Comparison of injuries sustained by drivers and pillion passengers in fatal head-on motorcycle collision accidents

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1. Introduction

The latest statistics revealed that motorcycle drivers have a 34-fold higher risk of crash-related death per vehicle mile traveled, compared with people driving other types of motor vehicles, and are eight times more likely to be injured\textsuperscript{[1]}. The production and sales of motorcycles in China exceeded 20 million in 2006 alone, and there are currently an estimated 98.93 million motorcycles in the country. The number of accidents and injuries caused by motorcycles has increased greatly over the last decade, along with an increase in the number of motorcycle registrations. There has been a consistent increase in the incidence of motorcycle accidents in China in recent times, accounting for a direct property loss of 0.86 billion RMB from 2000 to 2005\textsuperscript{[2]}. Among motorcycle accidents, head-on collisions with other motor-vehicle users and fixed objects (such as roadside guardrails and trees) have been reported to be the most common accident type, causing 79 deaths of drivers and 19 deaths of pillion passengers, using medical and medico-legal examination records. The distribution of superficial injuries, characteristic injuries, injury severity as well as fatal causes was evaluated and compared using $\chi^2$ tests.

The results revealed a significant difference in the distribution of superficial injuries between drivers and passengers. The proportions of injuries in the hand and perineum regions were significantly higher in drivers than passengers. Some characteristic superficial injuries on the palms, chest, abdomen as well as the perineum areas were observed in drivers, while none of these characteristic injuries were observed in pillion passengers. Drivers were found to have suffered more severe chest and abdomen injuries than passengers. In addition, there was a higher incidence of fatalities involving run-over injuries for drivers compared with pillion passengers. The proportion of fatal injuries related to tumbling was higher for passengers than for drivers.

Overall, our results revealed a difference in injury severity, superficial injury distribution and characteristic injuries between drivers and passengers. Few characteristic injuries were found in pillion passengers. These findings could help to guide medico-legal examinations, particularly in identifying drivers among victims involved in traffic accidents.
it has been reported that some injuries can provide evidential value in determining the role of individuals involved in accidents [8]. Several studies of the traffic injuries involved in motorcycle collision accidents have reported that injuries around the groin area, commonly known as 'fuel tank injuries', are associated with motorcycle drivers [6,9]. However, few studies have directly compared injury patterns between motorcycle drivers and pillion passengers [10].

To test whether there is a difference in injury patterns between motorcycle drivers and pillion passengers in motorcycle head-on collision accidents, we investigated and compared injury patterns including superficial injury distributions, typical superficial injuries, injury severity by body region, and causes of fatality. If a difference in injury pattern exactly exists, it may provide evidential value in identifying motorcycle drivers and pillion passenger among victims. Therefore, the purpose of this paper was to conduct a comparative analysis of injury patterns among drivers and pillion passengers from fatal head-on motorcycle collision accidents.

2. Methods

A multidisciplinary research team was set up, involving specialists including engineers, psychologists, medical doctors and data processing experts. The research was conducted in Chongqing, China between July 2006 and September 2009 at the Institute of Surgery Research, Daping Hospital, Third Military Medical University.

The research team cooperated with law enforcement agencies, hospitals and medical examiner-coroners so that we were able to access the details of the accidents, interviews with victims and witnesses, and information about injuries. Material evidence regarding the environment, vehicles and humans involved were photographed, and later represented in diagrams. A form containing accident characteristics including the environment, details of the motorcycle, other vehicles, driver and helmet was developed before we began acquiring accident information. Some aspects of accidents including the combination of relative pre-crash positions, pre-crash motion, evasive actions, and collision dynamics were also included in this form. The research group members were trained so that they were experienced in terms of collecting accident data, and filling out the form following standardized procedures.

Details of injuries were obtained from the medical and autopsy records, and were coded by a medical doctor according to the AIS 1998 [11]. Each injury description was assigned a unique 6-digit numerical code, describing the body region injured, type of anatomical structures involved, nature of injury, and a severity score, ranging from AIS 1 (minor), AIS 2 (moderate), AIS 3 (serious), AIS 4 (severe), AIS 5 (critical) to AIS 6 (beyond treatment).

χ² tests were used to perform statistical analysis using SPSS® software (SPSS Inc., Chicago, IL). Data was expressed as mean ± SEM. P-Values of <0.05 were considered statistically significant.

3. Results

We examined a total of 84 fatal head-on collision motorcycle accidents, where the traveling motorcycle collided head-on with another motor vehicle or fixed object. Data from 98 victims involved in these accidents were collected, including 79 motorcycle drivers (81%) and 19 motorcycle pillion passengers (19%). Two of the 79 deceased motorcycle drivers and three of the pillion passengers were female. Among all fatalities, only 13 motorcycle drivers (13%) were wearing a helmet. The average age of the victims was 33.9 ± 11.8 years (16–59 years).

3.1. Superficial injury distributions

The 98 fatal cases examined in this study suffered a total of 562 superficial injuries. The percentage of superficial injury distributions are shown in Fig. 1, divided into several regions comparing drivers and pillion passengers. The results revealed a high incidence of injuries to the head (97%), lower extremities (89%) and chest (74%) in all victims examined. Importantly, there was a significantly higher proportion of injuries to the hands and perineum regions of drivers compared to pillion passengers (p < 0.05). In addition, other body regions showed a trend towards a higher incidence in drivers compared with passengers, including the neck, upper arm, abdomen, lower leg as well as foot, but none of these trends reached statistical significance.

3.2. Typical superficial characteristic injuries

The most common superficial injuries suffered by drivers and pillion passengers included abrasions, contusions and lacerations. Because of the contact between the hands of motorcycle drivers and handlebars, injuries to the palms were observed frequently, as shown in Fig. 2. In addition, some characteristic (fuel tank) injuries to the groin and perineum areas (shown in Fig. 3) were also observed in some of the motorcycle drivers. Although the superficial injury distributions in the chest and abdomen regions were not significantly different between drivers and passengers, we found some typical abrasions in these body regions to be associated with driver fatalities, as shown in Fig. 4. Compared with the injury characteristics associated with driver fatalities, few of the typical superficial injuries described above were observed in pillion passenger fatalities.

Fig. 1. Distribution of superficial injuries between drivers and pillion passengers.

Fig. 2. Injuries to the palms characteristic of driver fatalities. Contusion in thenar area: (a) right palm, (b) left palm, (c) the abrasion inner side of lefthand.
3.3. Injury severity compared between drivers and pillion passengers

Both drivers and pillion passengers exhibited a range of lesion types, including abrasion, contusion, dislocation, fracture, hemorrhage, and amputation, among others. The injury severity suffered by drivers and pillion passengers are compared in Table 1. From the table, it can be seen that the most common region of severe injury was the head. However, head injury severity was not statistically different between drivers and pillion passengers. In addition, it can be seen that drivers might suffered more serious injuries to the neck region than pillion passengers, and that chest severe injury was higher in drivers than pillion passengers, but these differences were not statistically significant. The results revealed that drivers suffered significantly more severe injuries to the abdomen compared to pillion passengers \((p < 0.05)\), although the proportion of minor abdomen injuries (AIS1) in drivers (28%) was almost the same as for pillion passengers (26%). While no pillion passengers suffered abdomen AIS2+ injuries, AIS2–3 and AIS4+ accounted for 6 (8%) and 8 (10%) of abdomen injuries in drivers. Extremities were the most commonly injured regions for drivers and pillion passengers, and no significant differences in injury severity in these regions were found.

### Table 1
Comparison of injury severity in drivers and pillion passengers.

<table>
<thead>
<tr>
<th>Category label</th>
<th>Drivers (n = 79) (%)</th>
<th>Passengers (n = 19) (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>AIS1</td>
<td>AIS2–3</td>
</tr>
<tr>
<td>Head</td>
<td>6(8)</td>
<td>7(9)</td>
</tr>
<tr>
<td>Neck</td>
<td>11(14)</td>
<td>3(4)</td>
</tr>
<tr>
<td>Chest</td>
<td>20(25)</td>
<td>24(30)</td>
</tr>
<tr>
<td>Abdomen</td>
<td>22(28)</td>
<td>6(8)</td>
</tr>
<tr>
<td>Upper extremity</td>
<td>63(80)</td>
<td>6(8)</td>
</tr>
<tr>
<td>Lower extremity</td>
<td>57(72)</td>
<td>20(25)</td>
</tr>
</tbody>
</table>

3.4. Fatal causes

In this investigation, the most common fatal causes were impact, falling, and crushing. The fatal causes were significantly different between drivers and pillion passengers \((p < 0.05)\). As shown in Fig. 5, fatalities because of impact injuries, tumbling injuries and run-over injuries accounted for 68%, 30% and 2% of cases, respectively. In addition, we found that motorcycle drivers were more likely to suffer impact injuries and run-over injuries than passengers, but the pillion passengers were more likely to sustain tumbling injury than drivers.
4. Discussion

In developed countries motorcycles are often used for recreation [10,12]. In developing countries, however, motorcycles are one of the most important means of transportation, commonly used to reduce commuting times from home to workplace and vice versa. In developing countries in Asia, several characteristic features of motorcycle use have been found [10], such as a dramatic increase in the number of motorcycle registrations, unique road environments, and low levels of use of motorcycle safety devices such as helmets. Accidents associated with motorcycles are particularly common in these countries. However, determining accident responsibility is currently a difficult issue for legal courts, because there are not clearly established methods for identifying motorcycle drivers among accident victims. Previous studies suggested that fuel tank injuries are associated with drivers, but few comparative analyses have been conducted. In this paper, we performed a comparative study of injury patterns in terms of superficial injury distributions, superficial characteristic injuries, injury severity by body region, and the proportion of fatal causes.

During motorcycle head-on collisions, the motorcycle front cowl and wheel often contact other road users or fixed objects such as guardrails and trees. This can cause a sudden deceleration of the motorcycle, catapulting the driver and passenger forward over the saddle. For drivers and pillion passengers, two impact stages typically occur in these accidents. First, victims may impact with the front end of other vehicles or fixed obstacles when they are catapulted, due to the high degree of inertia involved. Secondary injuries can then occur if there is contact with the ground while falling. Head injuries are commonly observed in both of these stages. The findings of the present investigation are in accord with a study by Michael et al. [13], who showed that head injuries accounted for the majority of injuries suffered. In the current study, the proportion of severe head injury was highest among the fatal cases studied, accounting for 81% and 90% of fatalities in drivers and pillion passengers, respectively. However, our investigation did not reveal any difference in the distribution of superficial head injuries, injury severity, or characteristic injuries between drivers and pillion passengers. Compared with pillion passengers, we found that drivers were more likely to suffer neck injury, but no characteristic injuries in this region were found.

Ankarath et al. [14] retrospectively reviewed patients involved in motorcycle crashes, reporting that chest and abdominal trauma, besides head injuries, were found to predict reduced survival rate. A comparative analysis of different collision types conducted by Corinne and Jess [5] revealed that driver chest and abdomen regions tended to sustain more serious injuries, and exhibited the highest injury percentage in head-on collisions, compared with other crash types. In motorcycle head-on collisions, drivers’ chest and abdomen regions are typically directly exposed to the front end of oncoming vehicles or fixed obstacles, leading them to suffer more serious injuries in these areas. The results of the current investigation demonstrated that AIS2+ chest injuries were involved in 47% of drivers, and 31% of the pillion passengers we studied. In addition, it was found that 18% of all driver fatalities suffered AIS2+ abdomen injuries, while none of the pillion passengers suffered AIS2+ abdomen injuries (Table 1). In addition, long friction or pressure abrasions in the abdomen and chest [15] regions caused by torsion of the handlebars were found to be characteristic injuries suffered by drivers, as shown in Fig. 4. Therefore, some injury patterns in the chest and abdomen regions could provide useful information for distinguishing drivers from pillion passengers in fatal accidents.

When drivers and pillion passengers are thrown, striking of the fuel tank with the groin and perineum can result in characteristic fuel tank injuries. Pillion passengers, seated behind the driver, are typically thrown over the driver’s back and launch unrestrained to impact. As such, fuel tank injuries are seldom sustained by pillion passengers. Some authors have thus proposed that the presence of fuel tank injuries constitute evidence that individuals with these characteristic injuries were driving the motorcycle [6,8]. However, a case report by Ihama et al. [16] revealed that pillion passengers might also suffer injuries to the groin area, and considered traumatic testicular dislocation as an important finding related to fuel tank injuries. It is not possible to perform medico-legal autopsies in all traffic accidents [17]. In the current study, injuries to the perineum were only found in driver fatalities, while none of the pillion passengers exhibited these characteristic injuries. Therefore, we considered that injuries in the perineum region are important, although non-conclusive, evidence in identifying motorcycle drivers.

Most drivers attempt to dodge collision by gripping the handlebars at the moment of the collision. Drivers’ hands were more likely to be injured than those of pillion passengers, owing to direct exposure in collisions. The present study showed that drivers sustained a higher percentage of hand injuries (60%) compared with pillion passengers (32%). A large amount of energy tends to be transferred between drivers’ hands and the handlebars, causing characteristic contusions and abrasions on drivers’ palms, as shown in Fig. 2. Lower extremity injuries were the most common injuries sustained in all cases in this study, in accord with the finding reported by Peek et al. [18] that drivers and pillion passengers did not differ in the risk of lower extremity injuries.

Ejection kinematics would be expected to differ between drivers and pillion passengers, because of differences in initial position and posture. Drivers grip the handlebars with their hands, forming a joint linking the driver with the motorcycle, which would be expected to delay ejection, or even prevent the driver from being thrown. Pillion passengers, on the other hand, can support themselves by grasping a tandem bar attached to the tail of the motorcycle, or can grip the handlebars of the driver in front of them. Because of their position of weak balance, the pillion passengers would be expected to be thrown higher in the air, and thus to fall to the ground from a greater distance. As such, they would be expected to suffer more serious head injuries when their heads hit the ground, as reported in a previous study [19]. Pillion passengers might, thus, be expected to suffer fatal injuries more frequently that drivers, owing to the higher falling height. This speculation is in accord with the current study. Compared with motorcycle drivers, pillion passengers tend to suffer less run-over injuries because they were thrown a further distance from the impact point. On impact, contusions and bruises are formed in protruding parts of the extremities. In our opinion, however, none of characteristic injuries would be expected in pillion passengers. Besides comparative analysis of the injury patterns sustained by victims, accident reconstruction with computer simulation might be helpful for identifying drivers and pillion passengers among victims of motorcycle accidents. Guo et al. [19] reconstructed two motorcycle-car crashes using MADYMO® software, and revealed that computer simulation can be a useful tool for determining accident responsibility, by revealing the mechanism of injuries of motorcycle victims and to resolve the doubts left by forensic examination. However, computer simulation is time-consuming and expensive because accurate motorcycle accident reconstruction depends heavily upon the ability to collect accurate data regarding human, vehicle and accident environment variables, among other factors. This complexity means that it is impossible for computer simulation alone to adequately examine all motorcycle accidents.

Although injury outcomes may show a high degree of variation for different types of accidents, comparative analysis of injury...
patterns between drivers and pillion passengers can highlight the characteristic injuries sustained by drivers. Therefore, the results of the current investigation are useful for guiding medico-legal examinations of victims involved in traffic accidents. However, characteristic injuries are not observed in every accident, and cases of head-on motorcycle collisions involving none of the injury patterns discussed above are possible. The factors involved in determining the nature of injuries sustained by the victims in head-on motorcycle accidents are extremely complex. Thus, to distinguish drivers from victims, material evidence other than characteristic injuries must be considered.

5. Conclusion

Head-on motorcycle accidents, one of the most common types of motorcycle-related accident, usually result in more serious injuries to motorcyclists than other motor-vehicle users. Distinguishing motorcycle drivers from pillion passengers is a difficult task, because both victims are typically thrown from the vehicle in head-on collisions. Previous studies have reported that some injuries related to a person’s position on the motorcycle can be considered evidence for identifying drivers, in addition to evidence provided by expensive and time-consuming computer simulation. To our knowledge, few studies have been conducted to compare injury patterns between drivers and pillion passengers in detail, with the aim of informing medico-legal examination. The results of this investigation revealed some differences in injury severity, superficial injury distribution and characteristic injuries besides the fuel tank injuries previously reported to be associated with drivers. Compared with drivers, few characteristic injuries were found in pillion passengers. The findings of this study could be useful for guiding medico-legal examinations in identifying drivers among victims involved in traffic accidents.

Conflict of interest

None to declare.

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