The Influence of Cyclist Lower Extremity Postures and Bicycle Velocity in Vehicle Collisions

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I. INTRODUCTION

In a vehicle-cyclist collision, cyclist kinematics are comparable with that of a pedestrian, except that the cyclist exhibits a pelvis slide behaviour on the hood/bonnet top [1]. When pedalling, a cyclist will assume various cyclic postures of the lower extremities while pushing on the pedals in a rotary motion. It is not clear whether these lower extremity postures and velocities of the cyclist affect kinematics and injuries. In this study, the influence of lower extremity posture on cyclist kinematics and injuries was investigated with and without bicycle velocity.

II. METHODS

In this research study, FE models of a human, a bicycle and a car were used (Fig. 1). The THUMS Version 3.0 AM50th percentile occupant model was used as the cyclist model. The THUMS model was validated under frontal and side impact [2]. Although there are no standard postures for the lower extremities of a cyclist, past research studies employed one of three representative postures of the lower extremities based on struck foot position: struck foot down, struck foot front, and struck foot up. These three postures were examined in this study (Fig. 1). An FE model of a small sedan was used. The car has a bumper absorber and a lower absorber, both designed to protect a pedestrian's lower extremities. The car model was validated based on pedestrian impact tests [3]. From accident data, it is shown that cyclists were frequently collided from the side by the front of a car, and that the cyclists' velocities were mostly less than 20 km/h [1]. Thus, in this simulation, the car impacted the right side of the cyclist at 40 km/h. The cyclist was either stationary or had a velocity of 20 km/h.

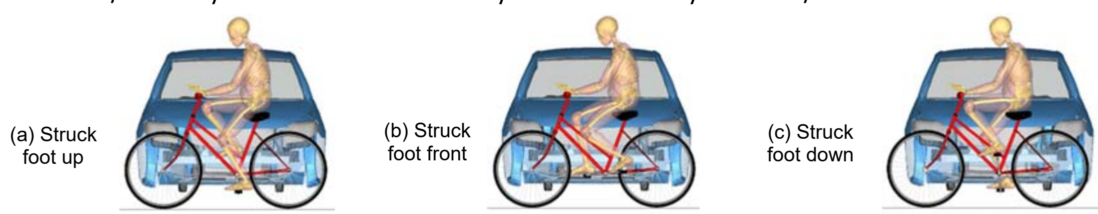

Fig. 1. Initial posture of lower extremities of cyclist model.

III. RESULTS

Kinematics

The kinematics of the cyclists and the head trajectories are shown in Figs. 2 and 3, respectively. Although the global kinematics of the cyclists were similar for all cases, there were differences depending on lower extremity posture and bicycle velocity. In the foot up and front postures for a stationary bicycle (Fig. 2 (a)(b)), the initial position of the struck knee was higher than the hood/bonnet leading edge, and the femur and pelvis overrode the hood/bonnet top. The pelvis slid over the hood/bonnet top, and the bumper applied a force on the right leg in the car's forward direction. The right femur then acted as a moment-arm (crank) and the cyclist's torso rotated about his/her superior-inferior axis, and the occiput of the head impacted the windshield. For the struck foot down posture (Fig. 2 (c)), the cyclist rotated with the femur as the pivot point about the hood/bonnet leading edge, and there were no phases of pelvis slide on the hood/bonnet top. The head made a lateral impact against the lower part of the windshield. Overall, the head contact on the windshield for the foot up posture had the largest wrap-around distance.

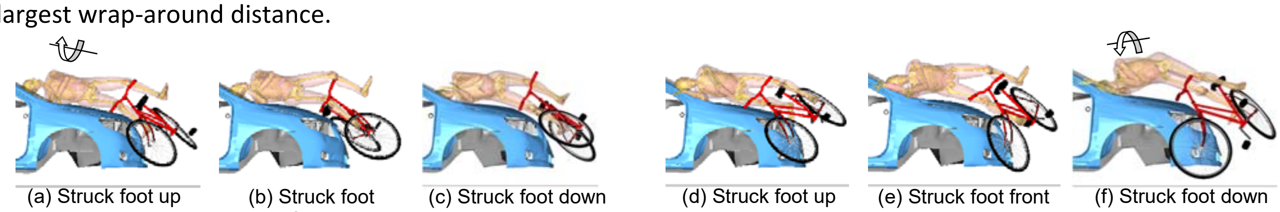

Fig. 2. Cyclist kinematics (*left*: bicycle stationary, *right*: bicycle speed 20 km/h).

With a bicycle velocity of 20 km/h, for all postures the head of the cyclist moved toward the initial resultant velocity w.r.t the car (Fig. 3). The initial cyclist velocity had little effect on the magnitude of the cyclist's head

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impact velocity since the vehicle impact velocity was the dominant component. Although the right side of the body stopped upon contact with the car, the left side of the body continued to move due to inertia. As a result, a moment was applied such that the body rotated clockwise about the superior-inferior axis. This direction of moment is opposite that applied by the right lower extremity. For the struck foot up and front posture, the cyclist's head impacted against the A-pillar. For the struck foot down posture (Fig. 2 (f)), as the moment by the right lower extremity was small due to the small knee flexion angle, the cyclist's head struck the windshield face first.

Knee loading

The knee deformations are shown in Fig. 4, and the knee ligament ruptures are presented in Table I. Complex loads were applied on the knee depending on the car front structure and thigh kinematics. In the foot up and front postures, the knee first deformed in the lateral shear mode due to the leg contacting the hood/bonnet leading edge, and later changed to the lateral bending mode. Torsion of the knee was also generated since the knee was in flexion and the thigh exerted a torsion moment against the leg. Hence, the ACL ruptured because of a large shear load, and the MCL also ruptured in the foot front posture. In the foot down posture, the lower absorber and bumper absorber contacted the foot and the leg, and there were no ligament ruptures.

When the bicycle had a velocity, the leg was stopped by the car bumper w.r.t the car, whereas the thigh continued to move in the anterior direction. As a result, a forward shear loading was also applied on the knee, and the PCL was tensed instead of the ACL. According to the initial lower extremity posture, bending and torsion loading was applied on the knee, and the LCL or MCL ruptured.

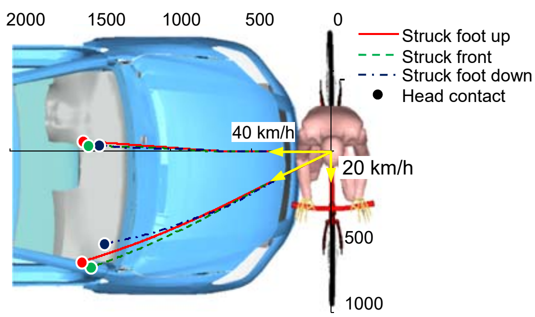
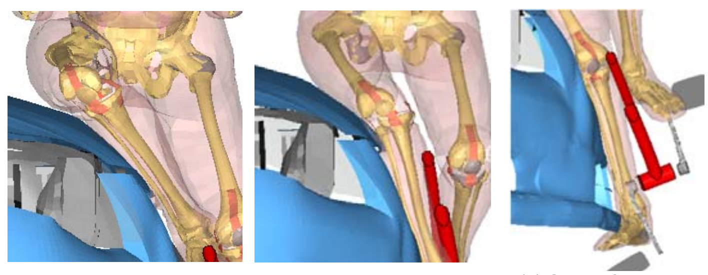


Fig. 3. Cyclist head trajectory kinematics.



(a) Struck foot up (b) Struck foot front (c) Struck foot down

Fig. 4. Kinematics of lower extremities (bicycle speed 0 km/h).

TABLE I
LIGAMENT RUPTURE TIME

		Struck foot up		Struck foot front		Struck foot down	
Bicycle velocity (km/h)		0	20	0	20	0	20
Ligament rupture	ACL	37 ms		22 ms			
	PCL		56 ms		57 ms		
	MCL			31 ms	56 ms		
	LCL		54 ms				

IV. DISCUSSION

Both lower extremity postures and bicycle velocities affected cyclist kinematics: pelvis slide behaviour on the hood/bonnet top and the direction of the torso rotation about the superior-inferior axis. The bicycle velocity changed the direction of the head trajectory and the head contact location on the car. The knee may be loaded with a lateral shear by the hood/bonnet leading edge, and the bicycle velocity can change the loading conditions of the knee. From in-depth accident data, it is seen that knee injuries by the hood/bonnet leading edge account for 14% of injuries in vehicle-cyclist collisions [4], which indicates that knee injuries occur frequently in real-world accidents. In this research, various knee injuries were observed. However, the THUMS occupant model is not validated for knee side impact in its flexion postures (THUMS ligament rupture threshold: strain 0.2). More research is needed to identify the knee injury mechanism with various postures and cyclist velocities.

V. REFERENCES

[1] Maki, T. *et al*. *Accid Anal Prev*.,2003. [2] Iwamoto, M. *et al*., SAE Paper 2000-01-0621. [3] Han, Y. *et al*., *Safety Science,* 2012. [4] Neal-Sturgess, C. E. *et al*., 20th ESV, 2007.