



## Protective effect of helmet use on cervical injury in motorcycle crashes: A case–control study

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### ABSTRACT

**Introduction:** Helmet use during motorcycle crashes (MCCs) has been shown to reduce traumatic brain injury and mortality. However, preventive effects of its use on cervical spine injury remain controversial. In this study, we evaluated whether helmet use can reduce cervical spine injury during MCCs.

**Patients and Methods:** A case–control study using data from the Emergency Department-based Injury In-depth Surveillance (EDIIS) registry was conducted. Cases were defined as patients with cervical spine injury [ $\geq 2$  points in the Abbreviated Injury Scale (AIS)] in MCCs from 2011 to 2016. Four controls were matched to one case with strata which included age and sex from the EDIIS registry. Primary outcome was cervical spine injury, secondary outcome was intensive care unit (ICU) admission, and tertiary outcomes was mortality. Multivariable logistic regression analysis was used to calculate odds ratios (OR) with 95% confidence intervals (CIs) to evaluate the associations between helmet use and related outcomes.

**Results:** In total, 2600 patients were analysed; among these, 1145 (44.0%) used helmets at the time of crashes. The helmet group showed lower alcohol consumption and mortality rates than the no helmet group (alcohol: 3.2% vs. 9.2%, respectively, and mortality: 2.4% vs. 7.1%, respectively;  $p < 0.01$ ). Compared with the no helmet group, the helmet group was less likely to have cervical spine injury [adjusted OR, 0.62 (0.51–0.77)]. In addition, helmet use has been shown to help prevent ICU admission and mortality [adjusted OR, 0.45 (0.36–0.56) and 0.32 (0.21–0.51), respectively].

**Conclusion:** Helmet use was found to have significant preventive effects on cervical spine injury during MCCs.

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### Introduction

In 2016, 5286 motorcyclists were killed in motor vehicle traffic crashes in the United States, accounting for 14% of all traffic fatalities [1]. In Korea, 428 deaths from motorcycle crashes (MCCs) occurred in 2016, accounting for 10% of all fatalities and representing a 6.7% increase from the previous year [2]. Compared with automobile drivers, motorcyclists are 30-times more likely to be killed in MCCs [3]. Accident survivors might suffer from disabilities, imposing economic and public health burdens [4].

Several strategies have been implemented in many communities to reduce the fatality from MCCs: public campaigns and education about safe road use, such as helmet use; reducing alcohol-impaired driving; enacting laws requiring universal helmet use; proper rider licensing and training and designation of available roads [5].

Helmet use during MCCs has been shown to decrease the risks of serious head injury by 69% and of mortality by 42% [6]. However, whether helmet use decreases the risk of cervical spine injury is controversial. Reportedly, helmet use increased the risk of cervical spine injuries [7,8]. A possible mechanism to explain this result is that helmets increase the weight on the head, resulting in an increased momentum on the cervical spine and increased risk of flexion and extension of the neck during MCCs. Therefore, helmet use at the time of a crash could lead to worse neck injuries [7,8]. Other studies have shown that helmet use neither increased the risk of cervical spine injuries nor decreased the risk during MCCs [9–14]. Especially in frontal collisions, helmet use can reduce serious cervical spine injury [8].

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We hypothesised that helmet use would reduce cervical spine injuries. The aim of this study was to evaluate the preventive effect of helmet use on cervical spine injuries, intensive care unit (ICU) admission and mortality due to MCCs. This study was approved by the Institutional Review Board of Chung-Buk National University Hospital (IRB No. CBNUH 2018-06-017).

## Patients and methods

### Study design and setting

We conducted a case–control study using the Emergency Department-based Injury In-depth Surveillance (EDIIS) database in Korea. The EDIIS is a nationwide prospective database of injured patients who visited an emergency department (ED) financially supported by the Korea Centres for Disease Control and Prevention (CDC). It was established in five hospitals in 2006; currently, a total of 23 EDs gather injury-related information from patients for establishment of a regional surveillance system based on each emergency centre and for development of a national policy related to injury prevention.

### Data source and collection

The EDIIS database was constructed using the dataset of the International Classification of External Causes of Injuries proposed by the World Health Organisation. The database comprises 58 items, including patients' demographics, injury-related information, prehospital emergency medical service records, clinical findings, diagnosis and treatment at an ED and treatment outcomes. Primary data collection was performed by general physicians, and the recorded information was supervised and revised regularly by emergency physicians and trained research coordinators. All research coordinators regularly uploaded the surveillance data to a web-based database system of the Korea CDC. The Quality Management Committee of the project trained all research coordinators in each study hospital prior to joining this project, monthly reviewed the data and provided feedback to research coordinators to maintain the quality of the data [15].

### Study population

This case–control study was nested within a longitudinal cohort study of patients by MCCs in the EDIIS database from January 2011 through December 2016. Case patients were eligible if they had a confirmed diagnosis (recorded on the discharge summary after ED or hospital admission) of cervical spine injury [ $\geq 2$  points in the Abbreviated Injury Scale (AIS 2+)] based on the diagnostic criteria of the International Classification of Diseases, Tenth Revision (ICD-10) code.

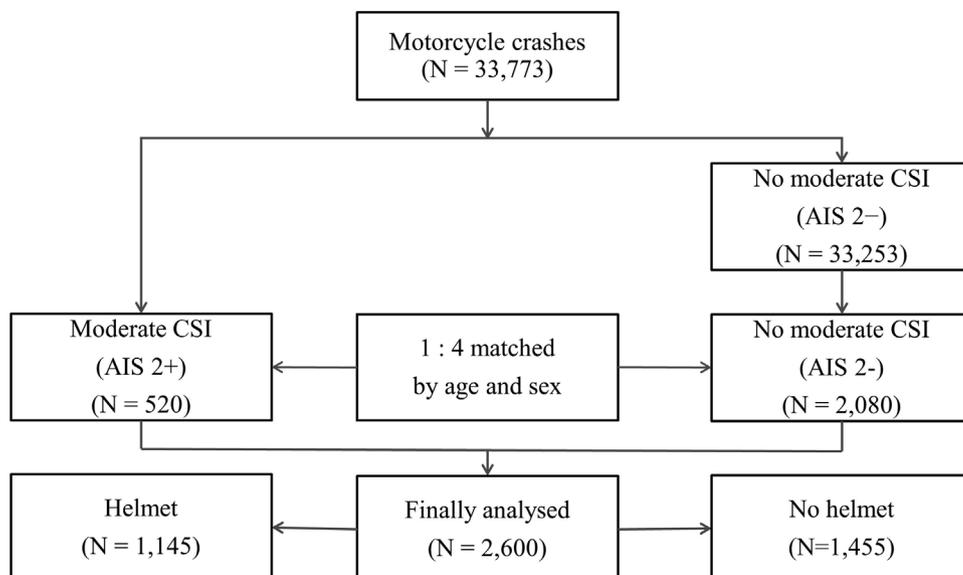
Cases that were followed included those involving fracture of the cervical vertebra and other parts of the neck (S12.0–S12.9), traumatic rupture of the cervical intervertebral disc (S13.0), dislocation of the cervical vertebra and other parts of the neck (S13.1–S13.3), cervical spinal cord injury (S14.0–S14.1), nerve root injury of the cervical spine and other parts of the neck (S14.2–S14.6), fractures involving the head with neck (T02.0), or injuries of nerves and spinal cord injury at the neck level and multiple injuries (T06.0–T06.2). The control group comprised patients with no cervical spine injury (AIS 2–) in the same database, with superficial injury, open wound of the neck, or sprain or strain of the cervical spine. Subsequent to enrolment of a case, eligible control patients of the same sex and 1-year age categories were approached until four control patients were individually matched to each case patient.

### Main outcomes

The primary outcome was cervical spine injury, secondary outcome was ICU admission and tertiary outcome was mortality, defined as death at an ED or during admission within 30 days after injury. These outcomes were determined during discharge from an ED or a hospital.

### Variables and measurements

The main exposure variable was helmet use detected by the EDIIS database. We collected information on the demographic factors (age and sex), injury-related information (day of injury, time of injury, road type and alcohol consumption),



**Fig. 1.** Patients' flow chart.  
CSI: cervical spine injury, AIS: Abbreviated Injury Scale.

pre-hospital, ED and hospital information (EMS use, time interval from injury to ED admission, mental status at an ED, sustained injury part, traumatic brain injury, injury severity according to the excess mortality ratio-based injury severity score [EMR-ISS], length of ED stay, operation and ED disposition). Road types at MCCs were divided into expressway, national highway, alleyway and other/unknown according to the excess mortality ratio-based injury severity score. Traumatic brain injury was defined as the ICD-10 diagnostic codes from S06.1 to S06.9 assigned on the discharge summary following ED or hospital admission.

### Statistical analysis

Categorical variables are expressed as counts and proportion and continuous variables as median and interquartile ranges. Between-group differences were compared using the Pearson's

chi-square test and Wilcoxon rank sum test. We performed univariate analyses of the relationships between cervical spine injury and risk factors and between helmet use and risk factors to identify potential confounders. We calculated adjusted odds ratios (ORs) with 95% confidence intervals (95% CIs) of helmet use for the study outcomes using multivariable logistic regression analysis to evaluate the association between helmet use and related outcomes (cervical spine injury, ICU admission and mortality), with no helmet use as reference. Age, sex, time of injury, road type, alcohol consumption, and use of emergency medical services (EMS) were possible risk factors with a significant relationship to spine injury or helmet use if the *p*-value was <0.20 and were therefore used as adjustment factors for potential confounding in the logistic models. The criterion for the *p*-value was defined as a two-sided significance level of 0.05. All statistical analyses were performed using SAS software (version 9.4; SAS Institute Inc., Cary, NC, USA).

**Table 1**  
Demographic findings of study population by serious spine injury 2011–2016.

	Total		Cervical spine injuries (AIS2+)		Controls (AIS2-)		p-value
	N	%	N	%	N	%	
Total	2600		520	20	2080	80	
Helmet use							<0.01
Yes	1145	44.0	174	33.5	971	46.7	
No	1455	56.0	346	66.5	1109	53.3	
Gender							0.94
Male	2392	92.0	478	91.9	1914	92.0	
Female	208	8.0	42	8.1	166	8.0	
Age							0.1
Median (IQR), year	51 (30–69)		52 (32–69)		50 (29–68)		0.1
Time of injury							0.01
00–06	287	11.0	77	14.8	210	10.1	
06–12	699	26.9	128	24.6	571	27.5	
12–18	918	35.3	186	35.8	732	35.2	
18–24	696	26.8	129	24.8	567	27.3	
Day of injury							0.51
Weekend	801	30.8	154	29.6	647	31.1	
Road type							0.66
Expressway	5	0.2	1	0.2	4	0.2	
National highway	1679	64.6	346	66.5	1333	64.1	
Alleyway	65	2.5	6	1.2	59	2.8	
Other/unknown	851	32.7	167	32.1	684	32.9	
Alcohol consumption							<0.01
Yes	171	6.6	56	10.8	115	5.5	
EMS use							<0.01
Yes	2020	77.7	482	92.7	1538	73.9	
Mental status at the ED							<0.01
Alert	1918	73.8	328	63.1	1590	76.4	
Verbal response	101	3.9	29	5.6	72	3.5	
Pain response	102	3.9	40	7.7	62	3.0	
Unresponsiveness	78	3.0	40	7.7	38	1.8	
Unknown	401	15.4	83	16.0	318	15.3	
Time interval from injury to ED							<0.01
Median (IQR), min	60 (30–176.5)		70 (32–224)		57 (30–152)		<0.01
Length of stay in ED							<0.01
Median (IQR), min	255 (129–490)		429.5 (232–935)		224 (116–417)		<0.01
Injury severity							<0.01
EMR-ISS ≥9	1427	54.9	400	76.9	1027	49.4	<0.01
EMR-ISS ≥16	998	38.4	394	75.8	604	29.0	<0.01
Median (IQR)	17 (9–34)		41 (25–57)		12 (8–25)		<0.01
Operation							<0.01
Yes	379	14.6	127	24.4	252	12.1	<0.01
ED disposition							<0.01
Discharge	1107	42.6	33	6.3	1074	51.6	<0.01
Admission, total	1177	45.3	400	76.9	777	37.4	<0.01
Admission to ICU	447	17.2	187	36.0	260	12.5	<0.01
Transfer to other hospital	254	9.8	63	12.1	191	9.2	<0.01
Death	60	2.3	24	4.6	36	1.7	<0.01
Others	2	0.1	0	0.0	2	0.1	<0.01
Mortality							<0.01
	120	4.6	45	8.7	75	3.6	<0.01

AIS: Abbreviated Injury Scale; IQR: interquartile range; EMS: emergency medical services; ED: emergency department; ICU: intensive care unit.

## Results

Among 33,773 patients who suffered from MCCs, 520 (20%) were those who had a cervical injury and were matched to 2080 no cervical injury patients at a 1:4 ratio by same age and sex, excluding a 93-year-old male in the case group who was matched to a pair of 92-year-old males and another pair of 94-year-old

males (n = 4, total) in the control group. In total, 2600 patients were enrolled in this study (Fig. 1).

Table 1 shows the demographic characteristics based on cervical spine injury. The proportion of patients who used helmets was higher in the no cervical spine injury group (46.7%) than in the intracranial injury group (33.5%;  $p < 0.01$ ). The proportions of injury time between 0 and 6, EMS use, alcohol consumption and

**Table 2**  
Demographic findings of study population by helmet use.2011–2016.

	Total		Helmet		No-helmet		p-value
	N	%	N	%	N	%	
Total	2600		1145	44.0	1455	56.0	
Gender							<0.01
Male	2392	92.0	1073	93.7	1319	90.7	
Female	208	8.0	72	6.3	136	9.3	
Age							<0.01
0–19	926	35.6	452	39.5	474	32.6	
20–39	491	18.9	242	21.1	249	17.1	
40–59	516	19.8	251	21.9	265	18.2	
60–79	612	23.5	188	16.4	424	29.1	
80–	55	2.1	12	1.0	43	3.0	
Median (IQR), year	51 (30–69)		46 (29–61)		54 (31–71)		0.1
Time of injury							0.64
00–06	287	11.0	117	10.2	170	11.7	
06–12	699	26.9	315	27.5	384	26.4	
12–18	918	35.3	402	35.1	516	35.5	
18–24	696	26.8	311	27.2	385	26.5	
Day of injury							0.4
Weekend	801	30.8	343	30.0	458	31.5	
Road type							<0.01
Expressway	5	0.2	4	0.3	1	0.1	
National highway	1679	64.6	858	74.9	821	56.4	
Alleyway	65	2.5	37	3.2	28	1.9	
Other/unknown	851	32.7	246	21.5	605	41.6	
Alcohol consumption							<0.01
Yes	171	6.6	37	3.2	134	9.2	
EMS use							<0.01
Yes	2020	77.7	838	73.2	1182	81.2	
Mental status at the ED							<0.01
Alert	1918	73.8	984	85.9	934	64.2	
Verbal response	101	3.9	29	2.5	72	4.9	
Pain response	102	3.9	21	1.8	81	5.6	
Unresponsiveness	78	3.0	17	1.5	61	4.2	
Unknown	401	15.4	94	8.2	307	21.1	
Anatomical classification of injury							
Head & face	1233	47.4	424	37.0	809	55.6	<0.01
Neck	612	23.5	224	19.6	388	26.7	<0.01
Chest	481	18.5	186	16.2	295	20.3	<0.01
Abdomen	343	13.2	143	12.5	200	13.7	0.35
Upper extremity	659	25.3	329	28.7	330	22.7	<0.01
Lower extremity	721	27.7	366	32.0	355	24.4	<0.01
Diagnosis							
Traumatic brain injury	1142	43.9	378	33.0	764	52.5	<0.01
Cervical spine injury	520	20.0	174	15.2	346	23.8	<0.01
Time interval from injury to ED							<0.01
Median (IQR), min	60 (30–176.5)		46 (30–137)		60 (30–181)		
Length of stay in ED							<0.01
Median (IQR), min	255 (129–490)		227 (109–422)		276 (147–557)		
Injury severity							
EMR-ISS $\geq 9$	1427	54.9	535	46.7	892	61.3	<0.01
EMR-ISS $\geq 16$	998	38.4	336	29.3	662	45.5	<0.01
Median (IQR)	17 (9–34)		13 (8–25)		22 (9–41)		<0.01
Operation							<0.01
Yes	379	14.6	158	13.8	221	15.2	
ED disposition							<0.01
Discharge	1107	42.6	626	54.7	481	33.1	
Admission, total	1177	45.3	428	37.4	749	51.5	
Admission, ICU	447	17.2	123	10.7	324	22.3	
Transfer to other hospital	254	9.8	75	6.6	179	12.3	
Death	60	2.3	14	1.2	46	3.2	
Others	2	0.1	2	0.2	0	0.0	
Mortality							<0.01
	120	4.6	25	2.2	95	6.5	

AIS: Abbreviated Injury Scale; IQR: interquartile range; EMS: emergency medical services; ED: emergency department; ICU: intensive care unit.

poor mental status at an ED in the cervical spine injury group were higher than those in the no cervical spine injury group ( $p < 0.01$ ). The time interval from injury to ED admission and length of ED stay in the cervical spine injury group were longer than those in the no cervical spine injury group (injury to ED admission: median 70 vs. 57 min and length of ED stay: median 429.5 vs. 224 min, respectively; both  $p < 0.01$ ) Clinical outcomes in terms of admission, operation, transfer to another hospital and mortalities were worse in the cervical spine injury group than in the no cervical spine injury group (Table 1).

Table 2 summarises the demographic characteristics of patients based on helmet use. Among 2600 eligible patients, 1145 (44.0%) were using helmets at the time of MCCs (median age, 51 years). The age of the no helmet group subjects was higher than that of the helmet group patients (median: 54 vs. 46 years, respectively;  $p < 0.01$ ). The proportions of females, elderly, EMS use and alcohol consumption in the no helmet group was higher than those in the helmet group ( $p < 0.01$ ), and the time interval from injury to ED admission in the no helmet group was longer than that in the helmet group (median: 60 vs. 46 min, respectively;  $p < 0.01$ ).

Regarding clinical outcomes, the no helmet group had higher proportions of poor mental status, injuries (including head and face, and neck and chest), traumatic brain injury and cervical spine injury (all  $p < 0.01$ ); in contrast, the helmet group had higher proportions of upper and lower extremity injuries ( $p < 0.01$ ). Further, length of ED stay was longer in the no helmet group than in the helmet group (276 vs. 227 min, respectively;  $p < 0.01$ ). The median EMR-ISS was 17, with higher EMR-ISS for the no helmet group than for the helmet group (median: 22 vs. 13, respectively;  $p < 0.01$ ). The proportions of admissions, operations, transfers to another hospital and mortalities in the no helmet group were higher than those in the helmet group (all  $p < 0.01$ ; Table 2).

The results of multivariable logistic regression model, including adjusted ORs (95% CIs), for helmet use are shown in Table 3. The helmet group was less likely to have cervical spine injury at the time of MCCs than was the no helmet group [adjusted OR (95% CI): 0.62 (0.51–0.77)]. Helmet use decreased the likelihood of ICU admission [adjusted OR (95% CI): 0.45 (0.36–0.56)] and mortality [adjusted OR (95% CI): 0.32 (0.21–0.51), respectively; Table 3].

## Discussion

Although several studies have shown conflicting results on the association between helmet use and risk of cervical spine injury, this case–control study using a nationwide injury surveillance database showed that helmet use reduced the risk of cervical spine injury. Further, helmet use was found to reduce mortality and

shorten ICU admission due to MCCs, that is consistent with the results from a systematic review [6].

According to the Haddon matrix, many risk factors associated with severe injury in MCCs can be classified as human (male, youth, low socioeconomic status, alcohol consumption, speed, helmet use), vehicle (motorcycle conspicuity), or environment (night time, summer) [16]. A helmet is a principle human factor that can prevent head injury in an MCC [6]. In this study, a higher proportion of unhelmeted riders in MCCs were female and/or elderly (age  $\geq 60$  years), which are demographic characteristics noted in MCC studies conducted in Korea [17,18]. Elderly Korean riders were more likely to wear only a half coverage helmet or to be unhelmeted [18]. In other studies, most female motorcycle riders injured in MCCs were riding pillion. Those who ride pillion and are reportedly less like to wear a helmet than the drivers [19,20].

A review of helmet use to prevent injury in MCC found them to be effective in reducing both head injury and death [6]. In our comparison of injury area, unhelmeted riders were more likely to have injury to the face and chest as well as to the head and neck. Lastfogel et al. also reported that unhelmeted riders are more likely to have a neck injury [21]. Interestingly, helmeted riders were more likely to have extremity injuries, which is consistent with the study by Lastfogel et al.. Even though there was insufficient evidence to prove that helmets prevent facial injury, the ability of a helmet to do so differs by helmet type. Firm fixation helmets are more important to prevent both facial and head injury in MCCs [22–24].

Goldstein's study has been frequently cited as providing evidence for the increased risk of cervical injury with helmet use [7]. A possible explanation for the increased risk of cervical spine injuries in the MCC of helmeted riders is that helmets add weight and exert a mass effect which increases neck loads. However, a recent study re-analysed the data used during Goldstein's analysis and demonstrated that helmet use reduced the risk of neck injury by 3%, head injury by 60% and fatal injury by 56% [14]. Other studies have also found that helmet use did not increase the risk of cervical spine injuries, but the limitation of the studies was that most were retrospective and had a small sample size [9–11]. Our case–control study was nested within the longitudinal cohort database covering 5 years using AIS and ICD-10 code. This selection of strong study designs ensured that the data on the protective effect of helmet use on cervical spine injury are more reliable than those from less stringent study designs.

The anatomical construction of the head and neck dictate the forces generated by head acceleration or direct impact on the head leading to cervical injuries during MCCs [25]. A recent simulation test reported that helmets reduce the impact force and linear and angular head acceleration; the differences in terms of neck loads

**Table 3**

Association between helmet use and study outcomes.

	Total N	Positive outcomes		Unadjusted OR (95% CI)	Adjusted <sup>a</sup> OR (95% CI)
		N	%		
Primary outcome: cervical spine injury					
Total	2600	520	20.0		
Helmet use	1145	174	15.2	0.57 (0.47–0.70)	0.62 (0.51–0.77)
No helmet use	1455	346	23.8	1.00	1.00
Secondary outcome: ICU admission					
Total	2600	447	17.2		
Helmet use	1145	123	10.7	0.42 (0.34–0.53)	0.45 (0.36–0.56)
No helmet use	1455	324	22.3	1.00	1.00
Tertiary outcome: mortality					
Total	2600	120	4.6		
Helmet use	1145	25	2.2	0.32 (0.20–0.50)	0.32 (0.21–0.51)
No helmet use	1455	95	6.5	1.00	1.00

OR: odds ratio; CI: confidence interval; ICU: intensive care unit.

<sup>a</sup> Adjusted for age, sex, time of injury, road type, alcohol consumption, and EMS use.

between the tests with and without helmets were small [26]. Although the total weight of the head in helmeted riders is greater than that in unhelmeted riders, there is only a minor difference in the distance between the location of the center of mass and the neck. Thus, the biomechanical properties with or without a helmet may not be drastically different. Moreover, in a ballistic test using helmet, head and neck dummy model, it was observed that the ballistic impact force transmitted to the head and neck of the helmeted dummy model decreased [25]. Therefore, helmet use may have protective effects on the head and neck, while not wearing a helmet may increase the probability of cervical injury.

Several studies demonstrated that required helmet use for all motorcyclists, i.e. the so-called universal helmet use law, was effective in increasing helmet use and subsequently reduced injuries and decreased hospital admission and treatment costs [3,27]. In most countries globally, helmet use is mandatory, including for passengers [28]. In the United States, however, only 19 states, the District of Columbia and Puerto Rico have universal helmet use laws [1]. In Korea, helmet use is compulsory for drivers and passengers, and fines are imposed in cases of failure to comply with such laws. However, according to the traffic accident statistics in 2016, MCCs were reported to be the most common among <20-year-old individuals and breach of safety driving was the most common violation of the law [2]. In our study, the proportion of helmet use was only 44.0% and the no helmet group showed a higher proportion of alcohol consumption, possibly leading to poor clinical outcomes. More effective strategies, including public campaigns, education on the need for using safety equipment while riding and strong enforcement of the laws, are needed to improve the safety of those involved in MCCs.

There are certain limitations to our study despite its powerful study design. First, we did not collect injury-related data, such as helmet type, type of head impact, point at which the helmet was ejected and motorcycle speed at the time of collision, regarded as potential confounders. A recent study reported that helmet fixation was more effective than helmet type in protecting motorcyclists [29]. Second, helmet use was only determined via face-to-face interviews with patients and guardians in an ED, possibly leading to another type of bias.

## Conclusions

Helmet use was found to have strong protective effects against cervical spine injury, ICU admission and mortality. Multidisciplinary efforts are needed to increase helmet use for all motorcyclists and should help reduce the public health burden of MCCs. Future studies on the protective effects of helmet use on cervical injuries and on experimental and computational assessment approaches are necessary to investigate biomechanical parameters, including the centre of mass, acceleration of the head and momentum on the cervical spine between helmeted and unhelmeted motorcyclists.

## Conflict of interests

Each author certifies that he or she has no commercial associations (e.g., consultancies, stock, ownership, equity interest, patent/licensing arrangements, etc.) that might pose a conflict of interest in connection with the submitted article.

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