A preliminary comparative study on rider kinematics and injury mechanism in car-to-two-wheelers collisions

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I. INTRODUCTION

Electric two-wheelers (E2Ws) are becoming increasingly popular as a convenient and efficient mode of personal transport, especially in Europe and Asia [1-2]. E2W riders are considered to be vulnerable road users (VRUs) due to the high injury risk in collisions with cars, and this has raised significant traffic safety concerns [3-4]. Compared to other two-wheelers, such as bicyclists, riders on E2W exhibited different initial posture, mass distribution and geometry, which possibly result in their specific impact responses in car-to-two-wheelers collisions. The objective of this study is to make a preliminary comparison of the kinematics and injury mechanisms between E2W riders and bicyclists using computational biomechanical analysis.

II. METHODS

Finite element (FE) models of representative car-to-two-wheelers collision scenarios were constructed and consisted of a rider, a two-wheeler (E2W/bicycle) and a small-sized sedan. The two-wheeler models were developed based on a popular E2W brand (SUNRA) and a common medium-sized bicycle available in the Chinese market (Fig. 1(a)), with the geometry, mass distribution and assembly of the major parts precisely replicated. A mid-size adult male human body model (HBM) (Academic THUMS Version 4.0.1 for LS-Dyna) was adopted as the rider, with the pre-crash posture adjusted by pre-simulation according to the geometry of the two-wheelers (Fig. 1(b)). An open-sourced validated sedan model (Toyota Yaris, supplied by National Crash Analysis Center) was used (Fig. 1(b)). In the simulation cases, the sedan travelled at an initial velocity of 40 km/h and collided with a static two-wheeler laterally at the middle of the sedan front-end (Fig. 1(c)).

A matched-pair analysis was performed comparing the overall kinematics and head injury risk of the E2W rider and the bicyclist during the collisions. This decision was made based on the dominant role of head injuries in cause of death for VRUs in real-world accidents [5]. Indicators on brain injury and skull fracture were calculated by the outputs from an accelerometer at the centre of gravity and in the local coordinate system of the head [6], including a kinematic metric (i.e. Rotational Velocity Criteria Index, RVCI) and the Head Injury Criteria (HIC15). The RVCI is based on angular acceleration values in three directions [7] and was morphed to strain-based metrics (Cumulative Strain Damage Measure, CSDM) and Maximum Principal Strain (MPS) for calculating AIS4+ injury risk probability of diffuse brain injury [8-9]. The HIC15 is based on resultant linear acceleration to evaluate injury risk probability (AIS3+) of skull fracture [10].

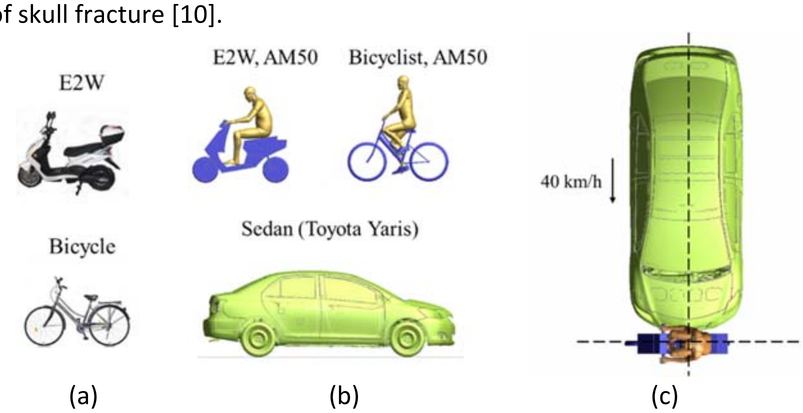

Fig. 1. (a) Two-wheelers selected for model development; (b) FE models of the rider and the sedan; (c) collision scenario (top view).

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III. INITIAL FINDINGS

For both the E2W rider and the bicyclist, the knee area first impacted with the bumper area of the sedan, followed by the upper body falling onto the vehicle front. Some characteristic whole-body kinematics were observed for the two riders (Fig. 2(a)). The E2W rotated away from the sedan as it was struck above its centre of gravity. The E2W rider was initially at a relatively low sitting height, with the lateral side of the femur loaded by the bumper and the head impacted on the windshield following falling motion with a high rotation centre. By contrast, the bicyclist had a higher sitting height with a riding posture; the tibia was first impacted by the bumper, then the femur interacted with the hood, and finally the head impacted on the upper edge of the windshield.

Overall, the E2W rider head sustained an earlier contact on vehicle with higher velocity and different location than the bicyclist (13.5 m/s at approximately 125 m/s vs 5.2 m/s at approximately 170 m/s). Such head kinematics led to different levels of injury probabilities (Fig. 2(b)). Compared with the bicyclist, the E2W rider exhibited lower injury risk of both skull fracture (19% vs 100%) and brain injury (45–50% vs 69–86%).

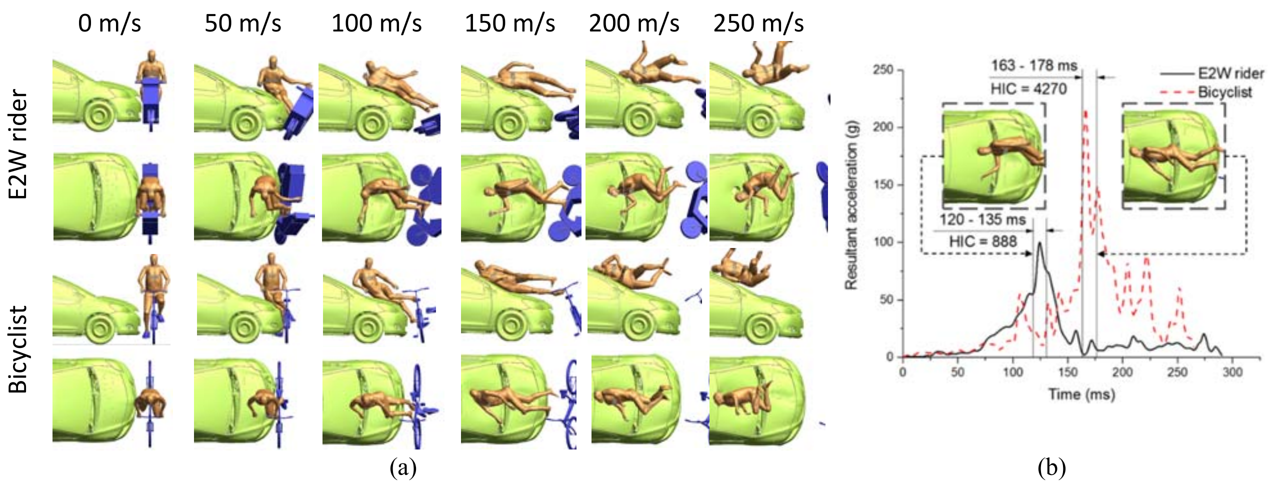

Fig. 2. (a) Kinematics of the E2W rider and the bicyclist in collision with car; (b) resultant acceleration of rider's head and the time window for HIC calculation.

IV. DISCUSSION

The pre-collision posture contributed to the specific kinematics and head injury risks for the E2W rider and the bicyclist. With regard to the kinematic characteristics, the E2W rider was initially seated, loaded more uniformly on the lower extremities and the upper body fell down around a higher rotational point and with a higher rotational velocity. In contrast, the tibia of the bicyclist in a riding posture contacted the bumper area first, and the femurs and the upper body then fell down onto the vehicle. As a result, the head of the E2W rider impacted on the vehicle with higher velocity but lower stiffness than the bicyclist. In this matched-case study, component stiffness of the vehicle played a leading role in the resultant head acceleration due to the inertia effect. The E2W rider has relatively low risk of skull fracture and high risk of brain injury, while the bicyclist has extremely high risk of skull fracture. We proposed a preliminary assumption that a 'stretched' initial posture (i.e. bicyclist) is more vulnerable than a 'wrapped' posture (i.e. E2W rider) in the present car-to-two-wheelers collision scenario.

Several limitations must be noted. The braking action of the vehicle and moving velocity of the E2W were not considered. Potential injury risks of other body parts, except for the head, have not been included. The present simulation covered kinematic and injury outcomes of limited specific collision configurations and might not be necessarily representative. Overall, the present preliminary analysis suggests the E2W rider-specific kinematics and the resultant loading mode and injury mechanism. Further studies are underway to comprehensively evaluate the injury mechanism of the E2W rider and quantify the effects of potential influencing factors (e.g. vehicle category, impact velocity, rider population, etc.) via a large-scale simulation investigation.

V. ACKNOWLEDGEMENTS

This study is in part supported by National Natural Science Foundation of China (Grant No. 51675295, 51705276). Educational licenses of THUMS, LS-DYNA, Hyperworks and Oasys are provided by Toyota, LSTC, Altair

and Arup, respectively.

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