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Baković, Marija; Mažuranić, Anton; Petrovečki, Vedrana; Mayer, Davor

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TITLE

Fatal motorcycle crashes in wide urban area of Zagreb, Croatia – a 10-year review

AUTHORS

Marija Bakovic, Anton Mazuranic, Vedrana Petrovecki, Davor Mayer

¹Institute of Forensic Medicine and Criminalistics, School of Medicine, University of Zagreb
Šalata 11, 10000 Zagreb, Croatia

E-MAIL ADDRESSES

Marija Bakovic: mbakovic@mef.hr

Anton Mazuranic: anton.mazuranic@mef.hr

Vedrana Petrovecki: vedranap@mef.hr

Davor Mayer: dmayer@mef.hr

ABSTRACT

Objective:

The objective of our study was to determine the prevalence of alcohol and drug intoxication among fatally injured motorcyclists in wide urban area of Zagreb, Croatia.

Methods:

We conducted a single centre observational retrospective study over a 10-year period (2007 – 2016) in three counties covering an area of 1.2 million residents. We have reviewed the records on fatally injured motorcyclists, collecting the information relating to sex, age, cause of death, time of death in dependence with the time of the crash and the circumstances of the crash (time of day, day of the week, season). Blood alcohol concentration (BAC) and toxicology analysis results were collected and analysed.

Results:

We identified 163 deaths (95.7% male, 4.3% female). Overall, 64.2% of the victims were 20 to 39 years old. The majority (50.9%) of the fatally injured were responsible for causing a traffic crash, while the rest were determined not responsible or the responsibility could not be determined. The most frequent cause of death were multiple injuries (55.8%) and isolated head trauma (23.3%). The rider's blood alcohol concentration (BAC) was above the legal limit for driving (>0.50 g/kg) in 53.8% of cases with a mean BAC of 1.91 g/kg. There was no difference in riding a motorcycle with BAC above the legal limits between groups defined as 'younger' (≤ 39 years of age) and 'older' (≥ 40 years of age). The number of people with illegal BAC was significantly higher during weekends than during working week. The BAC of riders who were responsible for the crash was significantly higher than in those who were not responsible or whose responsibility could not be determined. Use of illegal drugs or nontherapeutic use of legal drugs was not common and was detected in 10.4% of fatally injured.

Conclusions:

Alcohol intoxication has a major role in motorcycle crashes related mortality. Significant difference of BAC between the fatally injured riders responsible for the accident and those who were not responsible implies that measures directed towards prevention of 'drinking and driving' behaviour could lower the number of fatal motorcycle crashes. Weekend measures, especially during spring and summer, could have particularly significant effect.

Key words:

Traffic Crashes, Motorcycles, Fatal Outcome, Alcohol Abuse

INTRODUCTION

Without reliable information, the priorities for road traffic injury prevention cannot be rationally or satisfyingly determined (Peden 2004). An important but often not widely recognized task of forensic medicine is an engagement in prevention of various fatal accidental injuries. Information on the deceased, causes, mechanisms and modes of death collected through the autopsy, as well as toxicology analysis results are very useful inputs in creating preventive policies.

Motorcycle riding is particularly risky mode of transportation due to the lack of barrier between the rider's body and outside forces emerging during the crash, which causes more injuries and deaths among motorcyclists than with any other mean of transport (Servadei 2003, Elliot 2009). For every mile travelled, motorcyclists are nearly 28 times more likely to die than passenger car occupants are (NHTSA 2016). According to the report of the World Health Organization, crashes involving motorized two- and three-wheelers are responsible for 28% of 1.35 million deaths annually in the world (World Health Organization 2018). Furthermore, 90% of those deaths occur in low and middle-income countries (Mock 2005). Between the year 2007 and 2016, motorcycle and moped riders constituted 6% of all traffic accident victims in Croatia. In the same period, they have constituted 22.9 % of all fatally injured in traffic accidents (Ministry of Interior 2017).

In order to reduce the motorcycling related mortality by implementing effective measures it is necessary to have a broad overview of the problem. Besides the external factors of the environment (quality of the roads, weather, traffic flow) and the vehicles (the quality of the brakes, tires), the most important factor in generating traffic crashes are the road users themselves.

Motorcycle riding is more challenging regarding coordination and attention than driving four-wheelers, and authors suggested that alcohol has greater impairment effect on motorcycle riders than on automobile drivers (Colburn 1993, Sun 1998). Furthermore, the link between driving under the influence of alcohol and motorcycle crashes (MCCs) has been well established (Lin and Kraus 2009). Villaveces et al have established a link between drunk driving and fatal MCCs, and the link is stronger when compared to other fatal motor vehicles crashes – 49% of motorcycle deaths were attributable to alcohol use in motorcycle riders, as opposed to 26% for other motor-vehicle fatalities (Villaveces 2003).

Therefore, objective of our study was to collect available information on the prevalence of alcohol and drug intoxication among the fatally injured motorcyclists in wide urban area of Zagreb, Croatia, and analyse these data regarding sex, age, time of crash and responsibility for the accident.

Blood alcohol content (BAC) above 0.50 g/kg or milligrams per litre (mg/L) of exhausted air (illegal BAC, IL-BAC) is an offense in Croatia. BAC above 0.0 g/kg or mg/L of exhaled air is a traffic violation for 'young drivers' (drivers between 16 and 24 years of age under the law of the Republic of Croatia) and professional drivers. For one short period (since July 21 2004, until June 9 2008) any BAC above 0.0 g/kg, or mg/L, of exhausted air was a traffic violation for every driver. There is no specific IL-BAC determined for motorcycle riders. Besides driving with IL-BAC, it is forbidden to transport any person or persons under the influence of alcohol or drugs on moped or motorcycle. The legal consequences for driving under the influence are monetary fines, which are dependent on the level of BAC, suspension of driver's license as well as possible jail penalty (60 days) for BAC over 1.5 g/kg. In addition, when measured BAC exceeds 1.5 g/kg, a person must undertake obligatory medical examination to determine potential chronic alcoholism. The police controls driving under the influence by conducting random breath testing with a breathalyser. In cases when IL-BAC is determined, police officer can temporary deprive driving license and send person on maximal 12 h 'sobriety detention'.

MATERIALS AND METHODS

We have performed the retrospective review of the records from our Institute of Forensic Medicine and Criminalistics, School of Medicine in Zagreb to identify all fatally injured motorcyclists between 2007 and 2016. Our Institute is responsible for conducting all forensic autopsies (including victims of traffic accidents) occurring in Zagreb County, as well as two neighbouring counties covering together a population of approximately 1.2 million residents. Toxicology laboratory is also a part of the Institute where all samples collected during autopsy were analysed.

The fatality cases include victims who died immediately at the scene, but also late deaths in hospitals after sustaining motorcycle-related injuries. According to Croatian Road Traffic Safety Act, a '*traffic accident*' is defined as 'event that occurs on the road and is caused by violation of traffic rules, where at least one moving vehicle took part, and in which at least one person was injured or fatally injured, or died within 30 days from the accident due to consequences of the accident, or material damage has been caused'. Although this definition does not include crashes in which there were no violations of traffic rules, in common praxis, these situations are also considered traffic accidents. In our study, we have included all persons fatally injured in a motorcycle crash, including late deaths in hospitals that have occurred within, but even after, 30 days from injury, if the causal connection between the motorcycle crash and death outcome was obvious.

Information relating to age, sex, time of the crash and causes of death were obtained using the autopsy reports. Information relating to the circumstances of the crash and the information on whether a fatally injured person was a rider or a passenger were acquired from the Traffic Police Department.

Blood alcohol concentrations (BAC) and results of toxicology analysis were collected from toxicology reports. Based on their responsibility for the crash we have divided fatally injured riders into two groups - 'responsible' and 'undetermined'. A 'responsible' group consists of all fatally injured riders who died in crashes that were caused exclusively by the motorcycle riders' actions. The 'undetermined' group consists of all motorcycle riders who were fatally injured in crashes where the responsibility for the crash was not theirs or responsibility hasn't been established. Pillion riders are a part of this group as well. We did not include bicycle riders and their pillion riders in our study.

The use of a helmet in Croatia is obligatory for motorcycle driving. However, we did not have reliable information on the use of helmets for a considerable proportion of the fatally injured riders so we did not include that issue in our analysis.

IBM SPSS Statistics 21 was used for statistical analysis of the data. Pearson – Chi square tests were used for determining the significance of the results. A P-value of <0.05 was considered statistically significant.

RESULTS

A total of 163 fatally injured motorcyclists were identified in the observed area (counting 1.2 million residents) in the 10-year period. This accounts for approximately 13.6 fatalities per one million residents per year.

The total number of the motorcycle crashes (MCC) was 155. In addition to 155 fatally injured riders, there were 8 fatally injured pillion passengers.

Sex and Age

The vast majority of the fatally injured were male (156; 95.7%) and only seven were female (4.3%). Among pillion riders, seven were female and one was male. The age of the victims ranged from 15 to 81 years (mean 35.6; median 33). Among the victims, there were 4 minors, and 7 of the victims were 65 years old or older. Male MCC victims were on average older (mean 36, median 33 years) than the female victims (mean 27.3, median 28 years). Most of the victims who died in MCCs were in their twenties (54; 33.1 %) and thirties (49; 31.1 %). On

average, in the first 5 years of measurement, riders were slightly younger (33.4 mean, median 31) than in the last 5 years (mean 39.7, median 36). During the working week, the average age of the fatally injured motorcyclists (mean 37, median 34.5) was somewhat higher than during the weekend (33.6 mean, median 32).

Year, Season, Week

The number of collisions per year averaged 16.3 and the range was from 7 (2014) to 27 (2009) crashes per year. Through the years of measurement, a clear crash reduction trend can be detected (Figure 1 – dotted line). There were on average 20.8 fatally injured MCC victims per year in the first 5 years of measurement compared to 11.6 in the last 5 years of measurement (Figure 1.)

In the spring (47; 28.8 %) and the summer (69; 42.3 %) months combined, a total of 116 (71.2 %) crashes occurred. (Figure 2).

The total number of crashes during the working week (96; 58.9 %) was higher than during the weekend (67; 41.1 %), but the number of crashes per day was higher during the weekend (33.5) than during the working week (19.2).

Time and Cause of Death

Death has occurred immediately at the scene, during the emergency transport to the hospital or shortly after the admittance (within hours) in 81% (132 cases), while the remaining 19% (31 injured) of the victims died at the hospital after being treated for injuries sustained in the crash. Average survival in the hospital was 17 days, with a maximum survival of 122 days. Most of the late deaths in hospitals occurred within 30 days from the crash (28 cases with average survival of 11 days) while three victims survived for 64, 104 and 122 days respectively.

The causes of death (COD) were divided into five major groups: multiple lesions (ML) (a large number of injuries with no dominant injury as a COD); isolated head trauma (cranial vault fracture, skull base fracture, brain contusion, brain haemorrhage, subdural hematomas, subarachnoid haemorrhages, and other head injuries); pneumonia (unilateral/bilateral pneumonia as a consequence of trauma); exsanguination (as a result of large blood vessels rupture, internal organ rupture, partial or complete traumatic loss of a body part); other COD (all of the causes which cannot be categorized in the aforementioned groups). The most common assigned causes of death were multiple injuries in 55.8% (91 cases) and craniocerebral injuries in 23.3% (38 cases). Exsanguination was the third most common cause of death (8%; 13 cases) and several other causes of death (4.3%; 7 cases combined) were asphyxiation due to compression to thorax, fracture of vertebral spine and severe burns.

Among those who have been in hospital for more than 24 hours (19%; 31 cases), pneumonia (14; 45.2 %) was the leading COD.

Blood Alcohol Content and Toxicology

Samples for alcohol and toxicology analysis were collected during the autopsy in all cases where death occurred immediately or shortly after the incident – a total of 132 cases. Among analysed samples, fatally injured motorcyclists had a measurable BAC in 59.8% (79 cases). The dispersion of measured BAC is shown in Table 1. There was no statistically significant increase or decrease over the ten years period in the share of alcohol-intoxicated riders – the percentage of people with illegal BAC (IL-BAC) was almost identical in the first (53.2%) and the last (54.7 %) 5 years of the measurement.

The continuous line in Figure 1 shows the number of fatally injured with BAC above 0.00 g/kg in the analysed period. There was no significant difference ($p=0.39$) between the proportion of fatally injured with IL-BAC during the ‘zero tolerance’ period (10 out of 22) opposed to period with legal limit set to 0.5 g/kg (61 out of 110). The average BAC in all analysed samples was 1.04 g/kg. The average BAC in all samples of those who

were above the legal limits for driving was 1.91 g/kg, with almost identical average IL-BAC in two periods, 1.90 g/kg and 1.91 g/kg, respectively.

Due to small amount of female victims, the relation of the sex of fatally injured and BAC could not be statistically determined. Blood samples of three victims were not analysed due to hospitalization, two victims did not have measurable BAC and two victims had BAC of 0.47 g/kg and 0.42 g/kg, respectively.

The relation of the age of fatally injured (groups defined as 'younger' (≤ 39 years of age) 'older' (≥ 40 years of age)) and riding a motorcycle with BAC above the legal limits calculated by using Chi-square test showed no statistical significance ($p=0.942$).

The number of people with IL-BAC was higher at weekends (39) than during the working week (32), and thus the number of people with IL-BAC per day was also higher during weekends (19.5) than during working week (6.4). These results are statistically significant ($p = 0.002$).

According to the police reports, in 83 incidents (50.9%) motorcycle riders were responsible for causing the crash, while in 80 incidents (49.1%) riders were not directly responsible for causing the crash or their responsibility could not be determined with certainty. It should be noted that the IL-BAC was not taken as a stand-alone criterion of culpability, although it is a traffic offense according to the Road Traffic Safety Act. Two-thirds (65.8%) of the riders who were found responsible for the crash had a measurable BAC and the great majority were above legal limit (only two riders had measurable BAC but below legal limit). The average BAC of riders who were found responsible for the crash was 1.39 g/kg, while those who were placed in the category 'not responsible/undetermined' had an average BAC of 0.63 g/kg. This difference calculated by independent samples t-test was statistically significant ($p=0,000021$).

Of riders who at the time of the crash had a BAC below the legal limit of 0.5 g/kg for driving in Croatia (61 cases), one third (21) was found responsible for causing the crash.

On the other hand, a total of 71 riders had BAC above the legal limit for driving in Croatia (0.5 g/kg) and 70% of them were considered responsible for the crash. We found that IL-BAC had statistically significant positive association with the responsibility for the occurrence of MCCs ($p=0,000035$). The relationship between BAC and responsibility for the crash calculated by using Chi-square test are shown in Table 2.

In 28 cases where BAC was not analysed, 11 riders (39%) were responsible for the crash, while remaining 17 (61%) were not responsible for causing the crash or their responsibility could not be determined with certainty.

Toxicology analysis revealed that 17 of the fatally injured motorcyclists were under the influence of one or more psychoactive drugs. The identified drugs were benzodiazepines (diazepam), opioid analgesics (codeine and methadone), atypical antipsychotic agents (quetiapine), selective serotonin reuptake inhibitor (citalopram), dissociative anaesthetic (ketamine), heroin, cocaine and tetrahydrocannabinol (THC). Nine of the fatally injured motorcyclists were under the influence of alcohol together with one or more drugs at the time of the crash.

DISCUSSION

Without reliable information, the priorities for road traffic injury prevention cannot be rationally determined (Peden 2004). We find this study to be a small contribution to assessing the risk factors and raising awareness on motorcycle related fatalities in our area.

Fatality rate (fatalities per million inhabitants) of powered two-wheel riders in European Union (EU) for the years 2009 and 2010 was 13.5 and 12.9 respectively (Yannis 2010). The rates show high discrepancy between northern and southern states in the EU. In the mentioned period Croatia was highly above the European average – the fatality rate was 24 in 2009 and 16.5 in 2010. The fatality rate in our area in the investigated ten-year period was 13.6, significantly lower than other parts of Croatia. The discrepancy is because the area observed in

this study is highly urbanized and therefore it is not an attractive area for leisure motorcycle rides. This is consistent with the fact that the majority of motorcyclist (56%) in the EU are injured or fatally injured on inter-urban roads (Yannis 2010). In line with the overall crash reduction trend, the number of fatally injured MCC victims in the EU has decreased by 17 % between 2010 and 2013 (European Commission 2015). We have observed the same trend in our study (Figure 1 – full line).

Substantial seasonal variation in motorcycle crashes has been expected, reflecting the continental climate features with cold winter temperatures accompanied with rain or snow. Such conditions make motorcycle riding a seasonal activity for most of the bikers. One would guess that this winter break would make riders more susceptible to crashes at the beginning of the riding season, acting together with lower sensitization of car drivers to bikers after their absence from the roads during winter months. However, our study did not detect any measurable seasonal peak possibly caused by this 'first ride effect' in spring months.

The male to female ratio in motorcycle fatalities is high in all parts of the world (Ankarath 2002; Villaveces 2003; Yannis 2010, Christophersen et Gjerde 2015). In 2010 in EU, six percent of fatally injured motorcycle riders were females as well as 11% of fatally injured moped riders (Yannis 2010). In our studied sample a vast majority of fatally injured were male (95.7%) which is very similar to the EU rates (European Commission 2015) and all fatally injured females were pillion riders. To our knowledge, the proportion of female motorcycle riders in Croatia is unknown. Therefore, relative number of fatally injured motorcyclists is unknown.

Traffic fatalities in general represent a target group for reducing mortality in the population since great majority of these deaths are preventable. Reducing the number of casualties among the motorcycle users is an important task especially when age of the fatally injured is taken into account. Mean age in our sample was 35.6 years with most of the victims (64.2%) between 20 and 39 years of age. This is similar to the previous study by Villaveces, which found that 61% of the fatally injured were between 21 and 39 years of age (Villaveces et al. 2003). In the EU, 57% of the fatally injured motorcycle riders were between 25 and 49 years old, which means that young and middle-aged people are most at risk (European Commission 2015). The vast majority of the victims in our study (152; 93.3 %) are a part of the working-age population (between the age of 18 and 65).

The majority of the deaths in our sample (81%) have occurred shortly after the crash which is similar to large number of studies that have shown that a high percentage of motorists die on the spot or while being transported to the hospital (Ankarath 2002, Lin and Kraus 2009). The results indicate that investing resources in preventing potentially fatal motorcycle crashes and injuries is crucial, while improving the acute treatment of MCC victims appears to be limited. On the other hand, analysing the causes of late deaths in hospitals shows the high prevalence of death due to pneumonia, which indicates that better care in prevention and treatment of pneumonia in severely injured persons could lower the number of deaths.

Alcohol Intoxication

Determining the prevalence of alcohol and drug intoxication was the main objective of our study since alcohol intoxication is well recognized risk for death in motorcycle crash (Lin and Kraus 2009, Villaveces 2003). The legal limit for driving in Croatia is set to 0.5 g/kg of alcohol in blood (0.0 for drivers/riders younger than 24 and professional drivers) with the exception of time span from July 21 2004 until June 9 2008 when zero tolerance was imposed. The comparison of these two different periods within our sample shows no statistically significant difference between the proportions of fatally injured motorcyclist driving with the IL-BAC. In addition, the average IL-BAC is practically the same in the two periods. These data suggest that imposing zero tolerance for BAC did not show effect on fatally injured motorcycle riders. It is interesting to notice that the share of riders

with IL-BAC among fatally injured was not significantly different between first and second 5-year period, although the total number is lower due to steady decline in number of fatal crashes.

In our study, only 40.15% of the fatally injured had 0.0 g/kg of alcohol at the time of the crash, and another 6% had a measurable BAC but were within the legal limits. This leaves a large proportion of almost 54% of alcohol intoxicated fatally injured motorcycle riders. The percent of alcohol intoxicated riders in our study was markedly above the percentage of alcohol intoxicated motorcycle riders in USA in 2016 (25% of the fatally injured riders had a BAC above legal 0.08 g/dL (0.76 g/kg)) (NHTSA 2016) and above 27.1% established motorcycle riders under the influence of alcohol or drugs in Norway (Christophersen et Gjerde 2015). On the other hand, it was close to the findings of Carrasco who established BAC in 42.3% of samples of fatally injured motorcycle riders in Brazil (Carrasco 2012) and 48% of samples positive for alcohol or drugs in fatally injured motorcycle riders in UK (Elliot 2009). Motorcycle riding is more challenging regarding coordination and attention than driving four-wheelers, and it has already been suggested that alcohol has greater impairment effect on motorcycle riders than on automobile drivers (Colburn 1993, Sun 1998). Creaser et al. report that impairment of basic riding skills considered important for safely riding is detectable on BAC 0.5 g/L (0,47 g/kg) and particularly on BAC of 0.8 g/L (0,76 g/kg) (Creaser 2009). This makes the fact that the average blood alcohol concentration in alcohol intoxicated riders was 1.91 g/kg even more concerning. In addition, the majority of those whose alcohol concentrations were above the legal limits had the concentrations of alcohol higher than 1.3 g/kg (59 cases out of 79). A person with BAC over 1.3 g/kg suffers significant impairment of motor coordination with loss of good judgement and decrease in balance, vision and reaction time (Jones 2014) – all things crucial for driving a motorcycle in a safe manner. Our study showed a statistically significant positive association between the responsibility for the fatal crash and the consumption of alcohol. This is consistent with the findings of Soderstrom who reported a correlation between alcohol intoxication and culpability for the crash among injured motorcycle riders (Soderstrom 1993). That research revealed that 83% of alcohol-intoxicated riders caused their crashes opposed to 46% of those who were negative for alcohol. Similar findings are observed in study conducted by Christophersen and Gjerde where prevalence of alcohol or drug intoxication among motorcycle riders killed in single-vehicle crashes was 44.6 as opposed to 15.3% among those killed in multiple-vehicle crashes (Christophersen and Gjerde 2015). Interestingly, our study found no difference between culpability between motorcycle riders who had BAC between 0.5 g/kg and 1.3 g/kg compared to those whose BAC was above 1.3 g/kg. Some authors have already proposed lower blood alcohol concentration limits for motorcycle riders (Colburn 1993, Sun 1998). We are under the impression that our results imply that such measure would have a small effect on the motorcycle related fatalities in our area. The legal limit is set to 0.5 g/kg and only six of the fatally injured had alcohol in their blood with concentrations within the legal limit. Lowering the BAC limit would possibly affect this small part of the fatally injured, but not all other riders whose concentrations were above the legal limits. In addition, in our sample we did not find significant difference between the proportions of the level of IL-BAC among fatally injured MCC victims in period of 0.0 g/kg tolerance compared to 0.5 g/kg tolerance.

Limitations of the Study

In this study, only data referring to the fatally injured motorcycle riders that were collected at the autopsy were analysed together with the information on culpability of the rider from the police reports. We did not have other information pertaining to the riders (driving experience, helmet use, purpose of using the motorcycle at the time of the accident, valid driver's license etc.), external factors of the environment (quality of the roads, weather,

traffic flow etc.) and the vehicles (the quality of the brakes and the tires etc.). It is possible that in some cases some of these factors were also involved in the occurrence of the crash.

It is important to emphasize that our sample included crash victims from three counties, which are mostly urban area and almost exclude leisure rides. It is possible that leisure riders show different prevalence of BAC.

Another limitation is the fact that BAC and toxicology analysis for psychoactive drugs was conducted only on victims that died immediately after or within 24 hours from the crash. The reason for this is the fact that hospitals do not perform toxicology analysis on every victim of traffic accident and even when the analysis is performed, our Institute would not get the results of the analysis.

The proportion of 59.85% of fatally injured riders that were under the influence of alcohol at the time of crash in our sample is among the highest in the cited literature. Considering the fact that the risk of a motorcycle crash is five times greater with blood alcohol content than with no alcohol in the blood (Haworth 2000), we believe there is a place for significant reduction of motorcycle crashes and related deaths in our observed area. Significant difference of BAC between the fatally injured riders responsible for the accident and those who were not responsible implies that measures directed towards prevention of 'drink and drive' behaviour would lower the number of fatal motorcycle crashes. Weekend measures, especially during spring and summer months, would have particularly significant effect.

Bikers cannot control many factors in traffic that are life threatening for them, however, the high proportion of alcohol intoxicated riders in our sample that were responsible for the crash indicates that the elimination of alcohol use when driving a motorcycle would lower the number of deaths related to MCCs.

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TABLES AND FIGURES

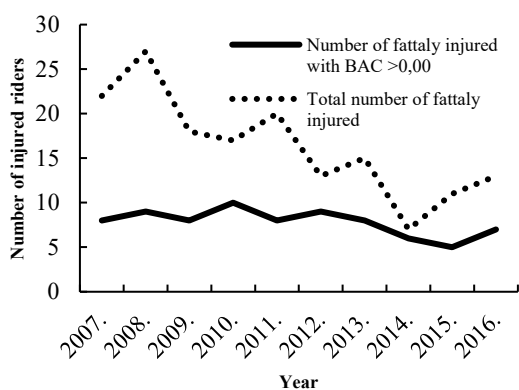


Figure 1 - Number of fatally injured motorcycle riders per year (Total and those with BAC>0.00)

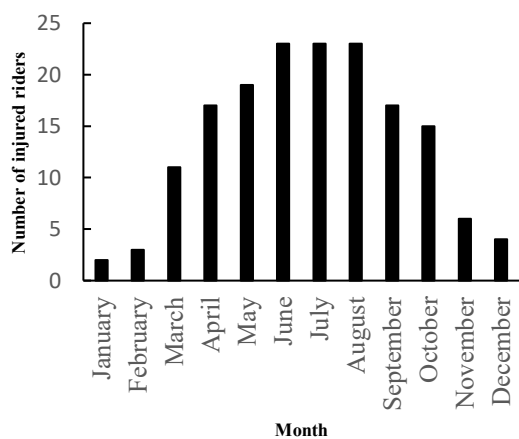


Figure 2 - Number of fatally injured motorcycle riders per month

BAC (measured in 132 cases)		
Negative 40.15% (53)	Positive 59.85% (79)	
	0.01 – 0.50 g/kg	6 % (8)
	0.51 – 1.3 g/kg	9.1% (12)
	1.31 – 2.50 g/kg	35.6% (47)
	2.51 – 3.50 g/kg	8.3% (11)
	Above 3.51 g/kg	0.76% (1)

Table 1. The results of BAC measured on all fatally injured victims (0.50 g/kg – legal limit for driving in Croatia)

(p = 0, 000035)	BAC ≤ 0.5 g/kg	BAC > 0.5 g/kg
Responsible	21 (34%)	50 (70%)
Undetermined	40 (66%)	21 (30%)

Total number of motorcycle riders	61	71
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Table 2. The results of BAC in relation to the responsibility of the motorcycle rider for the crash