INJURIES AMONG MOTORIZED TWO-WHEELERS IN RELATION TO VEHICLE AND CRASH CHARACTERISTICS IN RHONE, FRANCE

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ABSTRACT

We described injuries among helmeted motorized two-wheelers injured in a road crash between 1996 and 2003 and recorded by the Rhone Road Trauma Registry in France. The registry data were linked to police data for 3727 riders to describe injuries according to vehicle and crash characteristics.
Extremity injuries were the most common injuries sustained. A substantial proportion of riders sustained head, chest abdominal and spinal injuries, which tended to be severe. Half of severely injured riders sustained severe chest injuries and 44.8% suffer from severe head injuries.
Whatever the body region injured, head-on collisions accounted for more than 30% of injuries. A high proportion of head, facial, chest, abdominal and spinal injuries occurred in single vehicle crashes with a fixed object. Compared to single vehicle crashes with no object hit, those with a fixed object resulted in a higher risk of head, facial, chest and abdominal injury. Collisions between the front of the two-wheeled motorized vehicle and the side of another vehicle resulted in a higher risk of upper extremity injury than single vehicle crashes with no object hit. Head-on, rear-end, broadside and multiple collisions resulted in a higher risk of lower extremity injury than single vehicle crashes with no object hit. The highest risk of lower extremity injury was observed for broadside collisions. Motorcyclists, which accounted for 62.4% of injured riders, had a higher risk of chest, abdominal, spinal and upper extremity injuries than moped riders. The risk of facial injury was greater for moped riders.
The use of safety devices must be promoted as well as their improvement. The attention given to head protection shouldn't ignore the vulnerability of other body regions. Public awareness campaigns on motorized two-wheeler vulnerability and their crash risks, the improvement of driver experience as well as road infrastructure could contribute to reducing crashes.

INTRODUCTION

In France, according to Road Crash statistics based on police records, motorized two-wheelers accounted for 21.7% of deaths in road crashes and 32.5% of those severely injured (ONISR, 2005). In the fatal crashes they were involved in, motorized two wheelers represented 90% of fatally injured victims (ONISR, 2005).
Epidemiological studies conducted on motorized two-wheeler crashes have aimed to identify risk factors that increase injury severity or to study injury patterns sustained as a result of two-wheeled motorized vehicle crashes, with regard to frequency, nature and severity. Some studies are based on police data and others on medical data coming from emergency, hospital or registry records. Police reports are the most complete source of information available about the crash. Many factors such as vehicle characteristics, crash characteristics and crash conditions have been pointed out by recent studies on the subject as important factors in predicting injury severity (Lin et al. 2003; Lin et al. 2001; Peek-Asa and Kraus 1996; Quddus et al. 2002; Zambon and Hasselberg 2006). Few studies combined both information from medical and police sources and have been published for motorised two-wheelers (Peek-Asa and Kraus 1996; Peek et al. 1994; Richter et al. 2001). In order to broaden our understanding of motorized two-wheeler crashes, studies that provide injury pattern descriptions and contribute to improve knowledge of mechanisms by which crashes cause injury are welcome. Information on vulnerable body region to protect will make possible to propose recommendations for rider protection.
This study was conducted on motorized two-wheelers fatally and non-fatally injured, recorded in the Rhone Road Trauma Registry. For a sizeable group of these riders, information on both the crash characteristics and the medical diagnoses were available, thanks to police reports. In France, helmet use is mandatory by law from 1979 for riders of all type of motorised two-wheeled vehicles (ONISR, 2005). This study focused on helmeted riders. The primary objective of this study was to describe injuries among helmeted motorized two-wheelers receiving medical care after a crash in the Rhone County in France. Specifically, we sought to focus on severe injuries, which are life-threatening or fatal, and may lead to long term

disability and impairment. The secondary objective was to describe injuries among helmeted motorized two-wheelers in relation to vehicle and crash type.

METHODS AND DATA SOURCES

The Rhone road trauma registry

This study is based on the road trauma registry (Laumon et al. 1997), which has been in use since 1995 in the Rhone region of France (population, 1.6 million inhabitants; main city, Lyon). The registry covers all victims from road crashes that occur in the Rhone county and seek care in health facilities, whether they are hospitalised or not. Data are collected by the medical units involved in the health care of crash victims of the county and its close surroundings: it includes some 201 health care units, from emergency departments and follow-up services (intensive care, surgery and rehabilitation units). The registry is not restricted to only motor vehicle crashes: crashes with pedestrians are also included. This registry has been approved by the French National Registry Committee.

Information collected by the registry for each victim contains the victim's characteristics (name, gender, and date of birth), a few crash characteristics (crash location, date, time of the crash, road user type and riding position, safety device use such as helmet, and type of collision) and injury assessment. Victims are defined as road users sustaining at least one injury. The registry provides a complete injury assessment coded according to the Abbreviated Injury Scale (AIS),1990 revision (AAAM, 1990). The AIS divides injuries into body region, type, nature and severity. The AIS uses nine body regions including head, chest, abdomen, neck, face, upper extremity, lower extremity and external. Each injury is assigned a severity code, ranging from AIS 1 (minor) to AIS 6 (unsurvivable injury). Each victim could have more than one body region affected and could have more than one injury to a specific injured body region. The overall severity of a victim with multiple injuries can be measured with the maximum Abbreviated Injury Severity (MAIS) Score. It denotes the most severe injury.

Police traffic crash data

The French police are required by law to fill in a crash report for every road crash causing at least one victim. A road crash is defined as a crash occurring on the network open to public traffic and involving at least one vehicle. The police crash report includes information on everyone involved in the crash (non-injured, slightly injured, severely injured or dead) and detailed information on the crash and the vehicles involved. However, information on the people involved is limited. For each identified crash, the following information were used: vehicle type involved in the crash (moped, motorcycle), crash location (urban or rural area), day of the week (weekday, weekend), time of the crash (daytime, night), and type of road at the crash location (motorway, main road and secondary highway, minor road/street, other). The nature of the crash opponent was defined in 6 categories: single vehicle (no opponent, the two-wheeled motorized vehicle was the only moving vehicle), pedestrian/bicyclist, two-wheeled motorized vehicle (TWMV), car, truck, other. Collision type was defined according to the nature of crash opponent (motorized, non motorized vehicle) and impact location on the TWMV: single vehicle crash - no object hit; single vehicle crash - fixed object hit; head-on collision between the TWMV and another motorized vehicle; collision with pedestrians or bicyclists; collision between the front of the TWMV and the rear of another motorized vehicle; collision between the front of the TWMV and the side of another motorized vehicle; broadside collision (i.e. the TWMV collided with any other motorized vehicle in a broadside of any angle); rear-end collision (i.e. a motorized vehicle struck the rear of the TWMV); multiple collision or undefined collision.

Analysis

Firstly, we identified all fatally or non-fatally injured motorized two-wheelers who wore a helmet recorded by the road trauma registry in the Rhone from 1996 to 2003. It is now clear that unhelmeted riders are more likely to suffer a head injury and to be critically injured compared to helmeted riders (Ankarath et al. 2002; Rowland et al. 1996; Sarkar et al. 1995). Helmets provide protection for all types and locations of head injuries. They are not associated with an increase in the occurrence of other injuries (Richter et al. 2001; Sarkar et al. 1995). As unhelmeted riders accounted for only a small proportion of the riders in the Rhone road trauma registry (6.0%), we focused our analysis on helmeted riders.

Fatally injured riders without injury coding were excluded. We described the body region injured according to injury severity. Then the nature of severe injuries was detailed. Victims were considered severely injured if they sustained at least one injury greater than or equal to AIS severity level 4 (AIS4+). Severely injured riders were fatally or non-fatally injured. This choice of severity level implied that we emphasized life-threatening injuries (such as injury to internal organs or crushing injuries), that could lead to severe impairment and disability. In the AIS classification, all upper extremity injuries and with a few exceptions, all lower extremity injuries are coded with severity level ranging from 1 to 3. It is also the case of uro-genital injuries with severity level below 4. Although these injuries could be severe and could account for high degree of impairment and disability, they are not life threatening in the AIS classification.

Then, the registry medical data were linked to the French police data recorded between 1996 and 2003 for the Rhone County. Data were linked using a semi-automated record-linkage procedure (Amoros et al. 2006; Laumon and Martin 2002) at the victim level. Linking variables were date and time of crash, crash location, type of road user, date of birth (year and month) and gender. This selection process led to the exclusion of data not reported by police records. These crashes corresponded to crashes not-reported to the police (crashes when no-one called the police) or not-reported by the police (when police did not write a crash report even though present at the crash scene, or omitted some of the victims within the reported crash). The level of being reporting varies according to injury severity (Amoros et al. 2006). Although crashes resulting in fatally or severely injured road users are well reported by the police, this is not the case of crashes where road users are slightly injured. Therefore, our sample of riders involved in crashes identified by both sources represents more seriously injured riders than the overall population of injured riders.

For the victims identified as common to the Registry and the police file, we described the main vehicle and crash characteristics according to overall injury severity and we examined the injured body region according to vehicle and collision type. The $\chi 2$ test was used for statistical analyses. A p-value below 0.05 was considered statistically significant. Logistic regression analyses were performed, with crude odds ratios (OR) and corresponding confidence intervals to assess the risk of being injured in each body region associated with collision type and vehicle type. Data analyses were done with SAS software.

RESULTS

Over the 1996-2003 observation period, 14749 helmeted injured riders were recorded in the Rhone Road Trauma Registry and had a complete injury coding.

Table 1.
Body region injured, injury type and AIS Group among the 14749 helmeted motorized two-wheelers, Rhone Trauma registry, 1996-2003

Injury sustained		AIS>0 N=14749		AIS4+ N=328		
		No. of Riders	%	No. of Riders	%	% of AIS≥4
Head		**1640**	**11.1**	**147**	**44.8**	**9.0**
	Cranial or intracranial injuries	187	11.4	118	80.3	63.1
	Loss of consciousness	1328	81.0	8	5.4	0.6
	Head/nerves	208	12.7	23	15.6	11.1
Face		**990**	**6.7**	**8**	**2.4**	**0.8**
Neck		**575**	**3.9**	**2**	**0.6**	**0.3**
Chest		**1480**	**10.0**	**164**	**50.0**	**11.1**
Abdominal		**800**	**5.4**	**45**	**13.7**	**5.6**
Spinal		**1251**	**8.5**	**32**	**9.8**	**2.6**
	Cervical	876	70.0	14	43.8	1.6
	Thoracic	149	11.9	17	53.1	11.4
	Lumbar	282	22.5	1	3.1	0.4
Upper extremity		**6679**	**45.3**			
	Shoulder/Upper arm	3203	48.0			
	Forearm/ Elbow	1561	23.4			
	Wrist/Hand/Finger	1235	18.5			
Lower extremity		**9265**	**62.8**	**14**	**4.3**	**0.2**
	Pelvic	213	2.3	9	64.3	4.2
	Hip	827	8.9			
	Upper leg/Thigh	440	4.7	5	35.7	1.1
	Knee	2925	31.6			
	Lower leg/Ankle	2572	27.8			
	Foot/Toes	590	6.4			
External		**2179**	**14.8**	**3**	**0.9**	**0.1**

Among them, 152 (1.0%) were fatally injured. The number of riders severely injured (i.e. with at least one injury with a severity score greater than or equal to 4) was 328 (2.2%). Each victim could have more than one body region affected and could have more than one injury to a specific injured body region. Multiple injuries to the same body region are counted only once in the following tables.

Injury patterns

Among all the injured riders, lower extremity injuries (62.8%) and upper extremity injuries (45.3%) were the most common injuries (see table 1). Head injuries occurred in 11.1% of the helmeted riders, which were severe in 9.0% of the cases. Regardless of injury severity, 11.4% of the riders who sustained head injuries suffer from cranial or intracranial injuries and 81.0% had a loss of consciousness.

Ten percent of the riders sustained chest injuries. Chest injuries tended to be severe in 11.1% of the cases. Abdominal injuries affected 5.4% of the riders, which were severe in 5.6% of the cases. A substantial proportion of riders sustained spinal injuries (8.5%). Among the riders sustaining a spinal injury, cervical spine was the most commonly injured region (70.0%). The lumbar spine and the thoracic spine were injured in 22.5% and 11.9% of the riders sustaining a spinal injury.

Among the 328 severely injured riders, half of the riders sustained severe injuries to the chest (see table 2). Among these riders, the lungs were the most frequent intrathoracic organ severely injured including lung contusions (33.5%) and lung lacerations (5.5%). Rib fractures occurred in 18.9% and 29.9% of the riders sustained hemothorax or pneumothorax. Head was the second leading body region severely affected. Among riders who suffered from severe head injuries, 54.4% suffer from cerebral hematoma (extradural, intracerebral or subdural), 15.6% from massive destruction or penetrating injuries, 23.8% from cerebral oedemas and 14.3% from intracranial hemorrhage.

A sizeable proportion of severely injured riders sustained severe abdominal or spinal injuries (13.7% and 9.8% respectively). Among the riders with severe abdominal injuries, spleen and liver were the most frequently abdominal organs severely injured. Among riders who suffer from severe spinal injuries, more than half sustained severe injuries in the thoracic region (53.1%) and severe cervical spine injuries occurred in 43.8% of the cases. Severe lower extremity injuries were pelvic deformity or displacement or amputations. Three riders sustained second/third degree burns covering over 30% of the body.

Table 2.
Nature of severe injuries among the 328 helmeted motorized two-wheelers severely injured, Rhone Trauma registry, 1996-2003

	AIS4+ N=328	
Injury sustained	No. of Riders	%
Head	**147**	**44.8**
Massive destruction/ penetrating injuries	23	15.6
Brain stem injury	9	6.1
Cerebellum injury	2	1.4
Cerebral contusion	1	0.7
Diffuse axoma injury	13	8.8
Extradural hematoma	13	8.8
Intracerebral hematoma	50	34.0
Subdural hematoma	17	11.6
Cerebral Tumefaction	1	0.7
Cerebral oedema	35	23.8
Intracranial hemorrhage	21	14.3
Fracture skull	17	11.6
Loss of consciousness	8	5.4
Face	**8**	**2.4**
Neck	**2**	**0.6**
Chest injuries	**164**	**50.0**
Crushing injury	17	10.4
Rupture of thoracic aorta	17	10.4
Myocardial injuries	1	0.6
Lung contusion	55	33.5
Lung lacerations	9	5.5
Hemo/pneumothorax	49	29.9
Rib fractures	31	18.9
Abdominal injuries	**45**	**13.7**
Bladder injuries	2	4.4
Intestinal injuries	1	2.2
Kidney laceration	6	13.3
Liver lacerations	13	28.9
Spleen injuries	25	55.6
Stomach lacerations	1	2.2
Spinal injuries	**32**	**9.8**
Cervical	14	43.8
Thoracic	17	53.1
Lumbar	1	3.1
Lower extremity injuries	**14**	**4.3**
Pelvic injuries	9	64.3
Upper leg/thigh	5	35.7
External injuries	**3**	**0.9**

Crash features

Successful record-linkage has led to 3727 helmeted victims identified as common to police and Registry sources with complete injury coding. Police reports were available for 25.3% of injury crashes which accounted for 90.1% of total fatalities and 76.2% of severely injured riders recorded in the Rhone Trauma Registry.

Of these linked victims, 250 (6.7%) riders suffer from at least one severe injury, among which 137 were fatally injured (3.7%). Motorcyclists accounted for 62.4% of the helmeted injured riders. Most of the injured riders were involved in crashes that occurred in urban area (81.6%) but 33.6% of severely injured riders were the result of crashes in rural area. The majority of the crashes happened on minor road or streets (58.3%), while 34.5% occurred on main road and secondary highway and 4.2% on motorways. However, crashes on main roads and secondary roads accounted for more than half of the severely injured riders (52.8%). Most crashes happened on a weekday (74.6%) and during daylight hours (88.9%). Among severely injured riders, 20% of the riders were involved in a crash at night. The most common injury crash type was collision with at least one another motorized vehicle, which accounted for 84.9% of the victims. Collision with car accounted for 71.7% of total victims. Collisions with pedestrians or bicyclists, another TWMV or trucks accounted respectively for 2.1%, 1.9% and 2.0% of the crashes.

Overall, single-vehicle crashes accounted for 13.0% of total victims, of which 7.8% with a fixed object (see table 3). In 20.6% of the cases, single vehicle crashes with a fixed object resulted in severe injuries. Among the group of severely injured riders, 24.0% of the riders had single vehicle crash with a fixed object. Head-on collisions between the TWMV and another motorized vehicle were the most frequent collision type, involving 37.1% of the riders. This kind of collision accounted for 26.8% of the severely injured riders.

Table 3.
Collision type according to vehicle type among the selected 3727 helmeted riders identified as common to police and Registry sources between 1996 and 2003

	Moped riders N=1402		Motorcycle riders N=2325		Total N=3727	
	No. of riders	%	No. of riders	%	No. of riders	%
Single vehicle - no object hit	44	3.1	150	6.5	194	5.2
Single vehicle – fixed object hit	79	5.6	212	9.1	291	7.8
Collision with pedestrians/bicyclists	39	2.8	41	1.8	80	2.1
Head-on collision	606	43.2	777	33.4	1383	37.1
Front TWMV to rear of a motorized vehicle	198	14.1	336	14.5	534	14.3
Front TWMV to side of a motorized vehicle	133	9.5	275	11.8	408	10.9
Rear-end collision	55	3.9	63	2.7	118	3.2
Broadside collision	66	4.7	64	2.8	130	3.5
Multiple/other	182	13.0	407	17.5	589	15.8

The type of collision was different between moped and motorcycle riders (p-value $\chi^2<0.05$). Head-on collisions accounted for 43.2% of the moped crashes and 33.4% of the motorcycle crashes. The percentage of motorcycle riders involved in single vehicle crashes was higher than the one of moped riders. Among motorcycle riders, 9.1% were the result of single vehicle crashes with a fixed object. In contrast, this crash type accounted for 5.6% of injured moped riders.

When we looked at the distribution of the injured body regions in relation to collision type, it appeared that, for a given collision type, the proportion of riders injured in each body region was approximately the same as the collision type's share of total accidents (see table 4). Therefore, it was difficult from these results to single out which particular body region is injured in a specific collision type. On the whole, more than 30% of injuries of each body region are the result of head-on collisions.

Overall, there were significant differences seen in the proportion of riders sustaining head, facial, chest, abdominal, spinal, upper and lower extremity injuries according to collision type (p-value $\chi^2<0.05$) (see table 4). A high proportion of head, facial, chest, abdominal and spinal injuries occurred in single vehicle crashes with a fixed object hit. Collision with pedestrians or bicyclists accounted for 4.0% of facial injuries whereas this crash type occurred in 2.1% of the cases. Collision where the front of the TWMV struck the side of another motorized vehicle accounted for a high percentage of upper extremity injuries (13.2%). Most of lower extremity injuries (40.9%) were observed in head-on collision.

When we looked at the distribution of the injured body regions in relation to vehicle type, it appeared that the proportion of chest, abdominal, spinal and upper extremity injuries was statistically greater among motorcycle riders than among moped riders (p-value $\chi^2<0.05$) (see table 5). On the contrary, the percentage of facial injuries was higher among moped riders than motorcycle riders. There was no difference seen in the proportion of riders sustaining head injuries according to vehicle type. When we estimated the risk of being injured in each body region, logistic regression results

Table 4.
Body region injured in relation to collision type among the selected 3727 helmeted riders identified as common to police and Registry sources. Percentages were defined as the number of victims of a given collision type suffering from injury in a given body region among the total number of victims affected in the given body region.

Collision type	% of total N=3727	Head N=721	Face N=371	Neck N=176	Chest N=578	Abdomen N=358	Spine N=447	Upper extremity N=1674	Lower extremity N=2602	External N=518
Single vehicle - no object hit	5.2	5.8	3.8	5.7	5.4	4.5	5.6	6.0	4.3	6.4
Single vehicle - fixed object hit	7.8	13.2	11.1	6.3	13.8	12.8	12.8	8.4	6.9	7.9
Collision with pedestrians/bicyclists	2.1	2.1	4.6	4.0	1.6	2.8	2.0	2.3	1.8	2.3
Head-on collision	37.1	32.5	32.3	33.5	33.6	35.8	30.2	34.3	40.9	36.7
Front TWMV to rear of a motorized vehicle	14.3	11.1	11.3	17.0	13.8	14.2	13.9	15.0	13.1	15.8
Front TWMV to side of a motorized vehicle	10.9	11.5	13.2	14.8	11.2	10.3	11.9	13.4	9.9	10.8
Rear-end collision	3.2	3.1	3.0	2.8	1.6	3.6	3.8	2.2	3.2	3.1
Broadside collision	3.5	4.2	3.5	2.3	1.9	1.4	3.4	2.8	3.9	2.9
Multiple/other	15.8	16.6	17.3	13.6	17.1	14.5	16.6	15.7	16.1	14.1

Table 5.
Body region injured in relation to vehicle type among the selected 3727 helmeted riders identified as common to police and Registry sources. Percentages were defined as the number of victims suffering from injury in a given body region among the total number of victims of each vehicle type.

Collision type	% of total N=3727	Head N=721	Face N=371	Neck N=176	Chest N=578	Abdomen N=358	Spine N=447	Upper extremity N=1674	Lower extremity N=2602	External N=518
Moped riders	37.6	19.0	13.3	4.8	10.5	7.7	9.7	41.4	70.0	14.6
Motorcycle riders	62.4	19.6	8.0	4.7	18.5	10.8	13.4	47.1	69.7	13.5

showed that the risks of head, facial, chest and abdominal injury were significantly greater for riders involved in single vehicle crashes with a fixed object hit than for riders involved in single vehicle crashes with no object hit (see table 6). Riders involved in collisions where the front of the TWMV struck the rear of another motorized vehicle were less likely to sustain a head injury. Riders involved in rear-end collisions had a significantly lower risk of chest injury. The risk of facial injuries was significantly higher for riders involved in a collision against a pedestrian or a bicyclist. Riders involved in collisions where the front of the TWMV struck the side of another motorized vehicle were more likely to sustain an upper extremity injury. The risk of lower extremity injury for riders involved in head-on, rear-end, broadside and multiple collisions were significantly greater than the risk for riders involved in single vehicle crashes with no object hit (see table 6). The highest risk was observed for broadside collision. Logistic regression results showed that the risks of chest (OR=1.94 95%CI=1.59, 2.37), abdominal (OR=1.44 95%CI=1.14, 1.83), spinal (OR=1.44 95%CI=1.16, 1.78) and upper extremity injury (OR=1.26 95%CI=1.10, 1.44) were significantly greater for motorcycle riders than moped riders. There was no significant difference in the risk of head, lower extremity and external injury according to vehicle type. The risk of facial injury was lower for motorcycle riders than moped riders (OR=0.57 95%CI=0.46, 0.70).

Table 6.
Risk of being injured in each body region associated to collision type, crude odds ratios and the corresponding 95% confidence intervals

	Head	Face	Chest	Abdomen
Single vehicle - no object hit	1.00	1.00	1.00	1.00
Single vehicle - fixed object hit	1.75(1.15,2.67)	2.11(1.12,3.98)	1.99(1.26,3.17)	2.09(1.15,3.81)
Collision with pedestrians/bicyclists	0.84(0.43,1.61)	3.47(1.62,7.45)	0.67(0.30,1.47)	1.59(0.69,3.67)
Head-on collision	0.74(0.51,1.07)	1.22(0.69,2.17)	0.86(0.57,1.30)	1.14(0.66,1.95)
Front TWMV to rear of a motorized vehicle	0.64(0.42,0.97)	1.10(0.59,2.06)	0.93(0.59,1.46)	1.18(0.65,2.11)
Front TWMV to side of a motorized vehicle	0.92(0.61,1.40)	1.76(0.94,3.26)	1.00(0.63,1.59)	1.11(0.60,2.05)
Rear-end collision	0.83(0.47,1.48)	1.32(0.58,3.02)	0.43(0.20,0.95)	1.38(0.64,2.98)
Broadside collision	1.09(0.64,1.85)	1.43(0.65,3.15)	0.49(0.24,1.01)	0.45(0.16,1.25)
Multiple/other	0.93(0.63,1.38)	1.57(0.86,2.86)	1.06(0.68,1.65)	1.08(0.60,1.93)

	Spine	Upper Extremity	Lower Extremity
Single vehicle - no object hit	1.00	1.00	1.00
Single vehicle - fixed object hit	1.65(0.99,2.74)	0.87(0.61,1.25)	1.17(0.81,1.69)
Collision with pedestrians/bicyclists	0.86(0.38,1.93)	0.89(0.53,1.51)	1.04(0.62,1.77)
Head-on collision	0.73(0.46,1.15)	0.67(0.49,0.90)	2.43(1.78,3.32)
Front TWMV to rear of a motorized vehicle	0.89(0.54,1.46)	0.83(0.60,1.16)	1.29(0.93,1.81)
Front TWMV to side of a motorized vehicle	1.01(0.61,1.68)	1.14(0.81,1.61)	1.26(0.89,1.78)
Rear-end collision	1.14(0.59,2.21)	0.41(0.26,0.67)	1.67(1.03,2.71)
Broadside collision	0.88 (0.45, 1.75)	0.53(0.34,0.84)	2.67(1.61,4.42)
Multiple/other	0.97 (0.60, 1.58)	0.76(0.55,1.05)	1.79(1.28,2.50)

DISCUSSION

This study was based on an eight-year period and was conducted on a large number of injured riders. The first part of the analysis based on the medical records makes it possible to quantify injuries among 14749 helmeted motorized two-wheelers. It provided information on the body regions frequently and severely injured. Whatever the injury severity extremity injuries were the most common injuries. Head and chest injuries affected ten percent of helmeted riders.

When we looked at severe injuries, we identified chest as the most affected body region for severely injured helmeted riders, as it was shown elsewhere (Ankarath et al. 2002; Kraus et al. 2002). Despite helmet use, a high percentage of injured riders suffer from severe head injuries, which is in agreement with previous findings (Ankarath et al. 2002; Kraus et al. 2002). A substantial proportion of severely injured riders sustained life-threatening injuries to the abdomen and to the spine. Spinal injuries are known to lead to a significant functional impairment, long-term disability and morbidity (Daffner et al. 1987; Gadegbeku et al. 2006; Robertson et al. 2002b; Shrosbree 1978). Previous studies identified the thoracic spine as the most commonly injured body region in motorized two-wheelers (Robertson et al. 2002a; Robertson et al. 2002b). This location is though to occur as a result of hyper flexion of the spine on impact with objects (Drysdale et al. 1975). In our dataset, cervical spinal injury predominated but more than half of the severe spinal injuries sustained by those severely injured were in the thoracic region. A substantial proportion of severe spinal injuries were also to cervical spine as reported in other studies (Ankarath et al. 2002).

We aimed to provide information on the injured body region in relation to vehicle and crash type. This part of the study was conducted on the injured riders identified as common to the Registry and the police file and is not a representative sample of all injured riders. As the degree of being reported by the police varies depending on injury severity (Amoros et al. 2006), crashes resulting in severely injured riders have a higher probability of being reported by the Police than crashes resulting in slightly injured riders. The selected sample of riders involved in crashes identified by both sources represents more seriously injured riders than the overall population of injured riders. The ideal study population for this investigation would include all riders, regardless of injury severity. Therefore, results should be taken with caution.

It appeared that, for a given collision type, the proportion of injured riders in each body region was approximately the same as the collision type's share of total accidents. We did not single out which particular body region is injured in a specific collision type. Whatever the body region affected, head-on collisions, which is the most frequent collision type, accounted for a third of injured riders. As it has been shown elsewhere (Chang and Yeh 2006; Lin et al. 2003; Lin et al. 2001), our results showed that single-vehicle crashes with a fixed object accounted for a sizeable proportion of injured riders in each body region. This was particularly the case of injuries to the head, chest abdomen and spine, which tended to be severe.

Among single vehicle crashes, there were some differences between crashes with a fixed object and crashes with no object. The risks of head, facial, chest and abdominal injury were significantly greater for riders involved in single vehicle crashes with a fixed object hit than for riders involved in single vehicle crashes with no object hit. Head-on crashes with a fixed object could explain these results.

Compared to helmeted riders involved in single vehicle crashes with no object hit, the risk of facial injury was significantly higher for riders involved in a collision with a pedestrian or a bicyclist. Riders involved in collisions between the front of the TWMV and the side of another vehicle were more likely to sustain upper extremity injuries. The risk of lower extremity injury for riders involved in head-on, rear-end, broadside and multiple collisions were significantly greater than the risk for riders involved in single vehicle crashes with no object hit. The highest risk was observed for broadside collisions as it has been shown elsewhere (Peek et al. 1994). Riders involved in collisions where a motorized vehicle hit the rear of the TWMV had a significantly lower risk of chest injury.

The risk of chest, abdominal, spinal and upper extremity injury were significantly higher for motorcyclists than moped riders. The differences between moped and motorcycle crashes (speed, energy involvement, crash location) explain these results. In our study, we didn't take into account crash dynamics because it wasn't possible to estimate relevant measures such as Delta V or Equivalent Energy Speed. A published study focused on the injury pattern of moped and motorcycle crashes to see if a difference exists between the two (Matzsch and Karlsson 1986). Moped crashes were similar to motorcycle crashes in their injury patterns. They differ in degree of severity, due to the lesser speed and energy involved in moped accidents (Matzsch and Karlsson 1986).

Contrary to motorcycle riders, moped riders had significantly more risk of facial injury. We could suppose that the choice of helmet type could have an influence on the incidence of facial injury: the increase in facial injury risk among mopeds riders could be explained by the lower proportion of moped riders using a full-face helmet compared to motorcyclists.

Our results give a good insight into injuries sustained by riders in motorized two-wheeler crashes. Despite helmet use, a sizeable proportion of helmeted riders suffer head injuries, even severe ones and in many cases, there remains a high degree of impairment in the long-term outcome (Gadegbeku et al. 2006). First, we should encourage the future studies to get the information on helmet type in order to specify the level of protection of each helmet type. We should also support research on better helmet design (Richter et al. 2001). Second, our results indicated that the attention given to head protection shouldn't ignore the vulnerability of other parts of the body. In fact, prevention strategies should also provide better protection for vital organs in the chest, abdomen, and spine, as it has been emphasized in previous studies (Ankarath et al. 2002; Kraus et al. 2002). The use of equipment such as "back protectors" or "airbag" has been suggested to protect against chest and spinal injuries (Robertson et al. 2002a; Robertson et al. 2002b). This equipment may prevent injuries but at present the effect of such clothing on injury reduction has not been evaluated. Future studies should get the information on the use of such equipment by the riders and might measure the explicit protective effect of such equipment. The use of protective clothing may prevent some lower extremity injuries in motorcycle crashes like soft-tissue injuries (Kraus et al. 2002; Peek et al. 1994).

The use of safety devices is a necessary but not a sufficient condition for preventing motorized two-wheeler injuries. Despite the use of safety devices, motorized two-wheeler crashes could result in injuries that cause a permanent disability and impairment.

As factors such as being on rural roads, collisions with a heavier object, darkness, might increase the severity of injuries (Chang and Yeh 2006; Lin et al. 2003), the improvement of road infrastructure is needed to reduce the occurrence of motorized two-wheeler crashes. Public awareness campaigns on the vulnerability of motorized two-wheelers and their crash risks could contribute to a reduction in road crashes. Finally, as driver behaviour or human factors contribute to crash severity especially in single vehicle crashes, policies should be developed to improve driver experience (familiarity with a specific vehicle, licensing process…) as proposed by several studies(Chang and Yeh 2006; Harrison 1997; Mullin et al. 2000).

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REFERENCES

AAAM (Association for the Advancement of Automotive Medicine). The abbreviated injury scale (1990 revision). Des Plaines, IL, USA, 1990.

ONISR. La sécurité routière en France. Bilan de l'année 2004. La Documentation Française, Paris, France, 2005.

Amoros, E., Martin, J.L. and Laumon, B., 2006. Under-reporting of road crash casualties in France. *Accid Anal Prev* 38 (4), 627-635.

Ankarath, S., Giannoudis, P.V., Barlow, I., Bellamy, M.C., Matthews, S.J. and Smith, R.M., 2002. Injury patterns associated with mortality following motorcycle crashes. *Injury* 33 (6), 473-477.

Chang, H.L. and Yeh, T.H., 2006. Risk factors to driver fatalities in single-vehicle crashes: comparisons between non-motorcycle drivers and motorcyclists. *Journal of transportation engineering* 132 (3), 227-236.

Daffner, R.H., Deeb, Z.L. and Rothfus, W.E., 1987. Thoracic fractures and dislocations in motorcyclists. *Skeletal Radiol* 16 (4), 280-284.

Drysdale, W.F., Kraus, J.F., Franti, C.E. and Riggins, R.S., 1975. Injury patterns in motorcycle collisions. *J Trauma* 15 (2), 99-115.

Gadegbeku, B., Ndiaye, A. and Chiron, M., 2006. Séquelles majeures en traumatologie routière, registre du Rhône, 1996-2003. *Bulletin épidémiologique hebdomadaire* 36, 267-272.

Harrison, W.A., 1997. An exploratory investigation of the crash involvement of disqualified drivers and motorcyclists. *Journal of safety research* 28, 213-219.

Kraus, J.F., Peek-Asa, C. and Cryer, H.G., 2002. Incidence, severity, and patterns of intrathoracic and intra-abdominal injuries in motorcycle crashes. *J Trauma* 52 (3), 548-553.

Laumon, B. and Martin, J.L., 2002. Analysis of biaises in epidemiological knowledge of road accidents in France. *Rev. Epidemiol. Sante. Publ.* 50 (3), 277-285.

Laumon, B., Martin, J.L., Collet, P., Chiron, M., Verney, M.P., Ndiaye, A. and Vergnes, I., 1997. A french road accident trauma registry: first results. In: *41st Annual Proceedings of the Association for the Advancement of Automotive Medicine*, Orlando, Florida, 127-137

Lin, M.R., Chang, S.H., Huang, W., Hwang, H.F. and Pai, L., 2003. Factors associated with severity of motorcycle injuries among young adult riders. *Ann Emerg Med* 41 (6), 783-791.

Lin, M.R., Hwang, H.F. and Kuo, N.W., 2001. Crash severity, injury patterns, and helmet use in adolescent motorcycle riders. *J Trauma* 50 (1), 24-30.

Matzsch, T. and Karlsson, B., 1986. Moped and motorcycle accidents--similarities and discrepancies. *J Trauma* 26 (6), 538-543.

Mullin, B., Jackson, R., Langley, J. and Norton, R., 2000. Increasing age and experience: are both protective against motorcycle injury? A case-control study. *Inj Prev* 6 (1), 32-35.

Peek-Asa, C. and Kraus, J.F., 1996. Alcohol use, driver, and crash characteristics among injured motorcycle drivers. *J Trauma* 41 (6), 989-993.

Peek, C., Braver, E.R., Shen, H. and Kraus, J.F., 1994. Lower extremity injuries from motorcycle crashes: a common cause of preventable injury. *J Trauma* 37 (3), 358-364.

Quddus, M.A., Noland, R.B. and Chin, H.C., 2002. An analysis of motorcycle injury and vehicle damage severity using ordered probit models. *J Safety Res* 33 (4), 445-462.

Richter, M., Otte, D., Lehmann, U., Chinn, B., Schuller, E., Doyle, D., Sturrock, K. and Krettek, C., 2001. Head injury mechanisms in helmet-protected motorcyclists: prospective multicenter study. *J Trauma* 51 (5), 949-958.

Robertson, A., Branfoot, T., Barlow, I.F. and Giannoudis, P.V., 2002a. Spinal injury patterns resulting from car and motorcycle accidents. *Spine* 27 (24), 2825-2830.

Robertson, A., Giannoudis, P.V., Branfoot, T., Barlow, I., Matthews, S.J. and Smith, R.M., 2002b. Spinal injuries in motorcycle crashes: patterns and outcomes. *J Trauma* 53 (1), 5-8.

Rowland, J., Rivara, F., Salzberg, P., Soderberg, R., Maier, R. and Koepsell, T., 1996. Motorcycle helmet use and injury outcome and hospitalization costs from crashes in Washington State. *Am J Public Health* 86 (1), 41-45.

Sarkar, S., Peek, C. and Kraus, J.F., 1995. Fatal injuries in motorcycle riders according to helmet use. *J Trauma* 38 (2), 242-245.

Shrosbree, R.D., 1978. Spinal cord injuries as a result of motorcycle accidents. *Paraplegia* 16 (1), 102-112.

Zambon, F. and Hasselberg, M., 2006. Factors affecting the severity of injuries among young motorcyclists--a Swedish nationwide cohort study. *Traffic Inj Prev* 7 (2), 143-149.