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Fatal and survived motorcycle accidents: a selected topics for medicolegal evaluation

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SUMMARY

Motorcyclists are extremely vulnerable road participants who are exposed to severe, often fatal injuries. Relative to four - wheeled vehicles, motorcycle pose a greater hazard of death or serious injury to operators and passengers. In fatal crashes, the motorcyclist typically collides with moving or stationary objects in the riding environment. The most common mechanism of crashes is hitting a moving vehicle followed by hitting a stationary object. The mechanism of injury resulting in death usually comes from severe blunt force trauma, creating internal and external injuries to the motorcyclist, especially craniocerebral, spinal, and sometimes with very characteristic injury patterns. The paper also identified effects of alcohol, which represent a significant risk factor for motorcycle operators. Presented concise review of selected risk factors and typical motorcycle-related injuries may be useful for both forensic pathologists, clinicians and law enforcement in preventive and repressive steps.

Keywords: motorcycle fatalities – risk factors – injury patterns – alcohol impairment – medicolegal study

Motocyklové nehody: vybraná témata pro soudnělékařské hodnocení

SOUHRN

Motocyklisti sú vystavený závažným až smrteľným poraneniam omnoho častejšie ako ostatní účastníci cestnej premávky. Typickým mechanizmom smrteľnej dopravnej nehody motocyklistu je jeho kolízia s pohybujúcim sa dopravným prostriedkom alebo náraz motocyklistu do pevnej prekážky. Najčastejším mechanizmom vzniku poranení je tupý náraz, zapríčiňujúci rozsiahle vonkajšie a vnútorné poranenia, z nich najviac nebezpečné sú úrazy hlavy a miechy. Predkladaný článok taktiež poukazuje na výrazne negatívny účinok alkoholovej opitosti na dopravnú úrazovosť motocyklistov. Prehľad vybraných rizikových faktorov s rozborom typickým poranení motocyklistov má za cieľ pomôcť nielen súdnym lekárom a klinikom pri ich dennodennej praxi, ale aj predstaviteľom represívnych zložiek štátnej moci v účinnejšej prevencii takýchto úmrtí.

Kľúčové slová: úmrtia motocyklistov – rizikové faktory – poranenia motocyklistov – ovplyvnenie alkoholom – súdnolekárska štúdia

Soud Lek 2012; 57(4): 71–74

The ubiquitous character of motor vehicles in modern society is reflected in the practice of forensic medicine. Road accidents are a leading cause of deaths and serious injuries around the world, with about 1.2 million people killed each year (1). World Health Organisation has predicted that traffic fatalities will be the sixth leading cause of death worldwide and the second leading cause of disability in developing countries by the year 2020. The risk of death for motorcyclists in Europe is 18 times greater that of other road users (2). In U.S., per vehicle mile traveled, motorcycle riders have even a 34-times higher risk of death in a crash than road participants driving other types of motor vehicles (3). While lower - extremity injuries most commonly occur in all motorcycle collisions, head and spinal injuries are most frequent in fatal crashes. In 2009 *Lin* and *Kraus* created comprehensive review of risk factors and patterns of motorcycle injuries, which comprises 220 articles (4). However, this study synthesize recent reports concerning motorcycle accidents from a medicolegal point of view.

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ALCOHOL IMPAIRMENT

Traffic accidents are often associated to the use of alcohol, psychoactive medicaments or illict drugs (5–11). When motorcycle operators are under influence of drugs or alcohol, their death rates are worse than those of nonalcohol or nondrug motorcyclists (12–15). Approximately one in four automobile driver fatalities in the U.S. was alcohol – related during 2005, in comparison, a higher proportion of motorcycle rider fatalities (one in three) were related to alcohol in the same year (16). According to MAIDS study, alcohol use by motorcyclists was reported in 36 of the 921 investigated cases (17). For example, *Larsen* analyzed a series of fatal motorcycle accidents, from 41 victims, 26 (66 %) had measureable blood alcohol concentration (18). The large prospective study of 1082 accident - involved riders revealed, that 393 motorcyclists had been drinking alcohol prior to crash (19). A single motorcycle simulator study has shown that the most common fault for intoxicated operators at blood alcohol concentration ranging from 0,36 to 0,56 $g.kg^{-1}$ was to "run-off-road", particularly when negotiating curves (20). Four motorcycle basal riding skills (*offset weave, hazard avoidance task, curve circuit and emergency stop*) under the influence of alcohol were analyzed by

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Creaser et al (21). There was a statistically significant main effect of alcohol for *offset weave* (the weave task required riders to maintain control and balance of the motorcycle through a simple weave (inline) and a complex weave (offset) and *curve circuit* (the curve circuit task required riders to control the lateral position and speed of the motorcycle through a loop circuit with curves marked by lane boundaries). The *hazard avoidance task* (pay attention to a directional signal that was turned on just before reaching an obstacle, and then control the motorcycle through an indicated escape lane to simulate a hazard avoidance maneuver) was a marginally statistically significant. Alcohol have no statistically significant effects on *emergency stop* (rapid breaking while maintaining suitable control of the motorcycle). In general, intoxicated motorcyclists demonstrate longer response times and adopted larger tolerances leading to more task performance errors (9,21).

MECHANISM OF INJURY

Motorcyclists are vulnerable road users who are exposed to severe trauma. Physical coordination, balance, and skills are required to operate an unstable vehicle (22). Motorcycle accidents are complicated situational transactions in which motorcycle rider are in motion among other motor vehicles, pedestrians along public roads that are composed of a variety of natural and engineered objects (23). Of all types of road users, motorcyclists have the highest risk for fatal and non-fatal injuries (4). The risk for death of motorcyclists is 30-times greater than in car drivers (4). Generally, motorcycle accidents kill motorcyclists in one of the following ways: (a) collision with another motor vehicle, (b) collision with stationary, nonvehicular object, (c) some other injurious maneuver by motorcyclists, for example loss of control and falling of motorcycle. Hitting a moving vehicle (collision with motor vehicles or other motorcycles) is the main mechanism of injury (24). Roadside trees had the largest positive effect among all objects on the odds that a colliding motorcyclist would be killed (23). Other engineered systems that are part of the road infrastructure were also potentionally lethal – bridge components, guardrail ends, lampposts, etc.

Public policy implications of the object of impact analysis include more careful consideration of (i) locations chosen for signage and other roadside objects and (ii) choices for the type, density, and elastic limits of roadside architecture put in place in areas with more operating motorcyclists (23). This could be called a *target softening* initiative that creates roadside arrangements less harmful to motorcyclists or other motor vehicle occupants. In conjunction with the object of impact, higher-speed collisions substantially increase the risk of death.

SELECTED INJURY PATTERNS OF MOTORCYCLISTS

One of the most commonly encountered types of trauma resulting in serious injury or in death is blunt force injury. Many blunt force injuries, such as those that occur in traffic accidents, involve forces that are associated with sudden deceleration (or acceleration in certain motor vehicle – related cases). By virtue of their exposed position, motorcyclists are functionally similar to ejected vehicle occupants. Similar types of injuries are often seen, including extensive road rash. In addition, pelvic and extremity injuries are often severe because of the rider's exposed position and because of the interaction between the motorcycle and rider in the course of attempted evasive maneuvers. Motorcyclists are also unique in the extent of interaction with the *other* vehicle during collisions. Either the motorcycle or the colliding vehicle may produce patterned injuries on the body of the rider.

1. Spinal injuries

Traffic accident accounted for more than 50 % of spinal cord injury in the European countries (25). Although spinal injuries sustained during motorcycle crashes are relatively low (ranging from 1 % to 11 % of all injuries) compared to lower extremity or head injuries, often lead to death, or severe impairment and disability (26–30). The overall statistics on the reported incidence of motorcycle spinal injury may be underestimated as many crash victims do not survive the accident and their deaths are attributed to more pronounced visible lethal injuries such as head injuries (31,32). Single vehicle crashes are well - known to be more severe compared to multiple vehicle crashes for both passenger cars and motorcycles (13,32,33,34). A single vehicle crash exhibits a higher likelihood of death when the vehicle runs off the road and collides with a fixed object, such as a tree or a pole (35–37).

In single vehicle crashes, the factor most strongly associated with the risk of serious injury is collision with fixed objects (38,39,40). For example, guardrails, one of the most common types of barrier, have been demonstrated to cause a significantly higher fatality risk to the motorcyclist than the person in a passenger vehicle upon collision (41). In France and Austria, 4,7% of motorcycle accidents involving injury or death entail guardrail impacts, with mortality rates ranging from 9,75 to 15 % (42). Furthermore, a recent study in the United States by *Daniello and Gabler* shows that compared to collision with the ground, collision with a roadside fixed object is at least 4 times more likely to result in fatality (43). They also show that fatality risk of striking a guardrail is 7 times greater than the risk of striking the ground (43). The main spinal segments typically injured in this manner are thoracic as this segment is firm and rigid; therefore, it requires a high impact loading to cause the injuries (44). Although crash configuration involving side impact and head-on occurred more frequently, the rear-end impacted motorcyclist shows the highest risk of spinal injury (45).

Helmets have helped to reduce head injury but they did not seem to offer corresponding protection for the spine. Some of the studies suggested that helmets could cause spinal injury especially to the neck or cervical spine (46,47) but some other studies have found no difference in the incidence of spinal injury between helmeted and unhelmeted motorcyclists (48,49,50). Furthermore, *Goslar et al* found that there was no significant association between location of spine fracture and helmet use (51). According to study of *Hitosugi et al.* most brain stem injuries involving the pons or medulla oblongata were accompanied by skull base fractures and atlantooccipital and atlantoaxial dislocation, regardless of the impact area (52). In most cases of cervical spinal injury (C_1 – C_7), the impact was from the anterior direction (52).

2. Perigenital and genital injuries

In „ tandem" motorcycle accidents, especially when one rider survive, it is very important to distinguish the motorcycle driver from the passenger. Certain parts of motorcycle, such as handlebars, pedals, fuel tank as well as other components may cause characteristic injuries in occupants at collision. One of the characteristic and most useful injury complex that distinguishes the driver from a passenger are contusions and lacerations around the scrotum, perineum and inguinal region, known as a *fuel tank injury* (53,54). The fuel tank injury results from gliding and striking of the scrotum and perineum of the rider on the fuel tank. Fuel tank injury is comparatively rare in even drivers of motorcycle accidents because it may occur only from a head-on collision (55). However *Ihama et al.* published extremely rare case, where also passenger suffered injuries around the groin area (55). Presence of genital and perigenital injuries, including traumatic testicular dislocation, although there are not pathognomic, may be very useful in forensic evaluation of motorcycle - related accidents (56).

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3. Massive traumatic lesions

A motorcycle rider often sustains multiple injuries in a collision occurrence. Impact of a motorcyclists by a large vehicle or solid object often produces extensive deformation of the head and crushing thoracoabdominal injuries. A more clear view of the nature of head injuries can be made by manual reposition of the cranial and facial parts of the skull, or in extreme cases stuffed cranial cavity with operating masks or paper pulp, then sewn back to reapproximate the edges of the lacerations (57). *Di Maio* reports number of motorcycle operators beheaded or having arms avulsed (58). Examination of the amputated heads and extremities shows sharp edges of the wounds, almost as if they had been produced by a sharp, edged instrument. *Brandimarti* published case of collision of motorcyclist and guardrail, where the body of victim was torn apart at a level of twelfth thoracic vertebra (59). *Ihama et al* described unusual case of complete decapitation in which a roadblock chain had been wrapped around the neck of a motorcycle driver (60).

MISCELLANEOUS RISK FACTORS

Younger motocyclists are more likely to be at-fault in the event of a collision, as a riders without insurence, or not wearing helmet (61). Similarly, motorcyclists were less likely to be at-fault when the other driver was of younger age or was driving under the influence of alcohol, without insurance, or not wearing their safety belt (61). Riders on newer motorcycles were also more likely to be at-fault (61). *Byard* point out peculiar, however relatively frequent risk factor - increasing of body weight of motorcycle riders (62). While it is recognized that obesity increases the risk of a range of medical conditions, including hypertension, diabetes mellitus, cardiac disease, and pulmonary thromboembolism, the association with injuries is less well appreciated (63). It has, however, been shown that there is an increased risk of lethal and nonlethal injuries in motor vehicle crashes in obese individuals (63). Given that the energy involved in an impact is directly proportional to both mass and velocity (squared), it is perhaps not surprising that large unrestrained individuals would be at higher risk of injury (64). Age increased the chances of death. The effects of age among the correlates of death by motorcycle are likely related to (a) less physical resiliency on the part of older riders to patterns of injury generated in motorcycle crashes and (b) the slower reaction time and reduced sensory and perceptual ability of older riders to avoid lethal crashes (65,66).

CONCLUSIONS

Recent trends in motorcycle fatalities may have changed in developed and developing countries. Although helmets are efficent in reducting severe head injuries among motorcyclists, they not offer corresponding protection for the spine. Sobriety checkpoints, mandatory jail terms and administrative licence revocation should be effective in reducting alcohol-related motorcycle deaths. Differences in risk and injury patterns between motorcycle operators and passenger remain to be investigated. Injuries around the groin area and traumatic testicular displacement, know as fuel tank injury are rare, but very specific and important findings in medicolegal assessment. Competent researchers messaged that "the greatest potential to reduce the death rate lies with accident prevention, rather than through improved treatment of injuries". Future research should focus more frequently on the cooperation between hospital and trauma information and police reporting on motorcycle-related deaths. In cases of fatal motorcycle accident close communication between police and forensic pathologists is essential, because autopsy findings may be misleading in the absence of satisfactory accident scene information.

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