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Injury patterns and outcomes in motorcycle driver crashes in the United States: The effect of helmet use

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ABSTRACT

Background: Motorcycle crashes pose a persistent public health problem with disproportionate rates of severe injuries and mortality. This study aims to analyze injury patterns and outcomes with regard to helmet use. We hypothesized that helmet use is associated with fewer head injuries and does not increase the risk of cervical spine injuries.
Methods: The National Trauma Data Bank was queried for all motorcycle driver crashes between 2007-2017. Univariable analysis was used to compare demographics, clinical data, injury patterns using abbreviated injury scale, and outcomes between helmeted motorcycle drivers and non-helmeted motorcycle drivers who were injured in traffic crashes. Independent factors associated with mortality were determined by regression analysis after adjustment for potential confounders.
Results: A total of 315,258 patients were included for analysis, 66 % of these patients were helmeted. The sample was 92.5 % male and the median age was 41 years. Non-helmeted motorcycle drivers were more likely to sustain severe head trauma (head abbreviated injury scale $\geq$ 3: 28.5 % vs. 13.3 %, ***p < 0.001***), had higher intensive care unit-admission (38 % vs. 30.2 %, ***p<0.001***), mechanical ventilation (20.1 % vs. 13 %, ***p<0.001***) and overall mortality rates (6.2 % vs. 3.9 %, ***p<0.001***). Cervical spine injuries occurred in 10.6 % of non-helmeted motorcycle drivers and in 9.5 % of helmeted motorcycle drivers (***p<0.001***). Helmet use was identified as an independent factor associated with lower mortality [*OR 0*.849 (0.809–0.891), ***p<0.001***].
Conclusion: Helmet use is protective for severe head injuries and associated with decreased mortality. Helmet use was not associated with increased rates of cervical spine injuries. On the contrary, fewer injuries were observed in helmeted motorcycle drivers. Public health initiatives should be aimed at enforcement of universal helmet laws within the United States and across the world.

Background

Motorcycle crashes remain a significant public health problem worldwide. According to the World Health Organization (WHO), approximately 1.25 million people die annually as a result of road traffic crashes globally, with motorcyclists accounting for almost one third of these deaths (28 %) [1]. In many countries, motorcyclists are involved in a higher proportion of road traffic crashes than any other type of vehicle. In the United States (US), motorcycles account for only 3 % of all registered vehicles, but are involved in 14 % of all traffic fatalities [2].

Numerous factors contribute to motorcycle crashes: road conditions, vehicle defects and driver behavior including speeding, alcohol and drug consumption, as well as lack of protective gear are major contributors to motorcycle injuries [3–7]. While helmets have been shown to be effective in reducing the risk of injury and death in motorcycle crashes, they are still underutilized by motorcyclists [8]. According to the National Highway Traffic Safety Administration (NHTSA) and the National Safety Council (NSC) approximately 30 % of motorcyclists involved in fatal crashes were not wearing helmets at the time of injury [2].

Helmet laws vary within the US, resulting in inconsistent

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enforcement of helmet prevention measures [9]. Based on early scientific reports, there has been an ongoing debate regarding the association of helmet use and the risk of neck and cervical spine injuries [10,11]. The aim of the present study is to provide an update on injury patterns and outcomes of motorcycle collisions across the US over a period of 11 years. In particular, the use of helmets was evaluated with respect to cervical spine injuries. The findings of this study can help to inform evidence-based strategies aiming to reduce the incidence and consequences of motorcycle crashes.

Methods

Study design

This cross sectional registry study was performed using data from the American College of Surgeons National Trauma Data Bank (NTDB) over a period of 11 years (2007–2017). This study followed the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) reporting guidelines [12].

Ethical considerations

This study was approved by the Institutional Review Board of the University of Southern California (HS-17-01019).

Participants and data sources

The NTDB collects data from more than 750 trauma centres across the US and represents one of the largest trauma registries in the world [13]. The NTDB data are standardised according to the rules and validation system of the National Trauma Data Standard (NTDS) data dictionary [14].

Study population

Motorcycle drivers who suffered injuries in road traffic crashes were identified by the external cause of injury codes according to the International Classification of Disease, Ninth and Tenth revision. The exclusion criteria were defined as follows: motorcycle passenger or unspecified rider, injuries during boarding or alighting, non-traffic crashes including off-road collisions, missing data regarding helmet utilization, missing both Abbreviated Injury Scale (AIS) and Injury Severity Score (ISS), and missing data regarding emergency department (ED) and hospital disposition. The study population was stratified according to helmet utilization into helmeted motorcycle drivers (HMD) and non-helmeted motorcycle drivers (NHMD).

Study size

All patients in the NTDB meeting criteria were considered for the present study.

Quantitative variables

The following data were extracted for analysis: demographics, the use of helmets or other protective devices at the time of injury, alcohol and illicit drug tests on admission, inter-hospital transfer, admission vital signs [including systolic blood pressure, heart rate, and Glasgow Coma Scale (GCS) score], injury data (including the AIS for each body region and ISS), comorbidities, in-hospital complications, and disposition after hospital discharge. We also recorded specific injuries within each body region, with severe injury defined as AIS $\geq$ 3. Hypotension was defined as systolic blood pressure $<$90 mmHg. Tachycardia was defined as heart rate $>$120 bpm.

Studied characteristics and outcomes

The primary outcome for this study was the difference in mortality between HMD and NHMD. Secondary outcomes included differences in severe head injuries, cervical spine injuries, intensive care unit (ICU) admission rate, mechanical ventilation days (MVD) and hospital length of stay (HLOS).

Statistical analysis

Univariable analysis was used to compare demographics, clinical data and outcomes between HMD and NHMD. Chi-square test or Fisher exact test were used for hypothesis testing of categorical variables, while Mann–Whitney *U* test was applied for non-parametric continuous variables. Descriptive statistics were used to summarize results, which were presented as percentages for categorical variables and medians with interquartile ranges (*IQR*) for continuous variables. A multivariable logistic regression analysis was carried out to determine independent risk factors for mortality including clinically established variables such as age, sex, interhospital transfer, helmet utilization, documented alcohol or drug positive test on admission, hypotension, tachycardia, and GCS $<$ 9 on admission, as well as severe (AIS $\geq$ 3) injury within each body region. Several subgroup regression models were conducted for sensitivity analysis as follows: (1) regression model including helmet use but no GCS $<$ 9 or head AIS $\geq$ 3 (2) regression model including helmet use and GCS $<$ 9 but no head AIS $\geq$ 3. (3) regression model including helmet use and head AIS $\geq$ 3 but no GCS $<$ 9. Predictor variable correlation was assessed through collinearity analysis, with a variance inflation factor less than 2.5 used to exclude significant collinearity. The model's accuracy was determined using the area under the receiver operating characteristic curve. Odds ratios (*OR*) with 95 % confidence intervals (*CI*) were reported, with statistical significance defined as a *p* value of less than 0.05. All statistical analyzes were conducted using IBM SPSS for Windows, Version 29.0 (SPSS Statistics for Windows, Version 29.0. Armonk, NY: IBM Corp).

Results

Study population

In total, 315,258 motorcycle drivers who were injured in traffic crashes were included in the study. Of these, 66 % were wearing a helmet and 34 % were not (Fig. 1). The median age of all included patients was 41 (*IQR* 27–53) years and 92.5 % (n = 291,437) were male. Helmeted motorcycle drivers were more likely to be wearing protective clothing (10.6% vs. 0 % ***p<0.001***). Patient demographics are summarized in Table 1A. The trend of helmet use at the time of the accident did not increase during the study period between 2007 and 2017. In line with our findings, the National Occupant Protection Use Survey (NOPUS) revealed little fluctuations in helmet use between 2007 and 2017 [15] (Fig. 2).

Alcohol and drugs

Overall, 59.6 % of patients were screened for alcohol intake and 20.1 % were screened for illicit drug use. Non-helmeted motorcycle drivers were significantly more likely to test positive for both alcohol and illicit drug use at the time of injury (Alcohol positive: 27 % vs. 13.6 %, ***p<0.001***; Illicit drug positive: 21 % vs. 16.4 %, ***p<0.001***) (Table 1A).

Clinical and injury data

Helmeted motorcycle drivers most commonly presented with lower and upper extremity injuries [lower extremity: 62.3 % (n = 129,511), upper extremity: 59.3 % (n = 123,321)], whereas NHMD most commonly sustained head injuries [54.4 % (n = 58,362)] (Table 1B).

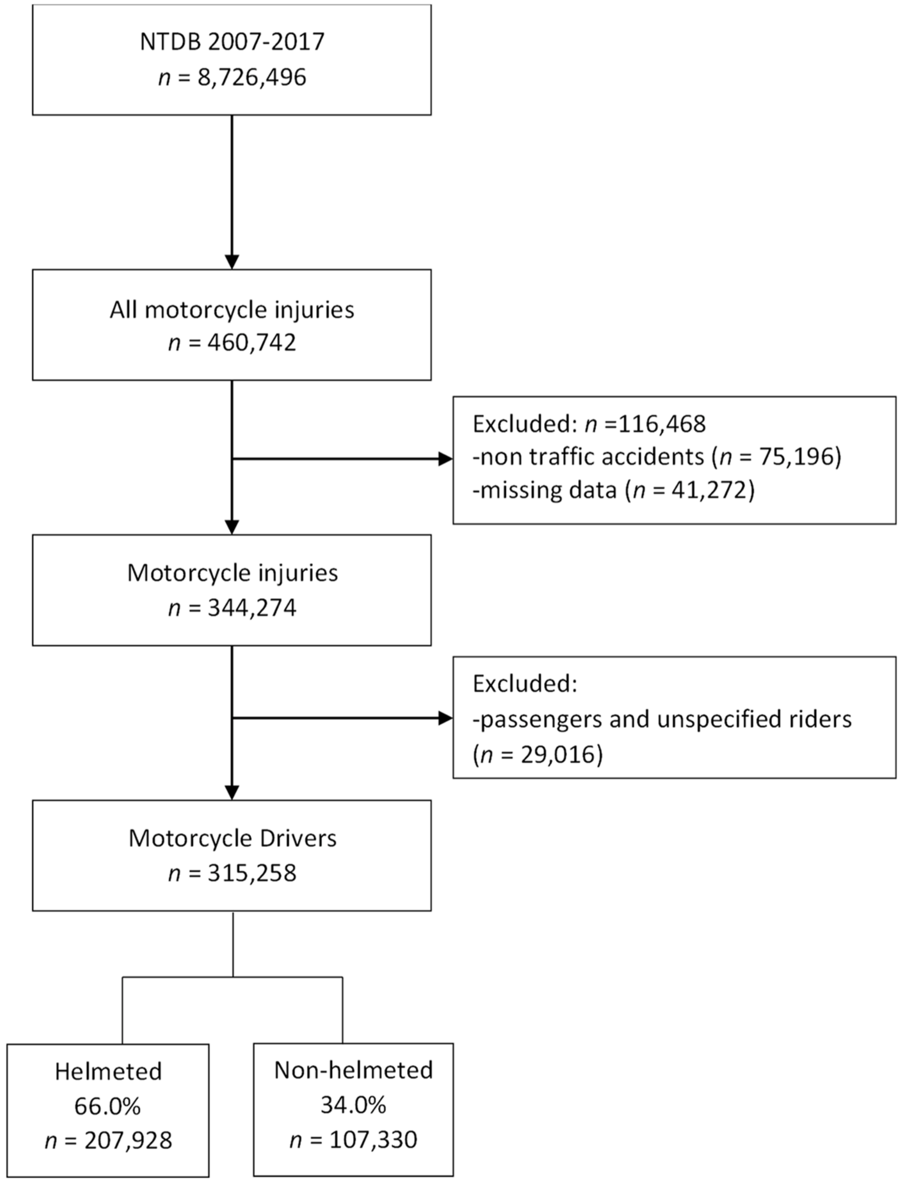

Fig. 1. Patient flowchart.

Non-helmeted motorcycle drivers were more often comatose on arrival (GCS < 9: 14.7% vs. 7.5 %, ***p<0.001***). The median ISS was 10 in both groups, however, NHMD were more likely to sustain major trauma (ISS > 15: 34% vs. 28.8 %, ***p<0.001***; ISS ≥ 25: 15.3 % vs. 11.7 %, ***p<0.001***). Severe head injuries (28.5 % vs 13.3 %, ***p<0.001***) and face injuries (1.2 % vs 0.6 %, ***p<0.001***) were significantly more frequent in NHMD (Table 1B).

All head injuries including intracranial bleeding, skull fractures, and face fractures were more often seen in NHMD. Cervical spine injuries occurred in 10.6 % of NHMD and 9.5 % of HMD (***p<0.001***). Of these, cervical spine fractures were found in 8.2 % of NHMD and 6.6 % of HMD (***p<0.001***). Injuries to the thorax, spine, abdomen, pelvis, and extremities were more common in the HMD group (Table 2).

Patient outcomes

Overall, NHMD had higher mortality and worse outcomes compared to HMD as shown in Table 3. The ICU admission rate as well as the need for mechanical ventilation were higher in the NHMD group (ICU admission: 38% vs. 30.2 %, ***p<0.001***; mechanical ventilation: 20.1 % vs. 13 %, ***p<0.001***). The most common complications in patients who survived to discharge was deep vein thrombosis (NHMD 1.7 % vs. HMD 1.4 %, ***p<0.001***) and acute respiratory distress syndrome (NHMD 1.6 % vs. HMD 1.3 %, ***p<0.001***). The overall in-hospital mortality was 4.6 % and it was significantly higher in the NHMD (6.2 % vs. 3.9 %, ***p<0.001***).

Multivariable analysis

After controlling for covariates on multivariable analysis, helmet utilization was associated with decreased odds of death (*OR* 0.849, 95 % CI 0.809–0.891). The strongest predictors of mortality were GCS < 9 (*OR* 29.541, 95 % CI 27.851–31.333) and hypotension on admission (*OR* 10.73, 95 % CI 10.122–11.391) (Table 4). The subgroup analyses generated similar results with the total cohort in both magnitude and direction (helmet use is independently associated with decreased mortality) and are provided in the Supplemental Table 1.

Discussion

Motorcycle crashes continue to pose a significant public health

Table 1
A patient demographics.

	Total $n = 315{,}258$ (%)	Helmeted $n = 207{,}928$ (%)	Non-Helmeted $n = 107{,}330$ (%)	p value
Age, year (median, IQR)	41 (27–53)	40 (27–53)	42 (29–52)	***<0.001***
< 16 years	4350 (1.4)	2414 (1.2)	1936 (1.8)	***<0.001***
16–50 years	216,096 (68.7)	142,359 (68.6)	73,737 (68.9)	***<0.001***
51–65 years	78,662 (25)	51,710 (24.9)	26,952 (25.2)	***<0.001***
> 65 years	15,350 (5.3)	10,894 (5.3)	4456 (4.2)	***<0.001***
Sex				
Female	23,663 (7.5)	15,612 (7.5)	8051 (7.5)	.951
Male	291,437 (92.5)	192,222 (92.5)	99,215 (92.5)	.951
Work related accident	1221 (0.4)	1052 (0.5)	169 (0.2)	***<0.001***
Transfer-in patients	54,091 (17.2)	33,364 (16)	20,727 (19.3)	***<0.001***
Protective devices				
Protective clothing	22,027 (7)	21,990 (10.6)	37 (0)	***<0.001***
Protective non-clothing gear	2305 (0.7)	2302 (1.1)	3 (0)	***<0.001***
Intoxication				
Alcohol tested*	187,714 (59.6)	119,791 (57.6)	67,923 (63.3)	***<0.001***
Alcohol positive	57,225 (18.2)	28,237 (13.6)	28,988 (27)	***<0.001***
Illicit drugs tested**	63,378 (20.1)	38,615 (18.6)	24,763 (23.1)	***<0.001***
Illicit drugs positive	56,618 (18)	34,047 (16.4)	22,571 (21)	***<0.001***
Comorbidities				
Smoking	53,057 (16.8)	30,155 (14.5)	22,902 (21.3)	***<0.001***
Hypertension	49,188 (15.6)	32,561 (15.7)	16,627 (15.7)	.217
Diabetes	19,971 (6.3)	13,154 (6.3)	6817 (6.4)	.783
Congestive heart failure	1611 (0.5)	994 (0.5)	617 (0.6)	***<0.001***
COPD	2651 (0.8)	1512 (0.7)	1139 (1.1)	***<0.001***
Alcohol use disorder	17,938 (5.7)	8353 (4)	9585 (8.9)	***<0.001***
Substance abuse disorder	10,943 (3.5)	6102 (2.9)	4841 (4.5)	***<0.001***

B Admission vital signs, injury severity, and emergency department disposition

	Total $n = 315{,}258$ (%)	Helmeted $n = 207{,}928$ (%)	Non-Helmeted $n = 107{,}330$ (%)	p value
ED vital signs				
SBP < 90 mmHg	12,403 (4)	7815 (3.8)	4588 (4.3)	***<0.001***
HR > 120 bpm	21,051 (6.8)	12,821 (6.3)	8230 (7.8)	***<0.001***
GCS < 9	30,522 (9.9)	15,195 (7.5)	15,327 (14.7)	***<0.001***
Injured body region				
Head	121,640 (38.6)	63,278 (30.4)	58,362 (54.4)	***<0.001***
Head AIS ≥ 3	58,212 (18.5)	27,612 (13.3)	30,600 (28.5)	***<0.001***
Face	94,403 (29.9)	46,923 (22.6)	47,480 (44.2)	***<0.001***
Face AIS ≥ 3	2551 (0.8)	1217 (0.6)	1334 (1.2)	***<0.001***
Neck	5798 (1.8)	3728 (1.8)	2070 (1.9)	***<0.001***
Neck AIS ≥ 3	1652 (0.5)	1011 (0.5)	641 (0.6)	***<0.001***
Thorax	131,502 (41.7)	89,069 (42.8)	42,433 (39.5)	***<0.001***
Chest AIS ≥ 3	95,927 (30.4)	65,180 (31.3)	30,747 (28.6)	***<0.001***
Abdomen	67,366 (21.4)	47,447 (22.8)	20,029 (18.7)	***<0.001***
Abdomen AIS ≥ 3	20,817 (6.6)	14,707 (7.1)	6110 (5.7)	***<0.001***

Table 1 (*continued*)

B Admission vital signs, injury severity, and emergency department disposition

	Total $n = 315{,}258$ (%)	Helmeted $n = 207{,}928$ (%)	Non-Helmeted $n = 107{,}330$ (%)	p value
Spine	68,698 (21.8)	46,157 (22.2)	22,541 (21)	***<0.001***
Spine AIS ≥ 3	13,662 (4.3)	8916 (4.3)	4746 (4.4)	.080
Upper extremity	179,798 (57)	123,321 (59.3)	56,477 (52.6)	***<0.001***
Upper extremity AIS ≥ 3	14,652 (4.6)	10,751 (5.2)	3901 (3.6)	***<0.001***
Lower extremity	187,659 (59.5)	129,511 (62.3)	58,148 (54.2)	***<0.001***
Lower extremity AIS ≥ 3	62,628 (19.9)	43,756 (21)	18,872 (17.6)	***<0.001***
Injury severity				
ISS (median, IQR)	10 (5–17)	10 (5–17)	10 (5–19)	***<0.001***
ISS > 15	92,666 (30.6)	56,617 (28.8)	36,049 (34.0)	***<0.001***
ISS ≥ 25	39,238 (13)	23,010 (11.7)	16,228 (15.3)	***<0.001***
Disposition after ED				
Operating room	50,588 (16.7)	34,560 (17.3)	16,028 (15.7)	***<0.001***
Intensive care unit	67,502 (22.3)	39,734 (19.9)	27,768 (27.1)	***<0.001***
Telemetry	21,939 (7.3)	14,845 (7.4)	7094 (6.9)	***<0.001***
Observation unit	6543 (2.2)	4521 (2.3)	2022 (2)	***<0.001***
Floor	113,093 (37.4)	77,473 (38.8)	35,620 (34.8)	***<0.001***
Home	28,928 (9.6)	20,520 (10.3)	8408 (8.2)	***<0.001***
Other	8196 (2.7)	5060 (2.5)	3136 (3.1)	***<0.001***

COPD: chronic obstructive pulmonary disease; ED: emergency department; SBP: systolic blood pressure; HR: heart rate.

problem with increasing trends in recent years [4,5,16,17]. One third of all motorcycle drivers in the present study were not wearing a helmet at the time of the collision. More importantly, NHMD were more than twice as likely to suffer severe traumatic brain injury, which was the strongest predictor for mortality. Helmet use was associated with decreased odds of death without increasing the risk of neck or cervical spine injuries.

In terms of demographics, our findings are in line with previous studies which have shown that motorcycle drivers are predominantly men between 30 and 45 years old [18–22]. Our data show that NHMD were more likely to be intoxicated at the time of injury. In addition, we found a protective effect of alcohol and drug use in the regression analysis. Previous studies have also shown that alcohol and drug use are associated with lower mortality [23–25]. In particular, some animal studies revealed that alcohol may have neuroprotective effect after traumatic brain injury, which may explain the lower mortality [26,27]. However, alcohol and drug use are also associated with many factors that are not usually included in regression analyses because they are not readily available. These factors may explain the mortality advantage rather than alcohol or drugs themselves [28,29]. Given that alcohol and drug use increase the risk of a collision in the first place, enhanced public prevention efforts and educational campaigns discouraging their use may help to further decrease crashes in motorcycle drivers.

Musculoskeletal injuries including upper and lower extremity fractures comprise the most common injuries in both HMD and NHMD [30,31]. Overall, HMD sustained a higher injury burden to the torso as well as the extremities. It is likely that HMD are able to survive higher impact collisions resulting in the observed injury pattern. As expected, NHMD had significantly higher incidence of head and face injuries with associated higher mortality and ICU admission rates.

The overall mortality rate in the present study was 4.6 % and it was significantly higher in NHMD (6.2 % vs. 3.9 %). Interestingly, this

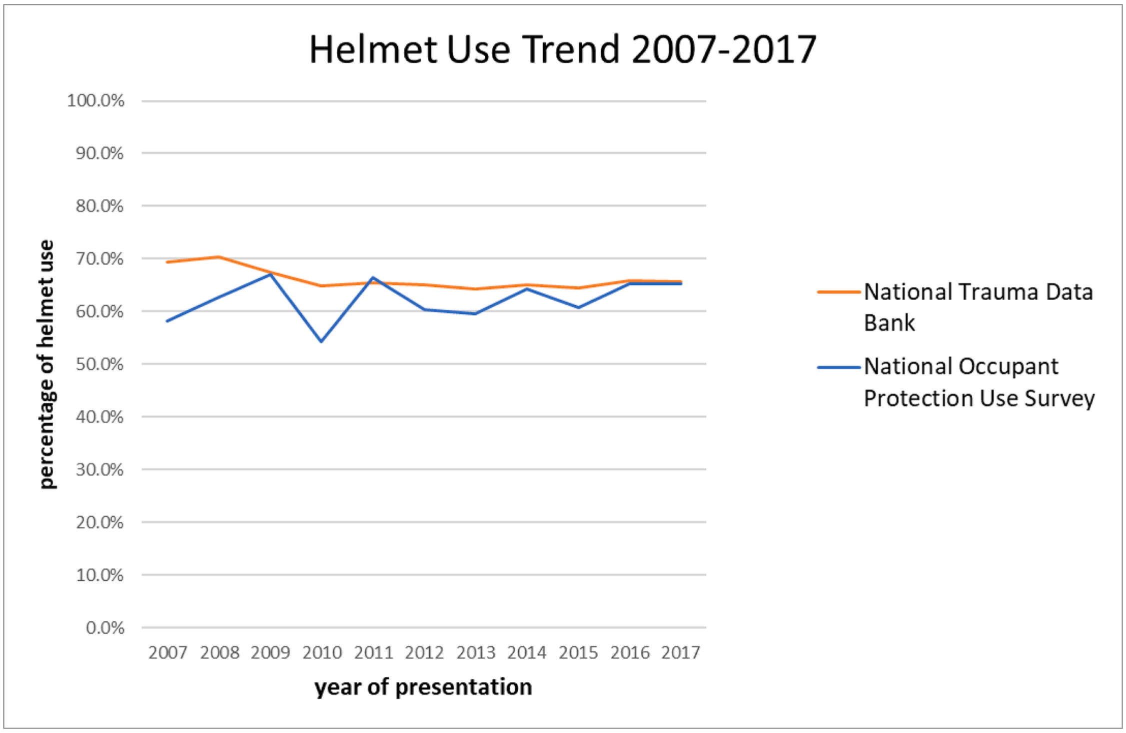

Fig. 2. Trend in helmet use 2007–2017. Comparison of national occupant protection use survey vs. national trauma data bank.

difference in mortality reflects the difference in the prevalence of severe head injuries between the groups. Multiple studies have shown better outcome on severe head trauma and mortality for patients involved in motorcycle crashes when wearing a helmet [21,22,30,32–34].

After adjustment for multiple covariates on regression analysis, helmet use was associated with a 15 % decrease in mortality risk. In line with prior research, our findings reveal that a decreased GCS upon admission emerged as the most powerful indicator of mortality [19,21,30,32,35–37].

Groups that oppose universal helmet laws support that motorcycle riders should have the freedom of individual choice when it comes to wearing a helmet. They also express concerns about the negative effects of helmets, such as reduced vision and potentially higher risk of injuries to the neck and cervical spine. Early reports on this subject generated a debate regarding helmet use as they demonstrated that helmets might reduce head and brain trauma at the expense of higher c-spine injuries [38]. However, more recent reports, including the present study with more than 300 thousands motorcycle drivers, have consistently refuted these findings showing that helmet use is not associated with increased cervical spine injuries [19,39–41]. A previous NTDB study including both motorcycle drivers and passengers, also reported that non-helmeted patients had a higher incidence of traumatic brain injuries, cervical spine injuries, and higher mortality rate compared to helmeted patients [19].

The protective role of helmet in reducing traumatic brain injury and mortality after a motorcycle collision has been consistently demonstrated in the literature [21,22,30,32–34]. In line with these findings, the Eastern Association for the Surgery of Trauma has recently published guidelines supporting the use of full-face as opposed to partial-face helmets as the former have been shown to significantly reduce traumatic brain injury, injury severity to the head and neck as well as injuries and fractures to the face [42,43].

After the Senate lifted sanctions on states without helmet laws in 1995, the rate of helmet use declined significantly with a decrease of 50 % in male NHMD (78 % to 39.1 %) [44]. Since the early 2000s, the percentage of helmet use has varied little, according to NOPUS [15]. Several investigations have also shown that universal helmet laws increase compliance with helmet use and are effective in reducing motorcycle-related injuries and fatalities [45,46]. Currently, 18 states and the District of Columbia have universal helmet laws in place [9]. Twenty-nine states have partial helmet laws (require helmet use by minors and typically do not apply to motorcycle passengers), and 3 states have no helmet laws [9]. Consistent with NHTSA data, we did not find an overall increasing trend in helmet use over the 11-year study period. The finding that one-third of motorcyclists in this large NTDB study were not wearing a helmet at the time of the collision clearly indicates room for improvement. Continued surveillance is warranted to monitor potential changes in legislation, compliance with helmet use, and outcomes for both motorcycle drivers and passengers. In addition to educational campaigns aiming at primary prevention, advances in the design of protective equipment (protective clothing, boots, motorcycle airbag jackets) and increased compliance with its use may also help to decrease the burden of torso and extremity injuries in motorcycle riders [5,6].

Several limitations must be acknowledged. This is a retrospective study and is therefore subject to reporting and recording bias. Only patients admitted to trauma centers are included in the NTDB. Therefore, the true incidence of motorcycle related injuries could not be assessed. In addition, patients who died at the scene are also not included in the NTDB. Hence, the true mortality rate is likely underreported in our study. In addition, important information such as vehicle speed at the time of the collision, helmet type, and specific details surrounding the accident such as the type of head impact are not provided in the database; therefore, adjustment for these potential confounders was not possible. Lastly, follow-up data were not available, limiting our understanding of the long-term outcomes in patients with severe traumatic injuries.

In conclusion, one third of all motorcycle drivers were not wearing a helmet at the time of the crash. Helmet use was associated with decreased risk for head injury and death without increasing the risk for cervical spine injuries. The findings of this study support the continued enforcement of universal helmet laws.

Table 2
Injury distribution.

	Total n = 315,258 (%)	Helmeted n = 207,928 (%)	Non-Helmeted n = 107,330 (%)	p value
Head				
Any head bleed	42,963 (13.6)	20,076 (9.7)	22,887 (21.3)	***<0.001***
Epidural	3706 (1.2)	1064 (0.5)	2642 (2.5)	***<0.001***
Subdural	23,620 (7.5)	9998 (4.8)	13,622 (12.7)	***<0.001***
Subarachnoid	27,196 (8.6)	12,915 (6.2)	14,281 (13.3)	***<0.001***
Skull fracture	30,603 (9,7)	11,353 (5.5)	19,250 (17.9)	***<0.001***
Face fracture	43,018 (13.6)	19,394 (9.3)	23,624 (22)	***<0.001***
Thorax				
Vascular injury	2837 (0.9)	1954 (0.9)	883 (0.8)	***<0.001***
Thoracic aorta	2123 (0.7)	1435 (0.7)	688 (0.6)	.110
Heart injury	2593 (0.8)	1810 (0.9)	783 (0.7)	***<0.001***
Lung injury	52,016 (16.5)	35,446 (17)	16,570 (15.4)	***<0.001***
Diaphragm	827 (0.3)	538 (0.3)	289 (0.3)	.607
Hemo-/Pneumothorax	58,705 (18.6)	40,746 (19.6)	17,959 (16.7)	***<0.001***
Sternum fracture	6436 (2)	4419 (2.1)	2017 (1.9)	***<0.001***
Rib fracture	96,493 (30.6)	65,543 (31.5)	30,950 (28.8)	***<0.001***
Flail chest	7322 (2.3)	4951 (2.4)	2371 (2.2)	***.002***
Scapula fracture	30,104 (9.5)	20,915 (10.1)	9189 (8.6)	***<0.001***
Clavicle fracture	39,579 (12.6)	26,893 (12.9)	12,686 (11.8)	***<0.001***
Spine				
Any spinal injury	68,700 (21.8)	46,157 (22.2)	22,543 (21)	***<0.001***
Cervical spine injury	31,100 (9.9)	19,713 (9.5)	11,387 (10.6)	***<0.001***
Thoracic spine injury	30,101 (9.5)	20,948 (10.1)	9153 (8.5)	***<0.001***
Lumbar spine injury	27,070 (8.6)	18,803 (9)	8267 (7.7)	***<0.001***
Any spinal fracture	59,213 (18.8)	39,488 (19)	19,725 (18.4)	***<0.001***
Cervical spine fracture	22,508 (7.1)	13,742 (6.6)	8766 (8.2)	***<0.001***
Thoracic spine fracture	28,878 (9.2)	20,028 (9.6)	8850 (8.2)	***<0.001***
Lumbar spine fracture	24,584 (7.8)	16,933 (8.1)	7651 (7.1)	***<0.001***
Abdomen				
Vascular injury	3142 (1)	2243 (1.1)	899 (0.8)	***<0.001***
Any solid organ	33,275 (10.6)	23,469 (11.3)	9806 (9.1)	***<0.001***
Any hollow viscus	3477 (1.1)	2410 (1.2)	1067 (1)	***<0.001***
Retroperitoneal hem.	4012 (1.3)	2859 (1.4)	1153 (1.1)	***<0.001***
Urogenital injury	2999 (1)	2112 (1)	887 (0.8)	***<0.001***
Upper extremity				
Any fracture	74,034 (23.5)	53,212 (25.6)	20,822 (19.4)	***<0.001***
Humerus fracture	15,321 (4.9)	10,982 (5.3)	4339 (4)	***<0.001***
Radius/Ulna fracture	41,232 (13.1)	29,895 (14.4)	11,337 (10.6)	***<0.001***
Hand fracture	32,604 (10.3)	23,514 (11.3)	9090 (8.5)	***<0.001***
Pelvic fracture	33,873 (10.7)	23,776 (11.4)	10,097 (9.4)	***<0.001***
Lower extremity				
Any fracture	106,817 (33.9)	73,509 (35.4)	33,308 (31)	***<0.001***
Femur fracture	32,056 (10.2)	22,498 (10.8)	9558 (8.9)	***<0.001***
Tibia/fibula fracture	72,171 (22.9)	49,273 (23.7)	22,898 (21.3)	***<0.001***
Foot fracture	36,436 (8.4)	18,430 (8.9)	8006 (7.5)	***<0.001***
Hip dislocation	3354 (1.1)	2319 (1.1)	1035 (1)	***<0.001***

Table 3
Outcomes.

	Total n = 315,258 (%)	Helmeted n = 207,928 (%)	Non-Helmeted n = 107,330 (%)	p value
Mechanical ventilation*				
No. ventilated	48,649 (15.4)	27,084 (13)	21,565 (20.1)	***<0.001***
Ventilator days	4 (2–10)	4 (2–11)	4 (2–11)	.545
Intensive care unit*				
No. admitted	103,473 (32.8)	62,712 (30.2)	40,761 (38)	***<0.001***
ICU LOS, days	3 (2–8)	7 (3–15)	7 (3–15)	.649
Hospital LOS, days*	4 (2–8)	4 (2–8)	4 (2–8)	***<0.001***
Complications†				
Cardiac arrest	3038 (1)	1836 (0.9)	1202 (1.1)	***<0.001***
Myocardial infarct	478 (0.2)	315 (0.2)	163 (0.2)	.980
ARDS	4491 (1.4)	2782 (1.3)	1709 (1.6)	***<0.001***
Extremity compartment syndrome	1533 (0.5)	1059 (0.5)	474 (0.4)	***.010***
Deep venous thrombosis	4766 (1.5)	2917 (1.4)	1849 (1.7)	***<0.001***
Pulmonary embolism	2040 (0.6)	1389 (0.7)	651 (0.6)	***.041***
Acute kidney injury	2417 (0.8)	1628 (0.8)	789 (0.7)	***<0.001***
Severe sepsis	922 (0.3)	600 (0.3)	322 (0.3)	.573
Hospital discharge*				
Home	233,101 (74.1)	156,245 (75.3)	76,856 (71.8)	***<0.001***
Rehabilitation center	29,918 (9.5)	18,951 (9.1)	10,967 (10.2)	***<0.001***
Extended care facility	11,402 (3.6)	7369 (3.6)	4033 (3.8)	***<0.001***
Nursing home	25,551 (8.1)	17,005 (8.2)	8546 (8)	***<0.001***
Other	14,577 (4.6)	7974 (3.8)	6603 (6.2)	***<0.001***
Mortality	14,603 (4.6)	7999 (3.9)	6604 (6.2)	***<0.001***

Categorical variables presented as number and percentage. Continuous variables presented as median (interquartile range).
LOS, length of stay; ARDS, acute respiratory distress syndrome.

Table 4
Multivariate analysis of independent risk factors for mortality.

	Adjusted *OR*	95 % CI for *OR*	**Adjusted *p***
Age > 65	2.381	2.173–2.608	***<0.001***
Sex, male	1.439	1.297–1.596	***<0.001***
Helmet use	.849	.809–0.891	***<0.001***
Transfer-in patients	.508	.475–0.544	***<0.001***
Alcohol	.617	.582–0.654	***<0.001***
Drugs	.664	.620–0.711	***<0.001***
SBP < 90 mmHg	10.737	10.122–11.391	***<0.001***
Tachycardia > 120 bpm	1.285	1.210–1.365	***<0.001***
GCS < 9	29.541	27.851–31.333	***<0.001***
Head AIS ≥ 3	1.941	1.836–2.052	***<0.001***
Chest AIS ≥ 3	1.750	1.666–1.838	***<0.001***
Abdomen ≥ 3	1.685	1.575–1.802	***<0.001***
Spine AIS ≥ 3	1.116	1.026–1.213	***.010***
Upper extremity AIS ≥ 3	.737	.667–0.815	***<0.001***
Lower extremity AIS ≥ 3	1.270	1.202–1.342	***<0.001***

AUROC 0.947 (95 % CI 0.945–0.950).

Author contributions

P.L., D.A.J., D.D. designed the study. L.B., P.L. did the literature search, L.B., P.L. and D.A.J. carried out data acquisition, L.B., D.A.J. analyzed data, L.B., P.L. and D.A.J. wrote the first draft of the manuscript. All authors contributed to the interpretation of the data and writing of the manuscript and approved the final version of the manuscript. D.A.J. and D.D. supervised all aspects of study design, data acquisition, analyzes, and article writing.

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Statement of human rights

This study was approved by the Institutional Review Board of the University of Southern California

Declaration of Competing Interest

The authors listed have no conflicts of interest and these data have not been published elsewhere.

Supplementary materials

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