Finite Element Simulations of Collisions between an Electric Kick Scooter Rider and a Stationary Car: Effects of Impact Location on Whole-body Kinematic Behaviour

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I. INTRODUCTION

The first fatal accidents involving an electric kick scooter occurred in Japan in 2022. Data provided from two US hospitals showed that the most common mechanisms of injury involve falls (80.2%), collisions with an object (11.0%), and impact from a moving vehicle or object (8.8%), with the most frequently injured body parts being the face and torso [1]. Although crash tests with dummies have been performed, the kinematics of a kick scooter rider during a collision remain unclear. The purpose of this study was to clarify the kinematic behaviour and injury mechanism of a rider in kick scooter–car collisions using finite element (FE) modelling.

II. METHODS

FE models of a human, kick scooter and car were used (Fig. 1). The THUMS AM50th percentile pedestrian model (ver. 402) with the positions of the arms and the legs changed to a riding posture was used as the rider model. An FE model of a sedan (Toyota Camry) [2] was used to model the car. From accident data, kick scooter riders frequently collide with the right side of a car [3]. In the FE simulation, the kick scooter impacted the right side of the stationary car at 20 km/h. Two impact locations were modelled: the car centre and the hood area.

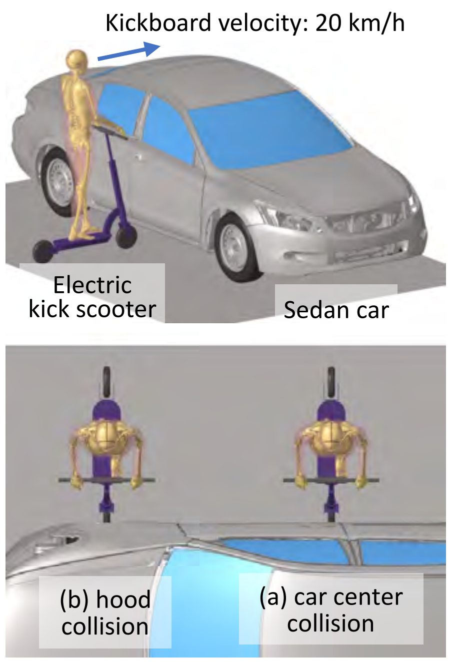

Fig. 1 Finite element models of kick scooter collisions with (a) the centre and (b) the hood of a car.

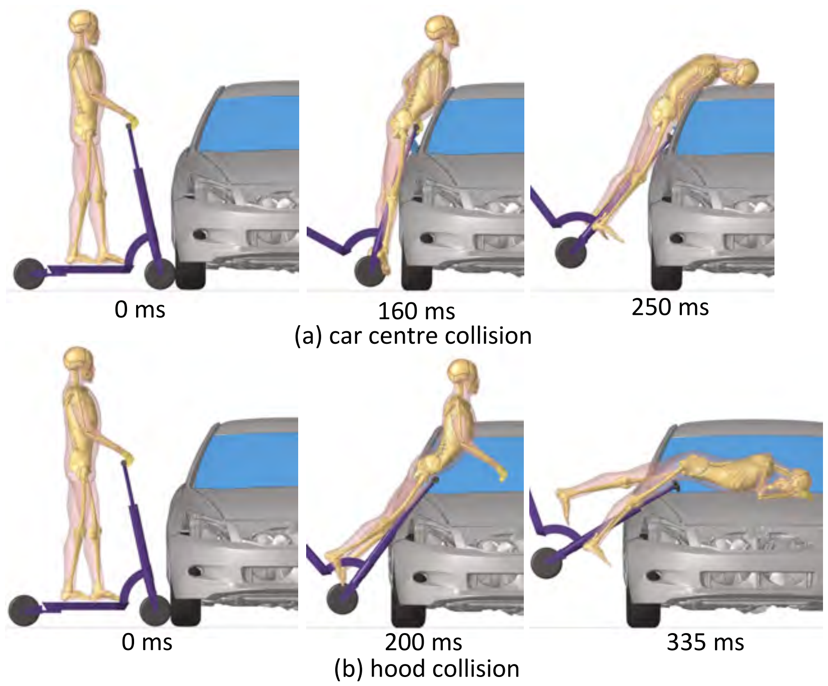

Fig. 2 Kinematic behaviour of a kick scooter rider during collisions with (a) the centre and (b) the hood of a stationary car at 20 km/h car.

III. INITIAL FINDINGS

Kinematics

The kinematics of the kick scooter rider in the centre collision are shown in Fig. 2a. After the front stem of the scooter impacted the side sill of the car, the scooter began to rebound while the rider continued to move forward

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until the chest, abdomen, and waist impacted the side of the car. During the forward displacement, the handlebar hit the abdomen (55 ms), the chest impacted the roof edge (160 ms) and the abdomen impacted the door (175 ms). Finally, the upper part of the torso bent over the roof edge, and then the head impacted the rooftop (250 ms).

The kinematics of the rider in the hood collision are shown in Fig. 2b. The kinematics of the kick scooter and the contact between the abdomen and the handlebar were similar to those in Fig. 2a, except that the scooter wheel initially collided with the front wheel of the car. The kick scooter and rider then tilted forward, and the elbows impacted the hood (290 ms), causing the torso to decelerate and the head and neck to bend forward. The head impacted the hood first (335 ms), then the chest (365 ms).

Ribcage Stress Distribution

Figure 3 shows the von Mises stress distribution at moment of highest stress on the ribcage. In the centre collision (Fig. 3a), chest deflection in the anterior–posterior direction and associated rib bending generated high stress on the left and right sides of the 5th and 6th ribs, placing them at risk of fracture. In contrast, the stress on these ribs was low during the hood collision because deceleration was aided by elbow contact with the relatively soft hood structure (Fig. 3b); however, high stress was generated on the 1st rib and 7th cervical vertebra (Fig. 3c). Initial contact of the hood with the lower thoracic region of the rib cage caused the sternum to move upward, which resulted in bending of the 1st rib. High stress in the spinous process was due to tension in the C6–C7 interspinous ligament, and high stress in the anterior side of the vertebral body resulted from compression of the intervertebral disc during neck flexion.

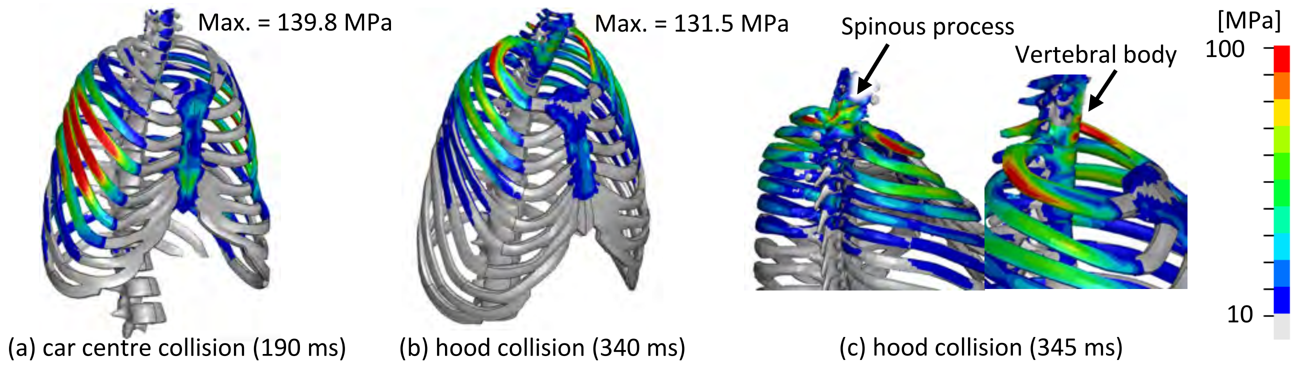

Fig. 3 Von Mises stress distributions in the ribcage of a kick scooter rider during collisions with (a) the centre and (b, c) the hood of a stationary car at 20 km/h.

Head Injury Risk

Low head injury criterion (HIC) scores of 107 (centre collision) and 303 (hood collision) were obtained because the head impacted the roof and the hood, both of which are easily deformable structures with good energy absorption performance.

IV. DISCUSSION

High stress on the ribcage caused by contact between the chest and roof edge was observed during the centre collision, placing the ribs at high risk of fracture. It is therefore necessary to consider whether load-dispersing and energy-absorbing chest protectors sold to motorcycle riders can reduce the risk of chest injury to kick scooter riders.

This study had some limitations. Only one car type and body size were considered, and many other collision scenarios, involving different whole-body kinematic behaviours and injury mechanisms, could be studied. Moreover, only the first contact between the head of the rider and the car body was analysed, but ground contact also poses a high risk of head injury. It is therefore necessary to extend the kinematic simulations to the point of road surface collision to fully evaluate the risk of head injury in the above scenarios.

V. REFERENCES

[1] Trivedi TK *et al.*, JAMA Netw Open. 2019.
[2] Singh H *et al.*, NHTSA Report No. DOT HS 812 237
[3] Shah NR et al., J. Safety Research. 2021