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A review of risk factors and patterns of motorcycle injuries

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ABSTRACT

Per vehicle mile traveled, motorcycle riders have a 34-fold higher risk of death in a crash than people driving other types of motor vehicles. While lower-extremity injuries most commonly occur in all motorcycle crashes, head injuries are most frequent in fatal crashes. Helmets and helmet use laws have been shown to be effective in reducing head injuries and deaths from motorcycle crashes. Alcohol is the major contributing factor to fatal crashes. Enforcement of legal limits on the blood alcohol concentration is effective in reducing motorcycle deaths, while some alcohol-related interventions such as a minimal legal drinking age, increased alcohol excise taxes, and responsible beverage service specifically for motorcycle riders have not been examined. Other modifiable protective or risk factors comprise inexperience and driver training, conspicuity and daytime headlight laws, motorcycle licensure and ownership, riding speed, and risk-taking behaviors. Features of motorcycle use and potentially effective prevention programs for motorcycle crash injuries in developing countries are discussed. Finally, recommendations for future motorcycle-injury research are made.

1. Introduction

Per vehicle mile traveled, motorcycle riders have a 34-fold higher risk of death in a crash than people driving other types of motor vehicles, and they also are eight times more likely to be injured (NHTSA, 2007). The higher risks of injury and death for motorcycle riders have been reported to be associated with a younger age, lack of protection, and poor visibility of the rider and vehicle to other road users (Hurt et al., 1981). However, modifiable factors such as helmet wearing, alcohol and other drug use, inexperience and driver training, conspicuity of the motorcycle and rider, licensure and ownership, riding speed, and risk-taking behaviors have recently been identified as contributing to this risk. This review examines the patterns and protective/risk factors of motorcycle injuries as well as features of motorcycle use and potentially effective prevention programs for mitigating motorcycle crash injuries in developing countries. In this review, moped injuries are not addressed separately from motorcycle injuries; nevertheless, findings of moped injuries concerning issues examined of this study are similar to those of motorcycle injuries (Aare and von Holst, 2003; Boström et al., 2002; Mätzsch and Karlsson, 1986; Salatka et al., 1990; van Camp et al., 1998).

2. Methods

A systematic, computerized literature search of Medline was conducted first. The medical subject headings, *motorcycles and wound and injuries*, identified approximately 178 candidates. After excluding reviews and non-English papers, 150 papers published from January 1980 to August 2008 were found. A number of technical reports of the US National Highway Traffic Safety Administration and articles from references of the above papers, which could not be identified from Medline, were also added to this review. In total, 220 articles were included.

3. Injury patterns

3.1. General patterns

A motorcycle rider often sustains multiple injuries in a crash (Bachulis et al., 1988; Rogers et al., 1991). Head injuries are most frequent in fatal motorcycle crashes, contributing to about one-half of all motorcycle deaths (Kraus, 1989). Chest and abdominal injuries (e.g., lung contusion and liver laceration) are the second most common cause of fatal motorcycle crashes comprising from 7% to 25% of motorcycle deaths (Ankarath et al., 2002; Mätzsch and Karlsson, 1986; Sarkar et al., 1995; Wick et al., 1998; Wyatt et al., 1999). Cervical spinal injuries are more likely to occur in fatal crashes than those to other spinal regions (Ankarath et al., 2002).

The lower extremity is the most common site of an injury in all motorcycle crashes (Bachulis et al., 1988; Braddock et al., 1992;

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Kraus et al., 1994a; Muelleman et al., 1992; Peek et al., 1994; Wladis et al., 2002). The thoracic spine is the most commonly injured spinal region in motorcycle crashes (Ankarath et al., 2002; Kupferschmid et al., 1989; Robertson et al., 2002), while riders with severe injury to the trunk are likely to have severe injuries in the same or other anatomic regions (Kraus et al., 2002). Facial injuries are diagnosed in one-fourth of all injured riders, and they are associated with a risk of traumatic brain injuries (Kraus et al., 2003).

3.2. Head injuries

Head injuries are the leading cause of death in motorcycle crashes (Ankarath et al., 2002; Kraus, 1989), particularly in single-motorcycle crashes and head-on collisions (Peek-Asa and Kraus, 1996b). For instance, in the US, 53% of motorcycle deaths from 1979 to 1986 were a result of head injuries, and 69% of head-injury deaths among motorcycle riders were white males aged 15–34 years (Sosin et al., 1990). Among motorcycle riders admitted to the hospital, the most common head injuries are concussions, followed by brain contusions or hemorrhage, facial fractures, and skull fractures (Braddock et al., 1992; Kraus and Peek, 1995a; Kraus et al., 2003). Brain injuries are frequently caused by deceleration forces, particularly with rotational kinetics (Richter et al., 2001). As the fixed and non-fixed parts of the body such as the skull and brain move differentially, deceleration injuries such as multifocal vascular injury, concussive brain injury, or diffuse axonal injury may occur (Feliciano and Wall, 1991; McSwain, 1987; Viano et al., 1989). Brain injuries such as skull base fractures and intracranial hematomas are more frequently observed in patients with upper cervical injury than in those with mid and lower cervical injury (Iida et al., 1999). It should be noted that head injuries are still the leading cause of death in helmeted riders (Aare and von Holst, 2003; Wyatt et al., 1999).

3.3. Lower-extremity injuries

Lower-extremity injuries are most common in non-fatal motorcycle crashes, affecting about 30–70% of injured riders (Bachulis et al., 1988; Craig et al., 1983; Peek et al., 1994; Peek-Asa and Kraus, 1996b; Ross, 1983; Shankar et al., 1992). In lower-extremity injuries, fractures are most frequent and have the most severe outcomes (Peek et al., 1994), in terms of permanent disability, economic costs, and the return to work (Clarke and Langley, 1995; MacKenzie, 1986). Of these fractures, the tibia is the most common site, followed by the femur, foot, and patella (Peek et al., 1994). Femoral fractures are the most common long bone injury in motorcycle deaths (Ankarath et al., 2002).

3.4. Protection devices and injury patterns

Helmets reduce the incidence and severity of head injuries in motorcycle riders (the effectiveness of helmets in reducing head injuries is discussed in a later section). Compared with helmeted riders, nonhelmeted riders are at greater risk for severe head injuries of all types (Bachulis et al., 1988; Kraus and Peek, 1995a; Lin et al., 2004a; Sarkar et al., 1995), as well as facial injuries and high-severity facial fractures (Sauter et al., 2005; Gopalakirshna et al., 1998). No differences between helmeted and nonhelmeted riders were detected in those with cervical and thoracic fractures and spinal cord injuries (Goslar et al., 2008; Lin et al., 2004a; Moskal et al., 2008; O'Conner, 2005; Orsay et al., 1994; Sauter et al., 2005; van Camp et al., 1998). While protective clothes seem to reduce the risk of soft tissue injuries among motorcycle riders, no advantages in the occurrence of fractures were found (Otte et al., 2002). Heavy boots and work shoes are effective in protecting against ankle and foot injuries (Hurt and Wagar, 1981), and crash bars on motorcycles protect riders' lower legs when the impact is from the side (Ross, 1983). Little empirical evidence on the effectiveness of other protection devices such as motorcycle airbag jackets and back and leg protectors is available.

4. Modifiable factors

Many factors are associated with the risks of the incidence and/or severity of motorcycle injuries, even though determinants of the injury incidence were rarely differentiated from those of injury severity in previous studies of motorcycle injuries. As shown in Fig. 1, risk factors for motorcycle crash injuries are classified according to the Haddon matrix. The Haddon matrix is composed of three time phases of a crash event (pre-crash, crash, and post-crash), along with the three areas influencing each of the crash phases (human, vehicle, and environment). Some risk factors such as age groups (young age or recently reported those aged ≥40 years in the US) (Baker et al., 1992; NHTSA, 2006), male gender, a low socioeconomic status (Zambon and Hasselberg, 2006a), nighttime (Nakahara et al., 2005), and summer period (Lin et al., 2003a; Zambon and Hasselberg, 2006b) cannot be directly modified to prevent the occurrence of motorcycle injuries and reduce their

	Human	Vehicle	Environment
Pre-event	Young age, male, low socioeconomic status, inexperience, crash history, no driving license, traffic violation history, high risk-taking behavior, alcohol and other drug use, motorcycle ownership, excessive and slow speeds, and rider's inconspicuity (e.g., without high-visibility clothing)	Motorcycle inconspicuity (e.g., without daytime headlight use)	Nighttime, poor light condition, poor road condition, summer period, rural area
Event	Large amount of riding distance and time, excessive speed, no safety devices (e.g., helmet wearing, leg protector, or airbag jacket)	Motorcycle make	Collision with a heavy object (e.g., moving car)
Post-event	Elderly person, pre-existing medical condition		Slow emergency response, poor rehabilitation programs

Fig. 1. Risk factors for motorcycle crash injuries using Haddon's matrix.

severity; in addition, their effects can often be accounted for by the amount of riding exposure (Lourens et al., 1999) as well as modifiable factors such as helmet wearing, alcohol and other drug use, inexperience and driver training, conspicuity of the motorcycle and rider, licensure and ownership, riding speed, and risk-taking behaviors. These modifiable factors have more relevance for developing and designing prevention programs.

4.1. Motorcycle helmets

4.1.1. Helmet effectiveness

Helmets, usually made of a rigid fiberglass or plastic shell, a foam liner, and a chinstrap, have been the principal countermeasure for preventing or reducing head injuries from motorcycle crashes. Based on police reports, helmets reduced the risk of motorcycle deaths by 29% during 1972–1987 (Evans and Frick, 1988; Wilson, 1989), and their effectiveness increased to 37% during 1993–2002 possibly due to improvements in helmet design and materials (Deutermann, 2004). After adjusting for age and crash characteristics, nonhelmeted riders were 2.4-times more likely than those wearing a helmet to sustain brain injuries or skull fractures (Gabella et al., 1995). After adjusting for collision type, posted speed limits, and environmental factors, nonhelmeted riders had a 3.1-fold increased risk of head injuries or death compared with helmeted riders (Rowland et al., 1996). Moreover, after stratification by crash severity measured by the Injury Severity Score (ISS) for other than head injuries or repair costs of motorcycle damage, the protective effect of helmets on head injuries remained significant (Rutledge and Stutts, 1993; Lin et al., 2001).

Table 1 summarizes results of helmet studies in the US from different sources of emergency room records, hospital discharge data, police reports, and trauma registries. The outcomes included are percentages of head injuries, deaths, and hospitalization as well as the average length of hospital stay and average hospital charge per patient for helmeted and nonhelmeted riders. As a whole, the results consistently indicate that nonhelmeted riders are more likely to have head injuries, die, require longer hospitalization, and have higher medical costs compared to helmeted riders.

While three types of helmets (full-face, full-coverage, and half-coverage) are effective in reducing head injuries (Hurt et al., 1981; Tsai et al., 1995), differences in the effectiveness among various types of helmets have not been well examined. In addition, detachment of helmets during motorcycle crashes is not uncommon (Richter et al., 2001; Richards, 1984), and head injuries seem to occur more frequently and are more severe for riders who wear a nonstandard helmet than those who wear a standard helmet (Peek-Asa et al., 1999). These findings reflect the importance of helmet fixation for maximal protection against head injuries during motorcycle crashes; nevertheless, the use of nonstandard helmets in terms of preventing head injuries or increasing potential side effects has not been examined.

There are possible side effects from helmet use. First, there has been speculation as to whether helmet use increases the risk of cervical spinal (cord) injuries in a crash, because injuries to the neck and base of the skull are occasionally found in helmeted riders (Cooter et al., 1988; Goldstein, 1986; Konrad et al., 1996; Krantz, 1985; Simpson et al., 1989). However, those findings were from studies with small sample sizes, lack of comparison group(s), or small numbers of fatal injuries, or they failed to adjust for confounders such as age and alcohol consumption (van Camp et al., 1998). Conversely, many more studies have found no evidence for such an association (Bachulis et al., 1988; Carr et al., 1981; Goslar et al., 2008; Kraus et al., 1994b; Lin et al., 2004a; McSwain and Belles, 1990; Muelleman et al., 1992; Murdock and Waxman, 1991; O'Conner, 2005; Orsay et al., 1994; Sauter et al., 2005; van Camp et al., 1998). Second, the influence of a helmet on the rider's vision and hearing has been raised. Although helmets have a small effect on the lateral vision of motorcycle riders, studies have shown that riders compensate for this restriction by increasing head rotation when making turns, and thus hearing and visual acuity are not overly restricted by helmet use (McKnight and McKnight, 1995). The third question infrequently raised is whether helmets increase the risk of a crash due to the added mass on the head or the increased size of the helmeted head (Bishop et al., 1983; Houston and Sears, 1981). In a prospective cohort study, no increased risk of motorcycle crashes occurring to helmeted riders was found, even after adjusting for riding distance, riding time, risk-taking level, and many other human, vehicle, and environmental factors (Lin et al., 2003a).

4.1.2. Helmet use laws

Significant reductions in head injuries, the likelihood of death, and medical costs due to helmet use provide the basis for mandatory helmet use laws (Mock et al., 1995). By increasing helmet usage among all motorcycle riders (comprehensive helmet laws) or only young riders (partial helmet laws), helmet use laws are enacted to reduce or prevent head injuries and deaths. For example, enactment of laws increased motorcycle helmet use from 20% to >95% in Italy and Spain (Guillen et al., 1995; Servadei et al., 2003). However, implementation of policies based only on these scientific data has been difficult (Chiu et al., 2000; Weisbuch, 1987). Policy waves in state legislative activity of helmet use laws have been stimulated by federal legislation in the US. For example, in 1991, the US Congress created economic incentives for states to enact helmet use laws, but by 1995 had reversed its position and lifted federal sanctions against states without such laws, which paved the way for state governments to repeal the laws (Jones and Bayer, 2007). As summarized in Table 2 , the reenactment and repeal of helmet use laws in the US provide opportunities to examine the effects of these laws on motorcycle injuries, particularly head injuries and fatalities. In general, comprehensive helmet laws are significantly associated with an increase in helmet usage followed by declines in the total number of motorcycle deaths, head injuries, days of hospitalization, and medical costs.

Helmet laws also had the least cost per year of lives saved among all major traffic safety programs (Graham, 1993) and their benefit–cost ratios range from 2.3 to 5.07 (Hyder et al., 2007).

4.2. Alcohol and other drug use

While alcohol is the drug associated most frequently with all kinds of motor vehicle crashes (Chang and Astrachan, 1988; Villaveces et al., 2003; Waller et al., 1986; Williams, 2006), motorcycle drivers are more likely to have consumed alcohol than are other motor-vehicle drivers in fatal and non-fatal crashes (McLellan et al., 1993; Rivera et al., 1989; NHTSA, 2007). For example, 49% of motorcycle crash deaths in US police reports were attributable to alcohol use, in contrast to 26% of other motor-vehicle crash deaths (Villaveces et al., 2003). Compared with multiple-vehicle crashes, single-vehicle crashes account for a greater proportion of motorcycle deaths with a blood alcohol concentration (BAC) of ≧0.1 g/dl, particularly at night (Baker et al., 1992; Kasantikul et al., 2005; Preusser et al., 1995; Williams, 1985). While the risk of being involved in a fatal crash increases with increased BAC levels for all age groups (Mayhew et al., 1986), more than 60% of motorcycle deaths among young riders aged 15–29 years involved alcohol (Holubowycz et al., 1994; Holubowycz and McLean, 1995; Larsen and Hardt-Madsen, 1987). However, in the US, the peak rate of deaths among motorcycle riders involving alcohol has recently shifted from this group to those aged 40–44 years (Paulozzi and Patel, 2004; NHTSA, 2006).

Drinking motorcycle riders involved in a crash are more likely than nondrinking riders to have lost control of their vehicle, and

Table 1

Comparison of head injury, death, required hospitalization, average length of hospital stay, average hospital charge, and number of subjects by helmet status in the US.

First author, year	Data description	Helmeted						Nonhelmeted					
		Head injury (%)	Death (%)	Hospitalization (%)	Hospital LOS[a] (day)	Hospital charge ($)	N	Head injury (%)	Death (%)	Hospitalization (%)	Hospital LOS* (day)	Hospital charge ($)	N
Carr, 1981	Emergency room data from 7 Minneapolis-St. Paul area hospitals during a 6-month period in 1979	40.6	1	–	–	–	96	65	4.5	–	–	–	177
Luna, 1981	Emergency room data from a trauma center from 7/1978 to 11/1979	11	4	47	–	–	101	31	7	59	–	–	162
McSwain, 1984	Emergency room data in Kansas from 1977 to 1978	–	–	25.5	11.2	2305	–	–	–	41.6	14.8	6666	–
Bried, 1987	Paramedic reports, emergency room data, and inpatient records in a hospital in Arizona, from 7/1984 to 6/1985	16.7	–	100	–	13,368	18	50.9	–	100	–	17,120	53
Lloyd, 1987	Hospital records linked with data in the Texas Department of Public Safety from 2/1985 to 1/1986	–	–	100	10.3	7211	30	–	–	100	22.2	17,155	58
May, 1989	Registry in a trauma center in California during 1987 to 1988	9	1	78	4.2	6637	60	37	4	80	8.2	12,108	153
Kelly, 1991	Emergency room data of 8 medical centers representing urban, suburban, and rural areas in Illinois from 4/1988 to 10/1988	12.1	1.7	32.8	–	5852	58	32.6	7.3	39.9	–	7208	340
Murdock, 1991	Trauma registry on a medical center in California during a 45-month period	20.7	5	100	–	16,154	111	48.3	6	100	–	29,905	236
Offner, 1992	Hospital records in a medical center from 1/1985 to 1/1990	38.4	9.1	100	10.8	13,070	164	65.9	7.7	100	15.5	17,173	264
Shankar, 1992	Emergency room data in Maryland from 7/1987 to 6/1988	20.6	–	33.0	–	10,442	330	39.9	–	44.4	–	30,365	391
Rutledge, 1993	Trauma registry in North Carolina from 10/1987 to 1/1991	28	5	100	12	16,000	314	53	7	100	12	17,000	146
Wagle, 1993	Patients admitted to a hospital in Connecticut over a 5-year period	–	4	100	16.2	18,762	22	–	16	100	25.4	30,036	58
Karlson, 1994	Police reports linked to hospital discharge records in Wisconsin in 1991	3.4	1.9	–	–	11,879[b]	994	7.6	2.7	–	–	18,940[b]	2,015
Orsay, 1995	Trauma registry from the Department of Public Health in Illinois from 7/1991 to 12/1992	30.2	–	100	–	15,528	222	51	–	100	–	43,214	689
Rowland, 1996	Police reports linked to hospitalization and death records in Washington in 1989	2.8	2.9	18	9.9	12,689	945	8.4	4.7	22	12.6	16,460	957
Brandt, 2002	Registry of a trauma center in Michigan from 7/1996 to 10/2000	–	4.0	100	11.4	31,158	174	–	4.8	100	13.5	37,317	42
Hundley, 2004	The National Trauma Data Bank from 130 hospitals in 25 states from 5/1994 to 4/2002	–	4.3	100	6.4	32,113	6,756	–	7.1	100	7.0	34,564	3,013
Eastridge, 2006	National Highway Transportation Safety Administration General Estimates System database and the National Trauma Data Bank from 1994 to 2002	–	3.6	32.8	6.5	36,334	94,150	–	8.3	39.9	7.1	39,390	54,362
Goslar, 2008	Trauma registry from St. Joseph's Hospital Medical Center in Arizona from 7/2002 to 6/2005	24.9	3.6	100	–	–	253	75.1	9.1	100	–	–	169

[a] LOS, length of stay.

[b] For head injuries requiring hospitalization.

Table 2
Effects of enactment and repeal of helmet laws on injury-related outcomes in the US.

First author, year	Data description	Event related to helmet law	Effects
McSwain, 1980	Injury and fatality data from the Kansas Department of Transportation and Kansas University Medical Centers in each 3-month period for 1975 and 1976	Repealed on 07/01/1976	↑19% in crash rate (per registered motorcycles) ↑95% in death rate (per registered motorcycles) ↑63% in case-fatality rate (per crashes) ↑21% in injury rate (per crash victims) ↑51% in head injury rate (per crash victims)
Muller, 1980	Evaluation of the costs and benefits of the repeal of motorcycle helmet laws based on motorcycle crashes in Colorado, Oklahoma, and South Dakota	Repeal	↑$16.1–18 million annually in medical care expenditures and ↓40–50% in helmet use
Watson, 1980	Comparison of deaths in 26 states that repealed or weakened helmet laws with those in matching state(s) without helmet law changes from the same geographic regions, based on the Fatal Accident Reporting System (FARS) during 1975 to 1978	Repeal	↑38% in fatalities in states which repealed or weakened the laws
Hartunian, 1983	Estimate excess fatalities due to helmet laws repealed or weakened in 48 states, based on the 1975–1980 FARS data	Repeal	↑516 fatalities in 1980 in the 28 states that weakened or repealed helmet laws ↑$177 million in economic costs due to excess fatalities, including $5.4 million in direct costs and $171.2 million for indirect costs
Scholten, 1984	Fatalities from police data in Indiana over the period of 1962–1981, and helmet use observed for May–August in 1977 and 1978	Repealed on 9/1/1977	From 1974–1977 to 1978–1981: ↑37% in death rate per crashes ↑97% in death rate per registered motorcycles ↓Helmet use from 75.6% to 36.8%
McSwain, 1985	Injuries and fatalities from all data sources in Louisiana in 1981–1982	Reenactment on 1/1/1982	↑helmet use from 22% to 74% among fatally injured riders ↑Helmet use from 47% to 74% among riders involved in crashes ↓70% in the death rate (per crashes) ↓12% in the injury rate (per crashes) ↓68% in the most severe head injuries ↓49% in total medical costs
Graham, 1986	Use of pooled time series and cross-sectional analysis based on FARS data 1975–1984	Enactment	↓12–22% in fatalities in states which had comprehensive helmet laws
Chenier, 1987	Evaluation of change in fatalities in states which repealed or weakened laws adjusted for the change in states without modifying the laws, based on 1975–1982 FARS data	Repeal	↑25% in fatalities in states which repealed or weakened helmet laws during the study period
Sosin, 1990, 1992	Nationwide fatalities with head injury from the Multiple Cause-of-Death Public-Use Data Tapes of the National Center for Health Statistics in 1979–1986	Enactment	For the head-injury death rate: States with comprehensive helmet laws had 5.5 per 10^6 population, 3.0 per 10^4 registered motorcycles, and 9.0 per 10^3 motorcycle crashes, and those with no comprehensive helmet laws had 10.3, 3.6, and 12.4 For the overall death rate: States with comprehensive helmet laws had 11.7 per 10^6 population, 6.5 per 10^4 registered motorcycles, and 19.1 per 10^3 motorcycle crashes, and those with no comprehensive helmet laws had 18.5, 6.4, and 22.1, respectively
Lund, 1991	Observation of helmet use on 8 occasions, 6 times before and twice after the law was reinstated in 18 cities of Texas	Reenacted on 9/1/1989	↑Helmet use from 38–62% to 90–96% among all riders ↑Helmet use from 44% to 91–98% among operators ↑Helmet use from 32% to 76–86% among passengers
Fleming, 1992	Analysis of data on motorcycle operators from reports of the Department of Public Safety in Texas 9/1984–8/1990	Reenacted on 9/1/1989	↓12.6% in total fatalities ↓57% in head-related fatalities ↓12.63% in total injuries ↓52.9% in head-related injuries

Table 2 (*Continued*)

First author, year	Data description	Event related to helmet law	Effects
Muelleman, 1992	Police reports, prehospital and hospital records, and autopsy data in 2 urban counties of Nebraska in 1988–1989	Reenacted on 1/1/1989	↓38% in the death rate per no. of registered motorcycles ↓54% in the head injury (AIS[a] 3) rate per no. of registered motorcycles ↓28% in the injury rate per no. of registered motorcycles ↓38% in total acute medical charges
Kraus, 1994b	Fatalities from police reports and death certificates, fatal injury sample in 11 California counties from coroner's reports, and non-fatal samples from medical records of 28 hospitals in 1991–1992	Enacted on 1/1/1992	↓70% of passenger fatalities and 33% of operator fatalities ↓26.5% in the death rate per no. of registered motorcycles ↓16% of fatal head injuries and 37% of non-fatal head injuries ↓7% in the mean ISS[b] of fatal injuries and 10% in mean ISS of non-fatal injuries ↓13% in average days of hospitalization
Kraus, 1995	Helmet use at 60 sites located in 7 counties in California observed twice before & 4 times after implementation of laws in 1991–1992	Enacted on 1/1/1992	↑Helmet use from 46% to 99% among riders ↑16% in riding operators ↓28% in riding passengers
Preusser, 2000	Data from the Federal Highway Administration (FHA), the FARS, prehospital care file, hospital discharge records, and observational surveys in Arkansas and Texas in 1996–2001	Repeal of comprehensive helmet laws in Arkansas on 8/1/1997 and in Texas on 9/1/1997	↓Helmet use from 97% to 52% in Arkansas and from 97% to 66% in Texas ↑21% in fatalities in Arkansas and 31% in Texas ↑Average hospital charges per case for traumatic brain injuries from $18,418 to $32,209 in Texas
Bledsoe, 2002	Retrospective review of the University of Arkansas for Medical Sciences trauma database which includes 38 months before and 38 months after 7/1/1997	Repeal of comprehensive helmet laws on 08/01/1997	Nonsignificant increase in total and fatal crashes between 1995–1996 and 1998–1999 ↑Nonhelmeted deaths from 39.6% to 75.5% ↑length of intensive care unit stay
Hotz, 2002	Hospital data from the Ryder Trauma Center or the University of Miami/Jackson Memorial Medical Center for the Miami-Dade County in July to December in 1999 and July to December in 2000	Repeal of comprehensive helmet laws in Miami-Dade County on 7/1/2000	↓Helmet use from 83% to 56% ↑No. of brain injuries from 18 to 35 ↑No. of fatalities from 2 to 8
Ulmer, 2003	Data from the FHA, the FARS, transportation center, Department of Safety, and observational surveys in Kentucky and Louisiana in 1996–2001	Repeal of comprehensive helmet laws in Kentucky on 7/1/1998 and in Louisiana on 8/1/1999	↓Helmet use from 96% to 56% in Kentucky and from 100% to 52% in Louisiana ↑58% of fatalities in Kentucky and 108% in Louisiana ↑34% of injuries in Kentucky and 40% in Louisiana ↑37.5% in the death rate and 17% in the injury rate per no. of registered motorcycles in Kentucky ↑75% in the death rate and 20.6% in the injury rate per no. of registered motorcycles in Louisiana
Muller, 2004	FARS data for Florida's monthly motorcycle deaths from 1994 to 2001 and yearly issues of Highway Statistics for motorcycle registration and travel miles for the period 1996 to 2001	Repeal of comprehensive helmet laws on 7/1/2000	↑Motorcycle deaths even after adjustment for a concurrent increase in motorcycle registrations and miles traveled
Bledsoe, 2005	Data from the Arkansas Department of Finance and Administration for motorcycle registration, the Arkansas State Police Highway Safety Office, and the FARS data from 1993 to 2001	Repeal of comprehensive helmet laws on 8/1/1997	↓Helmet use from 53% to 21.8% ↑Nonhelmeted deaths involving alcohol use ↑Nonhelmeted deaths from 37.9% to 87.5%
Ulmer, 2005	Data from the FHWA, the FARS, the Florida Department of Highway Safety and Motor Vehicles, and the Florida Agency for Health Care Administration, and observational surveys from 1998 to 2002	Repeal of comprehensive helmet laws on 7/1/2000	↑Noncompliant helmet use (not meeting Federal Motor Vehicle Safety no. 218) from 35% to 15% in fatalities ↑71% in fatalities and 21% in the death rate (per no. of registered motorcycles) ↑Nonhelmeted death rate from 0.7 to 6.1 ↓Helmeted death rate from 7.6 to 3.2 ↑Average hospital charges per case for traumatic brain injuries from $34,518 to $39,877

Table 2 (*Continued*)

First author, year	Data description	Event related to helmet law	Effects
Kyrychenko, 2006	Data on police-reported crashes for the period of 1998 to 2002 from the Florida Department of Highway Safety and Motor Vehicles	Repeal of comprehensive helmet laws on 7/1/2000	↑30.8 to 38.8 deaths per 1000 crashes ↑25% in the risk of death in a crash ↑ 117 fatalities during 2001 to 2002
O'Keeffe et al., 2007	Fatality data from the Miami-Dade County Medical Examiner's Office, helmet use status from the Florida Department of Highway Safety and Motor Vehicles, and motorcycle registrations from the Florida State Department of Transportation from 1997 to 2003	Repeal of comprehensive helmet laws in Miami-Dade County on 7/1/2000	↓Helmet use from 80% to 33% ↑Fatalities from 72 to 125 ↑Motorcycle registrations from 17,270 to 39,043 No change in fatality rate after adjusting for the no. of registered motorcycles
Houston, 2007	Fatality data extracted from the FARS files, motorcycle registrations and vehicle miles traveled (VMT) from FHA, and population data from the Census Bureau for the period 1975–2004	Repeal	↑12.2% in fatality rate per no. of registered motorcycles ↑615 fatalities from 1997 to 2004 due to repeal the laws
Houston, 2008	Fatality data extracted from the FARS files, motorcycle registrations and vehicle miles traveled (VMT) from FHA, and population data from the Census Bureau for the period 1975–2004	Enactment	For comprehensive helmet laws: ↓21.7% in the death rate per no. of registered motorcycles ↓33.1% in the death rate per capita ↓32.1% in the death rate per no. of VMT For partial helmet laws, ↓10.0% in the death rate per no. of registered motorcycles ↓7.5% in the death rate per capita ↓8.2% in the death rate per no. of VMT
Mertz, 2008	Data on fatality and hospital discharge from the Pennsylvania Dept. of Health and data on motorcycle registrations and motorcycle riders in crash involvements from the Pennsylvania Dept. of Transportation during 2001 to 2005	Repeal of comprehensive helmet laws on 9/1/2003	↓Helmet use from 82% to 58% ↑66% in head-injury deaths and 25% in nonhead-injury deaths ↑78% in head-injury hospitalizations and 28% in nonhead-injury deaths ↑12.2% of fatality rate per no. of registered motorcycles ↑615 fatalities from 1997 to 2004 due to repeal the laws

[a] AIS, Abbreviated Injury Scale.
[b] ISS, Injury Severity Score.

have lower rates of helmet use, more-severe head injuries, and higher ISS levels (Hundley et al., 2004; Luna et al., 1984; Peek-Asa and Kraus, 1996a; Zambon and Hasselberg, 2006b). Since motorcycle drivers are more vulnerable than other motor-vehicle drivers to alcohol's effects on balance, motor coordination, and judgment and more-basic skills are needed to operate the inherently unstable vehicle, a lower legal limit of BAC for motorcycle drivers has been suggested (Colburn et al., 1993; Sun et al., 1998). Nonhelmeted riders are also more likely to have been legally intoxicated in a fatal crash (Nelson et al., 1992), and the protective effect of helmets on severe head injuries among intoxicated riders is reduced (Luna et al., 1984), probably because alcohol increases susceptibility to hemorrhage shock by eliminating the rider's homeostatic response mechanism (Phelan et al., 2002). Alcohol use also confounds the measurement of injury severity because the severity levels of head injuries in intoxicated persons are often overestimated, and a better prognosis for the intoxicated may be incorrect (Waller, 1988). There is a positive association between culpability and BAC levels in motorcycle riders (Soderstrom et al., 1993).

No existing programs have specifically attempted to reduce alcohol consumption by motorcycle riders. Among general interventions such as sobriety checkpoints, legal limits on the BAC, zero tolerance, mandatory jail terms for first convictions, and administrative license revocation, only the enforcement of legal limits on the BAC was effective in reducing alcohol-related motorcycle deaths (Villaveces et al., 2003). The effects of other possible interventions such as a minimal legal drinking age, increased alcohol excise taxes, and responsible beverage service for motorcycle riders have not been examined.

As for drugs other than alcohol, 32% of motorcycle drivers treated in Maryland trauma centers during 1990–1991 had used marijuana (cannabis) prior to the crash, which was significantly higher than the 2.7% of car drivers (Soderstrom et al., 1995). Among fatally injured young motorcycle drivers, about one-third had used combinations of alcohol and other drugs such as cannabis, benzodiazepines, or cocaine (Cimbura et al., 1990; Williams et al., 1985). Of motorcycle drivers admitted to trauma centers, 24% had used both marijuana and alcohol vs. 16% of car drivers (Soderstrom et al., 1988). No statistically significant interactive effects among alcohol, marijuana, benzodiazepines, cocaine, or other drugs on injury severity were detected (Soderstrom et al., 1988; Stoduto et al., 1993).

4.3. *Inexperience and driver training*

Less driving experience is monotonically associated with a higher risk of motorcycle crashes and injuries (Ballestros and Dischinger, 2002; Lin et al., 2003a; Wong et al., 1990a). Formal driver training is expected to increase riding skills and reduce the risk of motorcycle crashes and injuries. However, riders who received training had no significant reduction in the risk of motorcycle crashes compared with those who did not receive a training course (Jonah et al., 1982; Mortimer, 1984; Namdaran and Elton, 1988; Rutter and Quine, 1996). In addition, no significant differences in traffic violations, costs of medical treatment, or motorcycle damage per crash were detected between trained and untrained riders (Jonah et al., 1982; Mortimer, 1984, 1988).

There are several possible explanations for the lack of benefits of training courses on reducing motorcycle crashes and injuries. First, riding experience per se might not be a determinant of motorcycle crashes and injuries, since it is often correlated with age, particularly in young riders. The protective effect of experience was not sustained when a rider's age was included in the analysis (Mullin et al., 2000). However, a national prospective survey of 4101 riders in the UK found that youth played a greater role in motorcycle crashes and injuries than inexperience through a pattern of risk-taking behaviors, i.e., a willingness to break the law and violate the rules of safe riding (Rutter and Quine, 1996). Second, the lack of a preventive effect of training programs on motorcycle crashes may result from differences in demographics, riding experience, and crash involvement between trained and untrained groups. Nevertheless, when matched by age, gender, location of licensing, time to obtain a license, and previous driving record, no significant difference in the incidence of motorcycle crashes was found between trained and untrained groups (McDavid et al., 1989). Third, the theory of risk homeostasis or risk compensation provides another possible explanation. When new safety measures are introduced, riders may adjust their behaviors to maintain the previous level of individual acceptable risk, and the crash rate should not change, if the level of individual risk is not modified (Wilde, 1998); in other words, trained riders may have more confidence for their operating skills and thus drive with more risk-taking behaviors. Finally, some unmeasured, selective factors for a training group may play a role and weaken the effect of driver training on motorcycle crashes and injuries. Nevertheless, no study has directly examined the interpretability of the theory of the ineffectiveness of training programs. To resolve the controversy about the effectiveness of motorcycle training in reducing the occurrence of motorcycle crash injuries, a better design such as randomized controlled studies to eliminate possible selective factors between trained and untrained riders is required.

4.4. Conspicuity and daytime headlight laws

In car–motorcycle collisions, two-thirds of car drivers claimed not to have seen the motorcycle or to have seen it too late to have avoided the collision (Hurt et al., 1981). Among a number of ways to improve the conspicuity of motorcycles or their riders, the use of high- or low-beam headlights during daytime hours was better than other devices designed to raise conspicuousness such as wind fairing and reflective fluorescent jackets (Olson et al., 1981). In New Zealand, high-visibility clothing and white-colored helmets were also found to reduce the risk of having a crash compared to other measures (Wells et al., 2004).

Daytime headlight use has been advocated to increase motorcyclists' safety; however, laws governing this have not consistently been found to reduce motorcycle crash injuries (Cercarelli et al., 1992; Muller, 1985; Olson, 1989; Radin-Umar et al., 1996; Wells et al., 2004; Yuan, 2000; Zador, 1985). There are several reasons for these inconsistent findings. First, conflicting assumptions were used across those studies to evaluate the impacts of daytime headlight use on motorcycle crash injuries. If the potential benefit of motorcycle daytime headlight use is assumed to prevent motorcycles and riders from being hit by other motor vehicles (i.e., avoiding multiple-vehicle crashes), those including all single- and multiple-vehicle crashes in the preventive outcome may have underestimated the effectiveness of daytime headlight use (Radin-Umar et al., 1996; Zador, 1985). However, a substantial portion of single-motorcycle crashes is the consequence of avoiding being hit by another motor vehicle (Preusser et al., 1995; Shankar, 2001). If so, the use of single crashes as a control group to evaluate the reduction in multiple-vehicle crashes would underestimate the effect of headlight use in reducing daytime crashes (Muller, 1982, 1984). Daytime headlight use is assumed to be effective only for fatal and other serious-injury crashes (Quddus et al., 2002; Yuan, 2000); thus the power to detect its effectiveness may be weakened when including all kinds of crashes. Second, the estimated effect of daytime headlight laws is often confounded by regional variations in motorcycle crashes (between-state comparisons) (Muller, 1985) or factors such as changes in speed limits, helmet use laws, alcohol use, and the minimum legal drinking age (within-state comparisons). Finally, increased visibility can be at the expense of other riders who do not use their lights, since car drivers may adopt a strategy of looking for a light rather than a motorcycle per se (Hole and Tyrrell, 1995). Moreover, motorcycle conspicuity may also be affected by the daytime headlight use of other motor vehicles.

4.5. Licensure and ownership

Riding a motorcycle without a valid license is associated with higher risks of crashing and serious motorcycle injury in the US and other countries (Dandona et al., 2006; Hurt et al., 1981; Lardelli-Claret et al., 2005). Among fatally injured motorcycle operators, only 75% had a valid license (NHTSA, 2007), and the lowest licensure rate often occurs in younger drivers aged ≦20 years (Dandona et al., 2006; Kraus et al., 1991). Compared with licensed operators, unlicensed ones were less likely to report using the low-beam headlight in daytime, wearing body protection, or driving without drinking alcohol (Peek-Asa and Kraus, 1996a; Reeder et al., 1996).

Motorcycle drivers who crashed and who did not own the motorcycle were more likely to be unlicensed than those owning the motorcycle, and owners involved in a crash were less likely to have a license than those not in a crash (Kraus et al., 1991). Lack of a license, ownership, and youth are correlated, and all of these factors are associated with higher risks of motorcycle crashes and injuries. For instance, in New Zealand where the minimal legal driving age is 15 years, only 36% of 18-year-old drivers had a valid license, and 72% did not own the motorcycle they were driving (Reeder et al., 1995). Drivers who borrowed a motorcycle were more likely to have a crash at night, while attempting to execute a turn, riding at slower speeds, or committing a traffic violation compared with those who owned the motorcycle (Dandona et al., 2006).

Countermeasures for lack of a valid license include proof of a valid license as a prerequisite for purchasing a motorcycle, stringent enforcement of licensure laws, severe penalties for lack of a license, and mandating an older age to obtain a motorcycle license (Kraus et al., 1991; Reeder et al., 1995). In a randomized trial using an educational mailing to unlicensed owners, the licensure rate in the intervention group over a 6-month period was 10.4% compared with 7.9% in the control group (Braver et al., 2007). Despite this difference in percentages being statistically significant, the licensure rate in the intervention group still remained low. Graduated driver licensing systems in the US and New Zealand were effective in reducing motorcycle injuries and deaths (Baldi et al., 2005; McGwin et al., 2004), particularly for riders aged 15–19 years (Reeder et al., 1999). The effect of the graduated driver licensing system may result from a reduction in exposure to motorcycle riding (Reeder et al., 1999) and/or from appropriate education (Baldi et al., 2005).

4.6. Riding speed

Higher speeds at the time of impact are associated with more-serious motorcycle injuries (Kraus et al., 1975; Lin et al., 2003b; Shibata and Fukuda, 1994). Of the 900 motorcycle crashes studied in Los Angeles County, California during 1976–1977, 40% occurred at crash speeds of 0–20 miles per hour (mph), 30% at 21–30 mph, 14% at 30–40 mph, and 16% at ≧41 mph, and the corresponding proportions for the 89 fatal crashes were 17%, 21%, 37%, and 25%, respectively (Hurt et al., 1981). Speeding by motorcyclists in fatal crashes in the US was about twice the rate for drivers of automobiles or light trucks (NHTSA, 2007). Speeding is also responsible for almost two-thirds of motorcycle deaths among single-vehicle crashes (Shankar, 2001). When crash speeds exceeded ≧50 km/h, there was a reduction in helmet effectiveness in preventing motorcycle deaths (Shibata and Fukuda, 1994). At high speeds, the fixed and non-fixed parts of the body such as the skull and brain move differentially, and brain injuries due to deceleration may occur (Feliciano and Wall, 1991; McSwain, 1987; Viano et al., 1989). During a high-speed crash, a helmet can also be lost if the chin strap is not securely fastened (Richter et al., 2001). Recently, while traffic crashes were significantly associated with an increase in mean speed, a stronger relationship between traffic crashes and a large variability in traffic speeds was also found (Aljanahi et al., 1999). In addition to excessive speed, inappropriate speed for traffic conditions and slow speeds were also associated with a high risk of initiating two-vehicle collisions (Lardelli-Claret et al., 2005).

Regulating speed limits is a means of reducing traffic speed. It was estimated that persons driving on highways with a speed limit of ≧55 mph were 3.7-times more likely to be killed in crashes than those driving at lower speed limits for all types of vehicles (NHTSA, 1993). In the 40 states in the US that increased speed limits on rural state highways to 65 mph in 1988, traffic deaths increased 26–36% (Baum et al., 1989, 1990). Following the 1995 repeal of the US national maximum speed limit, death rates due to motor vehicle crashes on interstate highways were 17% higher in the 24 states that raised interstate speed limits to 70 mph (Farmer et al., 1999). There are no specific data for examining the effect of speed limits on motorcycle deaths. On the other hand, speed camera networks were found to decrease all type of injurious crashes, including those occurring in daytime and nighttime, on roads with speed limits of 30 and 60–70 mph, and for crashes that injured motorcycle riders (by 63%) and other road users (by 17–78%) (Christie et al., 2003).

4.7. Risk-taking behavior

The risks of motorcycle injury and death are highest for the young (Baker et al., 1992; Braddock et al., 1992; Lardelli-Claret et al., 2005; Lin et al., 2003a; Shankar et al., 1992), even though riders aged ≧40 years are the fastest-growing group experiencing fatal motorcycle crashes in the US (NHTSA, 2006). Originally, the overrepresentation of young riders in motorcycle injuries was attributed to inexperience in operating a motorcycle or a higher exposure to riding (Chesham et al., 1993). There is evidence that the risk-taking characteristics of young riders contribute to the high risk of motorcycle injuries, and risk-taking behaviors among motorcycle drivers may include speeding, drinking while riding, not using a helmet while riding, unlicensed riding, running yellow lights, and driving with too little headway (Lin et al., 2003a; Rutter and Quine, 1996), and these behaviors are correlated with each other (Beirness and Simpson, 1988; Boyce and Geller, 2002; Jessor, 1987; Jonah et al., 2001).

Risk-taking can be grouped under the rubric of risk perception and risk utility (Hodgdon et al., 1981; Jonah, 1986). Motorcycle drivers aged ≦25 years perceived their crash risk as being medium or high, those aged 26–39 years as being medium, and those aged ≧40 years as being low; the perceived crash risk was associated with experience, gender, distance ridden, and geographic region (Mannering and Grodsky, 1995). Young drivers tended to underestimate the risk of being in a crash in the next 2 years but overestimated the risk of being killed (Leaman and Fitch, 1986). The risk perception of adolescent drivers corresponded to the actual risk of motorcycle crashes (Reeder et al., 1992), but they neither modified their risk-taking behaviors nor reduced risk-taking levels, even after experiencing a crash or injury (Lin et al., 2004b; Mangus et al., 2004). On the other hand, risk-taking behaviors among very young persons may represent an outlet or utility for stress and aggression, an expression of independence, or a means of increasing arousal or impressing other people (Hodgdon et al., 1981). As a result, health-promotion education only using negative consequences of motorcycle and other motor-vehicle crashes intended to reduce high risk-taking behaviors among young persons might not readily succeed, even if these educational materials do increase risk perception (Matthews and Moran, 1986; Rutter et al., 1998). To our knowledge, no intervention study of reducing risk-taking behaviors among motorcycle drivers has been conducted.

5. Motorcycle injuries in developing countries

Motorcycle riders have especially high rates of injury in developing countries (Ameratunga et al., 2006); transfer of effective interventions for motorcycle injuries from developed to developing countries is necessary and highly desirable. However, an understanding of the feasibility of, economic costs of, and potential barriers to implementing these interventions is vital for successful transfer. In developing countries, particularly in Asia, several special motorcycle-related features are evident. First, motorcycle use has been dramatically growing, and motorcycles are one of the most important means of transportation because of rapid economic development, convenience in congested traffic, and ease of parking on narrow streets (Krishnan and Smith, 1994). For instance, motorcycles comprise 95% of registered motor vehicles in Vietnam (Hung et al., 2006), 67% in Taiwan (MTC, 2007), 63% in China (Zhang et al., 2004), and 60% in Malaysia (Radin-Umar et al., 1996). Moreover, motorcycle crashes accounted for more than 50% of traffic deaths in Malaysia and Taiwan (MI, 2005; Radin-Umar et al., 1996), and 80% of traffic injuries in Thailand (Ichikawa et al., 2003; Swaddiwudhipong et al., 1994) and 42% in Singapore (Wong et al., 1990b). In contrast, motorcycles in the US comprise about 2% of registered motor vehicles (NHTSA, 2007), and they are often only ridden for recreation. Second, a large proportion of motorcycles in developing countries are scooters with a smaller engine capacity, like those used in some urban areas of European countries (e.g., France, Italy, and Spain). A scooter is a two-wheeled motorized vehicle with a step-through frame, small wheels, automatic transmission, and an engine located below the rider and to the rear. Characteristics of the crash rate, crash type and time, and injury severity and pattern for scooters seem to differ from those for motorcycles (Salatka et al., 1990), even though the differences are rarely reported. Third, there are some unique road environments in developing countries, such as more-congested traffic, intrusive store advertising signs, and a traffic mixture of motor vehicles, bicycles, and even rickshaws and animal-drawn vehicles (Mohan, 1984; Sahdev et al., 1994). Finally, a great proportion of motorcycle riders in developing countries incorrectly use motorcycle safety devices possibly due to inadequate education and lax law enforcement (Li et al., 2008); for example, about one-third of motorcycle riders in China and Indonesia had their helmets fastened improperly or were wearing nonstandard helmets (Conrad et al., 1996; Li et al., 2008).

Differences in the prevalence of motorcycle riders, the amount of riding exposure, the purpose of riding a motorcycle, type of motorcycle, and intervention programs should account for large differences in the numbers and incidences of motorcycle crashes and injuries between developing and developed countries, even though more empirical evidence is required. As a result, if these differences are not considered, applying risk factor analytical results and prevention programs from developed countries, particularly to costly road engineering projects, might not be appropriate or feasible for developing countries (Forjuoh, 1996; Zwi, 1996). Furthermore, road-injury prevention strategies in developed countries only incidentally consider protecting vulnerable road users such as motorcycle riders who comprise the majority of road traffic victims in developing countries. Malaysia provided exclusive lanes for motorcycles that reduced motorcycle deaths by 600% (Radin-Umar, 2006).

Nevertheless, the experience of successful motorcycle-injury prevention programs, particularly policy interventions such as helmet use laws, legal limits of BAC, enforcement of licensure laws, and speed limits, may directly be undertaken by developing countries since these interventions are widely effective (Chiu et al., 2000; Forjuoh, 2003; Ichikawa et al., 2003; Kasantikul et al., 2005; Ouellet and Kasantikul, 2006; Supramaniam et al., 1984) and have a high benefit–cost ratio of implementation (Hyder et al., 2007).

6. Recommendations for future research

Recent trends in motorcycle injuries may have changed in developed and developing countries; if so, new target groups and injury prevention programs need to be further identified and developed. For example, it is still unknown why motorcycle deaths have recently been increasing in the US, and why those aged ≧40 years are the fastest-growing group experiencing fatal motorcycle crashes. It is common to see mobile phone use among motorcycle drivers while driving in some developed and many developing countries; although sensibly they are more likely to have a higher risk of a crash, the amount of increased risk of a crash and differences in the resulting injury severity and patterns due to the distraction have not been elucidated. Moreover, differences in the risk and patterns of injuries between motorcycle drivers and passengers remain to be explored.

Although helmets are efficient and effective in reducing severe head injuries among motorcycle riders, differences in reductions of head injuries among various helmet types and incorrect use of helmets need to be further examined. Also, the reason why a motorcycle helmet drops off a rider during crashes at higher speeds has not been clearly determined. These results can facilitate better helmet design to reduce head injuries among riders. A rider can be protected by safety devices worn on the body, but other protection devices such as motorcycle airbag jackets and back and leg protectors may also be important, but little empirical evidence of their effectiveness is available.

A very clear limit of the BAC (e.g., zero tolerance) should be defined to reflect the need for greater coordination and balance when operating two-wheeled vehicles. While the influences of illicit drugs (e.g., amphetamines, marijuana, and cocaine) and polydrug use on increasing the risk of motorcycle crash injuries and its severity are understudied, the effectiveness of a minimal legal drinking age, increased alcohol excise taxes, and responsible beverage service specifically on reducing motorcycle crash injuries remains to be examined.

The effectiveness of motorcycle rider's education and training programs needs to be vigorously examined using better research designs (e.g., randomized controlled studies), with effective program components being identified. The effects of the graduated driver licensing system for motorcyclists require more evidence, particularly after adjusting for exposure to motorcycle riding and educational information. Furthermore, riders who operate a motorcycle with a smaller engine capacity (e.g., ≦50 cc) are not required in many countries to have a specialized motorcycle license; however, the risk of motorcycle crashes between riders with specialized licensure and those without may differ. There are no available data for daytime headlight use of four-wheeled motor vehicles on motorcycle conspicuity and injuries. Studies on regulating speed limits and reducing risk-taking behaviors to prevent motorcycle crash injuries among adolescent and young riders are strongly needed.

Finally, the greatest potential to reduce deaths among motorcycle riders lies in preventing crash and injury occurrence rather than through improved treatment of severe injuries. In previous epidemiological studies of motorcycle injuries, determinants of the injury incidence were rarely differentiated from those of injury severity. Doing so would allow for effective targeting of injury prevention programs.

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