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ORIGINAL ARTICLE

The impact of body mass index on abdominal injuries in motorcycle crashes in South Korea

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Abstract

Objective: Motorcyclists face a higher risk of severe morbidity and mortality compared to automobile passengers. This study aimed to determine the injury characteristics of motorcyclists according to their body mass index (BMI).

Methods: A retrospective observational cross-sectional study was conducted using data from the Emergency Department-based Injury In-depth Surveillance (EDIIS) registry. Motorcycle riders aged 18 or older who were injured and admitted to study hospitals between 2019 and 2020 were included. Patients were divided into three groups based on BMI cutoffs of 18.5 and 25 kg/m^2: the low, optimal, and high BMI groups. The primary outcome was anatomical injury location according to the abbreviated injury scale. The secondary outcomes were the surgery and intensive care unit admission rate, and the 48-h and 30-day in-hospital mortality. Multivariable logistic regression analysis was performed to assess the impact of BMI on outcomes.

Results: Among 1280 patients, the low and high BMI groups had higher risk of abdominal injuries (AIS $\geq$ 2) than the optimal BMI group, with adjusted odds ratios of 2.82 (95% CI 1.41–5.63) and 1.61 (95% CI 1.17–2.21), respectively. Only the low BMI group had a significant association with severe abdominal injury (AIS $\geq$ 3), with an adjusted odds ratio of 3.11 (95% CI 1.31–7.39). No significant association was found between BMI and surgery, ICU admission, or mortality.

Conclusion: The low BMI group was more likely to have an abdominal injury (AIS score $\geq$2 or AIS score $\geq$3) during motorcycle injuries. BMI was not associated with surgery, ICU admission, or mortality.

KEYWORDS

abbreviated injury scale, body mass index, injuries, motorcycles

Dae Kon Kim and Yu Jin Kim corresponding authors who contributed equally to this work.

1 | INTRODUCTION

Motorcycles are an important transport tool, with more than 770 million motorcycles on the roads and 380,000 annual deaths worldwide.[1] Motorcycle use as means of transport is increasing because of convenience, fuel efficiency, and easy maneuvering in congested areas.[2] However, compared to automobile passengers, motorcyclists are eight times more likely to be injured and 35 times more likely to die per vehicle mile.[3] Motorcyclists are extremely vulnerable and can suffer fatal injuries because they are exposed to the environment during motor vehicle crash.[4]

Obesity is a major health problem worldwide that is related to chronic metabolic disorders.[5] The medical effects of obesity have been widely studied, and are known to cause hypertension, diabetes mellitus, and cardiac diseases.[6] Furthermore, obesity causes abdominal fat accumulation.[7] Considering the physics of the injury mechanism, it is expected that obese patients are exposed to a higher risk of injury severity because the energy associated with an impact is proportional to the mass and the square of the velocity.[8] However, the role of fat in the abdominal region is unclear from the perspective of injury.[9] In some studies, obesity was associated with mortality, whereas other studies reported no significant difference in mortality between obese and non-obese patients.[10–13] Furthermore, few studies have examined the effect of low body mass index (BMI) on injuries in patients with motorcycle injuries.

In this study, we aimed to determine the injury characteristics and effects of BMI on motorcyclists. We hypothesized that underweight motorcyclists would have a higher injury severity scale (ISS) for the abdomen due to less fat accumulation and experience a higher surgery rate, intensive care unit (ICU) admission rate, and mortality.

2 | METHODS

2.1 | Study design and setting

This was a retrospective, multicenter, and cross-sectional study using the Emergency Department-based Injury In-depth Surveillance (EDIIS) database in South Korea.

2.2 | Data source and collection

The EDIIS was developed based on the International Classification of External Causes of Injuries proposed by the World Health Organization (WHO). This database is funded by the Korea Centers for Disease Control and Prevention (CDC). Since 2021, 24 hospitals located in urban or metropolitan areas have been participating in EDIIS. The participating hospitals were primarily academic teaching and tertiary hospitals. Ten of the participating hospitals were Level 1 trauma centers. Primary surveillance data were collected by residents at the emergency departments (EDs) in each hospital by checking the standardized EDIIS registry. Most of the recorded information were supervised and corrected by the emergency physicians and research coordinators at each hospital. All research coordinators reviewed the collected information and input the surveillance data into a web-based database system of the Korea CDC. The entered data were reviewed at monthly quality-assurance (QA) meetings, and the QA team provided regular feedback to maintain data quality.[14]

The participating hospitals were divided into four specific in-depth committees: eight hospitals in the transport injury committee, five hospitals in the head/spine injury committee, six hospitals in the suicide/intoxication/fall committee, and six hospitals in the infant/child committee. Each committee collected assigned committee-oriented in-depth variables for specific injury surveillance.

The database collects more than 200 variables, including patient's demographics, injury-related information, prehospital information, ED findings, diagnosis, medical treatment at the ED, ED disposition, and hospital outcomes after admission, if the patient was admitted.[15]

2.3 | Study population

All patients in eight hospitals participating as transport injury committees from January 2019 to December 2020 were enrolled for the initial analysis. All adult motorcyclists (≥18 years of age) involved in motor vehicle collisions were included. Motorcycle passengers, prehospital or in-hospital cardiac arrest after injury, death on arrival (DOA) at the ED, patients who were discharged or transferred to another hospital in the ED, unknown BMI, and unknown outcomes were excluded.

2.4 | Exposure and outcome variables

The main exposure was BMI. BMI was defined as the patient's body weight in kilograms divided by the square of height in meters. BMI was divided into three groups: low BMI (BMI<18.5 kg/m^2), optimal BMI (18.5≤BMI<25 kg/m^2), and high BMI (BMI≥25 kg/m^2). Multivariable logistic regression analysis was performed to calculate the odds ratios (OR) with 95% confidence intervals (CIs) to assess the impact of BMI on outcomes.

The following data were collected from the database: patient factors (age, sex, season, injury to ED visit time, ED visit method, ED visit time, weekend, alcohol consumption, and past medical history), injury characteristics (motorcycle collision object, road type, motorcycle engine capacity, helmet use, protective device, and collision pattern), and hospital information [initial ED systolic blood pressure (SBP), heart rate (HR), shock index (SI), Glasgow coma scale (GCS), injury severity score (ISS), trauma and injury severity score (TRISS),[16] and anatomical location of injury]. ED SI was calculated by dividing the ED HR by the ED SBP. According to convention, ISS from 1 to 8, 9–15, 16–25, and >25 were described as minor, moderate, severe, and very severe injuries, respectively.

The primary outcome was anatomical injury location according to the abbreviated injury scale (AIS). The secondary outcomes were the surgery and ICU admission rate, and the 48-h and 30-day in-hospital mortality. These outcomes were identified through a review of the medical records.

2.5 | Statistical analysis

Patient demographic factors, injury characteristics, hospital information, and outcomes were compared according to the BMI group. Categorical variables were described using counts and proportions and compared using the Kruskal–Wallis test. Continuous variables were described as mean and standard deviation (SD) or median and interquartile range (IQR) using one-way analysis of variance (ANOVA). A multivariable logistic regression analysis was performed to test the association between BMI groups and anatomical injury location according to AIS by calculating the adjusted odds ratios (AORs) with 95% CIs. The optimal BMI group was used as the reference category for the analysis. Potential confounders, such as age, sex, season, daytime, alcohol use, motorcycle collision object, road type, motorcycle engine capacity, helmet use, joint protection device, collision pattern, injury to ED time, past medical history, and SI were adjusted. All analyses were performed using SAS version 9.4 (SAS© Cary).

3 | RESULTS

Of the 164,745 EDIIS patients in eight transport injury committee hospitals, 1280 patients were finally analyzed, excluding pediatric patients (N = 41,804), injury mechanism other than traffic collisions (N = 100,185), traffic collisions other than motorcycle injury (N = 19,087), motorcycle pillion passengers (N = 180), dead on arrival (DOA) or cardiopulmonary resuscitation (CPR) at the time of ED arrival (N = 63), discharged or transported to another hospital in the ED (N = 1963), unknown exposure (N = 173), and unknown outcomes (N = 10) (Figure 1).

The numbers of patients with low, optimal, and high BMI were 53 (4.1%), 721 (56.3%), and 506 (39.5%), respectively. The proportions of males in each group were 84.9%, 91.8%, and 95.7%, respectively. (p < 0.01) The proportions of helmet use in the low, optimal and high groups were 49.1%, 54.1%, and 62.5% (p = 0.01), respectively. Regarding the anatomical location of injury, the proportion of AIS ≥2 for each group was 15.1%, 6.8%, and 9.5% (p = 0.04) in the abdomen, and 20.8%, 17.5%, and 21.9% (p = 0.05) in the lower extremities, respectively. There was no significant difference in clinical outcomes according to the BMI group (Table 1).

In multivariable logistic regression analysis for anatomical location of injury, compared to optimal BMI group, the AORs (95% CIs) for abdomen injury with AIS ≥ 2 were 2.82 (1.41–5.63) and 1.61 (1.17–2.21) in the low and high BMI group, respectively. The AORs (95% CIs) for abdominal injury with AIS ≥ 3 were 3.11 (1.31–7.39) and 1.26 (0.81–1.96) in the low and high BMI group, respectively (Table 2).

In multivariable logistic regression analysis for surgery, compared to optimal BMI group, the AORs (95% CIs) were 0.73 (0.38–1.38) and 0.97 (0.74–1.27) in the low and high BMI group, respectively. For ICU admission, compared to the optimal BMI group, the AORs (95% CIs) were 1.89 (0.87–4.14) and 0.77 (0.56–1.06) in the low and high BMI group, respectively. For 48-h and 30-day in-hospital mortality, the AORs (95% CIs) were 2.85 (0.81–10) and 2.86 (0.97–8.4) in the low BMI group and 0.47 (0.18–1.26) and 0.75 (0.38–1.48) in the high BMI group, respectively (Table 3).

4 | DISCUSSION

This study analyzed the injury characteristics of motorcyclists according to BMI, and evaluated the association between BMI and injury location and clinical outcomes using a multicenter ED-based injury in-depth surveillance registry. BMI was divided into three groups: low (BMI<18.5 kg/m^2), optimal (18.5≤BMI<25 kg/m^2), and high (BMI≥25 kg/m^2). In the hospitalized patients from motorcycle injuries, both low and high BMI groups had a higher likelihood of sustaining abdominal injuries with an AIS score ≥ 2. When considering severe abdominal injuries with an AIS score ≥ 3, only the low BMI group had a significantly increased risk compared to the optimal group, with no similar significant association noted in the high BMI group. The head and lower extremity with AIS ≥ 2 or 3 showed no significant difference in all BMI groups. For surgery, ICU admission, and 2-day and 30-day in-hospital mortality there was no statistical difference in all BMI groups.

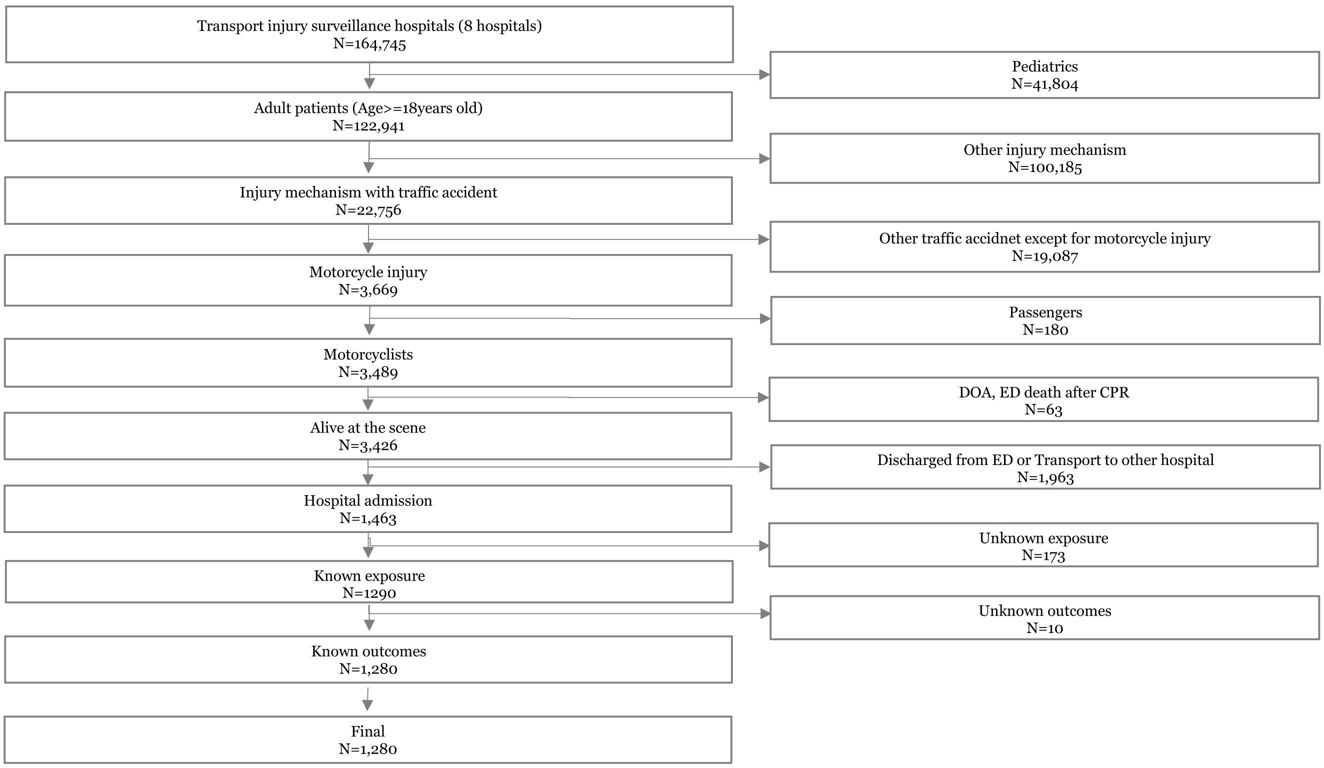

FIGURE 1 Study flow charts.

Conventionally, the existence of a "cushion effect" and "obesity paradox" has been proposed, suggesting a potential protective effect of abdominal fat accumulation in trauma.[17,18] However, the impact of BMI on trauma outcomes remains a subject of ongoing debate. Some studies have reported a protective effect of obesity against injury without affecting mortality, while others have identified associations between obesity and complications such as venous thromboembolism.[19–22] Before engaging in discussions concerning the findings of previous studies, it is crucial to meticulously examine the criteria employed to classify BMI. The application of diverse criteria based on regional and genetic variations, as well as the utilization of varying cutoff values within those criteria driven by researchers' intentions, can introduce ambiguity when interpreting the influence of BMI. For instance, unlike the WHO criteria for BMI in Caucasians, the BMI criteria differ for Asian populations in the Western Pacific Regional Office (WPRO).[23] In accordance with the WPRO criteria, overweight is defined as a BMI ranging from 23 kg/m^2 to 25 kg/m^2. Conversely, in an Asian study, the use of a cutoff value of 27.5 kg/m^2 to classify underweight and healthy weight hinders comparability and interpretation of findings with other studies.[18] Consequently, to minimize disparities with previous studies utilizing the WHO criteria for BMI (where overweight is defined as a BMI between 25 kg/m^2 and 30 kg/m^2), we categorized BMI≥25 kg/m^2 as overweight. It should be noted that the limited sample size in our study precluded separate classification of the WHO-defined categories of overweight, obesity 1 (30 ≤ BMI <35 kg/m^2), 2 (35 ≤ BMI <40 kg/m^2), and 3 (BMI ≥ 40 kg/m^2), and therefore, we incorporated them into the high BMI group.

It has been reported that underweight patients are more prone to sustaining pneumothorax and femoral fractures compared to healthy-weight patients in cases of all trauma injuries.[24] However, previous studies did not specifically focus on motorcycle injuries, which involve different mechanisms such as blunt and penetrating injuries. Previous research on motorcycle collision mechanisms has shown that abdominal injuries primarily occur due to rider-handlebar or rider-fuel tank collisions.[25–27]

Abdominal injuries resulting from handlebar collisions are caused by direct impact on the torso. Among the torso injuries resulting from handlebar impacts, the abdominal region may be relatively more susceptible to organ damage, even at lower energy levels, compared to the chest. The chest is anatomically structured to better absorb shock and protect internal organs with bony structure such as the ribcage, whereas the impact of the injury is directly absorbed by the abdominal organs, making them more vulnerable to injury.[26,27] Fuel tank injuries occur when a motorcycle abruptly stops, creating high peak loads between the rider's pelvis or abdomen and the motorcycle fuel tank. These injuries

TABLE 1 Demographic findings according to BMI group.

	All		Low BMI BMI<18.5 kg/m^2		Optimal BMI 18.5≤BMI<25.0 kg/m^2		High BMI BMI≥25.0 kg/m^2		
	N 1280	% 100.0	*N* 53	% 100.0	*N* 721	% 100.0	*N* 506	% 100.0	*p*-value
Age									0.004
18–39	487	38.0	21	39.6	232	32.2	234	46.2	
40–64	427	33.4	13	24.5	232	32.2	182	36.0	
≥65	366	28.6	19	35.8	257	35.6	90	17.8	
Median (IQR)	49 (30.5–67)		50 (28–74)		56 (33–71)		42 (29–60)		0.003
Sex (male)	1191	93.0	45	84.9	662	91.8	484	95.7	0.004
Season									0.163
Spring	358	28.0	8	15.1	220	30.5	130	25.7	
Summer	363	28.4	20	37.7	195	27.0	148	29.2	
Fall	340	26.6	14	26.4	190	26.4	136	26.9	
Winter	219	17.1	11	20.8	116	16.1	92	18.2	
Injury to ED time (median, IQR)	63 (34–168)		56 (30–121)		69 (35–172)		60 (33–166)		0.123
ED visit method									0.523
EMS ambulance	711	55.5	32	60.4	386	53.5	293	57.9	
Transfer by ambulance	493	38.5	20	37.7	288	39.9	185	36.6	
Direct visit	64	5.0	1	1.9	38	5.3	25	4.9	
Other	12	0.9	0	0.0	9	1.2	3	0.6	
Daytime (7A~7P)	830	64.8	33	62.3	488	67.7	309	61.1	0.053
Weekend	372	29.1	13	24.5	204	28.3	155	30.6	0.512
Alcohol Yes	157	12.3	8	15.1	83	11.5	66	13.0	0.589
Past medical history									
HTN	255	19.9	12	22.6	140	19.4	103	20.4	0.810
DM	154	12.0	7	13.2	93	12.9	54	10.7	0.481
Liver	16	1.3	0	0.0	9	1.2	7	1.4	0.689

(Continues)

TABLE 1 (Continued)

	All		Low BMI BMI<18.5 kg/m²		Optimal BMI 18.5≤BMI<25.0 kg/m²		High BMI BMI≥25.0 kg/m²		
	N **1280**	**%** **100.0**	***N*** **53**	**%** **100.0**	***N*** **721**	**%** **100.0**	***N*** **506**	**%** **100.0**	***p*-value**
CVD	21	1.6	0	0.0	12	1.7	9	1.8	0.623
CAD	32	2.5	1	1.9	17	2.4	14	2.8	0.865
Malignancy	40	3.1	1	1.9	33	4.6	6	1.2	0.003
Dementia	6	0.5	1	1.9	5	0.7	0	0.0	0.066
Epilepsy	5	0.4	0	0.0	4	0.6	1	0.2	0.551
Motorcycle collision object									0.006
Missing	1	0.1	0	0.0	1	0.1	0	0.0	
Pedestrian	41	3.2	1	1.9	22	3.1	18	3.6	
Vehicle	770	60.2	32	60.4	401	55.6	337	66.6	
Stationary object	444	34.7	20	37.7	281	39.0	143	28.3	
Others	24	1.9	0	0.0	16	2.2	8	1.6	
Road type									0.009
Missing	38	3.0	2	3.8	20	2.8	16	3.2	
Driving	1172	91.6	44	83.0	657	91.1	471	93.1	
Residential	31	2.4	1	1.9	19	2.6	11	2.2	
Rural	39	3.0	6	11.3	25	3.5	8	1.6	
Motorcycle engine capacity (cc)									0.170
≤50	43	3.4	1	1.9	27	3.7	15	3.0	
51–125	564	44.1	23	43.4	325	45.1	216	42.7	
>125	227	17.7	4	7.5	121	16.8	102	20.2	
Unknown	439	34.3	25	47.2	243	33.7	171	33.8	
Helmet use (Yes)	732	57.2	26	49.1	390	54.1	316	62.5	0.014
Joint protection device (Yes)	9	0.7	1	1.9	5	0.7	3	0.6	0.357

TABLE 1 (Continued)

	All		Low BMI BMI<18.5 kg/m^2		Optimal BMI 18.5≤BMI<25.0 kg/m^2		High BMI BMI≥25.0 kg/m^2		
	N	**%**	***N***	**%**	***N***	**%**	***N***	**%**	
	1280	**100.0**	**53**	**100.0**	**721**	**100.0**	**506**	**100.0**	***p*-value**
Collision pattern									0.003
Front	376	29.4	10	18.9	208	28.8	158	31.2	
Side	312	24.4	13	24.5	146	20.2	153	30.2	
Back	76	5.9	4	7.5	48	6.7	24	4.7	
Rollover	345	27.0	19	35.8	210	29.1	116	22.9	
Multi	59	4.6	3	5.7	37	5.1	19	3.8	
Others	112	8.8	4	7.5	72	10.0	36	7.1	
SBP (mmHg)									0.023
Missing	20	1.6	1	1.9	10	1.4	9	1.8	
<80	45	3.5	2	3.8	18	2.5	25	4.9	
80–139	713	55.7	36	67.9	415	57.6	262	51.8	
≥140	502	39.2	14	26.4	278	38.6	210	41.5	
Mean (Std)	130.95 (29.91)		124.42 (32.04)		130.61 (29)		132.11 (30.91)		0.028
HR (beats/min)									0.086
Missing	14	1.1	1	1.9	7	1.0	6	1.2	
<60	28	2.2	1	1.9	21	2.9	6	1.2	
60–99	916	71.6	37	69.8	528	73.2	351	69.4	
≥100	322	25.2	14	26.4	165	22.9	143	28.3	
Mean	89.44 (19.23)		86.87 (17.3)		88.29 (19.35)		91.36 (19.13)		0.013
SI									0.319
Missing	20	1.6	1	1.9	10	1.4	9	1.8	
SI < 1.0	1103	86.2	44	83.0	631	87.5	428	84.6	
SI ≥ 1.0	157	12.3	8	15.1	80	11.1	69	13.6	
Mean	0.73 (0.29)		0.75 (0.26)		0.71 (0.25)		0.75 (0.34)		0.413
GCS (median, IQR)	15 (14–15)		15 (14.5–15)		15 (14–15)		15 (15~15)		0.476
ISS									0.841
9<	351	27.4	11	20.8	197	27.3	143	28.3	

(Continues)

TABLE 1 (Continued)

	All		Low BMI BMI<18.5 kg/m^2		Optimal BMI 18.5≤BMI<25.0 kg/m^2		High BMI BMI≥25.0 kg/m^2		
	N **1280**	**%** **100.0**	***N*** **53**	**%** **100.0**	***N*** **721**	**%** **100.0**	***N*** **506**	**%** **100.0**	***p*-value**
9–15	443	34.6	21	39.6	248	34.4	174	34.4	
16–25	368	28.8	16	30.2	214	29.7	138	27.3	
≥26	118	9.2	5	9.4	62	8.6	51	10.1	
Median (IQR)	13 (8–18)		12 (9–18)		13 (8–18)		13 (8–18)		0.829
TRISS (median, IQR)	1 (0.99–1)		1 (0.99–1)		0.99 (0.98–1)		1 (0.99–1)		0.322
Location of injury									
Head	574	44.8	24	45.3	343	47.6	207	40.9	0.069
Face	478	37.3	18	34.0	291	40.4	169	33.4	0.040
Neck	8	0.6	0	0.0	1	0.1	7	1.4	0.021
Chest	493	38.5	19	35.8	261	36.2	213	42.1	0.104
Abdomen	287	22.4	16	30.2	140	19.4	131	25.9	0.011
Spine	221	17.3	6	11.3	130	18.0	85	16.8	0.431
Upper extremity	462	36.1	16	30.2	247	34.3	199	39.3	0.126
Lower extremity	604	47.2	26	49.1	322	44.7	256	50.6	0.118
Surface	7	0.5	1	1.9	4	0.6	2	0.4	0.375
AIS ≥ 2									
Head	496	38.8	20	37.7	299	41.5	177	35.0	0.071
Face	240	18.8	10	18.9	147	20.4	83	16.4	0.212
Neck	4	0.3	0	0.0	1	0.1	3	0.6	0.343
Chest	428	33.4	18	34.0	228	31.6	182	36.0	0.282
Abdomen	221	17.3	14	26.4	97	13.5	110	21.7	0.003
Spine	169	13.2	4	7.5	100	13.9	65	12.8	0.404
Upper extremity	342	26.7	11	20.8	192	26.6	139	27.5	0.574
Lower extremity	488	38.1	21	39.6	254	35.2	213	42.1	0.050
AIS ≥ 3									
Head	348	27.2	12	22.6	215	29.8	121	23.9	0.055
Face	13	1.0	0	0.0	6	0.8	7	1.4	0.481

TABLE 1 (Continued)

	All		Low BMI BMI<18.5 kg/m²		Optimal BMI 18.5≤BMI<25.0 kg/m²		High BMI BMI≥25.0 kg/m²		
	N	**%**	***N***	**%**	***N***	**%**	***N***	**%**	
	1280	**100.0**	**53**	**100.0**	**721**	**100.0**	**506**	**100.0**	***p*-value**
Neck	1	0.1	0	0.0	0	0.0	1	0.2	0.465
Chest	348	27.2	14	26.4	180	25.0	154	30.4	0.105
Abdomen	105	8.2	8	15.1	49	6.8	48	9.5	0.042
Spine	47	3.7	0	0.0	32	4.4	15	3.0	0.140
Upper extremity	13	1.0	0	0.0	7	1.0	6	1.2	0.730
Lower extremity	248	19.4	11	20.8	126	17.5	111	21.9	0.146
Clinical outcomes									
Surgery	813	63.5	31	58.5	447	62.0	335	66.2	0.238
ICU	682	53.3	33	62.3	397	55.1	252	49.8	0.078
48-h mortality	46	3.6	4	7.5	29	4.0	13	2.6	0.116
30-day mortality	76	5.9	6	11.3	44	6.1	26	5.1	0.186

Abbreviations: AIS, Abbreviated Injury Scale; BMI, Body Mass Index; CAD, Coronary-Artery Disease; CVD, Cerebro-Vascular Disease; DM, Diabetes Mellitus; ED: Emergency Department; EMS, Emergency Medical Service; GCS, Glasgow Coma Scale; HR, Heart Rate; HTN, Hypertension; ICU, Intensive Care Unit; IQR, Interquartile Range; ISS, Injury Severity Score; SBP, Systolic Blood Pressure; SI, Shock Index; Std, Standard Deviation; TRISS, Trauma and Injury Severity Score.

TABLE 2 Association between BMI groups and injury locations.

Injury location	BMI group	All	*N*	%	Unadjusted OR (95% CI)	Adjusted OR (95% CI)	*p*-value
AIS ≥ 2							
Head	Low	53	20	37.7	0.86 (0.48–1.52)	0.87 (0.47–1.6)	0.657
	Optimal	721	299	41.5	1.00	1.00	
	High	506	177	35.0	0.76 (0.6–0.96)	0.87 (0.68–1.12)	0.280
	Total	1280	496	38.8			
Abdomen	Low	53	14	26.4	2.31 (1.21–4.41)	2.82 (1.41–5.63)	0.003
	Optimal	721	97	13.5	1.00	1.00	
	High	506	110	21.7	1.79 (1.32–2.41)	1.61 (1.17–2.21)	0.004
	Total	1280	221	17.3			
Lower extremity	Low	53	21	39.6	1.21 (0.68–2.14)	1.04 (0.57–1.91)	0.888
	Optimal	721	254	35.2	1.00	1.00	
	High	506	213	42.1	1.34 (1.06–1.69)	1.12 (0.87–1.43)	0.393
	Total	1280	488	38.1			
AIS ≥ 3							
Head	Low	53	12	22.6	0.69 (0.36–1.34)	0.66 (0.33–1.32)	0.242
	Optimal	721	215	29.8	1.00	1.00	
	High	506	121	23.9	0.74 (0.57–0.96)	0.87 (0.66–1.15)	0.333
	Total	1280	348	27.2			
Abdomen	Low	53	8	15.1	2.44 (1.09–5.46)	3.11 (1.31–7.39)	0.010
	Optimal	721	49	6.8	1.00	1.00	
	High	506	48	9.5	1.44 (0.95–2.18)	1.26 (0.81–1.96)	0.298
	Total	1280	105	8.2			
Lower extremity	Low	53	11	20.8	1.24 (0.62–2.47)	0.93 (0.45–1.95)	0.853
	Optimal	721	126	17.5	1.00	1.00	
	High	506	111	21.9	1.33 (1~1.77)	1.1 (0.81–1.49)	0.536
	Total	1280	248	19.4			

Note: Adjusted for age, sex, alcohol, motorcycle collision object, road type, motorcycle engine capacity, helmet use, joint protection device, collision pattern, season, and daytime.

Abbreviations: AIS: Abbreviated Injury Scale; BMI, Body Mass Index; CI: Confidence Interval; OR, Odds Ratio.

are commonly associated with pelvic fractures or injuries to lower abdominal organs such as the bladder and bowel. Abdominal organ injuries are often associated with lower impact injuries, while fractures occur in cases of higher impact velocity at the time of the collision.[25] The effectiveness of wearing a helmet in preventing traumatic brain injury and reducing the severity and mortality of motorcycle injuries is well known.[28] However, in the context of motorcycle traffic collisions, there is currently limited emphasis on equipment or technological advancements aimed at preventing injuries beyond head trauma. On the other hand, in order to prevent injuries in car occupants involved in traffic collisions, the utilization of seat belts and airbags is highly recommended, and it is advised to use age and weight-appropriate restraint systems for infant and small children. Considering the severity of motorcycle injuries, it is essential to conduct fundamental research on protective devices and technological developments to promote safe riding, in addition to helmet use. In this study, the relationship between BMI and the occurrence of abdominal injury (AIS score ≥ 2) showed a U-shaped pattern. If we speculate on the reasons for these results in relation to the mechanism of abdominal injury, we could explain it as follows: the reason why the optimal BMI group had the lowest incidence of abdominal injury (AIS ≥2) could be the combined effect of the protective effect of abdominal fat accumulation and the negative effect of increased impact energy from increased body mass being the least in the optimal BMI group

TABLE 3 Association between BMI groups and clinical outcomes.

Clinical outcomes	BMI group	All	*N*	%	Unadjusted OR (95% CI)	Adjusted OR (95% CI)	*p*-value
Surgery	Low	53	31	58.5	0.86 (0.49–1.52)	0.73 (0.38–1.38)	0.329
	Optimal	721	447	62.0	1.00	1.00	
	High	506	335	66.2	1.2 (0.95–1.52)	0.97 (0.74–1.27)	0.810
	Total	1280	813	63.5			
ICU	Low	53	33	62.3	1.35 (0.76–2.39)	1.89 (0.87–4.14)	0.110
	Optimal	721	397	55.1	1.00	1.00	
	High	506	252	49.8	0.81 (0.65–1.02)	0.77 (0.56–1.06)	0.110
	Total	1280	682	53.3			
48-h mortality	Low	53	4	7.5	1.95 (0.66–5.76)	2.85 (0.81–10)	0.102
	Optimal	721	29	4.0	1.00	1.00	
	High	506	13	2.6	0.63 (0.32–1.22)	0.47 (0.18–1.26)	0.133
	Total	1280	46	3.6			
30-day mortality	Low	53	6	11.3	1.97 (0.8–4.85)	2.86 (0.97–8.4)	0.543
	Optimal	721	44	6.1	1.00	1.00	
	High	506	26	5.1	0.83 (0.51–1.37)	0.75 (0.38–1.48)	0.472
	Total	1280	76	5.9			

Note: Adjusted for age, sex, season, alcohol use, injury to ED time, daytime, past medical history, motorcycle collision object, road type, motorcycle engine capacity, helmet use, joint protection device, collision pattern, and SI.

Abbreviations: CI, Confidence interval ICU, Intensive Care Unit; OR, Odds ratio.

compared to the low and high BMI groups. On the other hand, when analyzing only severe abdominal injuries (AIS ≥3), it was found that the occurrence of injuries significantly increased only in the low BMI group compared with the optimal BMI group. These results suggest that safety measures targeting the low BMI group are particularly necessary for injuries caused by high-energy level impacts that result in severe abdominal injuries. Further research is required to determine the relationship between abdominal fat accumulation and impact energy according to changes in body mass in motorcycle injuries.

In this study, clinical outcomes such as 48-h in-hospital mortality, and 30-day in-hospital mortality were not associated with BMI. Several possibilities can be inferred from these findings. First, the limited sample size of the study could be a contributing factor. The observed trend toward an inverse correlation between BMI groups and ICU admissions, 48-h mortality, and 30-day mortality, despite not reaching statistical significance, underscores this possibility. Second, the involvement of various factors influencing the outcome could be a reason. Previous studies have also shown no association between BMI, injury severity, and mortality in blunt trauma.[24,29] Short term clinical outcomes such as 48-h in-hospital mortality and ICU admission are affected by injury severity and injury severity is affected by the speed at the impact, protective devices, and collision pattern. Long-term clinical outcomes such as 30-day in-hospital mortality are affected by the level of ICU care, surgery, and presence of complications. The longer the term between the impact and outcomes, the harder it is to identify the associations between risk factors and outcomes. This might have caused no significant difference in the clinical outcomes among the BMI groups. Future research must focus on risk factors and short-term outcomes, which are affected in a timely manner by risk factors to properly identify associations.

We excluded patients who died at the scene, DOA in the ED, and CPR in the ED. There exists a potential for selection bias due to the exclusion of early fatalities from the study. Our study specifically excluded initial fatalities from injury for the following reasons. First, the diagnostic uncertainty regarding the existence of abdominal injuries in these cases. In situations where life-saving resuscitation efforts are obstructed by comprehensive diagnostic procedures such as CT scans, confirming specific intra-abdominal injuries becomes unattainable. Similarly, the acquisition of accurate BMI data may be challenging. As such, our study targeted hospitalized patients with both confirmed abdominal injuries and available BMI information. Therefore, the findings of this study, based solely on motorcycle injury survivors, should be interpreted with caution, considering the exclusion of initial fatalities.

The strength of this study is that we divided the AIS anatomical regions into nine categories instead of six categories. In six categories that are used to calculate injury severity score, lumbar spine injury is included in abdominal injury due to anatomical location.[30] However, in this study, to investigate the relationship between abdominal fat accumulation based on BMI and abdominal organ injury, we defined abdominal injury as pure abdominal organ injury, excluding lumbar injuries, by classifying injury sites into nine categories of anatomical AIS regions, in order to exclude the relative energy resistance of the skeletal system, such as the cervical, thoracic, and lumbar vertebrae.[18] Another point is that we classified BMI into low, optimal, and high BMI groups. The low and high BMI groups possess different pathophysiologies, bone densities, and health behaviors. Grouping different populations may have caused a selection bias in the statistical analysis. Finally, this study included only motorcycle injuries, excluding other types of injury mechanisms. Even if the same motor vehicle crashes, automobiles, motorcycles, and bicycles have different injury pathophysiologies considering protective devices, impact energy, and vehicle design. Different injury mechanisms require different population selections and statistical analyses.

5 | LIMITATIONS

This study had several limitations. First, this was a retrospective study with an inherent selection bias. The database lacks crucial information on injury mechanisms, such as motorcycle model, impact speed, and cause of arrest or autopsy findings. Furthermore, the database also does not collect patient information if the patient is discharged from the emergency department or transferred to another facilities. Second, the findings of this study should be interpreted in consideration of the sociocultural environment. In South Korea, the use of motorcycles is markedly different from that in North America or Europe. Rather than for leisure or commuting, motorcycles are primarily used for work-related purposes, such as delivering food and parcels. This trend has been further accelerated by the COVID-19 pandemic, which increased the demand for contactless delivery services, leading to a noticeable rise in motorcycle crashes in South Korea compared to other countries.[31,32] Therefore, when interpreting the results of this study, it is crucial to consider the unique context of motorcycle use in South Korea. In addition, the BMI standard is different in the Asian population than that in the Western population. These genetic differences may have influenced our results. Third, there was a hospital-level difference in the participating hospitals. The difference in hospital level could have affected the hospital treatment outcomes, such as ICU admission or long-term mortality.

6 | CONCLUSION

Underweight motorcyclists experience more abdominal injuries with AIS $\geq$3 than optimal-weight or overweight motorcyclists. BMI was not associated with surgery, ICU admission, 48-h in-hospital mortality, and 30-day in-hospital mortality. Further research is required to clarify the mechanisms underlying the differences in abdominal injury occurrence in motorcyclists according to their BMI. A new approach to prevention targeting abdominal injuries in motorcycle injuries based on BMI, especially in underweight drivers, is necessary.

AUTHOR CONTRIBUTIONS

Yonghun Gwak: Writing—original draft. **Dae Kon Kim**: Formal analysis; writing—original draft; writing—review and editing. **Joo Jeong**: Data curation. **You Hwan Jo**: Writing—review and editing. **Dong Keon Lee**: Visualization. **Seung Min Park**: Visualization. **Yeongho Choi**: Data curation; visualization. **Yu Jin Kim**: Conceptualization; methodology; writing—review and editing.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

DATA AVAILABILITY STATEMENT

Data subject to third party restrictions.

ETHICS STATEMENT

The study was approved by the Institutional Review Board of Seoul National University Bundang Hospital, and the requirement for informed consent was waived (IRB No. B-2112-726-403).

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