

Development and Validation of a Six-Year-old Pedestrian Finite Element Model

Introduction

Child pedestrian protection deserves more attention in vehicle safety design since they are the weakest road users who face to the highest mortality rate. Finite Element (FE) models can be used to simulate the human body. Several pediatric pedestrian models have been developed and applied in the simulations of car to pedestrian collision (CPC) using multibody [1] and finite element methods [2, 3]. These existing models have several inherent limitations due to the lack of pediatric material data and age-dependent anatomical data.

The first objective of this study was to develop an advanced and computationally efficient FE model corresponding to a 6 year-old pedestrian child. The second objective of the study was to update the material properties of long bones. Finally, this study performed validation tests on the FE model and compared the results with test data using PMHS.

Methods

The child FE model (6YO) was developed based on an existing GHBM adult pedestrian model (Fig. 1). The model has a height of 117 cm and a mass of 23.86 kg. The FE model mesh was scaled by body regions and manually morphed to match child anthropometric data[4]. The material properties and contact definitions of model components were generally kept as similar to those in the detailed M50 pedestrian model. The material of long bones were improved based on the three-point anterior-posterior (AP) bending tests data.

In experimental tests, long bones of lower extremities (femurs and tibias) were loaded until fracture under quasi-static three-point AP bending [5] (Fig. 2). The long bone bending tests were simulated in LS-DYNA software under simplified conditions due to limited published test information. The FE models of the impactor, cup supports and ground were defined as rigid bodies. Nodes on both bone's ends were rigidly attached to the cup supports which were supported by the fixed ground. An impactor loaded the long bone at its middle location constantly with the same velocity as in testing.

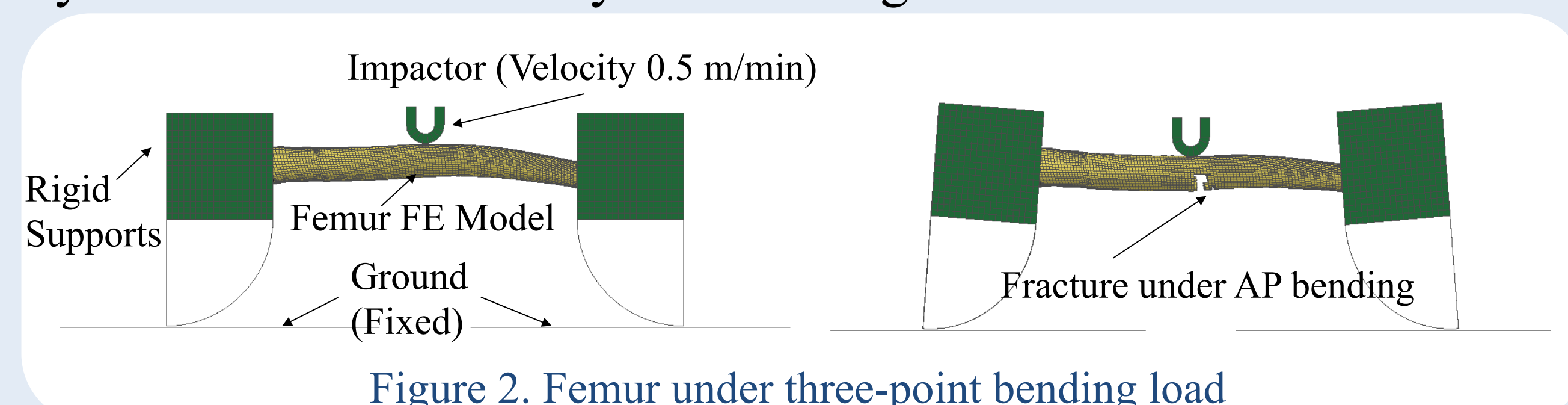


Figure 2. Femur under three-point bending load

The stability of child FE model (6YO) was verified during CPC simulation [6]. As in the previous CPC simulation with a 50th male pedestrian[7], the child FE model was set in a mid-stance gait posture and was impacted laterally by the vehicle model. Gravity was assigned to the model and the child model was preloaded before the impact through the ground by a force corresponding to the model's weight. Appropriate contacts were assigned between the vehicle and pedestrian models and a 40 km/h initial velocity was assigned to the vehicle model (Fig. 3). The model stability and overall behavior were verified and the injuries predicted by the model were investigated.

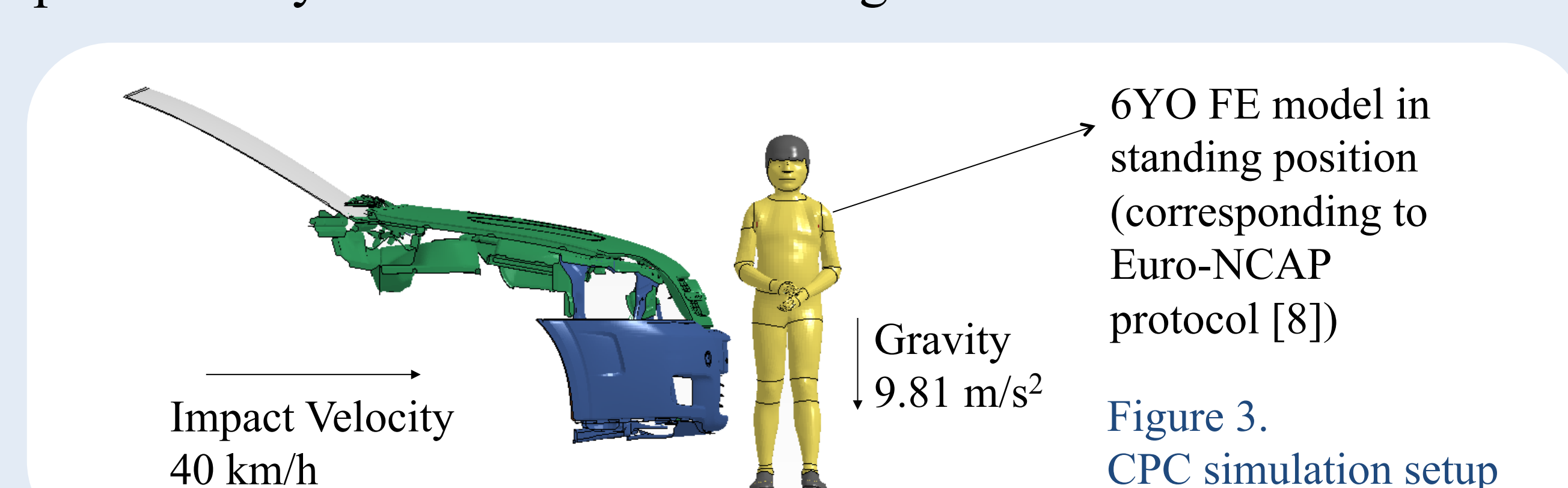


Figure 3. CPC simulation setup

Acknowledgement

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Results and Discussion

The material properties of the long bones were updated based on pediatric data from literature [9] or by scaling adult data during the validation of lower extremities at the component level (Table. 1).

Table 1. Material Properties of Long Bones	
	Material Properties
Femur	E = 9 GPa; $\nu=0.28$; $\sigma=0.0708$ Gpa; Failure strain =0.8%
Tibia	E = 11.67 GPa; $\nu=0.28$; $\sigma=0.0708$ Gpa; Failure strain =0.8%

The child pedestrian FE model showed numerical stability under CPC. The initial contact between the child pedestrian and the vehicle started at around 8ms. The right leg of the model was first impacted by the bumper, and then the torso rotated around the hood. The 6YO FE model head contacted with vehicle hood at around 76 ms. So the Head Impact Time (HIT) was recorded as 68 ms and the Wrap Around Distance (WAD) was 1125 mm (Fig. 4).

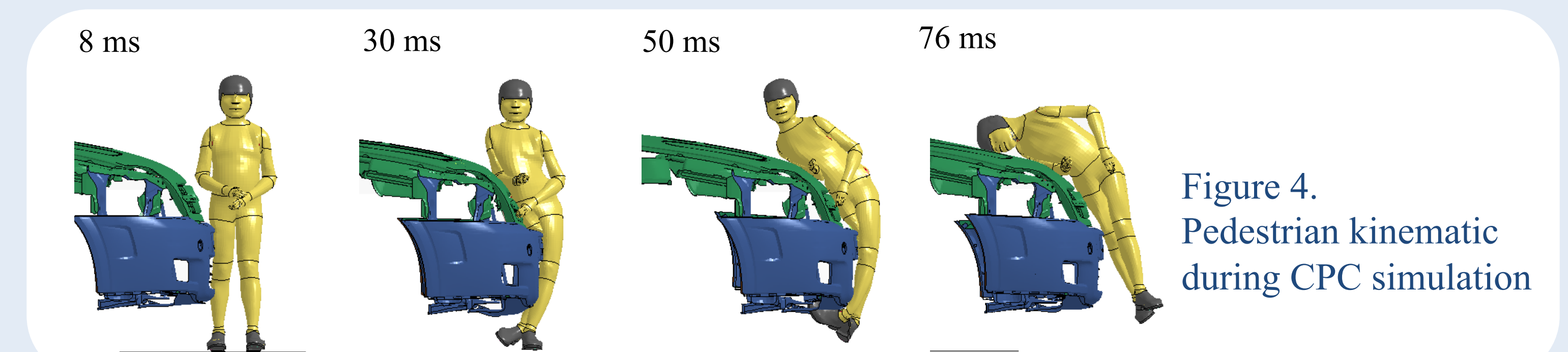


Figure 4. Pedestrian kinematic during CPC simulation

Injury mechanisms were also investigated on the results of CPC simulation (Fig. 5). Long bone fractures and ligament tears were observed. First, the right femur of 6YO FE model was impacted by the bumper and a fracture was predicted to occur at about 14 ms. Then the right knee was subjected to varus bending and its Medial Collateral Ligament (MCL) failed. After the body rotated around car front end, the left knee was subjected to valgus bending and a failure of its Lateral Collateral Ligament (LCL) was at 33 ms. Finally, two fractures in the left tibia and fibula near the ankle region was also observed around 41ms.

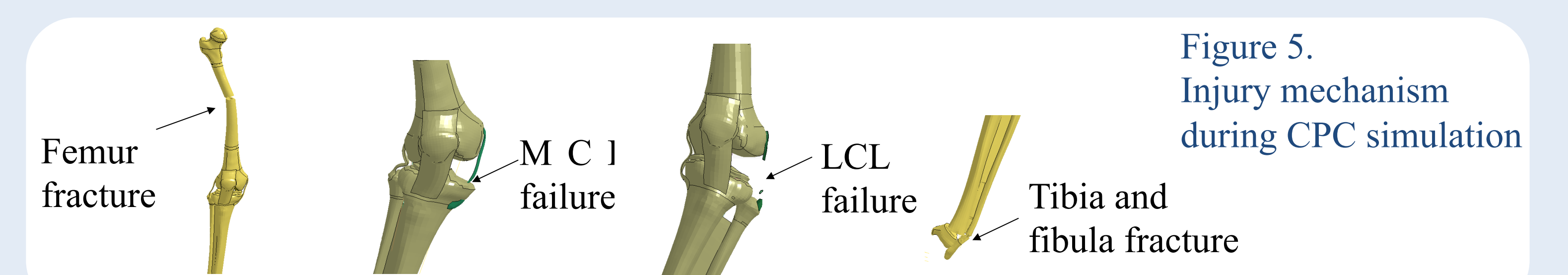


Figure 5. Injury mechanism during CPC simulation

Conclusion and Future Work

The 6YO FE model showed numerical stability during all the simulations, predicted the most common injuries observed in pedestrian accidents. The current study has a couple of limitations because experiments with children PMHS are extremely rare. Improvements could be made to the model mesh by adding more details which were neglected in these models (e.g. muscles, other ligaments) and especially to material properties. While the majority of material properties of children's bodies were assumed, material tests on children's bodies, especially in the lower limb region, are recommended to be performed in the future. Finally, model validation of the full child pedestrian model based on real-world accident data is highly recommended.

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