Original Article

E-Scooter Crashes: Are They a Risky Underestimated New Mode of Transport? A Medical and Technical Assessment

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Abstract:

Background and Objectives: In 2019, electric scooters (e-scooters) were legalized for use on German roads. Their popularity is attributable to their relatively cheap and easy availability. E-scooters had already been established in other countries for some time. A rising number of crashes involving e-scooters have been reported from different countries, but data about crashes in Germany are still limited. **Materials and Methods:** Our local accident research unit documented prospectively a statistically randomized sample of e-scooter crashes between July 2019 and December 2020. Collected data include, but is not limited to, injury details as well as technical characteristics and circumstances of the crashes. **Results:** Twenty-three crashes are included in this study. Two drivers (8.70%) were uninjured and 60.87% ($n = 14$) suffered only minor injuries (Maximum Abbreviated Injury Scale [MAIS] 1). Four drivers (17.39%) sustained a MAIS 2 and three drivers (13.04%) a MAIS 3. 41 injuries in total were recorded among the 23 patients included in this study. The Injury Severity Score ranged from 0 to 22. In our cohort, the main person responsible for the crash was most often the e-scooter driver him/herself ($n = 20$, 86.96%). In $n = 6$ (26.09%), a positive alcohol test was carried out, and one driver (4.35%) was under the influence of cannabis. **Conclusions:** Crashes involving e-scooters have the potential to cause severe injuries and e-scooters should not be considered harmless gadgets. The prevalence of drug and alcohol use during e-scooter driving and the high percentage of e-scooter drivers being responsible for the crash may indicate potential recklessness on the part of the drivers.

Keywords: Abbreviated Injury Scale, electric scooter, emergency, E-scooter, Maximum Abbreviated Injury Scale, road traffic collision, trauma

Introduction

E-scooters with an operating license have been permitted in Germany since June 2019.[1] They have mainly been promoted in cities to be an attractive and flexible mode of transportation.

As e-scooter usage increases, so too does the frequency of crashes involving e-scooters.[2,3] Data for Germany about typical patterns of injury and technical details of the circumstances of crashes is still lacking.[4] Other countries possess a larger volume of data because in these places e-scooters have been used for many years already. The purpose of this study is to analyze e-scooter crashes in Germany and compare the results with other research groups.

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Materials and Methods

We performed a retrospective analysis of prospectively collected data involving e-scooter crashes recorded between July 2019 and December 2020. The data were made anonymous. All crashes were documented prospectively by our local accident research unit in the metropolitan area of

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Hanover, Germany. This unit is affiliated with our Trauma Department at Hanover Medical School. The unit is specially trained in the documentation and analysis of road traffic collisions (RTC) resulting in injury. In any RTC recorded by the police, the research unit is alerted automatically by police dispatchers. In the event of collisions involving casualties, in cases of hit-and-run accidents, or significant damage to property, the police must be informed in Germany.[5] The accident research unit collects collision data of approximately a quarter of all RTCs in the region of Hanover. A randomization in data collection is performed with a statistical sampling plan based on temporal criteria. The accident research unit works 6-h shifts per day. A crash has to be fully documented until they can move to record and document a second crash which is usually the most recent crash reported to the police. The accident research team applies standardized guidelines for documentation. Due to the often simultaneous arrival of the emergency services and the research unit at the collision scene, they are able to investigate the crash from beginning to end.[6,7]

The staff of our accident research unit collects data regarding demographic information, the pattern of injury, and cause of injury, as well as many more technical details. Data collection begins at the crash site and is completed in the hospital if any crash victims need to see a doctor. Four hospitals were involved in the study, three of which are trauma centers (Hanover Medical School, Nordstadt Hospital, Hospital of the Friederikenstift). In addition to the documentation on site, all crashes are digitally reconstructed. The analysis also includes additional influencing factors such as weather conditions or drug use. The accident site is photographed using drone technology to document the crash in the greatest detail for further reconstruction. Using all this information, a detailed crash sketch can be created [Figure 1].

To determine the severity of trauma, we calculated the Maximum Abbreviated Injury Scale (MAIS) as well as the individual Abbreviated Injury Scale (AIS 1990, update 2005) and the Injury Severity Score (ISS).

The AIS evaluates objectively each individual injury with reference to nine body regions and categorizes each from one to six (minor to major) regarding the severity of the injury. In addition, the AIS is proven to be a valid method to predict the probability of survival of each patient with regard to any injuries sustained. The AIS is used universally in hospitals and research. The MAIS indicates the highest AIS level.[8-10]

The ISS is used for patients with multiple injuries and is calculated based on the MAIS. Each of the three of the most severe injuries in three body regions are squared and added. The ISS ranges from 0 to 75. A score of ≥16 is defined as polytrauma and the mortality to be expected is 10%. If any affected body region reaches a MAIS of 6, the ISS is automatically 75 and indicates lethal trauma.[10,11]

This study is compliant with our ethics committee guidelines. No approval was needed for the retrospective analysis of collected data which was made anonymous. Data collection and analysis performed by the accident research unit also followed our ethics committee guidelines.

Statistical analysis was carried out using SPSS Statistics 26.0 German (Windows, 64-Bit-Version, IBM, Armonk, New York, USA). Mean values and standard deviations were calculated. The mean value is defined as the statistical average. The individual values of a data set are added and the sum is divided by the total amount of individual values. The mean value is applicable for metric scales.

An important measure of dispersion in statistics is the standard deviation. The standard deviation shows the average deviation of all values from the mean value. It is an interval that indicates the dispersion around the mean value.[12]

Results

This study included 23 crashes. In four crashes, two people were riding on the same e-scooter, but this study focuses on the main driver. The majority of riders assessed were male (m = 16, 69.57%; w = 7, 30.43%) with a mean age of 28 ± 2.28 years.

Crashes occurred mainly at dusk (n = 7, 30.43%) and at night (n = 8, 34.78%). Only eight crashes (34.78%) happened during daytime. Out of the seven drivers breathalyzed, six drivers tested positive for alcohol (26.09%), and one tested positive for cannabis. The mean blood alcohol level was

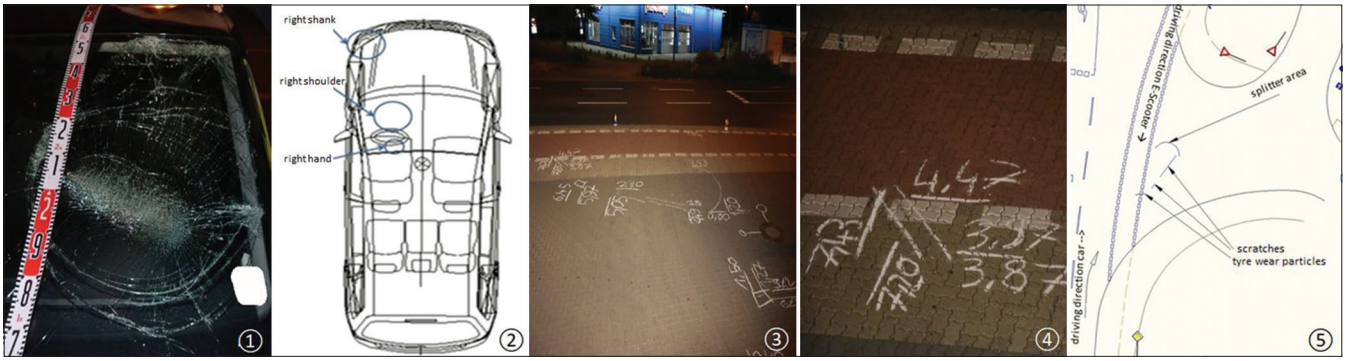

Figure 1: Extract from the documentation ① Impact of the right shoulder on the windscreen. ② Schematic figure of the impact on three body parts. ③ and ④ Marks and sketches on the road surface. ⑤ Overview sketch of the crash site

1.42 ± 0.31‰. In Germany, blood alcohol >0.5‰ is considered a criminal offense.

Demographics of drivers and circumstances of the crashes are presented in Table 1.

The opponents of the analyzed e-scooter users were in one case a pedestrian (n = 1, 4.35%), and in five cases cars (n = 5, 21.74%). 17 (73.91%) crashes happened without the involvement of any other road users. In this group of 17 riders, nine riders (39.13%) collided with a stationary obstacle. One out of 23 e-scooters had no operating license and 18 scooters were rented. None of the riders wore any protective equipment.

Two riders (8.70%) were not injured and 60.87% (n = 14) suffered minor injuries (MAIS 1). Four riders (17.39%) were diagnosed with a MAIS 2 and three riders (13.04%) with a MAIS 3. When two people were riding the e-scooter, the average MAIS of the second rider was 1. Among the opponents, only one pedestrian was injured. In this case, the MAIS was 2 due to a wrist fracture and a gaping head wound. Overall 41 injuries were detected, and in 14 patients (60.87%) more than one body region was affected. The most common injuries in the riders' group were contusion, superficial excoriation, or sprains (n = 32, 78.05%) followed by fractures (n = 8, 19.51%). Moreover, one patient suffered from subarachnoid bleeding. The ISS ranged from 0 to 22. The AIS for the neck, abdomen, and spine was not investigated in our cohort. The individual AIS, MAIS, and ISS scores are summarized in Table 2.

Table 1: Demographics and circumstances of the crashes

Sex	Age	Number of riders	Drugs	Time of crash [hh: mm]	Day of the week
Male	20	1	No	16.35	Weekday
Female	21	1	No	17.25	Weekend
Female	52	1	No	21.10	Weekday
Male	25	1	Alcohol	03.00	Weekend
Male	31	1	No	10.39	Weekday
Male	24	1	No	13.00	Weekday
Male	40	1	No	12.46	Weekday
Female	36	1	No	20.10	Weekday
Male	31	1	Alcohol	00.35	Weekend
Female	20	1	No	08.48	Weekend
Male	14	2	No	11.30	Weekday
Male	53	1	Alcohol	23.15	Weekend
Female	18	1	No	19.47	Weekday
Male	17	2	No	18.45	Weekday
Male	23	1	Cannabis	06.20	Weekend
Male	20	1	Alcohol	04.25	Weekend
Male	28	2	Alcohol	01.48	Weekend
Female	17	2	No	15.24	Weekend
Male	34	1	No	18.28	Weekend
Male	29	1	No	19.40	Weekend
Male	42	1	Alcohol	01.45	Weekend
Female	17	1	No	14.58	Weekday
Male	32	1	No	04.47	Weekend

The type, mechanism, and reason for these crashes were manifold. Eleven crashes happened on a straight road, and 45% involved a collision with a stationary obstacle. Car collisions occurred in five cases, all in turning-off situations. Detailed analysis revealed that 20 (86.96%) e-scooter riders were fully responsible for the crash, two riders (8.70) were partly guilty, and only one (4.35%) was innocent.

Detailed information on the issue of responsibility, type, mechanism, and reason for the crashes are presented in Table 3.

Discussion

We performed a medical and technical analysis of crashes involving e-scooters using a representative sample of traffic crashes with the trauma of all severity levels. With regard to injured body regions, similar results were presented by other authors.[13,14] For their study period of four years, Namiri *et al*. showed continuity of affected body regions and type of injury.[15] Contusions, abrasions, and lacerations represented 37% of injuries and fractures appeared in 23% of cases. The areas most often affected were the extremities and the head. In this study we detected 41 injuries, 19.51% (n = 8) fractures and 78% (n = 32) contusions, abrasions and lacerations. In contrast to the literature published to date, we did not find intra-abdominal injuries or fatal accidents.[16,17] Mayhew and Bergin presented a study of 63 patients admitted to the A&E Department because of injuries sustained in an e-scooter crash. They found head injuries in 13 patients. Three of them needed neurosurgical intervention due to intracranial bleeding.[17] In the current study, cranial injuries were also detected in 52.17% including subarachnoid bleeding in one case. With regard to the MAIS 3, the head showed the highest level of injury in our study.

According to EU guidelines, a MAIS ≥3 is classified as clinically seriously injured.[18] Therefore, the head-and-face region seems to be the body region at the highest risk in crashes with e-scooters. This is especially true without the use of protective clothing as indicated in studies about cyclists and the protective use of helmets.[19,20] These findings are in line with the results of Moftakhar *et al.* Although upper extremity injuries were most common (53.1%) in their study, the head region showed a major severity of the injury of 43.7%.[12]

The comparability of the aforementioned studies was limited due to a lack of a comprehensive and validated scoring system in the majority of studies. Blomberg *et al*. used the triage system rating from "most urgent" to "least urgent" in five graduations, whereas Mayhew and Bergin mentioned the necessity for admission or surgery.[13,17] A recently published study by Cicchino *et al*. determines the severity of trauma using the MAIS, with 62,13% (n = 64) suffering from injuries with a MAIS ≤1, followed by 39 (37,86%) riders with a MAIS ≥2 and two riders sustaining a MAIS ≥3.[21] Similar to our objective, this study group investigated the circumstances of injury. They interviewed the e-scooter riders and other participants involved in the crashes within 1 week after the crash. They

Table 2: Abbreviated injury scale, maximum abbreviated injury scale, and injury severity score of the presented patient cohort

AIS_{head}	AIS_{face}	AIS_{thorax}	$AIS_{upper\ extremity}$	$AIS_{lower\ extremity}$	$AIS_{external/other\ trauma}$	MAIS	ISS
0	0	0	1	0	0	1	1
0	0	1	0	0	0	1	1
1	0	0	2	2	0	2	5
3	1	0	0	1	0	3	11
0	1	0	0	0	0	1	1
1	0	0	0	0	0	1	1
0	0	1	1	1	0	1	3
0	1	1	1	0	0	1	3
1	1	0	0	0	0	1	2
0	0	0	1	1	0	1	2
0	0	0	2	0	0	2	4
0	1	0	1	0	0	1	2
0	0	0	1	1	0	1	2
0	0	0	0	0	0	0	0
0	2	0	0	0	1	2	5
1	1	0	0	0	0	1	2
3	3	0	2	1	0	3	22
0	0	0	0	0	0	0	0
0	0	0	2	2	0	2	4
1	0	0	1	0	0	1	2
3	2	0	0	0	0	3	13
0	0	0	0	1	0	1	1
0	0	0	0	0	1	1	1

AIS: Abbreviated injury scale, MAIS: Maximum abbreviated injury scale, ISS: Injury severity score

Table 3: Issue of responsibility, type, mechanism and cause of the crash

Guilt	Type	Mechanism	Reason	Opponent
Full	Turning-off situation	Sideways collision	Priority of the right	Car
Full	Turning-off situation	Sideways collision	Disregard of traffic lights	Car
Full	Turning-off situation	Sideways collision	e-scooter in opposite direction	Car
Full	Turning-off situation	Sideways collision	Priority of the right, alcohol	Car
Partial	Turning-off situation	Sideways collision	Illegal use of the road	Car
Full	Turning-off situation	Fall	Not clear	-
Full	Turning-off situation	Fall	Not clear	Curbstone
Partial	Straight road	Fall	Swerve of the handlebar	-
Full	Straight road	Fall	Alcohol	-
Full	Straight road	Fall	Not clear	-
Full	Straight road	Fall	Overload, 2 riders	-
Full	Straight road	Fall	Not clear	-
Full	Straight road	Fall over	Not clear	Curbstone
Full	Straight road	Bumper-to-bumper crash	Overload, 2 riders	Pedestrian
Full	Straight road	Direct collusion	Not clear	Pole
Full	Straight road	Direct collision	Alcohol	Pole
Full	Straight road	Direct collision	Alcohol, overload, 2 riders	Pole
Full	Straight road	Direct collision	Overload, 2 riders	Fence
Full	Bumpy road	Fall	Not clear	-
Non	Resting traffic	Direct collusion	Lack of attention when getting out	Open car door
Full	Traffic island	Fall	Alcohol	Curbstone
Full	Not clear	Fall	Not clear	-
Full	Not clear	Direct collision	Not clear	Parking car

found that 23% of the e-scooter riders were injured on the road, and 58% on the pavement. Crashes on the road are more likely to be associated with injuries to the upper extremities and were twice as likely to have an AIS ≥2. They attribute the

higher AIS on the road to higher speed, although the maximum speed of e-scooters investigated was 10 mph (16,09 km/h). The maximum speed allowed of an e-scooter in Germany is 20 km/h.[22,23]

Our principal finding is that 86.96% of riders (all except one) were themselves responsible for their trauma. Most of the crashes occurred without the involvement of others and on straight roads. It is worth noting that crashes without the involvement of other parties were related to a collision with a straight obstacle in 39.13% of cases, and in 34.78% of cases happened even without any obstacles at all. A study recently published by Ishmael *et al*. supports our results.[24] Although they did not investigate the responsibility for the crashes, they showed that just eight out of 73 injured riders were struck by cars, whereas 65 fell off their e-scooters. A retrospective analysis performed by a research group from Frankfurt (Germany) also confirms these results. Only six out of 70 patients were injured by another road user.[14] It appears that the riders themselves are the most critical factor behind these crashes.

The high proportion of riders consuming drugs in our patient cohort is worth emphasizing and underlines the risk for the riders. The mean alcohol level was three times higher than that permissible by law. A separate analysis of police checks in Hanover from August to December 2019 verified our findings. Here, 245 riders were under the influence of alcohol and 22 under the influence of other drugs.[25] Recent studies corroborate our results.[13,24] Therefore, the influence of alcohol and other drugs may play a pivotal role in e-scooter crashes.

Our study has some limitations due to its retrospective character and small cohort. Furthermore, riders were only included when police and our local accident research unit were involved. We expect some underreporting for individuals with minor injuries. However, the study represents an external validity regarding clinically relevant injuries in connection with a detailed technical analysis. The survey by the accident research unit in the area under review is comparable to all of Germany because of similar types of streets, the same ratio of developed and undeveloped areas as well as an investigation area of 1.1 million inhabitants. In addition, the randomization in data collection prevents a selection bias. E-scooters as a new and innovative type of transport play an important part in the current study. This effect of attraction might be lost in future studies. The main strength of our study is the analysis of causes and influencing factors.

Conclusion

E-scooters, which are a symbol of an easy-going lifestyle, should not be underestimated when used in mainstream traffic. Users have to be conscious of their vulnerability due to the high risk of suffering severe injuries. Our data may indicate that e-scooter riders tend to be reckless, as most crashes are the sole responsibility of the rider.

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Conflicts of interest

There are no conflicts of interest.

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