Trunk impact analysis based on real motorcycle accident multibody reconstructions

Selim Cheaibi, Maxime Llari, Wei Wei, Oscar Cherta-Ballester, Valentin Honoré,
Catherine Masson, Thierry Serre

I. INTRODUCTION

Powered Two-Wheelers (PTWs) are involved in nearly 30% of world traffic fatalities [1]. Head and trunk (thorax, abdomen, spine) sustain the most serious injuries (AIS3+) in motorcycle accidents [2]. While head is protected by helmet, which is mandatory in many countries, wearing rates of trunk protections are still low [3].

To understand the causes of these injuries, the investigation of accident scenarios and impacts sustained by the human body is crucial. Most real accident databases don't have the precision required to study the complex impact conditions of motorcyclists during accidents. Consequently, numerical simulation techniques, particularly multibody reconstructions, have emerged as valuable tools to analyse impact conditions in road accidents [4-5].

The aim of this work is to investigate trunk impact conditions leading to serious injuries through numerical simulations of real accidents.

II. METHODS

Eight real accident cases from two in-depth French accident databases were studied [6-7]. These cases have been chosen because at least one AIS3+ injury on the thorax, abdomen, spine or shoulders was sustained by the rider. Numerical reconstructions of these accidents using multibody models were carried out using Madymo software V2020.1. This work is based on a whole model previously developed and validated for motorcycle collisions from internal and literature experimental data [8]. Multibody models were modified based on information from accident databases and technical datasheets of the vehicles.

Motorcyclist impact conditions were analysed at two instants: the first human body impact; and the first trunk impact. For both impacts, the location of the impact on the human body, the speed of the thorax and the impacted surface were considered. Normal, tangential and resultant speeds are relative to the impacted obstacle and were computed from the thorax centre of gravity just before impact by defining a local coordinate system on the impacted surface. These speeds represent the perpendicular and tangent components and the Euclidean norm of both, respectively.

Design of experiments have been performed on the speed, position and angles of the PTW, the position of the motorcyclist on the bike and the position and velocity of other vehicles (if involved) to determine the most probable accident configuration. The final configuration was selected when the simulation results correlated with real elements from accident database: injuries, vehicle damages, final positions, road traces, etc.

III. INITIAL FINDINGS

From the eight numerical accident reconstructions, 11 potentially trunk injurious impacts were identified from which the motorcyclists' impact configurations have been established (Table I).

Two main categories of motorcyclist impacts leading to trunk injuries were observed: impact against a vehicle (four with a car and two with the own PTW); and impact against the ground (5). The first impacted body zone was on the trunk area for seven of the 11 impact cases. Among them, five impacts were on a shoulder (four against the ground), one on the thorax and one on the abdomen.

Regarding speeds at first body impact, the resultant thorax speeds are relatively close for all the impacts (38 km/h, sd = 16 km/h), but their distributions between normal and tangential are very influenced by the

S. Cheaibi (e-mail: selim.cheaibi@univ-eiffel.fr; tel: 04 90 56 86 21) is a PhD Student in the Gustave Eiffel Univ., LMA, Salon de Provence, France; Gustave Eiffel Univ, Aix Marseille Univ., LBA, Marseille, France and In&motion, Annecy, France. M. Llari is a research engineer, W. Wei is a researcher, C. Masson is a researcher and T. Serre is a researcher, all in the Gustave Eiffel Univ., LMA, Salon de Provence, France; Gustave Eiffel Univ., Aix Marseille Univ., LBA, Marseille, France. in the. O. Cherta-Ballester is the lead researcher and V. Honoré is the CTO at In&motion, Annecy, France.

impacted surface. For impacts against vehicles, the average normal speed is 33 km/h (sd = 12 km/h), which is higher than the tangential one of 11 km/h (sd = 13 km/h). For impacts against the ground, the average tangential speed is 45 km/h (sd = 15 km/h), while the normal component is 12 km/h (sd = 4 km/h).

Focusing on trunk impacts, the same trend was observed with an average normal impact speed of 22 km/h (sd = 4 km/h), 12 km/h (sd = 4 km/h) with cars and ground, respectively, when tangential average impact speeds were about 9 km/h (sd = 8 km/h) against cars and 45 km/h (sd = 15 km/h) against ground. When the first impacted body zone was not within the trunk area, a significant decrease of speed was observed, especially for resultant and normal speed components.

TABLE I
HUMAN BODY IMPACT CONDITIONS FOR THE 11 POTENTIALLY TRUNK INJURIOUS IMPACTS

Case	Impacted surface (first impact)	First body impact location	Normal thorax speed (km/h)	Tangential thorax speed (km/h)	Resultant thorax speed (km/h)	First trunk impact location	Normal thorax speed (km/h)	Tangential thorax speed (km/h)	Resultant thorax speed (km/h)	Trunk injuries (AIS) from real accidents
Case 1	Car (fender)	Hand	40	29	49	Sternum	25	16	30	Thorax(3)
Case 2	Ground	Shoulder	13	51	52	Shoulder	13	51	52	Thorax(4), Thorax(3), Spine(2)
	Car (bumper)	Head	46	10	47	Back	17	11	20	
Case 3	Car (door)	Shoulder	23	1	23	Shoulder	23	1	23	Thorax(3)
Case 4	Car (B-pillar)	Head	24	3	25					Thorax(4)
Case 5	PTW (handlebar)	Thorax	14	7	16	Thorax	14	7	16	Thorax(5), Shoulder(2), Shoulder(2)
	Ground	Shoulder	15	25	29	Shoulder	15	25	29	
Case 6	Ground	Shoulder	16	42	44	Shoulder	16	42	44	Thorax(2), Thorax(3), Shoulder(2)
Case 7	Ground	Shoulder	10	67	67	Shoulder	10	67	67	Thorax(4)
Case 8	Ground	Left leg	7	40	41	Shoulder	7	40	41	Abdomen(3), Thorax(2)
	PTW (suitcase)	Abdomen	7	23	24	Abdomen	7	23	24	

IV. DISCUSSION

This study allowed the analysis of trunk impact conditions from the reconstruction of eight motorcycle real-world accidents. Impact speeds and locations were studied and afforded new knowledge on body impact conditions leading to AIS3+ trunk injuries. Impacts against cars and the ground were identified as the main injury sources, which supports previous research from the GIDAS database [9]. The critical role played by the disparity between normal and tangential impact speeds in categorising the impacted obstacles was pointed out. For impacts against cars, the normal component of the speed was higher than the tangential one, while the opposite was observed for ground impacts. These results suggest that, during an accident, impacts of the motorcyclist against an obstacle or a vehicle show a more perpendicular trajectory to the impacted surface than impacts against the ground, which is consistent with previous findings [4]. The results of this research could serve as a foundation for future studies dedicated to enhancing and creating motorcyclist protections specifically for the trunk.

V. REFERENCES

[1] World Health Organization, Geneva, 2022.
[2] Schick, S., *et al.*, IRCOBI, 2019.
[3] Baldanzini, N., *et al.*, *Pioneers*, 2019.
[4] Cherta Ballester, O., *et al.*, *Accid Anal Prev*, 2019.
[5] Serre, T., *et al.*, *Int J Crashworthiness*, 2007.
[6] Ferrandez, F., *et al.*, Presses de l'Ecole nationale des ponts et chaussées, 1995.
[7] Serre, *et al.*, IRCOBI, 2019.
[8] Serre, T., *et al.*, WCB, 2010.
[9] Fredriksson, R., *et al.*, IRCOBI, 2016.