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Characteristics of injuries according to types of personal mobility devices in a multicenter emergency department from 2011 to 2017

A cross-sectional study

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Abstract

Personal mobility devices (PMDs) have emerged as new factors in motor vehicle accidents, and related injuries are increasing. We aimed to describe the characteristics of PMD-related injuries presented to emergency departments (EDs) through a cross-sectional study for 7 years.

This study is a multicenter cross-sectional study using the Emergency Department-based Injury In-Depth Surveillance database in South Korea. We identified all PMD-related injuries from 2011 to 2017 based on text searching. We categorized them into 3 groups based on their distinguishable characteristics: electric standing scooter (E-scooter), electric self-balancing wheel (E-wheel), and electronic board (E-board).

A total of 448 PMD-related injuries were observed during the observation period. E-scooter-, E-wheel-, and E-board-related injuries occurred in 284, 138, and 26 cases, respectively. Most patients were between the ages of 19 and 59 years (69.2%), men (66.3%), and injured because of leisure activity (61.2%). The mechanism of injury was mostly traffic accidents (75.2%), but regarding injuries involving E-wheel and E-board, 25.4% and 30.8% of patients slipped from the device. The most commonly injured body part was the head, which accounted for 58.1% of E-scooter injuries, 38.4% of E-wheel injuries, and 53.9% of E-board injuries. Only 6 of all patients wore a helmet at the time of accident.

PMD users and PMD-sharing programs are increasing, and more accidents are expected in the future. As PMDs are convenient to move and more people are willing to use them, proper riding and safety rules based on the type of PMD are needed to reduce the risk of injury. The results of this study can be used as basic data for developing safety policies.

Abbreviations: E-board = electronic board, ED = emergency department, EDIIS = emergency department-based injury in-depth surveillance, E-scooter = electric scooter, E-wheel = electric self-balancing wheel, ICD-10 = International Classification of Disease 10th Revision Code, KCDC = Korean Centers for Disease Control and Prevention, NEISS = National Electronic Injury Surveillance System, PMD = personal mobility devices.

Keywords: electronic balancing wheel, electronic board, electronic scooter, injury, personal mobility device

1. Introduction

Personal mobility devices (PMDs) are compact, new motorized vehicles for individual transporting. The terms of PMD are different from powered personal mobility aid, for example, an electric wheelchair for the disabled. PMDs have been increasing in popularity since Segway, a self-balancing personal transporter was introduced in 2001. In 2015, motorized self-balancing scooters without handles, commonly known as hoverboards, became available, and after 2017 electric scooter-sharing companies, such as Lime and Bird, have become popular with

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Figure 1. Type of personal mobility devices. (A) Electric standing scooter (E-scooter), (B) self-balancing wheel (E-wheel), and (C) electric board (E-board).

riders due to their ease of use and convenience. PMDs are convenient and efficient for short distance travel and give greater affordability.[1] The trend to use PMDs for leisure and short-distance commuting is spreading around the world in terms of sales and acceptance.[2,3] Expanding use of PMDs has also emerged as a safety issue.[1] PMDs so far have been categorized into 3 groups based on their distinguishable characteristics: electric standing scooter (E-scooter), self-balancing wheel (E-wheel), and electric board (E-board) (Fig. 1). Each type of PMD has a different shape, moving speed, and driving method and thus has a different purpose.

E-scooters are closer to transportation, and e-wheels or e-boards are often used for outdoor leisure or moving around large industrial buildings. Therefore, the nature of the injuries related with each PMD might be different.[4] About injuries caused by E-scooter, Trivedi et al[8] reported the highest number of head injuries (about 40%), and Bandzar et al[5] reported the most frequent fractures of the forearm, including the wrist, by observing the damage caused by the hoverboard and skateboard. McIlvain et al[6] reported that between 2015 and 2016, hoverboard-related injuries increased from 2416 to 22,234 due to their increased availability and popularity. Aizpuru et al[7] conducted an analysis using data from the United States Consumer Product Safety Commission National Electronic Injury Surveillance System (NEISS) and reported that 32,400 E-scooter injuries occurred from 2013 to 2017, with an estimated annual increase in incidence from 1.9 cases per 100,000 to 2.6 cases per 100,000. The fracture was the most common type of PMD-related injury, and the head was the most common site of injury caused by E-scooters.[6–8] A recent 5-year study using NEISS data reported that the majority of injuries related with E-scooters or E-boards occurred in patients younger than 20 years, and a multicenter emergency department (ED)-based study suggested that pediatric patients accounted for a higher percentage of fractures than adults.[9,10]

There have been several reports of injuries related with PMDs from developed countries with an injury surveillance system, but PMD-related injuries are also an important issue in other countries because the PMD sharing programs and PMD marketing are emerging without strict regulation. This PMD sharing program is usually for E-scooters, and most studies have dealt with injuries caused by standing E-scooters.[1,11–13] However, people using E-boards and E-wheels for leisure or short-distance transport are increasing so most of E-scooters are being used in the vehicle road, but E-boards or E-wheels could be used in parks or large buildings. Therefore, depending on the type of PMD, the characteristics and severity of injuries may vary due to the purpose and circumstance of an accident. As a result, different types of PMDs may require different precautions and regulations.

The aims of this study were to define the characteristics of patients with PMD-related injuries and to determine whether the types and body locations of injuries differed by the type of PMD using multicenter ED-based injury surveillance. Recently, the Korean National Assembly revised laws regarding E-scooters to ease regulations and boost ride sharing service industries. Some lawmakers and the media are of the opposite opinion. They have requested revisions to again toughen the rules.[14] This study may be the base of the social agreement for safety concerns of PMDs. Not all PMDs need strict regulations but they should be restricted in some situations and places. In this study, the characteristics and mechanisms of the injured patients who visited the emergency room were explained, and the body parts and patterns of injuries were described based on diagnosis.

2. Materials and methods

2.1. Study design, setting, and data source

This was an observational cross-sectional study conducted from 2011 to 2017 using the Emergency Department-based Injury In-Depth Surveillance (EDIIS) database in Korea. The EDIIS is a nationwide prospective database of patients visiting the EDs of 23 tertiary academic hospitals after injury and is led by the Korean Centers for Disease Control and Prevention (KCDC). The EDIIS was designed to collect and investigate in-depth data on the types and circumstances of injuries and to provide information for establishing injury prevention strategies. The number of EDs participating in the EDIIS increased to 15 hospitals in 2011, 20 hospitals in 2015, and 23 hospitals in 2016. The dataset is composed of core variables, including patient demographics, injury mechanisms and circumstances, clinical findings, ED diagnosis, ED disposition, and patient outcome after admission. ED diagnosis is collected using the International Classification of Disease 10th Revision Code (ICD-10), and for patients with multiple injuries, a maximum of 10 ICD-10 codes for each injury were collected. After initial data collection by physicians, trained coordinators at each hospital review data and upload it to the web-based system of the KCDC. Every month, a quality management committee reviews the collected data and provides regular feedback to each hospital for quality assurance.[15,16]

The present study protocol was reviewed and approved by the Institutional Review Board of Hallym University Dongtan Sacred Heart Hospital (approval No. 2018001). Informed consent was waived because of the retrospective nature of the study and the analysis used anonymous surveillance data.

2.2. Patient and public involvement

This research was done without patient involvement. Patients were not invited to comment on the study design and were not consulted for patient relevant outcomes or interpretation of results. Patients were not invited to contribute to the writing or editing of this document for readability or accuracy.

2.3. Case definition and variable measurements

The study population included all patients who visited the ED between January 2011 and December 2017 due to injuries caused by PMDs. We identified all injuries related with PMDs in patients of any age from the EDIIS (2011–2017). In the EDIIS, PMDs were categorized into "other specified vehicles" with detailed text of the type or brand name of PMDs. Further, PMDs could be described in terms of types and causes of injuries as a supplementary text in the EDIIS data. Therefore, PMD-related injuries were identified by free text searching. We searched the text for relevant terms such as "electric scooter," "electric wheel," or "electric board" and their product names such as "Segway," "Ninebot," or "Hoverboard." Each term was specified in the search to account for misspellings and typos.

Moreover, the terms related with powered personal mobility aid for the disabled, for example, motorized wheelchair, were excluded. PMDs were categorized into 3 groups based on their distinguishable characteristics: E-scooter, E-wheel, and E-board. From the EDIIS, we collected information on patient age, sex, ingestion of alcohol, method of ED arrival, mechanism of injury, place of injury, circumstances of the injury, use of helmet, anatomic site of injury, characteristic of injury, and ED disposition. The age variable was categorized into preschool (under 7 years), elementary school students (7–12 years old), junior high school students, and high school students (13–18 years old) if they were before the age of 19. Furthermore, adults were divided into 19- to 39-year-olds, 40- to 59-year-olds, and over 60-year-olds. The anatomic site and characteristics of injury were categorized based on the ED diagnosis described by the ICD-10. Among the head injuries, concussion and other severe injuries were distinguished from other mild injuries such as laceration, contusion, and abrasion. Concussion without skull fracture or intracranial injury was differentiated from all other head injuries. Cranial injury was defined as skull and facial bone fracture (S02 in ICD-10 code) or intracranial injury (S06.1-S06.9 in ICD-10 code).

2.4. Statistical analysis

The PMD text search and all statistical analyses were performed using SAS version 14.0 (SAS Institute, Cary, NC). Continuous variables are presented as medians with interquartile ranges, and categorical variables are presented as frequencies and proportions.

3. Results

Among 1,832,667 patients injured during the study period, 448 patients identified with relevant terms were enrolled in the study. E-scooter-, E-wheel-, and E-board-related injuries occurred in 284, 138, and 26 cases, respectively (Fig. 2). Fewer than 100 injuries were observed annually before 2016, but there were 125 injuries in 2016 and 257 injuries in 2017, indicating that the incidence of PMD-related injuries is increasing rapidly. The demographic and incident characteristics of these patients are shown in Table 1. Most patients were between the ages of 19 and 59 years (69.2%) and were men (66.3%). For E-wheel and E-board injuries, the prevalence of patients younger than 12 years was 28.3% and 30.8%, respectively. A total of 8.3% of injured patients ingested alcohol before driving PMDs, and only 6 patients were documented as wearing a helmet. Among PMD-

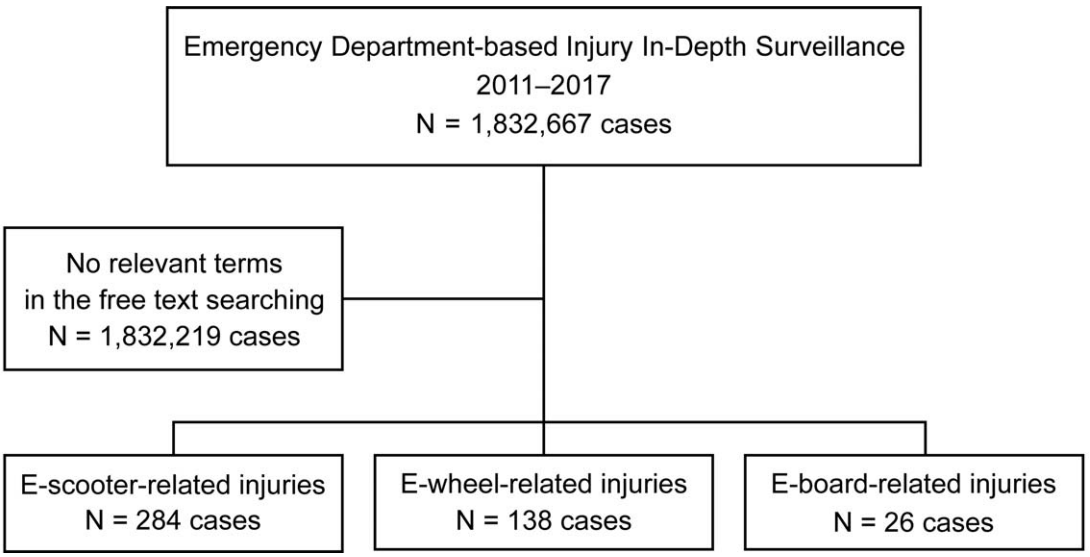

Figure 2. Flow chart for identifying cases of injuries related with personal mobility devices (PMDs) from the Emergency Department-based Injury In-Depth Surveillance (EDIIS).

Table 1

Demographic and incident characteristics of PMD-related injuries.

	Total		E-Scooter		E-Wheel		E-Board	
Injury characteristics	**N**	**%**	**N**	**%**	**N**	**%**	**N**	**%**
All	448	100.0	284	100.0	138	100.0	26	100.0
Male	297	66.3	185	65.1	94	68.1	18	69.2
Age								
Median (IQR)	29	18–40	30.5	22–42	25.5	12–38	27.5	12–34
Less than 7 years old	13	2.9	11	3.9	2	1.4	0	0.0
7–12 years old	71	15.8	24	8.5	39	28.3	8	30.8
13–18 years old	28	6.3	17	6.0	9	6.5	2	7.7
19–39 years old	216	48.2	149	52.5	56	40.6	11	42.3
40–59 years old	94	21.0	62	21.8	27	19.6	5	19.2
60 years old and over	26	5.8	21	7.4	5	3.6	0	0.0
Health insurance								
NHI	434	96.9	272	95.8	136	98.6	26	100.0
Other insurance	14	3.1	12	4.3	2	1.4	0	0.0
ED arrival by EMS	155	34.6	119	41.9	28	20.3	8	30.8
Injury mechanism								
Traffic accident	337	75.2	229	80.6	92	66.7	16	61.5
Fall/slip	91	20.3	48	16.9	35	25.4	8	30.8
Contusion	14	3.1	5	1.8	7	5.1	2	7.7
Other	6	1.3	2	0.8	4	2.9	0	0.0
Activity during injury								
Working	63	14.1	47	16.6	16	11.5	0	0.0
Exercise/education	26	5.8	21	7.4	3	2.2	2	7.7
Leisure	274	61.2	169	59.5	88	63.8	17	65.4
Daily activity	81	18.1	44	15.5	30	21.7	7	26.9
Other	4	0.9	3	1.1	1	0.7	0	0.0
Injury place								
Home	23	5.1	9	3.2	13	9.4	1	3.8
Road	327	73.0	227	79.9	85	61.5	15	57.7
Public facilities	52	11.6	29	10.2	17	12.3	6	23.1
Outdoor places	29	6.5	14	4.9	12	8.7	3	11.5
Others	17	3.8	5	1.9	11	7.9	1	3.8
Helmet use	6	1.3	4	1.4	2	1.4	0	0.0
Alcohol use	37	8.3	32	11.3	5	3.6	0	0.0
Role of patient								
Driver	315	70.3	211	74.3	89	64.5	15	57.7
Passenger	3	0.7	2	0.7	1	0.7	0	0
Pedestrian	18	4.0	15	5.3	2	1.4	1	3.8
Unknown	112	25.0	56	19.8	46	33.3	10	38.5
ED outcome								
Discharged	373	83.3	227	79.9	124	89.9	22	84.6
Hospitalized	75	16.7	57	20.1	14	10.1	4	15.4
Dead after hospitalization	1	1.3	1	1.8	0	0.0	0	0.0

ED = emergency department, EMS = emergency medical service, IQR = interquartile range, N = number, NHI = national health insurance, PMD = personal mobility device.

related injuries, the mechanism of injury was mostly traffic accidents (75.2%), but regarding injuries involving E-wheels and E-boards, 25.4% and 30.8% of patients slipped from the device. The road (73.0%) was the most common place of accidents. Considering purpose of riding PMDs at the time of accident, leisure activity (61.2%) was the most common and work accounted to 14.1%. Most of the patients (70.3%) drove the PMDs. A total of 16.7% of injuries related with PMDs required hospitalization, and 1 patient with femur fracture (95-year-old man who was hit by a backward-driving truck while riding on an E-scooter) died after hospitalization.

Table 2 and Fig. 3 show the body parts of patients that were injured in accidents related with PMDs. The most commonly injured body part was the head, which accounted for 58.1% of E-scooter injuries, 38.4% of E-wheel injuries, and 53.9% of E-board injuries. The second most commonly injured body part included the extremities, especially the lower arm (14.1% of E-scooter, 21.7% of E-wheel, and 15.4% of E-board), wrist and hand (13.7% of E-scooter, 14.5% of E-wheel, and 15.4% of E-board), and lower leg (16.9% of E-scooter, 13.0% of E-wheel, and 11.5% of E-board).

The type of PMD-related injury is described in Table 3. Cranial injuries accounted for 17.4%, and fractures other than those of the skull accounted for 22.5% of all PMD-related injuries. Among the PMDs, E-scooters were associated with the highest rate (22.2%) of cranial injuries. E-wheels were associated with the highest rate (28.3%) of fractures other than those of the skull. Of all injuries, the most commonly fractured body parts were the elbow and lower arm (8.5% of all injuries), shoulder and upper arm (5.8% of all injuries), and knee and lower leg (3.1% of all

Table 2

Body parts injured due to PMD-related accidents based on ED diagnosis using the ICD-10 code.

	Total (N = 448)		E-Scooter (N = 284)		E-Wheel (N = 138)		E-Board (N = 26)	
Injured body part	N	%	N	%	N	%	N	%
Head	232	51.8	165	58.1	53	38.4	14	53.9
Neck	11	2.5	7	2.5	4	2.9	0	0.0
Chest	21	4.7	12	4.2	9	6.5	0	0.0
Abdomen	21	4.7	15	5.3	5	3.6	1	3.9
Lower arm	74	16.5	40	14.1	30	21.7	4	15.4
Upper arm	45	10.0	27	9.5	17	12.3	1	3.9
Wrist and hand	63	14.1	39	13.7	20	14.5	4	15.4
Lower leg	69	15.4	48	16.9	18	13.0	3	11.5
Upper leg	14	3.1	13	4.6	0	0.0	1	3.9
Ankle and foot	32	7.1	21	7.4	11	8.0	0	0.0

ED = emergency department, ICD-10 = International Classification of Disease 10th Revision Code, N = number, PMD = personal mobility device.

injuries). Lacerations and other superficial injuries were common in all PMD types.

4. Discussion

Our study evaluated and characterized the injury patterns of patients presented to the ED after incidents related with PMDs from 23 emergency departments in Korea. Previous studies were often based on data from a few hospitals[8,13] or based on data with little clinical information.[5,7,12] Although this study is not a nationwide survey, it has the advantage of being able to see the overall characteristics of events and patients as it is a survey involving 23 hospitals across the country.

We found that almost one-third of patients with injuries related to E-wheels or E-boards were children under 12 years of age, and surprisingly, 98.7% of all patients did not wear helmets. These findings are consistent with the results of other studies wherein up to 61.4% of patients with hoverboard injuries were pediatric patients and 34.6% of E-scooter injury patients were school-aged children.[6,7] Based on data from EDs in California, only 4.4% of patients wore a helmet when driving an E-Scooter.[8] Before December 2020, the Korean law defined an electrically powered PMD as a motorcycle, and categorized it as a "motor vehicle" as per the Traffic Road Act. According to the law, a motorcycle licence is essential for driving a PMD, and the legal minimum age for obtaining a licence is 18 years. Additionally, the law requires

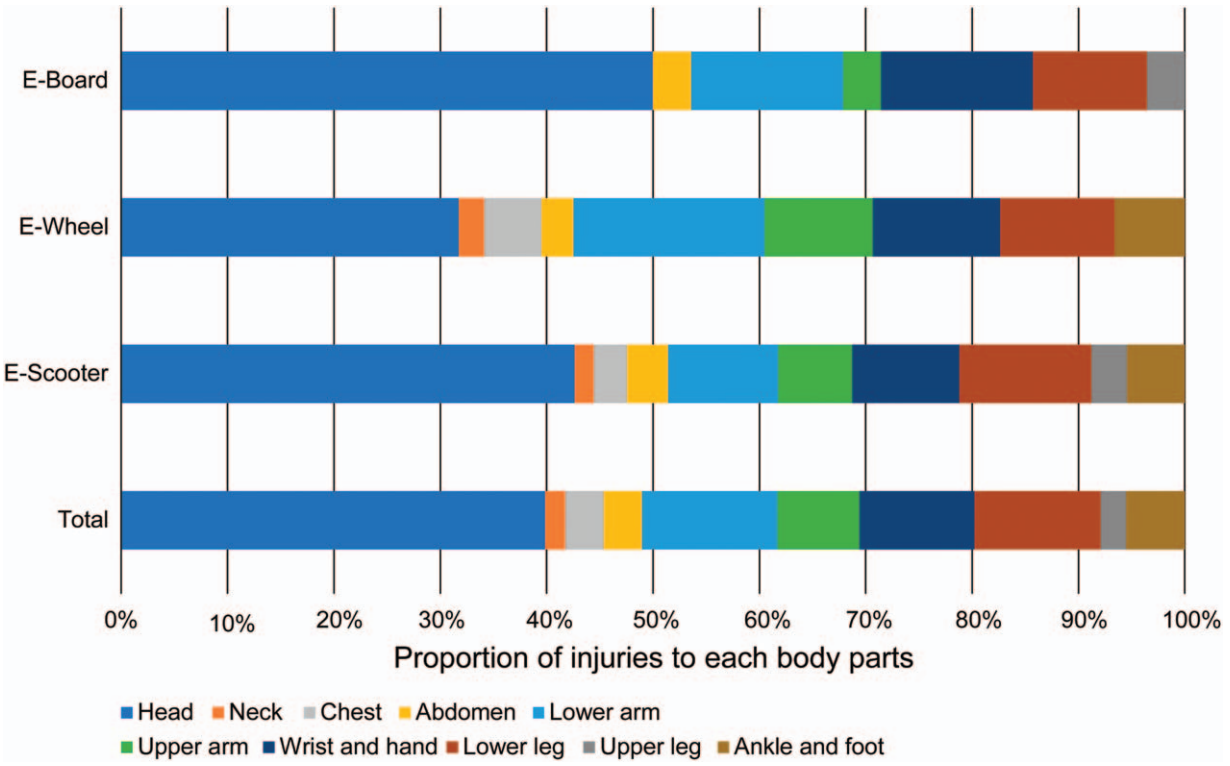

Figure 3. Body parts injured by personal mobility device (PMD)-related accidents.

Table 3

Types of PMD-related injuries based on ED diagnosis using the ICD-10 code.

Types of injuries	Total (N = 448)		E-Scooter (N = 284)		E-Wheel (N = 138)		E-Board (N = 26)	
	N	%	N	%	N	%	N	%
Concussion without skull fracture or intracranial injury	30	6.7	15	5.3	12	8.7	3	11.5
Cranial injuries	78	17.4	63	22.2	12	8.7	3	11.5
Fractures other than skull	101	22.5	58	20.4	39	28.3	4	15.4
Cervical spine and neck	2	0.4	2	0.7	0	0.0	0	0.0
Rib, sternum, and thoracic spine	6	1.3	3	1.1	3	2.2	0	0.0
Pelvis and lumbar spine	4	0.9	3	1.1	1	0.7	0	0.0
Shoulder and upper arm	26	5.8	14	4.9	11	8.0	1	3.8
Elbow and lower arm	38	8.5	18	6.3	18	13.0	2	7.7
Wrist and hand	11	2.5	6	2.1	5	3.6	0	0.0
Hip joint and femur	3	0.7	2	0.7	0	0.0	1	3.8
Knee and lower leg	14	3.1	11	3.9	3	2.2	0	0.0
Ankle and foot	4	0.9	4	1.4	0	0.0	0	0.0
Intrathoracic organ injury	2	0.5	1	0.4	1	0.7	0	0.0
Intra-abdominal organ injury	3	0.7	3	1.1	0	0.0	0	0.0
Crush injury	3	0.7	2	0.7	1	0.7	0	0.0
Sprain	56	12.5	29	10.2	25	18.1	2	7.7
Laceration	127	28.4	96	33.8	26	18.8	5	19.2
Superficial injury	185	41.3	125	44.0	47	34.1	13	50.0

ED = emergency department, ICD-10 = International Classification of Disease 10th Revision Code, N = number, PMD = personal mobility device.

drivers to wear protective gear while driving PMDs, and they are allowed to drive only on traffic roads.[17] However, as shown in the results, PMD-related injuries occur frequently among those under the legal age, and usage of helmets is very low. These results showed that despite the legal restrictions, people considered it safe to ride PMDs and did not comply with the regulations. Nevertheless, post revision of the relevant laws, E-scooter is classified as a type of bicycle. People are allowed to ride them on cycling paths along with pedestrians and without a driver's license since December 2020.[14] Further, the age limit has been lowered to 13 years.[14] These regulation changes are already causing concerns on safety and injury prevention.

Since the data in this study were collected before the full-scale PMD sharing program was introduced in Korea, activities that were "on the move" at the time of injuries were classified as "leisure." However, accidents occurred mostly on roads in this study. It means that most of the PMDs were used on roads before, and this trend may have been more noticeable in recent years after the PMD sharing program was introduced.

PMDs offer convenient means of short-distance transportation but are also associated with a risk of acute trauma, including severe head injuries. A few reports have shown that motorized PMD users had higher injury severity scores, with a significant proportion requiring surgical interventions compared with the injuries of non-PMD users.[11] Our study results showed that the body part most commonly injured in accidents related to PMDs was the head (Table 2), and cranial injury, including skull fracture and intracranial haemorrhage, accounted for 17.4% of all injuries (Table 3). Moreover, among the six patients wearing helmets, there was one open wound of head (S01.8 of ICD-10) and one contusion of the eyelid and periocular area (S00.1 of ICD-10), but concussion or cranial injuries were not observed. Comparing only injuries with E-scooters, a study conducted in California reported that 40.2% of injuries were head injuries and 2.0% of injuries were associated with intracranial hemorrhage,[8] whereas our data showed 58.1% for head injuries and 17.4% for cranial injuries (Table 3). A study using the NEISS reported that 27.6% of head injuries were related with E-scooters. Although further research on the risk of severe injuries related to PMDs is needed, it is interesting that in our study, 8.3% of patients were under the influence of alcohol, especially those with E-scooter injuries, and 11.3% of patients consumed alcohol when driving (Table 1). Of these 32 drunk E-scooter drivers, 62.5% had significant head injuries (17 patients with cranial injury, 3 patients with a concussion). E-scooters are often used on roads and are faster than E-wheels or E-boards. Thus, serious injuries, such as intracranial injury or skull fracture, might occur more often in E-scooter users than in E-boards and E-wheels users. Unlike E-wheels and E-boards, E-scooters are often used as a means of transportation, so it is necessary to improve driving regulations for safety. Additionally, countries must establish legislations regarding the use of protective devices, including helmets, and determine a precise definition of the shape, weight, and speed of PMDs suitable for roads (depending on the road).

In our study, 3 patients were passengers who were coriding with the driver. These were cases of E-scooter and E-wheel injuries in which the driver and passenger might have thought that they had enough space to put their feet on the foot deck or that it was safe to drive with 2 persons on 1 wheel. PMDs are meant to be "personal," that is, designed for individual use. It is dangerous to drive PMDs with passengers, as this would change the weight-bearing axis and make it difficult for the driver to steer cautiously. A social and legal consensus regarding the regulation of inappropriate and unsafe use of PMDs should be established.

This study has several limitations. First, this is a retrospective cross-sectional observational study, so potentially important risk factors related with PMD injuries, such as speed of the device or road environment at the time of injury, were not available. Future work should be conducted prospectively with data related to the device itself, driving habit of the driver, road circumstances, and costs of PMD-related injuries. Second, only patients visiting the ED after injury were included in the study, excluding those visiting local or private clinics, which might have underestimated the number of PMD injuries. Third, this study analyzed the surveillance system data of 23 emergency medical centers in Korea. This data does not cover all injuries across the country,

but it is a surveillance system for in-depth investigation of risk factors. Therefore, unfortunately, it is not possible to analyze regional differences.

5. Conclusion

In conclusion, PMDs are new and convenient vehicles that are becoming rapidly increasing forms of transportation to reduce traffic congestion. In our study, the number of patients with PMD-related injuries increased and mostly included young people. However, the proportion of helmet users was significantly low even though the most commonly injured part of the body was the head. The type of injury and the body part injured were different based on the type of PMD. Our report provides insight into public awareness on the safe use of PMDs and the need for appropriate regulations. This study may be the basis for detailed evidence and distinguished regulation for each type of PMD. Not all PMDs need strict regulations but some PMDs should be restricted to certain activities and places. Further studies are needed to establish risk factors and prevention strategies for reducing the incidence of significant injuries related with each type of PMD.

Author contributions

Conceptualization: Sanghun Lee, Ju Ok Park.
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Methodology: Joo Yeong Kim, Seung Chul Lee.
Writing – original draft: Joo Yeong Kim.
Writing – review & editing: Choung Ah Lee, Ki OK Ahn, Ju Ok Park.

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