in Japan 21.8. In developing nations, the number of killed vulnerable road users is even higher. The high number of pedestrian accidents justifies more safety efforts worldwide.

Full scale experimental studies were performed to represent condition of pedestrian accident. If impact configurations are complex and varied, nevertheless it can be seen that lateral impacts make up for 74% of pedestrian collision (Henary B, 2003). Chidester and Isenburg (2001) reports that 356 (68%) of the pedestrians struck were oriented with their side to the striking vehicle, with 89 (17%) facing the vehicle and 53 (10%) facing away.

Head (31.4%) and legs (32.6%) each accounted for about one-third of the AIS 2-6 pedestrian injuries (Mizuno, 2003). But pedestrian injuries depend on a lot of parameters as the subject anthropometry, the initial position of the pedestrian, the front-end vehicle geometry which influences its kinematics (Meissner, 2004).

Many tests have been performed to study the behaviour of the pedestrian positioned laterally at the vehicle center line in a mid-stance gait position ("standard position"). Kerrigan et al (2005) studied mainly the kinematics of the pedestrian lower limb during impact and the kinematics of the head just before impact on the windscreen. The purpose of Kam's study was to document the development of a full-scale pedestrian impact test plan for dummies and PMHS. These tests were designed to accurately reproduce the kinematics and some of the injuries experienced by pedestrians struck laterally.

The primary objective of the current study was to examine the pedestrian behaviour according real accidents conditions. Four full-scale pedestrian impact experiments were performed on embalmed PMHS. Two initial positions of the pedestrian were studied. The first concerns the "standard position", the pedestrian were struck laterally. The second is based on real accidents reconstructions, with a ¾ frontal right pedestrian struck.

MATERIAL AND METHODS

PMHS preparation and characteristics

All PMHS were obtained and treated in accordance with the ethical guidelines approved by the Timone Faculty of Medicine in Marseille, and all PMHS testing and handling procedures were approved by the Ethical committee of the Faculty of Medicine too. The subjects were embalmed and preserved at 3°C in Winckler's preparation which is made of many standard embalming ingredients: phenol, alcohol, formalin, glycerin, sodium and magnesium sulfate, potassium nitrate. Based on Crandall study, this fluid distorts only a few of the properties of hard tissues and the results for Winkler fluid appeared to approximate most closely those of the fresh tissue (Crandall, 1994). It allows to keep supple the sampling and to preserve for several months the soft tissues elasticity. Prior to testing, anthropometrical measurements were made and X-Rays radiographs of the body were taken to verify the osseous integrity. Mean anthropometric characteristics of PMHS used in this study are given in Table 1.

Table 1.
Cadaver Physical data

	Test01	Test02	Test03	Test04
Gender	M	M	M	M
Age	88	74	85	80
Height (cm)	175	185	161	175
Weight (kg)	67	86	44	62

Full scale methodology

Prior to the vehicle striking him, the PMHS was maintaining in initial position by a neck harness. This harness was attached to a tension load cell which determined the timing of surrogate release. It was switched off 10 milliseconds before the impact so the subject was submitted to the gravity during the 10 ms before the impact. This allowed for the subject to be nearly freestanding at the initial bumper contact and to take into account the friction shoe-ground as it is in reality. After positioning of the subject was complete, the car was propelled by a horizontal catapult toward the pedestrian and was decelerated 10ms after the impact.

Positioning

Two aspects of pre-crash stance were considered for this study. Two impacts were conducted with the PMHS in standard position. The 2 other tests were a reconstruction of two real accidents.

Standard position

Body orientation: Pedestrian is impacted on its right side. A lateral impact was chosen as standard position because this position is representative of real world accidents as a majority of pedestrians are struck laterally by a vehicle.

Leg positioning: both feet are in contact with the ground and support the body's weight equally. The width between both feet was chosen to have a stable stance.

Position in real accidents

Body orientation: the PMHS were hit by the vehicle front laterally from ¾ right, at the center line of the vehicle

Leg positioning: both limbs are in contact with the ground. The struck leg was back along the centerline of the vehicle.

Test Matrix

Four full-scale pedestrian impact tests were performed. The vehicle used for the standard tests are a small one (Test01) and a big one (Test02).

Table 2.
Test matrix

Subject position	standard	standard	Real position	Real position
Speed	39.2km/h	39.7km/h	29.7km/h	37.2km/h
Vehicle	Small sedan	Big sedan	Small sedan	Big sedan

Instrumentation and measurement

The instrumentation was mounted on the posterior side of the subject to avoid damages in the instrumentation during impact. The PMHS was instrumented with accelerometers fixed on the lower limb and the head. Four high-speed video cameras operating at 1000 frames per second were placed in order to record the kinematics during the impact event. After the test, the car deformations, the Wrap Around Distance (WAD) to head strike was measured. The WAD corresponds to the distance between the head impact and the floor along the front end of the car. An in-depth necropsy was performed. Trajectory and velocity data for the head were calculated from films.

RESULTS

Accelerations of the tibia and head

Head and proximal part of the tibia accelerations were recorded. Due to the variability in subject anthropometry, the PMHS responses were normalised to the standard characteristics of the 50th percentile male weighing 75kg (Eppinger, 1984). The scaling variable λ and the scaled test parameters with subscript *s* were expressed in terms of the initial parameters with subscript *i* in following equations.

Scaling variable $\lambda = (75/M_i)^{1/3}$ (1)

Velocity $V_s = V_i$ (2)

Acceleration $A_s = A_i / \lambda$ (3)

Time $T_s = \lambda \times T_i$ (4)

Acceleration-time histories are presented in Figures 1-4 for each test. The time of initial contact between the vehicle bumper and the PMHS's lower extremity was defined to be *t*=0.

Head impact occurred earlier in the standard tests (around 120ms after leg impact) than in real reconstruction (around 174ms after leg impact). We noted higher acceleration levels in real reconstruction (103g-112g) than in standard tests (67g-90g) although impact velocity was lower, especially for the test03. Moreover, if head impact peaks are very short in the case of real accident, the head acceleration at the head impact is clearly longer.

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Figures 1-4 (a) show the tibia acceleration during the first 25ms because the study focussed on the knee and leg injuries associated to the front bumper impact. Tibia acceleration showed a first initial peak with peak values between 89g (test03) and 245g (test02-test04), these two tests having been performed with the big sedans at a almost identical impact velocity. In test02, a second peak is recorded in the tibia acceleration around 3ms after the first one, with a peak value of 766g. After 15ms, in three tests (test01, test02, and test04) the tibia is accelerated again until a significant peak value. The analysis of these peaks will be proposed in the discussion according to necropsy results given the injuries sustained in each test.

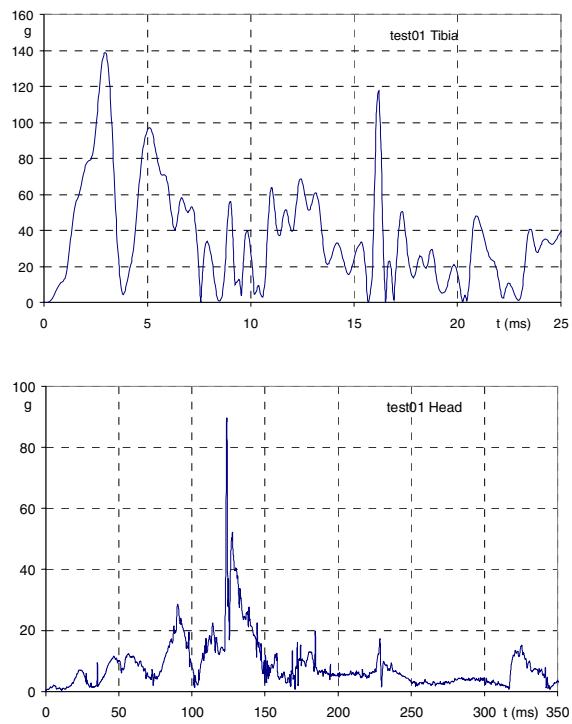

Figure 1. Test01: tibia acceleration (a) and head acceleration (b).

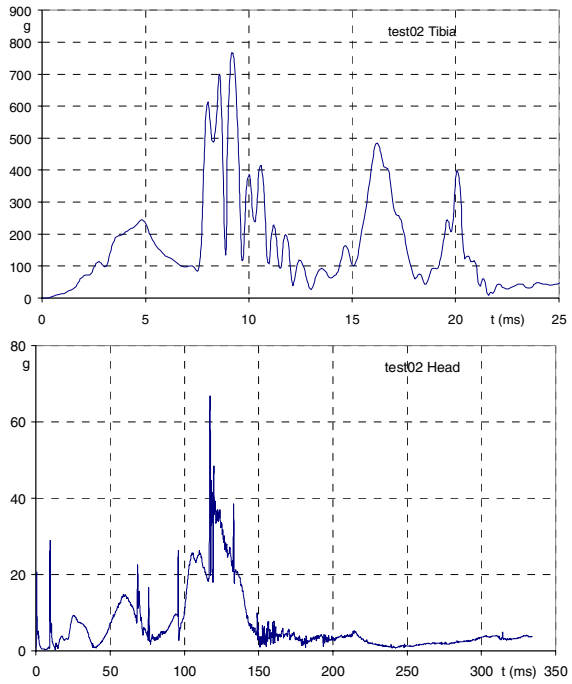

Figure 2. Test02: tibia acceleration (a) and head acceleration (b)

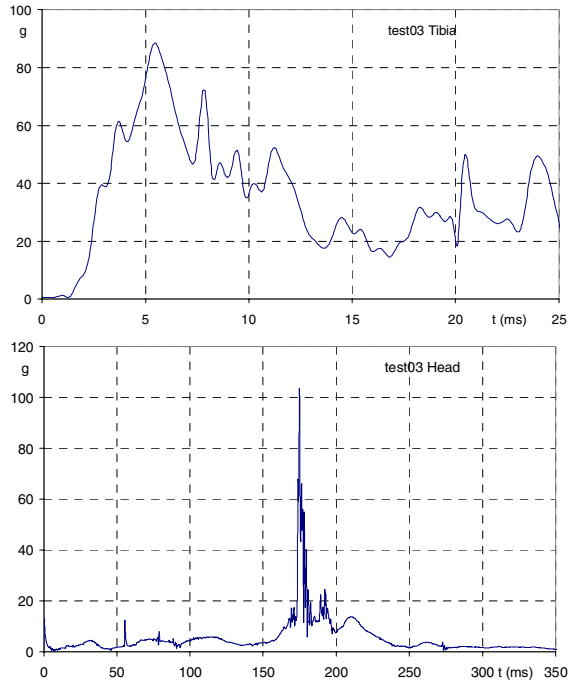

Figure 3. Test03: tibia acceleration (a) and head acceleration (b).

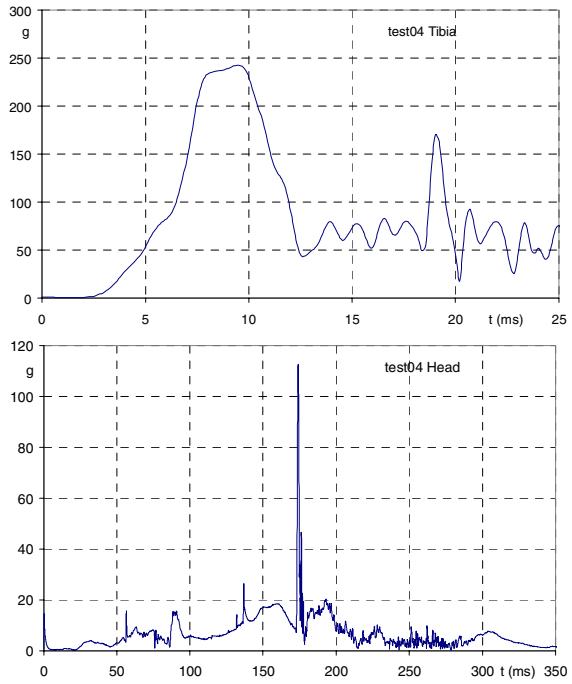

Figure 4. Test04: tibia acceleration (a) and head acceleration (b)

Kinematics

An important parameter is the specific pedestrian kinematics. The cinematic response of the pedestrian PMHS was evaluated using photo targets mounted on the head, on the proximal and distal parts of the femur, and on the proximal and distal parts of the tibia. The motion of each photo target was measured by recording the location of each photo target from high speed video images. The frame coordinate system, defined by the view of the high speed imager, is fixed with respect to the laboratory. A vehicle coordinate system was defined too.

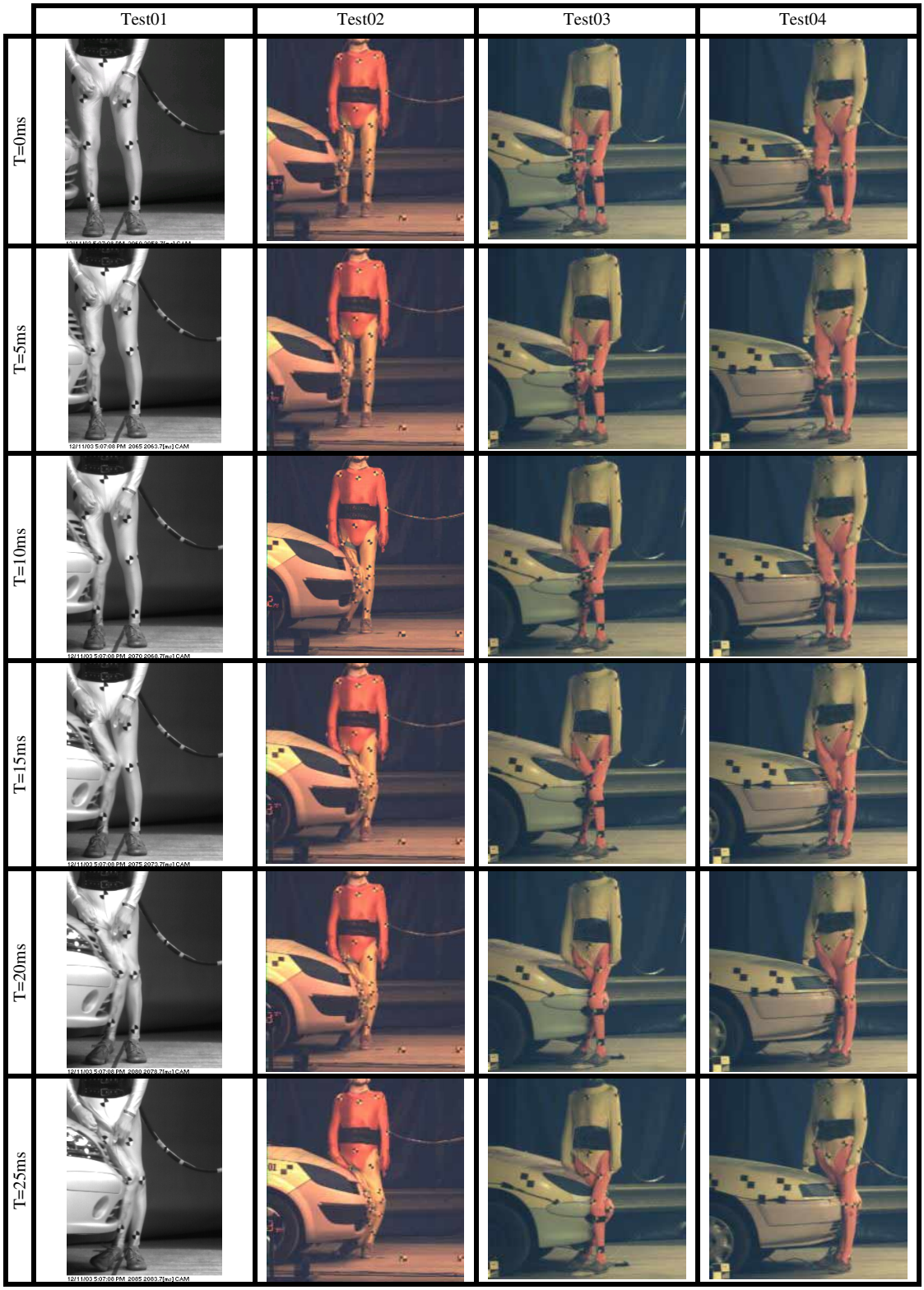

Figure 5. High speed video images for the lower limb.

Figure 6. High speed video images for the head.

Figure 5 shows the kinematics of the first impacted lower limb during the first 25ms. The first contact occurred between the bumper and the leg, followed by the pelvis or thigh-to-bonnet edge contact.

In the full scale tests in standard position, the right lower limb impacted then the left lower limb. This second impact occurred at 30ms in the test01, and at 15ms in the test02. In the full scale tests in real situation, because of a more frontal initial position, the bumper impacted the second lower limb directly after 24ms in the test03 and after 26ms in the test04.

Figure 6 shows the kinematics of the head. In each test a visual examination of the video data allowed to determine the time of head strike. The head impact velocity, in the vehicle coordinate system, and head impact angle were measured and are given table 3. There is a significant difference in the shape of the head trajectory with head impact angles between 33° and 50°. Head impact velocities differed too, and for an equivalent car impact speed in the same PMHS initial posture, they could be lower (test01) or higher (test04) than the impact vehicle velocity.

Table 3.
Impact velocity and angle of the head

	Test01	Test02	Test03	Test04
Head impact velocity	37km/h	58km/h	30km/h	46km/h
Head impact angle	33°	50°	42°	42°

Necropsy

After testing, radiographs were taken and pre- and post-radiographs of the both lower limbs were analysed and compared. The post test necropsy results are presented in table 4. Only one fracture of the tibial diaphysis was observed. Ligament damages were observed in 3 tests in which the anterior cruciate ligament of the first impacted leg, the right one, was always injured. The PMHS used in the test01 sustained a lot of lower limb injuries, in particular bone damage were noted in the second impacted lower limb.

Table 4.
Necropsy results

	Test 01	Test 02	Test 03	Test 04
Right knee				
Knee ligaments				
MCL	×			×
LCL				
ACL	×	×		×
PCL	×			
Articular capsule	×			
Fracture of the femur				
internal condyle	×		×	
external condyle				
Fracture of meniscus				
Fracture of the tibia				
plateau	×			
diaphysis		×		
spine				
malleolus			×	
Fracture of the fibula				
diaphysis		×	×	
malleolus				
Left knee				
Knee ligaments				
MCL				
LCL	×	×		
ACL				×
PCL				
Articular capsule	×			
Fracture of the femur				
internal condyle	×		×	
external condyle	×			
Fracture of meniscus	×			
Fracture of the tibia				
plateau	×	×		×
diaphysis				
spine	×			
Fracture of the fibula				
diaphysis				
malleolus				×

DISCUSSION-CONCLUSION

Four full scale tests were performed with PMHS. In two tests, the pedestrian had an initial lateral position (standard position) and in the next two tests, the pedestrian was impacted by the vehicle front laterally from ¾ right with a significant lower car impact velocity in one case (test03). These different initial configurations induced different consequences on the lower limb accelerations, head impact velocities and head impact angles.

The results have showed a higher tibia initial acceleration in two tests (test02 and test04). For both tests, the vehicle used was a big car and the impact speed around 39km/h. An identical impact velocity was chosen in test01 but the full scale test was performed with a small sedan. This suggests that shape and model of the car has an effect on the tibia acceleration more significant than car velocity only. Because of the small number of tests, this suggestion has to be confirmed

In the pedestrian leg impact requirement, the acceleration measured at the upper end of the tibia shall not exceed 200 g. (DIRECTIVE 2003/102/EC) to avoid contact bone fractures. In this present study, only one tibial diaphysis fracture was listed, but the maximal acceleration was around 760g. Peak acceleration around 200g induced no bone fracture. But the impact locations of the lower leg depend directly on the posture and the height of the pedestrian. An improved understanding of the relation between bumper height and knee-joint injuries is need.

Ligament injuries were noted in 3 tests, two tests being in standard position. With a lateral pure impact as test01, the knee was bent laterally without bone fracture; leading to medial collateral ligament injury Nevertheless in this kind of initial posture, the lateral position of the left lower limb in the tests induced injuries of collateral ligaments on the left knee while the ¾ right latero-frontal position of the PMHS in the tests in real configuration induced cruciate ligament injuries. The second tibia acceleration peaks, recorded 15ms after the impact seem to be due these ligament injuries.

The kinematics response of the head was analysed in the four tests. The head impact velocity and the head angle were calculated in the vehicle system to be compared to EEVC tests. Generally, between the time of initial impact and head impact, the pedestrian is accelerated up to the velocity of the vehicle. The ratio

of the head velocity to the car travel speed is 0.66 for the test01, 1.1 for the test02, 0.67 for the test03, and 1.12 for the test04. These results are in agreement with the ratios reported by Pritz. for big cars and Cavallero et all (1983) for small cars;
The head impact angle differed in the 4 analysed cars. The different pedestrian heights do not explain the variation in the measurement of the impact angle. An identical impact angle was found for two tests (test03, test04) while the pedestrian height was 161 cm (test03) and 175cm (test04). Moreover, the car velocity was higher in test04.

The pedestrian head impact requirement, proposed by the EEVC, with an impact angle and a head impact speed not depending on the car geometry do not reproduce correctly real conditions of pedestrian accident. It appears that new requirement have to be develop more especially for the head protection.

ACKNOWLEDGEMENT
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REFERENCES

Akiyma A., Okamoto M., Rangarajan N. 2001 "Development and application of the new pedestrian dummy". Paper 463, 17th Conference on the Enhanced Safety of Vehicles, Amsterdam, The Netherlands.

Cavallero C, Cesari D, Ramet M., Billault P., FarisseJ., Seriat-Gautier B., Bonnoit J. 1983. "Improvement of pedestrian safety: influence of shape of passenger Car-Front structures upon pedestrian impact injury & assessment", SAE pp225-237

Chidester A, Isenberg R. 2001. Final Report – The Pedestrian Crash Data Study. National Highway Traffic Safety Administration. United States of America. Paper Number 248.)

DIRECTIVE 2003/102/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 17 November 2003 relating to the protection of pedestrians and other vulnerable road users before and in the event of a collision with a motor vehicle and amending Council Directive 70/156/EEC

Henary B, Crandall J, Bhalla K, Mock C, Roudsari B. 2003. "Child and Adult Pedestrian Impact: The Influence of Vehicle Type on Injury Severity". 47th Annual Proceedings, Association for the Advancement of Automotive Medicine, 22-24

Kam CY, Kerrigan J, Meissner M, Drinkwater C, Murphy D, Bolton J, Arregui C, Kendall R, Ivarsson J, Crandall J, Deng B, Wang JT, Kerkeling C, Hahn W.2005 "Design of a Full-Scale Impact System for Analysis of Vehicle Pedestrian Collisions."Paper 05-433

Kerrigan J., Murphy D., Drinkwater D., Kam C., Bose D., Jeff R. Crandall J. 2005. "Kinematic corridors for PMHS tested in full scale pedestrian impact tests. Paper Number ESV 05-0394

Meissner M, van Rooij L, Bhalla K, Crandall J, Longhitano D, Takahashi Y, Dokko Y, Kikuchi Y. 2004 "A Multi-Body Computational Study of the Kinematic and Injury Response of a Pedestrian with Variable Stance upon Impact with a Vehicle". SAE 2004 World Congress, SAE Paper #2004-01-1607

Pritz H. B.1983 "Experimental investigation of pedestrian head impacts on hoods and fenders of production vehicles". SAE 67-76