World Academy of Science, Engineering and Technology
International Journal of Urban and Civil Engineering
Vol:12, No:1, 2018

Crash and Injury Characteristics of Riders in Motorcycle-Passenger Vehicle Crashes

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***Abstract*—**The motorcycle has become one of the most common type of vehicles used on the road, particularly in the Asia region, including Malaysia, due to its size-convenience and affordable price. This study focuses only on crashes involving motorcycles with passenger cars consisting 43 real world crashes obtained from in-depth crash investigation process from June 2016 till July 2017. The study collected and analyzed vehicle and site parameters obtained during crash investigation and injury information acquired from the patient-treating hospital. The investigation team, consisting of two personnel, is stationed at the Emergency Department of the treatment facility, and was dispatched to the crash scene once receiving notification of the related crashes. The injury information retrieved was coded according to the level of severity using the Abbreviated Injury Scale (AIS) and classified into different body regions. The data revealed that weekend crashes were significantly higher for the night time period and the crash occurrence was the highest during morning hours (commuting to work period) for weekdays. Bad weather conditions play a minimal effect towards the occurrence of motorcycle – passenger vehicle crashes and nearly 90% involved motorcycles with single riders. Riders up to 25 years old are heavily involved in crashes with passenger vehicles (60%), followed by 26-55 year age group with 35%. Male riders were dominant in each of the age segments. The majority of the crashes involved side impacts, followed by rear impacts and cars outnumbered the rest of the passenger vehicle types in terms of crash involvement with motorcycles. The investigation data also revealed that passenger vehicles were the most at-fault counterpart (62%) when involved in crashes with motorcycles and most of the crashes involved situations whereby both of the vehicles are travelling in the same direction and one of the vehicles is in a turning maneuver. More than 80% of the involved motorcycle riders had sustained yellow severity level during triage process. The study also found that nearly 30% of the riders sustained injuries to the lower extremities, while MAIS level 3 injuries were recorded for all body regions except for thorax region. The result showed that crashes in which the motorcycles were found to be at fault were more likely to occur during night and raining conditions. These types of crashes were also found to be more likely to involve other types of passenger vehicles rather than cars and possess higher likelihood in resulting higher ISS ($\geq$6) value to the involved rider. To reduce motorcycle fatalities, it first has to understand the characteristics concerned and focus may be given on crashes involving passenger vehicles as the most dominant crash partner on Malaysian roads.

***Keywords*—**Motorcycle crash, passenger vehicle, in-depth crash investigation, injury mechanism.

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I. Introduction

THE increasing traffic congestion, availability of parking space, and travel costs are encouraging the purchase of motorcycles, specifically mopeds (up to 50cc) and scooters (over 50cc) for transport. In the US, a significant increase in the number of motorcycles registered was observed in the last decade, a 75% increase from 1997 to 2006 [1]. In Malaysia, a similar trend was also imminent. The composition of annually registered vehicles on the Malaysian road consist of mainly motorcycles, passenger cars, buses and lorries and 50% of the total registered vehicles are motorcycles [2]. An increasing trend in terms of motorcycle ownership was also observed between year 1990 and 2001, from 0.13 motorcycles per person to an average of 0.23 [2]. Majority of motorcycles owners in the country belong to the lower and middle-income group, thus lower price motorcycles, generally speaking range between 70 cc to 115 cc are the better option. In year 2002, the number of motorcycles estimated on Malaysian road was approximately 5.8 million units [3].

Motorcycles are smaller, lighter, and more maneuverable, but at the same time require balance during manuever from the rider; the structure of a motorcycle offers very little protection to the rider and pillion in the event of a crash, as compared to other types of vehicle [4]. In Malaysia, road traffic accidents have resulted in more than 6000 fatalities every year and the numbers were increasing from year to year since 2007 [5]. Motorcycles are also found to have contributed to almost 70% of all injuries (death, serious injuries and minor injuries) in road crashes. Hazard associated to a motorcycle is significant due to the mixed traffic flow on roads. A report by the World Health Organization (WHO) highlighted that worldwide, motorized two or three wheelers had in sum a total of 23% of the entire road traffic death in year 2003 and the proportion was up to 34% for the South East Asian region.

A Swedish study of moped and motorcycle crash injuries from 1987 to 1999 reported that motorcycle and moped riders were respectively 10 and 20 times more likely to be injured in a crash than car occupants per distance travelled [6]. Per distance travelled, the rate of motorcyclist deaths is approximately 30 times the rate for car occupants, while the corresponding rate for a serious injury is approximately 41 times higher as indicated by a study in Australia [7]. In addition, elevated rates for motorcyclist deaths and injuries are also found in other developed countries such as Malaysia.

A Malaysian in-depth crash investigation study also confirmed that approximately 38% from the total fatal motorcycle crashes involved passenger vehicles (cars, SUVs & MPVs) as their crash partners and a majority of the injuries

involved frontal impact (40.0%) [8]. Compatibility of vehicles on vehicle-to-vehicle impacts is classified as the mass, stiffness and geometry compatibility, which are referred to as compatibility parameters [9]. Higher compatibility means a more comparable and in overall, higher level of crash protection in both striking and struck vehicle. The inferior design features of the motorcycles may end up causing incompatibility issue between the motorcycles and the passenger vehicles in crashes.

With regards to crash configurations, the Malaysian traffic police database showed that the largest group of motorcycle fatalities occurred from 'Angular or Side', followed by 'Out of Control' and 'Head-on' type of collisions [5]. However, more in-depth information such as the role of the motorcycle in such impacts was difficult to be retrieved from the available data. Looking deeper into the type of crash partner involve, collision between a motorcycle and passenger car is the most frequent in causing fatal, followed by crashes between motorcycles and 'single-motorcycle-accidents' which accounts for up to 25% each.

Motorcyclists are vulnerable road users, thus are more prone to injuries as compared to other modes of vehicle users on the road. Unlike cars whereby the outer structure provides survival space for car occupants and protection from collisions, these features are not available to motorcyclists [10]. This has led to higher likelihood of motorcyclists sustaining injuries resulting from road crashes. A previous study conducted analyzed hospital records and had found that among the motorcyclists involved in a crash, injuries to the head were the most common injury, followed by injuries to the upper extremity, and the lower extremity [11].

Reducing the numbers of motorcycle crashes will result in improving the overall road safety level, and thus, reducing economic loss as a whole [12]. To date, quite a numbers of motorcycle crash studies utilizing real world data have been conducted in other parts of the globe. However, as far as to the author's knowledge, in the context of Malaysia, such an approach was found to be limited. Moreover, due to the unreliable injury statistics in Malaysia, further analysis of road safety problems was mainly being based only on fatalities. Thus, it is worth to explore the characteristics of motorcycle impacts with passenger vehicles from the real world perspective in order to enhance the level of road safety in Malaysia by tackling the issue related to motorcyclists' safety.

II. Methods

In order to develop effective strategies to reduce road crashes and injuries, national administrations and the motor industry have long recognized the need to determine what is happening in the real world. However, much of the information that is necessary to understand these complex issues is found at the scene of the crash and is lost once the accident scene is cleared. This is best achieved through carrying out in-depth crash investigations. Thus, to avoid loss of information, particularly the volatile evidences, this project utilizes the on-the-spot investigation approach as the method of data collection. This enables the investigators to attend the scene of a crash within 15 minutes of the incident occurring, which allows the collection of crash data that would otherwise be quickly lost. For that particular purpose, an investigation team consisting of two personnel will be stationed at the Emergency Department of the treatment facility, in this study, refers to the Kajang Hospital, Selangor. Once receiving notification on crashes fulfilling the inclusion criteria, the team will deploy to the crash scene subsequent to the ambulance.

The study focuses only on crashes involving motorcycles with passenger cars. Upon arriving at the crash scene, technical parameters leading to the crash occurrence and crash dynamics such as physical evidence of tire marks, distance between vehicle rest positions and the occupants, evidence of protection device and other important parameters were measured and recorded. On the other hand, vehicle inspection mainly focuses on identifying structures and components of the vehicles (motorcycle and passenger car) which contributes to the injury occurrence, availability of vehicle safety features, evidence of restraint wearing and others. Standby period was performed in a total of three 8-hour shifts in a weekly alternate basis, as depicted in Table I. The purpose of having these alternate shift periods is to ensure randomness of the investigated cases in the study, at the same time ensuring that the investigation covers the entire periodic frame within a day (24-hour period). Furthermore, this standby method enables the team to collect the entire population of the cases.

TABLE I
STANDBY SHIFTS

Standby Shift	Type	Time Period
Shift 1	Normal Hours (NH)	06:01-14:00
Shift 2	Odd Hours (OH1)	14:01-22:00
Shift 3	Odd Hours (OH2)	22:01-06:00

The hospital is relatively closer in distance from the researcher's office (5 minutes via driving) as compared to any other general hospital and this will accommodate and ease any logistics or human resource support. The hospital holds coverage areas of its patient which inclusive of the nearby territory of Serdang, Kajang, Semenyih and Cheras, Kajang. For the purpose of data collection, a set of four dedicated data collection forms was utilized in the study which will record important parameters such as the general information of the crash, vehicle information of both passenger car and motorcycle pre- and post-crash specifications and conditions, and also the injury aspects of the involved motorcyclists.

Important parameters explaining the details of the crash were collected and transferred in the data collection forms. The related crash cases were analyzed and reconstructed to assess important parameters gathered during the vehicle and crash site investigation. Furthermore, crash dynamics, which include the movements of vehicles before and during impact, were also determined and reconstructions of the crash were performed. The injury information retrieved from the hospital was then coded in order to rank the injuries according to the level of severity using the AIS. This severity scoring system

classifies each injury in every body region according to its relative importance on a six-point ordinal scale.

The crash data were then analyzed collectively through descriptive and inferential statistical analysis method utilizing the SPSS program Version 17. Analysis and presentation of critical factors in relation to the general crash characteristics, crash configuration, vehicle details and kinematics and injury factors were performed through pie charts, bars and scattered graphs. The respond and predictor variables were cross-classified and the existence of association between the predictor variables and rider injury risk was tested using Chi-square statistics at 5% significant level.

III. Discussion

The study analyzes 43 real-world crashes involving motorcycles with passenger vehicles obtained from in-depth crash investigation process from June 2016 until July 2017. Analysis was performed based on the inputs gathered during vehicle damage inspection, crash site inspection and injury information obtained from the Emergency and Trauma Department of Kajang Hospital. First, the crash data are analyzed in terms of its temporal characteristics. The analysis looks into the crash occurrence distribution with regards to the day and time of crash occurrence. The analysis divides the day into weekday and weekend, in which the latter refers to Saturday and Sunday. The time of crash is divided into four six-hour intervals, which separates the peak hour from normal hours and also wee hours' period.

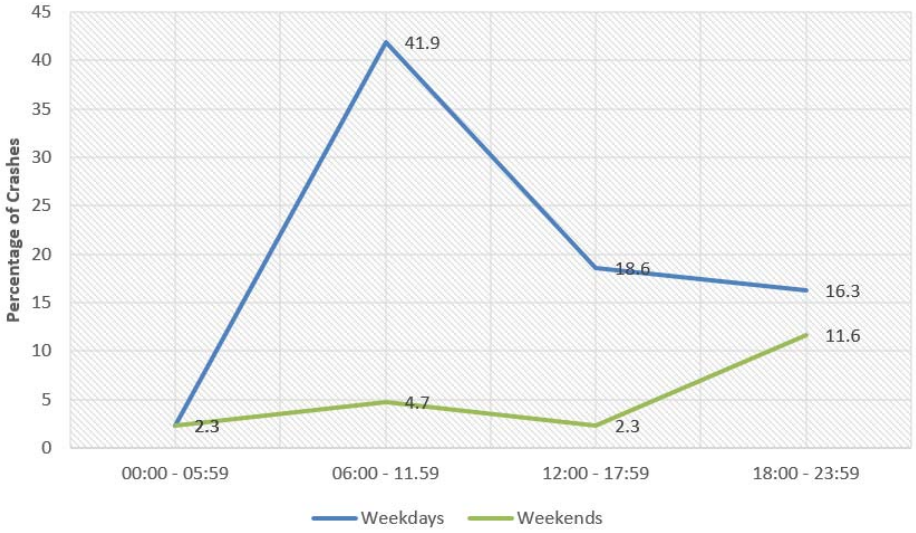

Fig. 1 Day and time of crash

The data shows different trends for weekends and weekdays. For weekdays, crashes often occurred during morning hours, which are the peak periods, particularly for commuting to-work purposes (06:00 – 11:59). The typically high number of traffic volume during this period may well have contributed to the high rate of motorcycle-passenger vehicle crash occurrence during the interval. The distribution is then followed by afternoon crashes (12:00 – 17:59) with 18.6% and night crashes (18.00 – 23.59). The latter period specifically refers to the off-to-work commuting hours for the majority of road users in Malaysia, while the prior refers to the lunch break period for the majority of workers in Malaysia. Meanwhile, the lowest distribution in the crash occurrence pattern can be seen during the wee hours' period between midnight and dawn, which possesses the lowest traffic volume in working day situations. Meanwhile, weekend crashes were found significantly higher for the night time period (18.00 – 23.59) with 11.6%, while other intervals showed quite similar distributions. This could again be due to the increasing motorcycle volume during weekend nights, whereby motorcyclists', and particularly teenagers, would generally go out. It is to be noted that Malaysia is also reporting a high incidence in illegal motorcycle racing among youngsters on public roads (known as *mat rempit*), in which the percentage is higher during weekend nights. Overall, weekdays have higher distribution of crash occurrence as compared to weekends. This concurred to the hypothesis of previous studies which indicated that the motorcycle is mostly used by Malaysian road users specifically to avoid traffic congestion and are particularly used for commuting to work and to run daily errands, rather than for recreational (during weekend) purposes [13], [14].

The study also revealed that bad weather conditions play a minimal effect towards the occurrence of motorcycle – passenger vehicle crashes, as shown in Fig. 2. The result shows that a large majority of the crashes were found to occur during good weather conditions (90.7%), while crashes during rain constituted just 9.3% of the total number of crashes. Although it is a known fact that travelling during raining and wet conditions may produce additional risks of the dangers caused by surrounding environmental factors that include slippery road pavements and limited driver sight and stopping

distance, the adverse pattern could well have contributed to the risk perception aspect from the road users themselves. The same trend was also observed for fatal motorcycle crashes utilizing the national police database [16]. Road users including riders of motorcycles often perceived that it is safer to over speed, taking risks during driving in good weather conditions as compared to when it is raining. This risk taking perception could have been the major contributing factor to the over reported number of motorcycle – passenger vehicle crashes in the study, as shown in Fig. 2.

From the 43 investigated crashes, 86% involved motorcycles with single riders. This again demonstrates the purpose of usage of the motorcycle for work commuting, as previously mentioned in the analysis, which generally will involve single riders. In Malaysia, the percentage of carpooling among road users is still considerably low, and the majority involved is among passenger car users. Motorcycle ride sharing is found to be almost none in the county, unless in typical village areas which are often for short commuting purposes. The unlikelihood of motorcycle sharing in the country was further emphasized by the stern action from the government in banning service providers offering motorcycle ride sharing services in the middle of 2017, unlike the more established e-hauling service involving passenger vehicles such as UBER and GRAB. Moreover, with regards to riding behavior, previous studies have shown that male motorcycle riders possessed a much higher risk of being injured in traffic collisions, typically contributed by the riding behaviors factors of such riders [13], [15].

Male riders were found highly involved from the total number of investigated crashes (average percentage of 90.4% for all group ages). Similar trends have been discussed in previous literatures analyzing motorcycle crash data in other countries [16], [22]. When segregated into different age segments, the data revealed that riders up to 25 years old are heavily involved in crashes with passenger vehicles (60.7%), followed by 26-55 year age group with 34.9%. The preceding age group is also the highest fatality group on Malaysian roads in recent years [7]. The overrepresentation of young riders in motorcycle injuries was attributed to inexperience in operating a motorcycle or a higher exposure to riding [22]. Moreover, the data revealed that two of the cases within the group involved riders aged 13 years and 15 years, which are below the legal riding age in Malaysia (16 years old). Unlicensed driving is still an unresolved issue in Malaysia despite all the regulations and enforcement practice being employed. On the other hand, elderly riders aged 55 years and above constituted less than 5% out of the entire age range. Furthermore, with regards to the riders' age, male riders were dominant in each of the age segments. No female riders from the age of 55 years and above were found to be involved in these crashes.

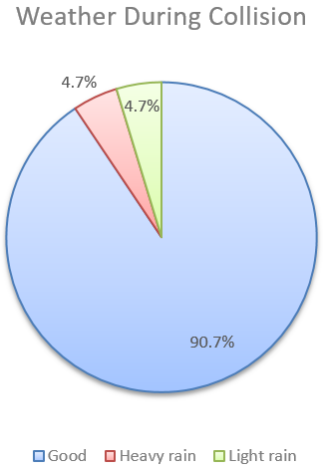

Fig. 2 Weather effect in crash occurrence

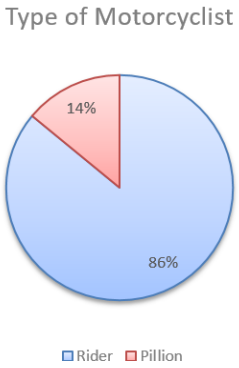

Fig. 3 Motorcycle occupancy during crash

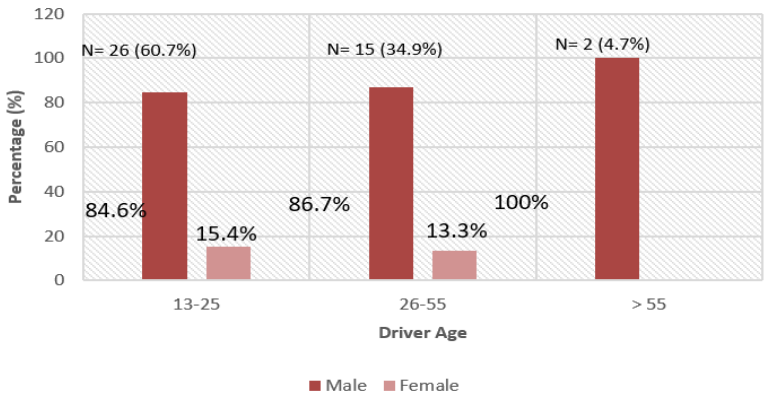

Fig. 4 Riders' demographic information

TABLE II
CRASH CONFIGURATION BY CRASH PARTNER

Crash partner	Crash configuration				Total
	Head on	Rear impact	Side impact	Side swept	
Car	3 (7.9%)	12 (31.6%)	16 (42.1%)	7 (18.4%)	38 (88.4%)
MPV	1 (25%)	1 (25%)	1 (25%)	1 (25%)	4 (9.3%)
SUV	0	1 (100%)	0	0	1 (2.3%)
Total	4 (9.3%)	14 (32.6%)	17 (39.5%)	8 (18.6%)	43

Majority of the motorcycle-passenger vehicle crashes involved side impacts (39.5%) followed by rear impacts at 32.6%, while head on crashes represented less than 10% of the entire configurations. The pattern is also parallel to the fatal motorcycle crash data in the national database which noted angular crashes as the most dominant impact configurations [20]. In terms of crash partner involvement, three types of passenger vehicles that were involved in crashes with motorcycles were identified as cars, multipurpose vehicles (MPV) and sport utility vehicles (SUV). Overall, cars outnumbered the rest of the passenger vehicle types in terms of crash involvement with motorcycles. The data revealed that nearly 90% of the crashed motorcycles collided with cars. This trend is similar to the findings of other motorcycle crash studies which also found cars the most likely crash partners [22]. Looking further into crash partners for each specific configuration, cars were also found to be the most involved crash partners in all of the crash configurations.

The in-depth data also revealed that passenger vehicles were the most at-fault counterpart (61.8%) when being involved in motorcycle crashes, as shown in Fig. 5. It is well documented in previous studies that most of the time in motorcycle crashes with another vehicle, the other vehicle is often found to be at fault [20], [22]. A previous study on Australian motorcycle crashes concluded that more than half of fatal motorcycle crashes involve another vehicle as their crash partner in which the other vehicle is most often at fault. Commonly, this involves violations of the motorcyclist's right of way [21]. Multiple factors came into consideration, which leads to the outcome. One of the factors was shown as the low level of awareness given by other drivers towards the motorcycle, and conspicuity issue. Due to its relatively small buildup, drivers sometimes tend to overlook motorcycles, particularly at intersections.

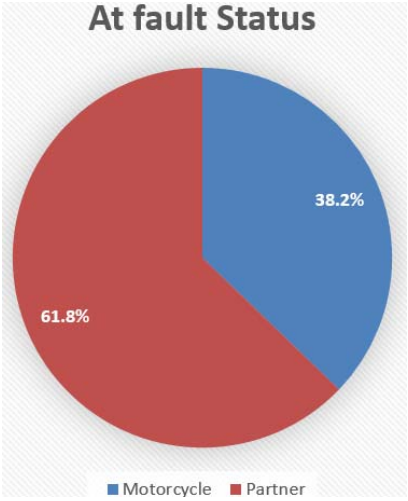

Fig. 5 Vehicle at-fault status

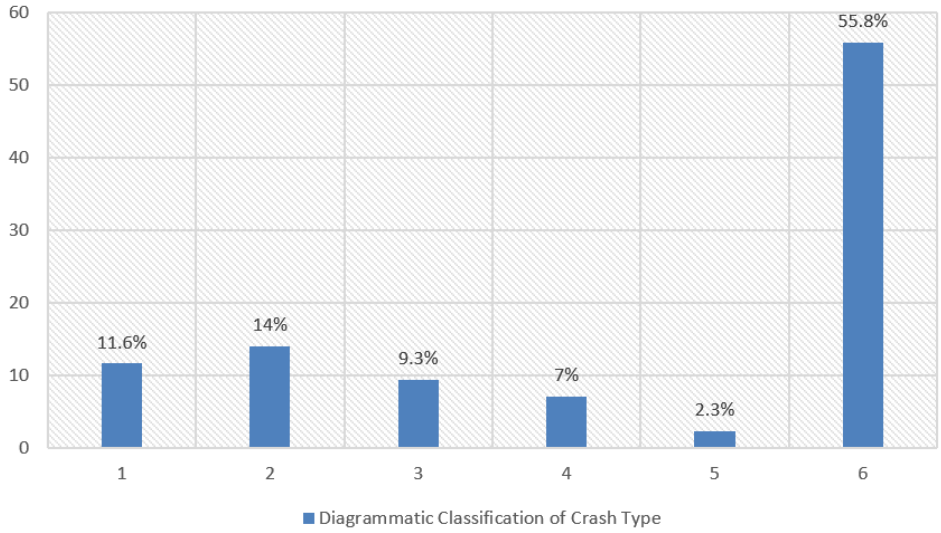

Fig. 6 Crash distribution by classification of crash type

With regards to crash classification, the investigated cases are divided into seven types of classification as follows:

1: Intersecting Direction of Travel
2: Intersecting Direction of Travel (At Least One Vehicle

Turning)
3: Opposing Direction of Travel (At Least One Vehicle Turning)
4: Opposing Direction of Travel (Head on Collision)
5: Running Off the Road
6: Same Direction of Travel (At Least One Vehicle Turning)
7: Same Direction of Travel (None of the Vehicles Turning)

In-depth crash data revealed that most of the motorcycle – passenger vehicle crashes involved situations whereby both of the vehicles are travelling in the same direction, and whereby one of the vehicles is in turning maneuver (denoted 6 in Fig. 6 with 55.8%). This type of crash consists of side impacts, rear impacts and side swept collisions. Meanwhile, crashes involving intersecting direction of travel with a turning vehicle ranked second with 14%, while opposing directions and crashes involving non-turning vehicles in the intersecting direction recorded the third highest with 11.6%. It is to be noted that three of the top ranking configurations highlighted in the study occurred at intersections, a factor which was also highlighted in a previous study [17]. Moreover, intersection crashes were often linked to crash partner vehicles' drivers' misjudgment of the oncoming motorcycle or even a conspicuity issue [17].

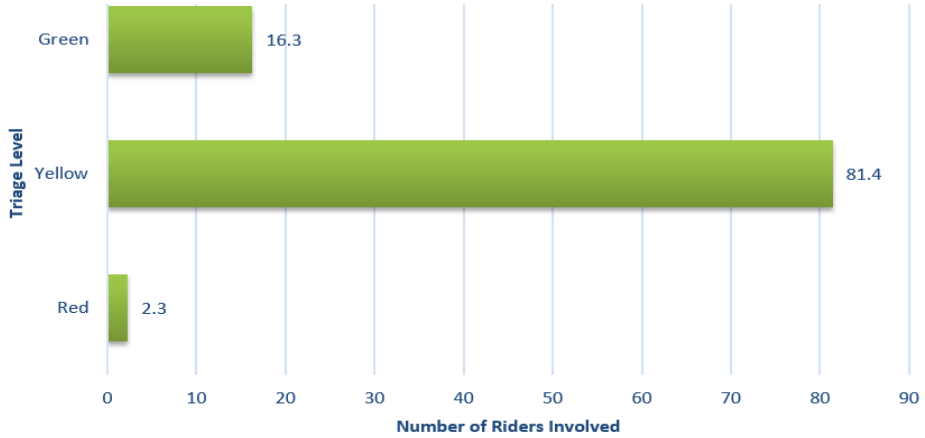

Fig. 7 Rider injury triage level

First level riders' severity assessments conducted at the treating institution are divided into three tag levels which are green, yellow and red (rhesus). Red tags refer to riders who sustained severe injuries and are at risk of non-survival without immediate medical treatment. Yellow tags refer to those patients (riders) with much more stable conditions, and who are not in immediate danger of death but who still need hospital care. Meanwhile, green tags refer to those walking wounded, and for whom medical care is needed at some point [18]. From the 43 investigated cases, more than 80% of the involved motorcycle riders had sustained yellow severity level during triage process during hospital emergency admission, while 16% of riders were assessed as green level patients, and less than 2% were diagnosed at the rhesus level.

Injury information obtained from hospital data for the involved motorcycle riders revealed that nearly 30% of all the riders sustained injuries to the lower extremities. This was followed by upper extremities injuries and injuries to the head and neck, with 23.1%, respectively. Lower-extremity injuries are most common in non-fatal motorcycle crashes, affecting about 30–70% of injured riders [19]. In lower-extremity injuries, fractures are most frequent and have the most severe outcomes [22], in terms of permanent disability and economic costs.

The pattern seems to diverse from the injury pattern obtained in previous studies on fatal motorcycle crashes [8], which found that head injuries are the most common type of injuries sustained by riders in motorcycle impacts in general. Head injuries were always found to be more severe and often involve fatality. As all of the investigated crashes in the study involved non-fatal riders, the data shows a different pattern, as shown in Fig. 8.

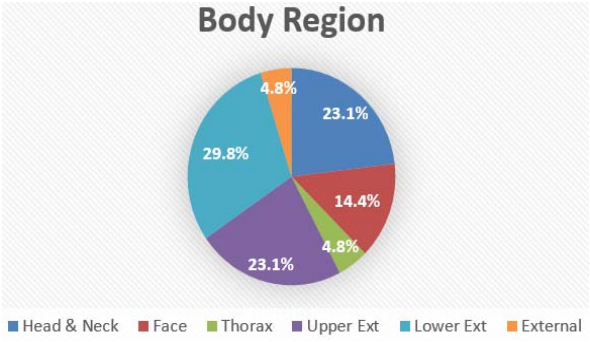

Fig. 8 Injured body region

As shown in Fig. 9, all of the injured body regions of the involved riders had a Maximum AIS value (MAIS) of 1, while MAIS 2 level was highest recorded for thorax injuries. On the other hand, MAIS 3 were recorded for all body regions except thorax and were found highest for upper extremities injury, with 29%. MAIS 4 occurrence was found for the head and neck body region, specifically referring to the cases involving the red triage rider.

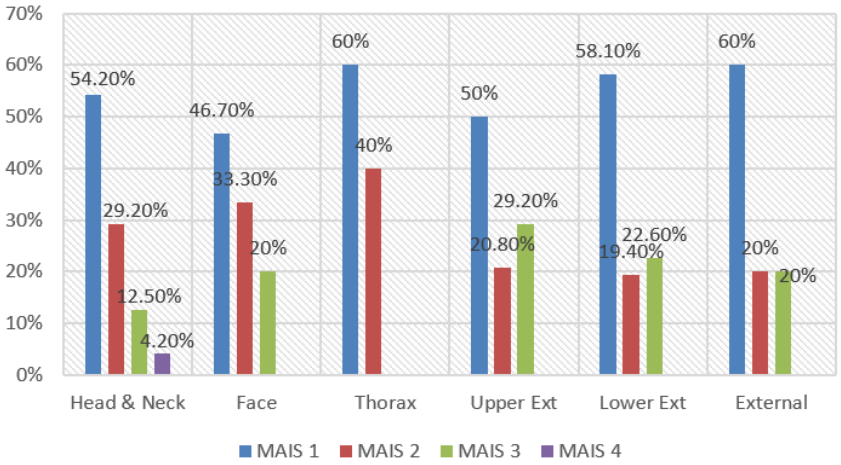

Fig. 9 MAIS according to body region

TABLE III
FACTORS FOR RIDER SEVERITY

Factor		Motorcycle at fault status	*p*-value
Weather condition	Fine Raining	0.115 (0.012, 1.146)	0.04
Rider Age	13-25 ≥26	0.286 (0.075, 1.086)	0.06
Gender	Male Female	0.542 (0.095, 3.076)	0.49
Time of crash	Daytime Nighttime	0.227 (0.057,0.903)	0.03
Crash partner	Car Others	0.115 (0.012, 1.146)	0.04
ISS	1 – 5 ≥ 6	0.253 (0.068, 0.933)	0.04

The involved riders' state of fault was then cross tabulated with different factors, in order to observe the association between each of the selected factor to the fault status outcome. The association is significant when the Asymp. Sig. value (*p*-value) is <0.05, which means that a particular factor is affected by whether the motorcycle was at fault or not in leading to the particular crash. As shown in Table III, weather conditions, time of crash, type of crash partner and rider Injury Severity Score (ISS) were found to be significantly associated with the motorcycle rider fault status ($p<0.05$). Crashes involving motorcycle at fault was 0.115 times less likely to occur during fine weather conditions as compared to raining conditions, and more likely to occur during nighttime. Meanwhile, crashes involving motorcycles at fault were lower likelihood to involve cars compared to other types of passenger vehicles such as SUVs and MPVs as the crash partners. Moreover, these types of crashes were 0.253 times less likely to resulted in ISS below 6 to the involved rider, as compared to higher ISS value (6 and above).

IV. Conclusion

To the knowledge of the authors', at the time that this study was conducted, information on motorcyclists' injury severity in crashes with passenger vehicles are still lacking. This valuable information is critical in assessing the injury outcome towards the pre-crash and during crash factors. Nonetheless, this information can be obtained through in-depth research studies and collaboration works with the treating institutions or hospitals. In limitation in this particular study, was the low frequency of red triage level riders. This information is important to enable observations to be conducted on trends involving those extreme cases and to understand the reasoning behind; as by establishing this knowledge further extension of the study including injury probability prediction can be conducted.

Acknowledgment

The authors would like to express their deep appreciation to Research Attaché, Nurul Syairazi binti Noor Hasmeera and to all support staffs of the Crash Reconstruction Unit for conducting and facilitating the data sorting and cleaning process during the case filtering and profiling activities in which the data was utilized in this report.

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