Pedestrian Model for Injury Prediction for Lateral Impact

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ABSTRACT: World-wide statistics still reflect a high percentage of seriously injured pedestrians in the urban areas. The lateral impact is the most common type of traffic accident in towns. This paper describes the validation of a pedestrian model that will be able to assess the type and level of injury. The human model used is rigid body based with realistic biomechanical joints. The human body model is validated for the case of a lateral pedestrian impact using published experimental cadaveric data. Particular body segment trajectories fit into given kinematic corridors. Based on the standard injury criteria the pedestrian model is able to predict life threatening risk.

KEY WORDS: Biomechanics, virtual human model, pedestrian impact.

1 INTRODUCTION

Walking is the most natural way to get from one point to another. As stated by the European Commission around 17% of all traffic fatalities in EU countries are with pedestrians. Based on the study (Maňas et al. 2009) pedestrians in the Czech Republic belong to a group of the most at risk vulnerable road users. The above mentioned study also summarizes that pedestrian road accidents are the most frequent in urban areas with a passenger car impact velocity up to 50km/h. Pedestrian protection is therefore still an important topic, as is also shown in the study of Obermann & Kovanda (2009).

In his article, Ishikawa et al. (1993) analyzes possible pedestrian impact scenarios and summarizes that the most frequent accident type corresponds to a lateral impact when a pedestrian is crossing the road.

The limited biofidelity of dummy models and, especially the actual tendency towards human models legalization (Haug et al. 2003) are the driving force for the creation of correct human body models. The aim of this study is to obtain a validated pedestrian model able to give the overall injury analysis and able to serve for the improvement of safety components in means of traffic.

The used human model Robby (Hynčík, 2001) belongs to a family of Human Articulated Rigid Body (HARB) models (Haug et al. 2004) developed on the PAM computational platform (PAM-System, 2009). The model consists of rigid bodies separated into segments connected by biomechanical joints (Robbins, 1983).

2 METHOD

2.1 External experimental background

The model is validated using both literature sources (Ishikawa et al. 1993; Kerrigan et al. 2005; Simms & Wood, 2006; Stammen & Barsan-Anelli, 2001) involving experiments with PMHS (Post Mortem Human Subject) and dummies, and also, in several cases, using computer simulations of performed tests. As a key source the work of Kerrigan et al. (2005), presenting the detailed description of the experiment with a full-scale pedestrian impact, is chosen.

The pedestrian in the mid-stance phase of a gait cycle is positioned laterally in front of the car. This position is the most characteristic of real pedestrian collisions and, moreover, represents a significant part of the normal gait cycle (Kam et al. 2005). The mid-stance is the period of the gait between the first contact of the front leg (heel strike) and the last contact of the rear leg (toe off) with the ground. It occupies the period from 7% to 32% of the gait cycle. The test was realized three times with cadavers and then with a Polar II Dummy with an impact speed of 40km/h (11 m/s). The experimental corridors for body segment trajectories scaled to 50 percentile male were established and the head velocity corridors were published. The analysis was focused only on the primary impact which is limited by the first contact of the car and the pedestrian and the head strike to the windscreen.

2.2 Impact scenario setup

The original Robby model of an average male (Robbins, 1983) is used. The Robby is 174 cm tall and he weighs 74 kg. The relative position of the car and the pedestrian is set according to the experiment (Kerrigan et al. 2005). It means that Robby in the mid-stance phase of the gait cycle is standing laterally to the car front with the struck limb in front, see Figure 1. The hands are connected together ahead of the body to restrict their influence on the body kinematics during the crash.

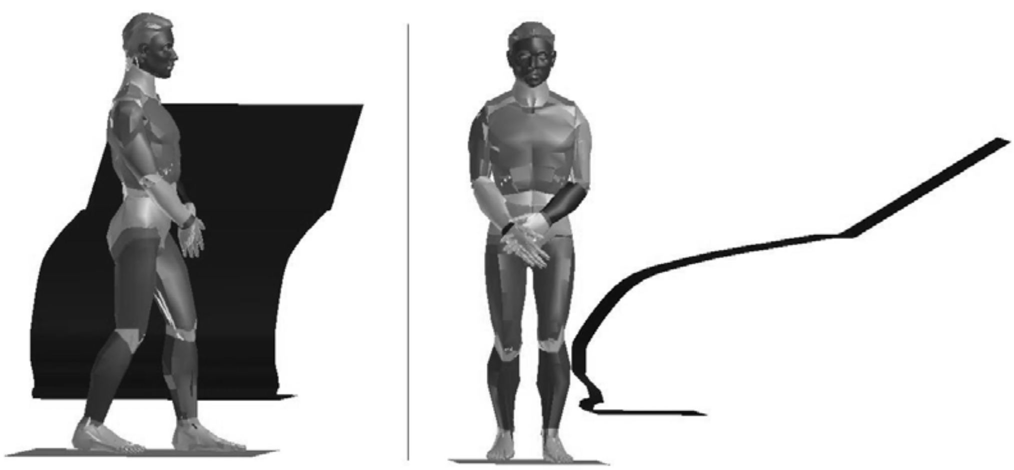

Figure 1: Pedestrian impact model, starting position.

Main car characteristics significantly influencing the seriousness of the pedestrian injury are the mass, the face geometry, and the stiffness. The car profile geometry is adapted from Kerrigan et al. (2005). Despite the precise description of the test itself, the publication lacks detailed information about the car material characteristics. Hence additional literature sources (Simms & Wood, 2006; Stammen & Barsan-Anelli, 2001) are used to complete the model parameters. The car is modeled as rigid with parameters defined according to a real small car, as reported in Table 1. The Robby's friction coefficient with the ground is set to 0.65, and with the car structure to 0.25 according to Ishikawa et al. (1993).

Table 1: Table of used car parameters, adapted from (Simms & Wood, 2006).

m [kg]	I_{xx} [kg mm^2]	I_{yy} [kg mm^2]	I_{zz} [kg mm^2]
1200	425e+6	1933e+6	2020e+6

A special contact type, including the stiffness characteristics of real car material properties, is used (PAM-System, 2009). It enables the simulation of a more realistic impact behavior of rigid bodies. The used bonnet and windscreen characteristics displayed in Figure 2 are adapted from (Simms & Wood, 2006).

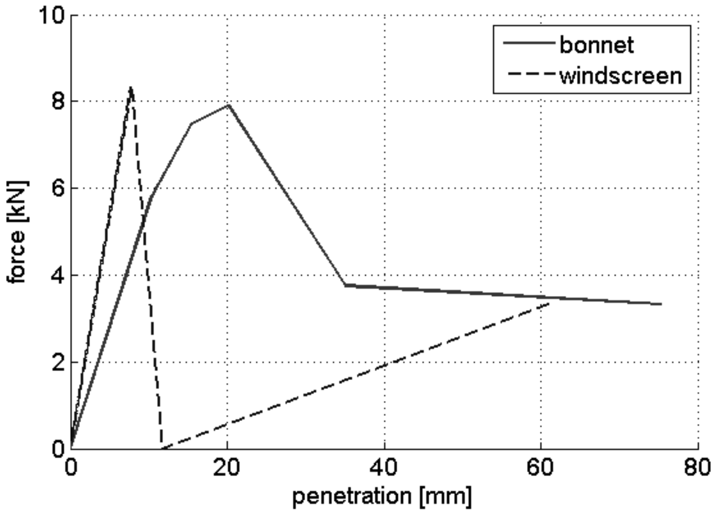

Figure 2: Car force penetration dependency, adapted from (Simms & Wood, 2006).

3 RESULTS AND DISCUSSION

3.1 Kinematics

The model kinematics is compared to the published experiments (Kerrigan et al. 2005). The car impacts the pedestrian at knee level, gathers him, and his body slides on the bonnet till the head hits the windscreen; at this instant both the computation and the experiment are stopped. The sequence of the pedestrian motion with the time step 20 ms is shown in Figure 3. The front struck limb tends to turn the model back, which was also proved by Kam et al. (2005). The body parts trajectories in the plane of the vehicle motion lie within the experimental corridors as can be seen in Figure 4 and Figure 5. The head velocity also fits in the experimental corridors, as shown in Figure 6.

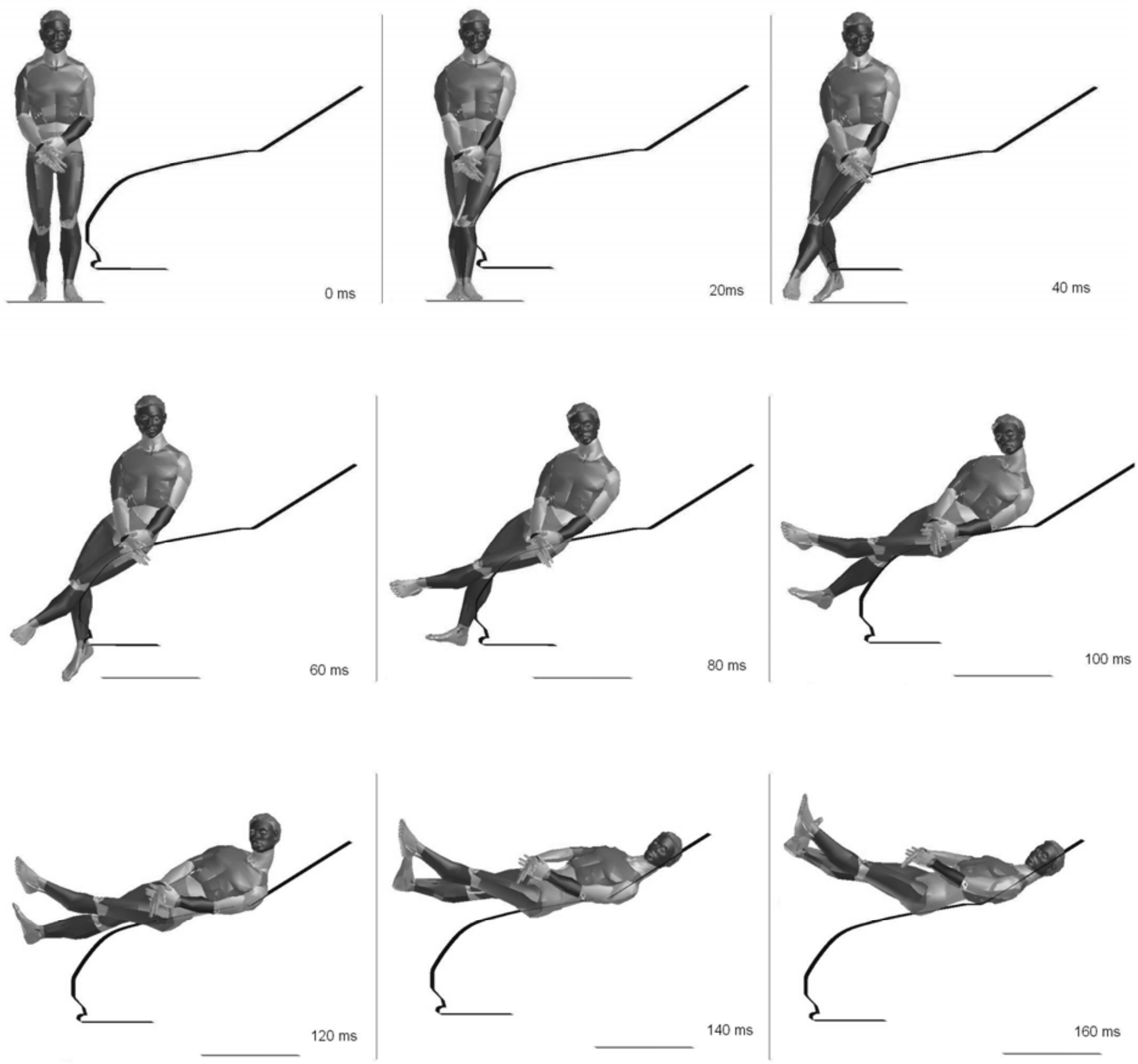

Figure 3: Time sequence of the impact simulation.

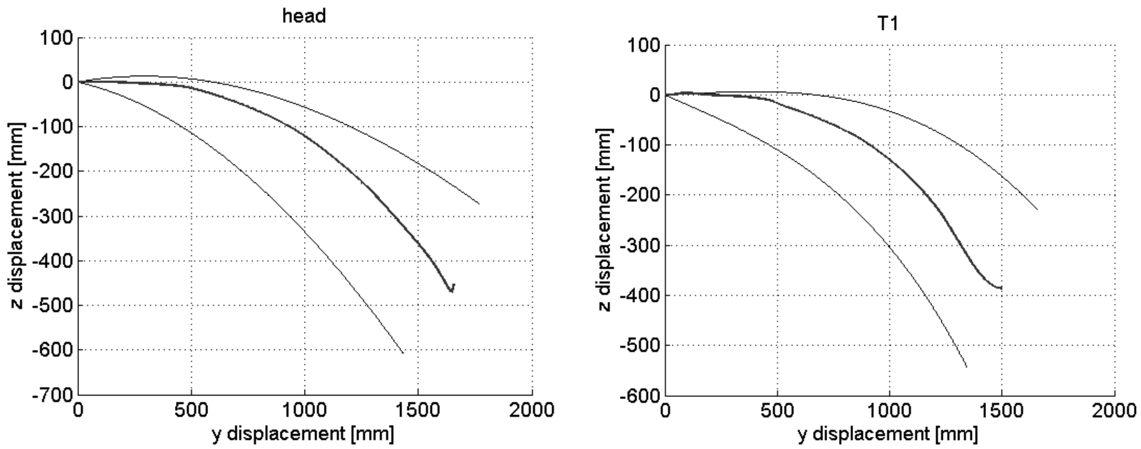

Figure 4: Trajectories of the head (left) and the T1 vertebra (right) in the experimental corridors (black lines) in the mediolateral plane.

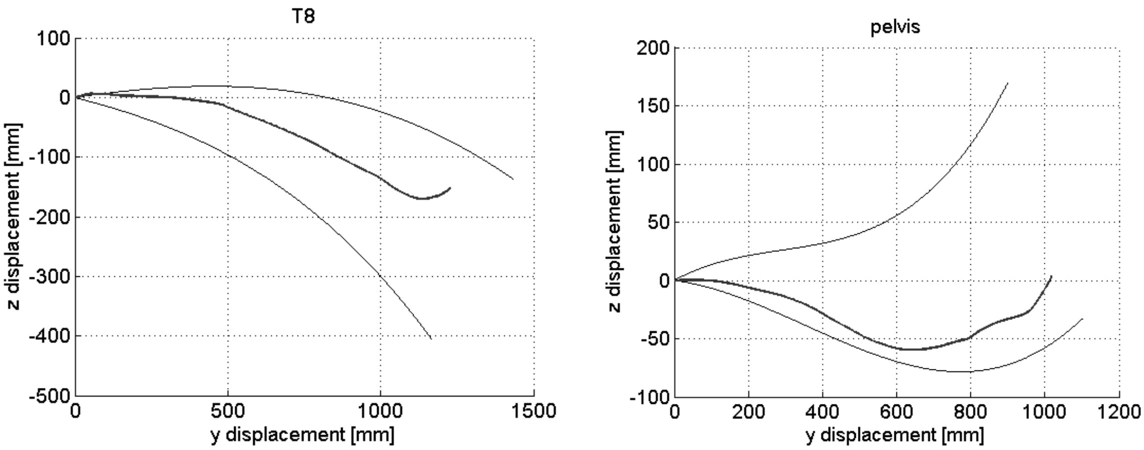

Figure 5: Trajectories of the T8 vertebra (left) and the pelvis (right) in the experimental corridors (black lines) in the mediolateral plane.

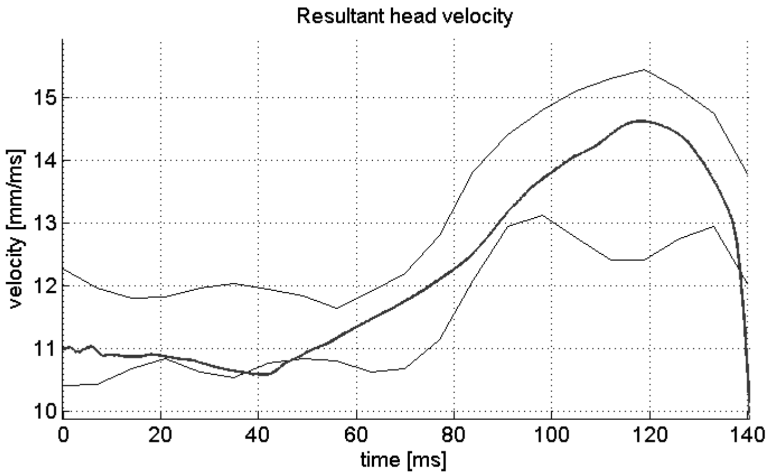

Figure 6: Head resultant velocity in the mediolateral plane in comparison with the experimental corridors (black curves).

3.2 Injury prediction

With regard to the successful kinematic model validation a degree of pedestrian risk can be predicted in the sense of directory information. Since Robby is a rigid body based model, injury criteria based on body parts accelerations are used. Despite being highly simplified, they perform an adequate estimation of injury level and their development results from many experiments (Schmitt, 2004).

The standard head injury criterion HIC_{36} is applied. It performs the 50% risk of skull fracture that is qualified as AIS $\geq$ 2 (Schmitt, 2004). The thorax injury is estimated using the 3ms criterion indicating the 25% risk of AIS $\geq$ 4 (Schmitt, 2004). The pelvic peak acceleration for pelvis fracture is 73 g as reported by Zhu et al. (1993). This criterion was derived from side impact with cadavers and it is also used by Simms & Wood, (2009) to indicate the pedestrian pelvic injury. The knees, especially in the case of a side impact, are under threat of bending. The maximum mediolateral bending angle according to van Rooij, (2003) is around 13 degrees.

Table 2: Injury analysis.

	HIC_{36} [-]	3ms [g]	Pelvis [g]	Knee bending angle [deg]	
				Right leg	Left leg
Injury limit	1000	60	73	± 12.7	± 12.7
Robby 40km/h	1483	66	80.6	26, -41	14, -57

All tested injury criteria and their limit values are summarized in Table 2. It is obvious that the tested criteria exceed their limits. Figure 7 demonstrates the knees' movement during the impact and the confrontation with the limit values. In conclusion, the pedestrian suffers serious injuries in all controlled body parts.

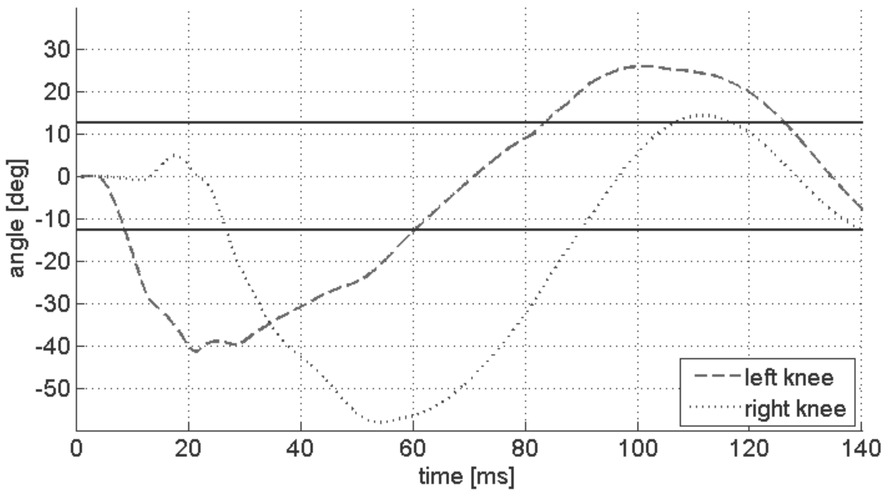

Figure 7: Pedestrian knee bending angles (dashed and dotted line) during the lateral impact and the injury limits (solid lines).

4 CONCLUSION

The previously developed rigid body based human model is validated in the full-scale pedestrian impact. Simulation results are compared to published cadaveric experimental data. Real car characteristics, including a detailed car profile, are used. All monitored body segments trajectories fall within the experimental corridors.

Despite the injury values only giving a general indication of the severity rather than a precise injury prediction, they perform as an appropriate tool in the case of rigid body based models. The presented injury analysis of the lateral impact in relatively low velocity (40 km/h) indicates the serious pedestrian injuries to the head, thorax, pelvic area, and both knees.

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