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The danger zone: Injuries and conditions associated with immediately fatal motorcycle crashes in the state of Michigan

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ABSTRACT

Background: Immediately fatal motorcycle crashes have not been well characterized. This study catalogues injuries sustained in fatal motorcycle crashes and assesses the impact of crash conditions on injury patterns.

Methods: Autopsy records from the office of the medical examiner of Kent County, MI and publicly available traffic reports were queried for information pertaining to motorcyclists declared dead on-scene between January 1, 2007, and December 31, 2016.

Results: A total of 71 autopsies of on-scene motorcycle crash fatalities were identified. The two most prevalent injuries were traumatic brain injury (TBI) (85%) and rib fractures (79%). The majority of fatalities occurred in daylight hours (54.3%) and in a 55 mph speed limit zone (63.8%).

Conclusions: This study provides a catalogue of the injuries sustained in immediately fatal motorcycle crashes and the associated conditions. Advocacy efforts that highlight the risks associated with motorcycle riding and that promote safe riding practices are warranted.

Introduction

Historically, traumatic deaths occurred in a trimodal distribution; the first peak is immediately after the traumatic insult, the second peak is hours after presentation to a trauma center, and the third peak is days to weeks later. Advances in trauma care have significantly reduced the third peak of trauma mortality leading to a bimodal distribution.[1] While efforts to improve trauma care and reduce in-hospital mortality are essential, decreasing the first peak of pre-hospital mortality represents a major opportunity. These efforts will be most effective if guided by a sound understanding of contributing factors to on-scene traumatic fatalities.

Motorcycle crashes are a leading cause of traumatic mortality. There is poor understanding of the injuries and causes of death (COD) of motorcyclists who die on-scene. No studies from the United States to date have examined injury patterns and associated crash factors.

The purpose of this study is to define injuries and COD and to identify associated motorcyclist, environmental, and traffic factors that contribute to on-scene motorcycle deaths. We hypothesized that on-scene fatalities were more likely to occur in adverse conditions and to involve dangerous behaviors such as alcohol use and hazardous acts.

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Methods

The office of the medical examiner of Kent County, MI was queried for motorcyclists declared dead on scene between January 1, 2007, and December 31, 2016. There were 71 on-scene motorcycle crash deaths. This included cases from 13 counties within Michigan. The Spectrum Health Institutional Review Board reviewed the study and did not consider it to be human subjects research. All autopsies were reviewed with a board-certified forensic pathologist to determine injuries present and COD for each subject. The Michigan Traffic Crash Facts' data query tool was utilized. This is a publicly accessible database that provides Michigan's traffic crash reports, which include the cause of crash, posted speed limit, weather conditions (dry vs wet pavement), lighting (e.g., daylight, dusk/dawn, dark-unlighted, dark-lighted) and the number of lanes of the road. Additionally, the motorcyclists' action prior to the crash, any hazardous acts by the motorcyclist, alcohol use, and illicit drug use are reported. Helmet status before and after the crash were confirmed using the documentation from the police crash and autopsy reports. Helmet use was defined in two ways: wearing a helmet prior to the crash and wearing a helmet after the crash.

Summary statistics were calculated. Quantitative data are expressed as the mean + SD, while nominal data are expressed as a percentage. Comparisons between groups for quantitative variables were performed using either the *t*-test for unequal variances, or the one-way analysis of variance. Nominal variables were evaluated using the chi-square test or the Fisher's Exact test, as appropriate. Significance was assessed at $p < 0.05$. Analyses were performed using Stata v.15.1 (StataCorp, College Station, TX).

Results

Seventy-one autopsies of on-scene motorcycle crash fatalities were reviewed. Traffic crash reports were available for 70 of these crashes. The average age was 41.1 years; 84.5% (60) were male; and 90.1% (64) were Caucasian. Average body mass index (BMI) was 29.5; 25.4% (18) were positive for alcohol; and 4.2% (3) were positive for illicit drugs. Sixty-four of the fatalities (90.1%) were the operator, and 10.9% (7) were the passenger. Forty-one of the subjects (57.7%) were helmeted before the crash. Only 36.6% (15/41) of the helmeted motorcyclists were still wearing their helmet post-crash. Within the subset of patients who were wearing a helmet before the crash (41), there was no difference in age, sex, BMI, alcohol use, illicit drug use, surface condition, lighting, number of lanes, hazardous acts, or cause of the crash between helmet retainers and helmet non-retainers.

Table 1 shows the frequencies of the injuries for the subjects. The three most common injuries were traumatic brain injury (TBI), rib fractures, and lung contusions. Significantly younger ages were seen for subjects with TBI (39.4 vs 50.6, $p = 0.049$), while significantly older ages were seen for subjects with rib fractures (43 vs 34, $p = 0.04$), pelvic fractures (46 vs 38, $p = 0.047$), and c-spine injuries (48 vs 37, $p = 0.004$). Females were significantly more likely to have injuries to the diaphragm (36.4% vs 10.0%, $p = 0.04$) and spleen (72.7% vs 38.3%, $p = 0.048$). Subjects with aortic dissection had significantly lower BMI than those without (28 vs 30, $p = 0.03$). Alcohol and illicit drug use were not significantly associated with any injuries. Helmet status prior to the crash was not significantly associated with TBI or cervical spine (C-spine) injuries. Helmet loss during the crash was not significantly associated with TBI, C-spine injuries, or any COD.

Table 2 shows frequencies of COD and a variety of other pertinent variables. The primary cause of death was TBI. No significant associations were found between COD categories and age, sex, BMI, helmet use, alcohol use, or illicit drug use. Most fatalities occurred on dry roads. There was no relationship between road conditions or speed limit and either type of injury or COD. Over half of the fatalities occurred during daylight hours. Spleen injuries ($p = 0.034$) and lung contusions ($p = 0.001$) were significantly more common in dark-lighted conditions. An increased number of lanes (3/4/5)

Table 1
Frequency of injuries identified in motorcyclists who died on-scene of a crash.

Injury	Frequency (n)
TBI	84.5% (60)
Rib Fractures	78.9% (56)
Lung Contusions	63.4% (45)
Liver	49.3% (35)
Aortic Laceration	43.7% (31)
Spleen	43.7% (31)
C-spine	36.6% (26)
Pelvic Fracture	35.2% (25)
Testicular[a]	35.0% (21)
Lung Lacerations	33.8% (24)
Heart Laceration	29.6% (21)
Pericardial Rupture	28.2% (20)
Kidney	25.4% (18)
Sternal Fracture	23.9% (17)
T-spine	23.9% (17)
Diaphragm	14.1% (10)
Bowel Mesentery	14.1% (10)
Amputation	9.9% (7)
Heart Contusion	9.9% (7)
Bladder	8.5% (6)
Aortic Dissection	4.3% (3)
L-spine	2.8% (2)
Pancreatic	2.8% (2)

TBI: Traumatic brain injury; C-spine: Cervical spine fracture or dislocation; T-spine: Thoracic spine fractures; L-spine: Lumbar spine fracture.
[a] Total of 60 males.

Table 2
Cause of death, cause of crash, and environmental variables identified in motorcyclists who died on-scene of a crash.

Variable	Frequency (n)
Cause of Death	
TBI	42.3% (30)
Hemorrhage	26.8% (19)
Cervical SC injury	22.5% (16)
Cardiac/Other[a]	8.5% (6)
Road Condition (% dry)	94.3% (66)
Lighting	
Daylight	54.3% (38)
Dusk/Dawn	5.7% (4)
Dark-Unlighted	22.9% (16)
Dark-Lighted	17.1% (12)
Speed Limit	
70 mph	10.1% (7)
55 mph	63.8% (44)
<55 mph	26.1% (18)
Lanes (% 1/2) [b]	77.1% (54)
Hazardous Act[c]	65.7% (46)
Cause of Crash	
Struck object[d]	45.1% (32)
Lost control	42.3% (30)
Struck by vehicle	12.7% (9)

TBI: Traumatic Brain Injury; SC: Spinal cord.
[a] Three with cardiac injury, two with tension pneumothorax, one with pulmonary edema.
[b] One or two lanes of traffic, compared to the composite of 3, 4, or 5 lanes of traffic.
[c] e.g., speeding, reckless driving, drove left of center.
[d] Struck a vehicle, deer, or stationary object.

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was significantly associated with more lung contusions ($p = 0.03$) and fewer pelvic fractures ($p = 0.03$), relative to fatalities on a smaller number of lanes (1/2).

The following hazardous acts by the motorcyclist were reported: speed too fast: 24.3% (17), reckless driving: 5.7% (4), drove left of center: 5.7% (4), disregard traffic control: 2.8% (2), careless: 2.8% (2), improper lane use: 1.4% (1), failed to yield: 1.4% (1), and other: 21.5% (15). COD, age, BMI, helmet status prior to the crash and wearing a helmet after the crash were not significantly associated with a hazardous act being committed. Pelvic fractures were significantly more common in subjects who did not commit a hazardous act (58.3% vs. 23.9%, $p = 0.01$).

The most common reported cause for the crashes was the motorcyclist striking another vehicle, a deer or a stationary object (Table 2). TBI ($p = 0.015$) and mesenteric injury ($p = 0.048$) were significantly more common when a motorcycle stuck an object. Cardiac contusion($p = 0.049$), pelvic fracture ($p = 0.002$), and testicular injury ($p = 0.003$) were significantly more common when the motorcycle was struck by an oncoming vehicle.

Discussion

The first motorcycle, a steam powered bicycle referred to as a velocipede, was developed in the 1860s.[2] Tragically, one of its developers, died while demonstrating the machine.[2] Despite design changes, motorcycles remain dangerous. While motorcycles represent only 3% of vehicles registered in the United States, motorcyclists account for 17% of occupant fatalities.[3]

Injuries sustained by motorcyclists presenting to the hospital have been well described, but injuries sustained during on-scene fatal crashes have not been evaluated. All injuries and causes of death in this study were identified by a forensic pathologist. Autopsy evaluation does not have the benefit of imaging or physical examination with patient feedback; therefore, subtle injuries usually identified on radiography can be missed, and typical grading criteria, such as the Glasgow Coma Scale for TBI, are not possible to calculate.

In Michigan, the reported incidence of TBI in hospitalized motorcycle trauma patients ranges from 38.7% to 46.5%.[4–6] This is notably less than our on-scene fatality cohort's incidence of TBI (84.5%). This finding is consistent with a study from China that reported an 84% TBI rate in motorcycle crash fatalities.[7] Interestingly, we did not find an association between TBI and helmet use. This contradicts all data in motorcycle trauma patients, who survive to the hospital. This may indicate that a helmet is insufficient protection to prevent a TBI in high energy immediately fatal crashes.

The reported incidence of helmeted motorcyclists in hospitalized motorcycle trauma patients ranges from 61.8% to 82.3% in Michigan.[4–6] While over half (57.7%) of our on-scene fatality cohort was helmeted, only 36.6% still had their helmet in place after the crash. This implies that 63.4% of helmets became dislodged or destroyed during the crash. Previous work has shown that helmet retention is associated with helmet type and proper helmet fixation,[8] but in our cohort this is likely partially related to the devastating mechanism involved with on-scene deaths. Appropriate helmet use may limit the severity of TBI, which could reduce the number of on-scene fatalities related to TBI. Although we could not demonstrate a decreased proportion of TBIs or TBI as a COD in the helmet retainers, we believe this may become apparent in a larger cohort. Our data on helmet retention highlights the importance of proper helmet use.

Similar to TBI, the incidence of liver injuries (49.3% vs 4.7%), aortic injuries (46.5% vs. 0.4%), splenic injuries (43.7% vs 6.0%), pelvic fractures (35.2% vs 8.8%), and kidney injuries (25.4% vs 3.2%) were more common in our on-scene fatality cohort compared to previous reports of hospitalized motorcycle trauma patients.[9,10] In our study, aortic injuries, which are uncommon in the inpatient setting, had a higher prevalence than splenic injuries. In this study, we attributed 26.8% of our deaths to hemorrhage, and we hypothesize the high rate of pelvic fractures, solid organ injuries, and aortic lacerations in our pre-hospital fatality cohort contributed to this finding.

We had hypothesized that the majority of fatal crashes would occur in challenging environmental conditions and evaluated this with traffic crash reports. Our findings were incongruent with our hypothesis. 94% of our crashes occurred on dry roads compared to 97% of national fatal crashes occurring in clear or cloudy weather.[3] 54% of our crashes occurred in daylight conditions compared to 59% of national fatal crashes.[3] Contrary to our hypothesis, fatal crashes tend to occur in good weather and lighting conditions.

Based on current literature, it is unclear whether alcohol and drug use increase mortality in hospitalized motorcycle trauma patients.[4,6] We postulated that alcohol use, illicit drug use, and increased speed would be more common in on-scene fatalities. Our data demonstrated a 25% incidence of alcohol use in on-scene fatalities, which is not only the same incidence seen nationally in fatal motorcycle crashes, but also similar to the 26% rate seen in hospitalized motorcycle trauma patients.[3,4] Similar rates of alcohol use in on-scene fatalities and hospitalized patients is incongruent with our hypothesis that risky behavior is a major contributor to on-scene fatalities.

The average posted speed limit of fatal crashes was 51 mph, which is higher than the 46.4 mph seen in hospitalized motorcycle trauma patients.[5] We would have expected to see a larger difference, and this difference may exist if the study cohort was traveling faster than the posted speed. Increased estimated speed has been associated with an increased incidence of TBI in hospitalized motorcycle patients.[6] If our on-scene fatality cohort did have increased actual speeds, it could help explain the increased incidence of TBIs. Unfortunately, there were no documented estimated speeds in the autopsy or traffic crash reports.

We incorrectly hypothesized that hazardous acts by the motorcyclist would be more common in younger and un-helmeted motorcyclists. We did note that pelvic fractures were less common in motorcyclists committing hazardous acts, but more common when the motorcyclist was struck by an oncoming vehicle. In combination, these findings support the idea that motorcyclists are more likely to have pelvic fractures if they have minimal time to prepare for the impact. We are the first to assess the impact of hazardous acts on injury patterns and COD.

This study has several important limitations. The sample size is small and may not be generalizable to a larger population. Laws regarding motorcycle operation and safety regulations, including helmet use, vary by state and change. During our study period, the helmet use requirements in the state of Michigan were liberalized. Finally, all data are retrospective and rely on the accuracy of the traffic crash reports and autopsies. Thus, elucidating the most immediately fatal injury was left to the discretion and professional judgment of the pathologist.

Conclusion

This is the first autopsy study to evaluate traumatic injuries sustained in immediately fatal motorcycle crashes and correlate those injuries to associated motorcyclist, environmental, and traffic factors. Most fatal crashes occurred in favorable driving conditions. When compared to hospitalized motorcycle trauma patients, a higher proportion of our cohort had life threatening injuries such as TBI and aortic lacerations. TBI was the most common injury and

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cause of death in our cohort. Helmets were not clearly protective, although this finding may relate to our small cohort. Over half (63.4%) of helmeted motorcyclists lost their helmet during the crash, which raises concerns on the public's education on proper helmet fixation. Advocacy efforts that highlight the risks associated with motorcycle riding and promote safe riding practices are warranted, as is further research into crash causes and prevention.

Conflicts of interest

The authors have no conflicts of interest.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.amjsurg.2018.10.007.

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