

An Evidence-Based Review: Helmet Efficacy to Reduce Head Injury and Mortality in Motorcycle Crashes: EAST Practice Management Guidelines

Jana B. A. MacLeod, MD, J. Christopher DiGiacomo, MD, Glen Tinkoff, MD, FACS, FCCM

According to the National Highway Traffic Safety Association, in 2008, 5,290 motorcyclists died and 96,000 were injured. Motorcycles make up ~3% of all registered vehicles in the United States and account for only 0.4% of all vehicle miles traveled. However, motorcycle crashes accounted for ~10% of all motor vehicle crash fatalities, and per mile traveled, motor cycle crashes are ~37 times more lethal than automobile crashes.

Head injuries are one of the most common injuries after motorcycle crashes and were estimated to be the cause of death in >50% of these fatalities. In close to a third of these victims, the head injury is the sole organ system that is injured. However, in the majority of patients, estimated as high as 90% of some patient cohorts, a head injury is present along with other injuries. Despite these facts, it is estimated that only 50% of motorcyclists routinely wear helmets.

It was intuitive even to our earliest ancestors that a hard shell would protect the head from injury. However, establishing the effectiveness of the motorcycle helmet remains a challenging effort especially in light of the powerful opposition to universal helmet laws. Furthermore, quantifying the protective effect of helmets supports the promotion of helmet programs regardless of the controversial nature of legislative efforts.

In the United States, an increasing recognition that helmet use is associated with reductions in fatalities without apparent harm increased the implementation of universal helmet laws. In response to the 1966 Federal Highway Act, which withheld federal funds from states that did not enact a helmet law, Georgia became the first state to enact a mandatory universal motorcycle helmet law in 1967. By 1975, 47 of the 50 states had universal helmet laws. However, public and

political concerns over individual rights versus public safety opened a new debate. In the following years, political changes reversed and/or limited previous sanctions and grants that encouraged states to enact universal helmet laws, which further eroded support for helmet laws. An increasing number of states either repealed their mandatory laws altogether or significantly reduced the laws to apply only to minors. At present, only 20 states have universal helmet laws, another 26 states require only partial coverage, and 4 states have no helmet laws (Colorado, Illinois, Iowa, and New Hampshire).

A large volume of literature has quantified the consequences of not wearing a helmet while riding a motorcycle. Although motorcycle riding and registration are increasing and more states with universal helmet laws are introducing bills to repeal their laws, the debate continues on the personal advantages of helmet usage. Therefore, we have reviewed the literature and summarize the evidence basis for the use of motorcycle helmets. In particular, we have sought to assess the impact of helmet use on overall mortality, head injury-related mortality, nonlethal head injury after a motorcycle crash, and the impact universal helmet laws on helmet use.

STATEMENT OF PROBLEM

Motorcycles are a significant cause of injury-related fatality and disability. In particular, head injury is a common associated cause of death and long-term disability after a motorcycle crash. Despite these facts, there remains an ongoing controversy as to the survival and disability advantages for riders who wear motorcycle helmets. In the public and legislative sectors, there remains a significant policy controversy resulting in a push to retain partial coverage helmet laws and to repeal universal helmet laws in many others.

QUESTIONS TO BE ADDRESSED

- Do nonhelmeted riders in comparison with helmeted riders have a higher or lower overall death rate after a motorcycle crash?
- Do nonhelmeted riders in comparison with helmeted riders incur higher or lower rates of lethal head injury after a motorcycle crash?
- Do nonhelmeted riders in comparison with helmeted riders incur higher or lower rates of nonlethal head injury or is the nonlethal head injury more or less severe after a motorcycle crash?

Submitted for publication March 11, 2010.

Accepted for publication August 22, 2010.

Copyright © 2010 by Lippincott Williams & Wilkins

From the Department of Surgery (J.B.A.M.), Grady Hospital, Emory University School of Medicine, Atlanta, Georgia; The Port Authority Heroes of September 11 Trauma Center (J.C.D.), Jersey City Medical Center, Jersey City, New Jersey; and Department of Surgery (G.T.), Christiana Care Health System, Wilmington, Delaware.

Presented at the 23rd Annual Meeting of the Eastern Association for the Surgery of Trauma, January 19–23, 2010, Phoenix, Arizona.

Supported and commissioned by Injury Control and Violence Prevention Committee, Eastern Association for the Surgery of Trauma.

Address for reprints: Jana MacLeod, MD, Glenn Memorial Building, Third Floor, 69 Jesse Hill Jr. Drive, SE, Atlanta, GA 30303; email: jm7072003@yahoo.com.

DOI: 10.1097/TA.0b013e3181f8a9cc

D. Do geographical areas (i.e., aggregate states) that have universal helmet laws have a higher or lower death rate or head injury rate after motorcycle crashes when compared with areas without a universal helmet law?

METHODS AND PROCESS

A computerized search of the world's literature was undertaken using PubMed, of the US National Library of Medicine, extending back to 1990 to the present (2009) using the key words: helmet + (motorcycle OR crash). There were 507 citations identified. The abstract for each was reviewed, and 197 candidate articles having possible applicability to the guideline topic were retrieved and reviewed. General reviews, letters to the editor, single case reports, and retrospective reviews of poor quality were excluded. This left 45 articles that were felt to have sufficient merit to form the basis for the guidelines (Table 1). The articles were reviewed in detail by the authors J.M., G.H.T., and J.C.D.

Over the past decades, the volume of literature supporting helmet usage prevents, and ethically so, any randomized control trials or even controlled trials of helmet usage. Therefore, the most robust studies published in the past 20 years are predominantly prospective and retrospective epidemiologic studies. As there are no class I studies to review, the studies we did review do not vary across the classes of evidence in a useful manner. Therefore, we categorized the articles in this review by study design. There are prospective cohort and cross-sectional studies. However, the majority of the studies are retrospective, either before and after cross-sectional studies of helmet law changes or cross-sectional studies of helmeted in comparison with nonhelmeted riders. Finally, we also identified case-control studies.

RECOMMENDATIONS

Level I

All motorcyclists should wear motorcycle helmets when riding motorcycles to reduce the incidence of head injury and severe head injury after a crash.

NB: This statement was made a level recommendation despite a lack of class I data because of the volume of consistent class II data, including robust prospective data, to support this finding without any methodologically similar data to refute it.

Level II

All motorcyclists should wear motorcycle helmets when riding motorcycles to improve overall survival and reduce head injury-related mortality after a crash.

Mandatory universal motorcycle helmet laws should be introduced or reenacted to reduce mortality and head injury after a crash.

SCIENTIFIC FOUNDATION

The evidence reviewed here that assesses the effectiveness of helmets for motorcyclists comes from the following 45 study designs:

1. Prospective cohort study of motorcycle riders.¹
2. Prospective cross-sectional studies that compare helmeted riders with nonhelmeted riders for different outcomes.²⁻⁵

3. Retrospective before and after cross-sectional studies in which outcomes of motorcycle crashes are compared before and after either the repeal of or the enactment of a mandatory universal helmet law.⁶⁻²⁴
4. Case-control studies of motorcycle riders.²⁵⁻²⁷
5. Retrospective cross-sectional studies that compare helmeted riders with nonhelmeted riders across different outcomes.²⁸⁻⁴³
6. Comparison of mortality between states with helmet laws and states without helmet laws.^{44,45}

The outcomes reported included any one or more of the following: mortality, head injury-related mortality, prevalence of head injury, and prevalence of severe head injury.

Do Nonhelmeted Riders in Comparison With Helmeted Riders Have a Higher or Lower Overall Death Rate After a Motorcycle Crash?

Two prospective cross-sectional studies showed a reduction in mortality for helmeted riders in comparison with nonhelmeted riders, with an odds ratio (OR) of 0.40 and 0.22, respectively.^{2,5} However, Kelley's sample size was not adequate to reach statistical significance, and therefore, no death reduction can be concluded from this study. Nine retrospective cross-sectional studies reported mortality as an outcome, but two showed no reduction^{35,42} while seven showed reductions that varied from a maximal OR estimate of 0.29³³ to a minimal OR estimate of 0.84.²⁸ Of the studies that showed a mortality reduction, only three were adjusted for rider and/or environmental factors.^{28,33,34}

There were five studies that compared crashes before and after helmet law repeal. Two of the studies showed an increase in fatality after repeal of the helmet law, 26% and 30% increases, respectively.^{8,10} However, two further studies had nonsignificant increases in the ORs of death: OR of 1.08⁷ (per 10,000 motorcycle registrations) and OR of 1.01⁹ (per 1,000 crashes). Interestingly, although the study of Bledsoe and Li did not show an overall reduction in mortality, there was a significant increase in riders who were blood alcohol positive at the time of the crash and who were also not wearing a helmet after the repeal when compared with before (14.2% vs. 33.6%, OR: 2.37, $p < 0.05$).

There were 12 studies that compared crashes before and after helmet law establishment or reenactment. Auman et al. showed close to a halving of the relative risk (RR) of fatality after the law was reenacted (RR: 0.51, 9.3 fatalities per 10,000 motorcycle registrations to 4.7 fatalities per 10,000 registrations). Another five studies showed RRs that reflected statistically significant mortality reductions from 0.57 to 0.81.^{15,21-24} One study, by Chiu et al., showed no change in mortality during the study period (4.0%).

Do Nonhelmeted Riders in Comparison With Helmeted Riders Incur Higher or Lower Rates of Lethal Head Injury After a Motorcycle Crash?

The RR of head injury-related mortality was reduced by more than half after the enactment of a helmet law in Texas from 6.8 fatalities to 3.1 fatalities per 10,000 motorcycle

TABLE 1. References: Citation and Summary for EBR Articles on the Efficacy of Motorcycle Helmets 1990–2009

Class	Authors	Title	Citation	Summary
Prospective cohort studies				
II	Lin et al. ¹	Crash severity, injury patterns, and helmet use in adolescent motorcycle riders	<i>J Trauma.</i> 2001;50:24–30	4,721 randomly selected junior college students in Taipei were followed up prospectively for 20 mo, during which 1,284 were involved in 1,889 motorcycle crashes. In 33% of the crashes, the rider was wearing a helmet. Head injuries occurred in 4.7% of injured riders without a helmet compared with 1.9% of helmeted riders
Prospective cross-sectional studies				
II	Ouellet and Kasantikul ²	Motorcycle helmet effect on a per-crash basis in Thailand and the United States	<i>Traffic Inj Prev.</i> 2006;7:49–54	1,869 motorcycle crashes in Los Angeles and Thailand were prospectively investigated in detail. Approximately 6% of riders were killed at both locations and 20%–25% were hospitalized. Nonhelmeted riders were 2.5 times more likely to be killed and 3.5 times more likely to sustain a serious brain injury
II	LaTorre et al. ³	Epidemiology of accidents among users of two-wheeled motor vehicles. A surveillance study in 2 Italian cities	<i>Eur J Public Health.</i> 2002;12:99–103	Crashes for 14 to 35 yr olds 2-wheeled riders presenting to two hospitals in Italy after a crash were surveyed for a 6-mo period of time. Injury and crash data were collected. 12% of the riders wore a helmet at the time of the crash. The risk of head injury is 4.35 times higher when not wearing a helmet
II	Conrad et al. ⁴	Helmets, injuries and cultural definitions: motorcycle injury in urban Indonesia	<i>Accid Anal Prev.</i> 1996;28:193–200	Prospective observational study of motorcycle riders in Indonesia. Data collected from street observations, interviews, and riders admitted to four hospital emergency departments. 89% of drivers wore helmets but only 55% wore them correctly. Indonesia has a mandatory helmet law. The risk of a head injury was 0.41 for riders in a crash while wearing a helmet
II	Kelly et al. ⁵	A prospective study of the impact of helmet usage on motorcycle trauma	<i>Ann Emerg Med.</i> 1991;20:852–856	Prospectively collected data of motorcycle crash victims presenting to emergency departments in eight varying institutions across the State of Illinois, during a 7-mo period. Only 14.6% of the 398 patients were wearing helmets at the time of the crash. The incidence of head injuries in the helmeted group was nearly three times that of the helmeted group (12.1% vs. 32.6%)
Retrospective before and after cross-sectional studies				
II	Mertz and Weiss ⁶	Changes in motorcycle-related head injury deaths, hospitalizations, and hospital charges following repeal of Pennsylvania's mandatory motorcycle helmet law	<i>Am J Public Health.</i> 2008;98:1464–1467	Retrospective review of motorcycle head-related mortality and injuries comparing the prerepeal period (2001–2002) to the postrepeal period (2004–2005). There was a 32.8% increase in head injured-related mortality and a 42.2% increase in head injury-related hospitalizations per 10,000 motorcycle registrations after repeal of the helmet law
II	O'Keefe et al. ⁷	Increased fatalities after motorcycle helmet law repeal: is it all because of lack of helmets?	<i>J Trauma.</i> 2007;63:1006–1009	Retrospective review of fatalities pre- and postmotorcycle helmet law repeal (July 1, 2000) in Miami-Dade County, Florida. Police crash and medical examiners records were reviewed for fatalities per registered motorcycle riders from 1997 to 2003. Motorcycle helmet usage in fatal crashes dropped from 80% to 33%. An absolute number of deaths increased: 72 deaths pre- and 125 deaths postrepeal. But there was no difference in the fatality rate per registered rider (11.6 deaths pre- to 12.5 deaths postrepeal per 10,000 motorcycle registrations, $p = 0.61$)

TABLE 1. References: Citation and Summary for EBR Articles on the Efficacy of Motorcycle Helmets 1990–2009 (continued)

Class	Authors	Title	Citation	Summary
II	Kyrychenko and McCartt ⁸	Florida's weakened motorcycle helmet law: effects of death rates in motorcycle crashes	<i>Traffic Inj Prev.</i> 2006;7:55–60	Retrospective review of police-reported crash from 1998 to 2002 from the Florida Department of Highway, Safety and Motor Vehicles. The helmet law was changed from universal to exclude riders 21 years and older with at least \$10,000 of medical benefit insurance in mid 2000. Death rates were compared for 2 yr before with 2 yr after the law was changed. The death rate rose from 30.8 deaths per 1,000 crashes to 38.8 deaths
II	Bledsoe and Li ⁹	Trends in Arkansas motorcycle trauma after helmet law repeal	<i>South Med J.</i> 2005; 98:436–440	Retrospective review of data from the Arkansas Department of Finance and Administration for motorcycle registrations, motorcycle crash data and the Arkansas State Police Highway Safety Office, and motorcycle fatality data for Arkansas from the Fatality Analysis Reporting System (FARS). The Arkansas helmet law was repealed in 1997. The study compares the 4-yr before to the 4-yr after the repeal. Fatalities per crash increased nonsignificantly from 41.9 to 42.2 per 1,000 crashes, but in the same period of time, crashes and fatalities per 1,000 registered motorcycles decreased. The percentage of motorcycle fatalities not wearing a helmet increased from 47.0% to 78.2% after the repeal
II	Ho and Haydel ¹⁰	Louisiana motorcycle fatalities linked to statewide helmet law repeal	<i>J La State Med Soc.</i> 2004;156:151–157	In 1999, Louisiana repealed its universal motorcycle helmet law to exempt riders who are 18 years or older, with \$10,000 Health Insurance Policies. This is a retrospective review of 8,916 motorcycle crashes and 300 fatalities for 1994–2002, except 1999, combining data from NHTSA, Louisiana Highway Safety Commission, and a Level I trauma registry. The fatality rate increased from 3.0% per collision to 3.7% after repeal. Helmet use decreased from 71.4% to 35% after repeal
II	Ichikawa et al. ¹¹	Effect of the helmet act for motorcyclists in Thailand	<i>Accid Anal Prev.</i> 2003;35:183–189	Retrospective analysis of trauma registry data comparing 2-yr before to 2-yr after enactment of a motorcycle helmet law in Thailand. 12,002 patients were reviewed, including 129 deaths. When compared with the prelaw period, head injuries decreased 41.4% and motorcycle-related deaths decreased 20.8%
II	Servadei et al. ¹²	Effect of Italy's motorcycle helmet law on traumatic brain injuries	<i>Inj Prev.</i> 2003;9: 257–260	Retrospective review of traumatic brain injuries at a regional neurosurgery referral center for 1 year before and after implementation of a universal motorcycle helmet law. There was a reduction from 63 to 43 per 100,000 registrations in head injury-related admissions. There was also a 76% decrease in the diagnoses of traumatic subarachnoid hemorrhage, subdural hematoma, and epidural hematoma after the enactment of the law
II	Christian et al. ¹³	Motorcycle helmets and head injuries in Kentucky 1995–2000	<i>J Ky Med Assoc.</i> 2003;101:21–26	Retrospective review of head injury and head injury severity after a motorcycle crash from a single Level I trauma center from 1995 to 2000. Of note, Kentucky repealed their helmet law in 1998. A nonhelmeted rider was 4.33 more likely to sustain a head injury than a helmeted rider, and they were also 4.36 more likely to sustain a severe head injury than nonhelmeted riders
II	Auman et al. ¹⁴	Autopsy study of motorcyclist fatalities: the effect of the 1992 Maryland motorcycle helmet use law	<i>Am J Public Health.</i> 2002;92:1352–1355	Retrospective comparison of motorcycle fatalities in Maryland for 33 mo before and after implementation of a universal helmet law. 61.3% of fatalities occurred before the law was enacted and 38.7% after. The fatality rate per 10,000 registrations decreased from 9.32 to 4.7 per 10,000 motorcycle registrations in the 3-yr period before and after the enactment

TABLE 1. References: Citation and Summary for EBR Articles on the Efficacy of Motorcycle Helmets 1990–2009 (continued)

Class	Authors	Title	Citation	Summary
II	Ferrando et al. ¹⁵	Impact of a helmet law on 2 wheel motor vehicle crash mortality in a southern European urban area	<i>Inj Prev.</i> 2000;6:184–188	Retrospective study comparing the 2-yr period before and after implementation of a universal motorcycle helmet law in Spain. Data were compiled from the Medical Examiner, police records, and the Traffic Authority of Barcelona. Annual fatalities decreased from 60 in the first year of the review to 32 in the last year, with the crash mortality rate decreasing from 6.9 to 5.2 per 1,000 crashes. The authors estimated that 35 lives were saved in Barcelona during the first 2 yr of the motorcycle helmet law
II	Chiu et al. ¹⁶	The effect of the Taiwan motorcycle helmet use law on head injuries	<i>Am J Public Health.</i> 2000;90:793–796	Retrospective study comparing motorcycle-related head injuries seen at 56 major hospitals across Taiwan for 1 year before and after implementation of a universal helmet law, based on the Head Injury Registry of Taiwan. Total number of motorcycle-related head injuries decreased to 33%. In-hospital death rates remained unchanged at 4.0%
II	Tsai and Hemenway ¹⁷	Effect of the mandatory helmet law in Taiwan	<i>Inj Prev.</i> 1999;5:290–291	Retrospective review in three cities comparing 6 mo before to 6 mo after enactment of a mandatory motorcycle law in Taiwan. Fatalities after a crash decreased by 14% and head-related fatalities reduced by 22%
II	Peek-Asa and Kraus ¹⁸	Estimates of injury impairment after acute traumatic injury in motorcycle crashes before and after passage of a mandatory helmet use law	<i>Ann Emerg Med.</i> 1997;29:630–636	Retrospective review comparing 4,790 nonfatally injured motorcycle riders for 1 year before and after enactment of the California mandatory motorcycle law, linking medical records to police reports. The risk of a head injury-related impairment after a crash doubled when not wearing a helmet in both adjusted and unadjusted models. The models adjusted for alcohol, speeding, gender, and being thrown from the motorcycle
II	Kraus and Peek ¹⁹	The impact of two related prevention strategies on head injury reduction among nonfatally injured motorcycle riders, California, 1991–1993	<i>J Neurotrauma.</i> 1995;12:873–881	Retrospective review of nonfatally injured motorcycle riders before and after enactment of the California mandatory motorcycle helmet law of 1992. The law resulted in 85.6% of the injured riders wearing a helmet. Head injuries decreased from 38.2% of the injuries seen before the enactment to 24.1% of the head injuries after the law was enacted
II	Panichaphongse et al. ²⁰	Effects of law promulgation for compulsory use of protective helmets on death following motorcycle accidents	<i>J Med Assoc Thai.</i> 1995;78:521–525	Retrospective review comparing the 2 yr before and after implementation of a motorcycle helmet law. Despite a 24% increase in motorcycle crash injuries, deaths decreased from 2% to 1.4%. The percentage of patients who died because of brain injury remained constant during the 4-yr period, ranging from 81% to 86%
II	Mock et al. ²¹	Injury prevention strategies to promote helmet use decrease severe head injuries at a Level I trauma center	<i>J Trauma.</i> 1995;39:29–35	Retrospective review of the trauma registry of a Level I trauma center over 8 yr comparing helmeted to nonhelmeted motorcycle riders. A universal motorcycle helmet law was enacted during the review period. The mortality rate decreased from 10% before enactment of the helmet law to 6% after, and severe head injury decreased from 20% of crash admissions to 9%
II	Kraus et al. ²²	The effect of the 1992 California motorcycle helmet use law on motorcycle crash fatalities and injuries	<i>JAMA.</i> 1994;272:1506–1511	Retrospective review of all motorcycle fatalities for the year before and after implementation of a mandatory motorcycle helmet law, based on death certificates and police reports. There was a 37.5% decrease in absolute number of fatalities statewide during the first year after enactment and with a decrease in the fatality ratio from 70.1 to 51.5 fatalities per 100,000 registrations in California
II	Fleming and Becker ²³	The impact of the Texas 1989 motorcycle helmet law on total and head-related fatalities, severe injuries, and overall injuries	<i>Med Care.</i> 1992;30:832–845	Retrospective review of all motorcycle fatalities in Texas from 1984 through 1990, with a helmet law being enacted in 1989. Overall mortality reduced from 12.1 to 9.8 per 10,000 registrations. As a percentage of the total annual deaths, head-related fatalities decreased from 56% to 31.5%

TABLE 1. References: Citation and Summary for EBR Articles on the Efficacy of Motorcycle Helmets 1990–2009 (continued)

Class	Authors	Title	Citation	Summary
II	Muelleman et al. ²⁴	Motorcycle crash injuries and costs: effect of a reenacted comprehensive helmet use law	<i>Am Emerg Med.</i> 1992;21:266–272	Retrospective review of 1 year before and after the reenactment of the motorcycle helmet law in Nebraska. Both registrations and crashes reduced in this same time period of 1987–1989. The overall death rate dropped from 13 to 8 per 10,000 registrations. The frequency and severity of brain injury were similar for the two time periods
Case-control studies				
II	Norvell and Cummings ²⁵	Association of helmet use with death in motorcycle crashes: a matched-pair cohort study	<i>Am J Epidemiol.</i> 2002;156:483–487	Matched pair cohort study using the NHTSA-FARS database for fatalities within 30 d of the crash that occurred from 1980 to 1998. 60.8% of the fatalities involved nonhelmeted riders. The RR of death for a helmeted rider was estimated to be 0.61 compared with a nonhelmeted rider, controlling for motorcycle and crash-related variables, age, gender, and seat position
II	Tsai et al. ²⁶	Case-control study of the effectiveness of different types of helmets for the prevention of head injuries among motorcycle riders in Taipei, Taiwan	<i>Am J Epidemiol.</i> 1995;142:974–981	Motorcycle riders crash admissions in 15 hospitals in Taipei, Taiwan for 3 mo in 1990. Cases were head-injured motorcycle crash victims. Controls were motorcycle crash victims with injuries other than head. Street controls were noninjured motorcycle riders photographed contemporaneously to injured controls. Head injury was involved in 41.5% of the 1,351 injuries during the study period
II	Gabella et al. ²⁷	Relationship of helmet use and head injuries among motorcycle crash victims in El Paso county, Colorado, 1998–1990	<i>Accid Anal Prev.</i> 1995;27:363–369	A county-based study of head injury after motorcycle crashes determined by traffic accident reports and the injury epidemiology program of Colorado. A case was a motorcycle rider with a head injury after a crash in a 2-yr period of time from 1989 to 1990. A control was a motorcycle crash in the same county and time period but without a head injury. Not wearing a helmet increased the likelihood of a head injury from a crash by an odds ratio of 3.34 relative to those riders wearing a helmet
Retrospective cross-sectional studies				
III	Croce et al. ²⁸	Impact of motorcycle helmets and state laws on society's burden: A national study	<i>Ann Surg.</i> 2009;250:390–394	Retrospective review from 2002 to 2007 of National Trauma Data Bank. Helmeted trauma patients had lower odds of death when compared with nonhelmeted: adjusted odds ratio of 0.84 (95% CI: 0.76–0.93). N = 75,644 helmeted patients had better Glasgow Coma Scale scores
III	Goslar et al. ²⁹	Helmet use and associated spinal fractures in motorcycle crash victims	<i>J Trauma</i> 2008;64:190–196	Retrospective review of trauma registry of one Level I trauma center from July 1, 2002, to June 30, 2005. Nonhelmeted rider was 2 times more likely to sustain a brain injury and 3 times more likely to die from the crash than a helmeted rider
III	Houston and Richardson ⁴⁴	Motorcycle safety and the repeal of universal helmet laws	<i>Am J Public Health.</i> 2007;97:2063–2069	Retrospective review of all 51 states from the NHTSA Fatal Accident Reporting System from 1975 to 2004. Mortality was analyzed controlling for other riders and state factors that affect motorcycle-related mortality: demographic, social, traffic safety, and population density across states. There was a 13.7% mortality reduction in states attributable to universal helmet law

TABLE 1. References: Citation and Summary for EBR Articles on the Efficacy of Motorcycle Helmets 1990–2009 (continued)

Class	Authors	Title	Citation	Summary
III	Coben et al. ⁴⁵	Characteristics of motorcycle-related hospitalizations: comparing states with different helmet laws	<i>Accid Anal Prev.</i> 2007;39:190–196	A 1 year retrospective review of the Healthcare Cost and Utilization Project (HCUP) registry. The HCUP state inpatient database (SID) contains data from 33 states and captures ~80% of all hospital discharges in the United States. 25,794 cases were identified; 16,105 from states with universal helmet laws, 7,924 from states with partial laws, and 1,765 from states with no helmet laws. Cases from states without universal helmet laws were 52% more likely to sustain the most severe forms of traumatic brain injury (RR: 1.52) and had a mortality rate 39% higher than those states with universal helmet
III	Lin et al. ³⁰	Survey of traumatic intracranial hemorrhage in Taiwan	<i>Surg Neurol.</i> 2006;66:S20–S25	Retrospective review of 90,250 head trauma case admitted to the hospital in Taiwan, excluding dead on arrivals and outpatients during an 8-yr period. 47% of all injuries were motorcycle related. Those not wearing a helmet had a 32.9% incidence of intracranial hemorrhage compared with 25.2% for those who were. The chance of having an intracranial hemorrhage was 1.4 times higher for those not wearing a helmet compared with those who did (odds ratio of 1.40)
III	Eastridge et al. ³¹	Economic impact of motorcycle helmets: from impact to discharge	<i>J Trauma.</i> 2006;60:978–984	Motorcyclists who crashed and found in NHTSA GES database for prehospital data and NTDB for hospital data from 1994 to 2002. There was less than half the risk of death or admission with a head injury for helmeted riders in comparison to nonhelmeted riders
III	Javouhey et al. ³²	Incidence and risk factors of severe traumatic brain injury resulting from road accidents: a population-based study	<i>Accid Anal Prev.</i> 2006;38:225–233	Motorcycle crashes were identified in a population-based road trauma registry in France from 1996 to 2001 to determine risks for severe head injury. A nonhelmeted rider had an 18-fold higher risk of having a severe head injury as defined by AIS score 2 or higher as compared with helmeted riders
III	Nakahara et al. ³³	Temporal distribution of motorcyclist injuries and risk of fatalities in relation to age, helmet use, and riding while intoxicated in Khon Kaen, Thailand	<i>Accid Anal Prev.</i> 2005;37:833–842	Retrospective review of 9,552 patients injured in motorcycle crashes in Thailand and transferred to the regional medical center over 5 yr. The case fatality rate was 0.25 for helmeted riders and 0.94 for nonhelmeted riders. The fatality was also stratified by alcohol intoxication and time of day of crash
III	Hundley et al. ³⁴	Non-helmeted motorcyclists: a burden to society? A study using the National Trauma Data bank	<i>J Trauma.</i> 2004;57:944–949	Retrospective review of motorcyclist crashes identified in the NTDB from 1994 to 2002. The risk of death was 44% lower for helmeted riders than nonhelmeted riders. 69.2% of all riders were listed as wearing a helmet
III	Brandt et al. ³⁵	Hospital cost is reduced by motorcycle helmet use	<i>J Trauma.</i> 2002;53:469–471	Retrospective review of motorcycle crashes in the trauma registry at a Level I trauma center from 1996 to 2000. The risk of death was 16% lower in helmeted riders as compared with nonhelmeted riders

TABLE 1. References: Citation and Summary for EBR Articles on the Efficacy of Motorcycle Helmets 1990–2009 (continued)

Class	Authors	Title	Citation	Summary
III	Peek-Asa et al. ³⁶	The prevalence of nonstandard helmet use and head injuries among motorcycle riders	<i>Accid Anal Prev.</i> 1999;31:229–233	Retrospective review comparing helmets that met the 1992 California Mandatory Helmet Use Law requirements to those which did not. One-third of riders whose crash report indicated a nonstandard helmet were killed, compared with 15.5% on nonhelmeted riders and 13.6% of helmeted riders. Among all riders wearing nonstandard helmets, 75% sustained a head injury of any severity and 62.5% sustained a head injury ≥ 3 . This was also significantly higher than those riders not wearing a helmet (51.9% and 37.4%) and those wearing a standard helmet (30.7% and 21.8%). The authors conclude that nonstandard helmets do not provide protection
III	Petridou et al. ³⁷	Fatalities from nonuse of seat belts and helmets in Greece: a nationwide appraisal. Hellemic Road, traffic police	<i>Accid Anal Prev.</i> 1998;30:87–91	Retrospective analysis of all motorcycle crashes in Greece for 1985 and 1994. No motorcycle laws were in effect during either period, and helmet use rates were similar for two periods. In 1985, 3.5% of helmeted riders died in motorcycle crashes compared with 4.3% of unhelmeted riders. In 1994, 2.9% of the helmeted riders died in motorcycle crashes compared with 5.1% of the unhelmeted riders. The authors estimate that 38% of all motorcycle deaths could potentially be avoided if all motorcycle riders wore helmets
III	Rowland et al. ³⁸	Motorcycle helmet use and injury outcome and hospitalization costs from crashes in Washington state	<i>Am J Public Health.</i> 1996;86:41–45	Retrospective review combining state crash information, hospital records, and death records for 1989 in Washington State. There were 2,090 crashes with 59 fatalities (2.8%). Motorcycle riders who were hospitalized after a crash were 2.9 times more likely to be hospitalized with a head injury and 3.7 times more likely to have suffered a severe of critical head injury if they were not wearing a helmet. Nonhelmeted riders had 1.62 times the risk of a fatal crash compared with the helmeted riders
III	Orsay et al. ³⁹	Motorcycle trauma in the State of Illinois: analysis of the Illinois department of public health trauma registry	<i>Ann Emerg Med.</i> 1995;28:455–460	Retrospective review of the Illinois trauma registry for 18 mo comparing helmeted with unhelmeted motorcycle riders. Of 1,231, 18% were helmeted and 56% were not. 30% of the helmeted riders sustained head injuries compared with 51% for unhelmeted riders. The unhelmeted riders also had more severe head injuries
III	Rutledge and Stutts ⁴⁰	The association of helmet use with the outcome of motorcycle crash injury when controlling for crash/injury severity	<i>Accid Anal Prev.</i> 1993;25:347–353	Retrospective analysis of the North Carolina state trauma registry over 3.5 yr, comparing 892 patients. Helmet information was available for 460 (51.6%). Head injuries with AIS score 2 to 5 occurred in 53% of unhelmeted riders compared with 28% of helmeted riders
III	Braddock et al. ⁴¹	A population-based study of motorcycle injury and costs	<i>Ann Emerg Med.</i> 1992;21:273–278	Retrospective review of 112 motorcycle deaths in Connecticut during a 2-yr period. The fatality rate for unhelmeted riders was 26.7 per 1,000 crashes compared with 7.9 for helmeted riders
III	Offner et al. ⁴²	The impact of motorcycle helmet use	<i>J Trauma.</i> 1992;32:636–642	Retrospective review of admitted riders after motorcycle crash at one Level I trauma center. The trauma registry identified the cases from 1985 to 1990. Head injury was reduced by 68% when wearing a helmet, whereas there was no impact on death
III	Shankar et al. ⁴³	Helmet use, patterns of injury, medical outcome and costs among motorcycle drivers in Maryland	<i>Accid Anal Prev.</i> 1992;24:385–396	Retrospective review of all motorcycle crashes in the State of Maryland for one year, 1987 to 1988. Riders wore a helmet in 35% of the crashes

registrations²³ (RR: 2.19, $p < 0.05$). In Pennsylvania, after the repeal of the helmet law, the head injury-related death rate per 10,000 motorcycle registrations increased by 36.9%⁶ (1.6 to 2.2 fatalities per 10,000 registrations, $p < 0.05$).

Do Nonhelmeted Riders in Comparison With Helmeted Riders Incur Higher or Lower Rates of Nonlethal Head Injury or Severity of Nonlethal Head Injury After a Motorcycle Crash?

All 25 of the studies that had prevalence of a nonfatal head injury as an outcome had a significantly lower incidence for helmeted riders, after reenactment or before repeal of a helmet law. One of the prospective studies that observed motorcycle riders to determine the incidence of head injury-associated crashes showed that nonhelmeted riders sustained a head injury more than twice the rate of helmeted riders¹ (4.7% vs. 1.9%). Three studies showed an ORs of a head injury after a crash to vary from 2.3 times to 4.4 times higher for nonhelmeted riders when compared with helmeted riders^{3,4} ($p < 0.05$). Ouellet and Kasantikul showed an ORs of sustaining a serious injury to be 3.5 times higher ($p < 0.05$) for nonhelmeted riders.

Retrospective studies confirm the consistent findings of the prospective studies that head injury is uniformly more frequent and more severe when sustaining a crash without a helmet. The magnitude of the increased prevalence of a head injury after a nonhelmeted crash is as high as 4.3 times to a low of 1.7 times higher than after a helmeted crash in nine retrospective cross-sectional studies. However, for severe head injuries, most commonly defined as an Abbreviated Injury Scale score ≥ 2 , the magnitude of the estimate is uniformly larger. For three retrospective studies, the ORs of a severe head injury were 18.1 (12.5–25.3), 4.4 (2.58–7.37), and 3.7 (1.9–7.3), respectively.^{13,32,38} Lin et al. showed a 41% increase in trauma-induced brain hemorrhage, including subarachnoid, subdural, and epidural hematomas when a rider was nonhelmeted during a crash.

The case-control studies showed an adjusted OR of 0.26 (0.14–0.48) and 0.41 (0.21–0.81), which represents a significant protective effect of wearing a helmet in reducing the incidence of a head injury after a motorcycle crash.^{26,27} In four retrospective studies in which universal motorcycle helmet laws were enacted, the incidence of nonlethal head injury decreased from 29% to reductions of 63%.

In one study in which the motorcycle law was repealed, the incidence of hospitalizations for head injury increased by 42%, from 15.4 to 21.9 per 10,000 motorcycle registrations ($p < 0.05$).⁶

Do Geographical Areas (i.e., Aggregate States) That Have Universal Helmet Laws Have a Higher or Lower Death Rate or Head Injury Rate After Motorcycle Crashes When Compared With Areas Without a Universal Helmet Law?

Two studies compared regions with and without helmet laws. Houston and Richardson developed a model for motor-

cycle crash fatality as a function of the state's helmet law while controlling for minimal legal drinking age, partial versus full helmet laws, 0.08 blood alcohol concentration law, roads with maximum speed limit of 65, daily temperature, daily percent precipitation, gender, age, per capita income, per capita alcohol consumption, and population density. Their results showed 1.3 fewer fatalities per 10,000 motorcycle registrations in helmet law states that can be attributed in their model to the presence of the helmet law. Furthermore, using hospital discharge data from 33 states, Coben et al. calculated a RR of 0.65 ($p < 0.05$) and 0.72 ($p < 0.05$), respectively, for severe head injury and fatalities in states with universal helmet laws when compared with states without universal helmet laws.

STUDY LIMITATIONS

The main limitation of these uncontrolled and observational studies involves the collection and incorporation in the analysis of potential confounders for the outcomes studied. The wearing of helmets is associated with multiple factors, many of which have also been shown to be associated with the incidence and severity of crashes. Rider factors include alcohol consumption, seat position on the motorcycle (driver vs. passenger), age, and gender. There are also environmental factors such as weather, time of day; other policy factors such as speed limits and DUI laws; and other intrinsic motorcycle factors such as the size and type of motorcycle itself (the potential kinetic energy of the crash) also contribute to motorcycle crash occurrence and severity and ultimately crash consequences for the rider. Unfortunately, many of these factors are not easy to reliably measure on a crash-to-crash basis, and therefore, only nine studies, in part, adjusted for at least a portion of these factors. There were other studies that stratified the study group by various factors but did not control for them in their analysis. The majority of the studies did not control for any potential confounders. A second methodological concern is selection bias. The subjects in these studies were not selected randomly, except for the one cohort study that chose the students randomly. There were missing data, and no studies had information on those "not chosen" to confirm that they were the same as those included in the study.

A large number of the studies reported fatalities and prevalence of head injuries as a rate, a function of either the number of motorcycle registrations or the number of crashes. This eliminates the misinterpretation of changes in absolute fatalities that reflect changes in the number of riders or the number of riders who crash. However, changes in registrations may not be an accurate denominator to reflect the active riders who are engaging in motorcycle usage and, therefore, may obscure difference. Perhaps, vehicle miles driven are a better denominator for this purpose for the same reason it is used in motor vehicle collision fatality rates. A good example is in the study by Bledsoe and Li, in which registrations decreased and thereby crashes decreased, but the fatality rate increased. However, perhaps because of the decreases, the absolute increase seems minimal and statistically not significant.

The variation in helmet usage in these studies was substantial. Internationally, Conrad et al. reported that the helmet usage was as high as 89% in Indonesia, whereas LaTorre et al. reported only a 12% rate of helmet usage in Italy. Nationally, in America, Brandt et al. reported in their study from Michigan a prevalence of 80.5% of riders wearing a helmet during a crash, whereas a study conducted in Illinois by Kelly et al. reported a 14.6% prevalence of helmets in riders involved in crashes. Without nonrandom selection of these studies, the variation in helmet usage can also impact the results obtained.

The studies reviewed here discuss only the use of helmets. However, the issue of misuse as noted by Peek-Asa et al. in his 1999 study in Thailand can also be a major factor in postcrash injury. Further study is required to better understand and to quantify this problem. Furthermore, in these studies, we did not explore in depth the impact of partial helmet laws, although the studies by Houston and Richardson and Tsai SY attempted to address this issue. Interestingly, Houston and Richardson found that partial helmet laws showed no improvement in outcomes over states with no helmet laws.

SUMMARY

- A. The use of motorcycle helmets decreases the overall death rate of motorcycle crashes when compared with nonhelmeted riders.
- B. The use of motorcycle helmets decreases the incidence of lethal head injury in motorcycle crashes when compared with nonhelmeted riders.
- C. The use of motorcycle helmets decreases the severity of nonlethal head injury in motorcycle crashes when compared with nonhelmeted riders.
- D. Mandatory universal helmet laws reduce mortality and head injury in geographical areas with the law when compared with areas without it.

REFERENCES

1. Lin MR, Hwang HF, Kuo NW. Crash severity, injury patterns, and helmet use in adolescent motorcycle riders. *J Trauma*. 2001;50:24–30.
2. Ouellet JV, Kasantikul V. Motorcycle helmet effect on a per-crash basis in Thailand and the United States. *Traffic Inj Prev*. 2006;7:49–54.
3. LaTorre G, Bertazzoni G, Zotta D, Van Beeck E, Ricciardi G. Epidemiology of accidents among users of two-wheeled motor vehicles. A surveillance study in two Italian cities. *Eur J Public Health*. 2002;12:99–103.
4. Conrad P, Bradshaw YS, Lamsudin R, Kasniyah N, Costello C. Helmets, injuries and cultural definitions: motorcycle injury in urban Indonesia. *Accid Anal Prev*. 1996;28:193–200.
5. Kelly P, Sanson T, Strange G, Orsay E. A prospective study of the impact of helmet usage on motorcycle trauma. *Ann Emerg Med*. 1991;20:852–856.
6. Mertz KJ, Weiss HB. Changes in motorcycle-related head injury deaths, hospitalizations, and hospital charges following repeal of Pennsylvania's mandatory motorcycle helmet law. *Am J Public Health*. 2008;98:1464–1467.
7. O'Keeffe T, Dearwater SR, Gentilello LM, Cohen TM, Wilkinson JD, McKenney MM. Increased fatalities after motorcycle helmet law repeal: is it all because of lack of helmets? *J Trauma*. 2007;63:1006–1009.
8. Kyrchenko SY, McCartt AT. Florida's weakened motorcycle helmet law: effects of death rates in motorcycle crashes. *Traffic Inj Prev*. 2006;7:55–60.
9. Bledsoe GH, Li G. Trends in Arkansas motorcycle trauma after helmet law repeal. *South Med J*. 2005;98:436–440.
10. Ho EL, Haydel MJ. Louisiana motorcycle fatalities linked to statewide helmet law repeal. *J La State Med Soc*. 2004;156:151–157.
11. Ichikawa M, Chadbunchachai W, Marui E. Effect of the helmet act for motorcyclists in Thailand. *Accid Anal Prev*. 2003;35:183–189.
12. Servadei F, Begliomini C, Gardini E, Giustini M, Taggi F, Kraus J. Effect of Italy's motorcycle helmet law on traumatic brain injuries. *Inj Prev*. 2003;9:257–260.
13. Christian WJ, Carroll M, Meyer K, Vitaz TW, Franklin GA. Motorcycle helmets and head injuries in Kentucky, 1995–2000. *J Ky Med Assoc*. 2003;101:21–26.
14. Auman KM, Kufera JA, Ballesteros MF, Smialek JE, Dischinger PC. Autopsy study of motorcyclist fatalities: the effect of the 1992 Maryland motorcycle helmet use law. *Am J Public Health*. 2002;92:1352–1355.
15. Ferrando J, Plasència A, Orós M, Borrell C, Kraus JF. Impact of a helmet law on two wheel motor vehicle crash mortality in a southern European urban area. *Inj Prev*. 2000;6:184–188.
16. Chiu WT, Kuo CY, Hung CC, Chen M. The effect of the Taiwan motorcycle helmet use law on head injuries. *Am J Public Health*. 2000;90:793–796.
17. Tsai MC, Hemenway D. Effect of the mandatory helmet law in Taiwan. *Inj Prev*. 1999;5:290–291.
18. Peek-Asa C, Kraus JF. Estimates of injury impairment after acute traumatic injury in motorcycle crashes before and after passage of a mandatory helmet use law. *Ann Emerg Med*. 1997;29:630–636.
19. Kraus JF, Peek C. The impact of two related prevention strategies on head injury reduction among nonfatally injured motorcycle riders, California, 1991–1993. *J Neurotrauma*. 1995;12:873–881.
20. Panichaphongse V, Watanakajorn T, Kasantikul V. Effects of law promulgation for compulsory use of protective helmets on death following motorcycle accidents. *J Med Assoc Thai*. 1995;78:521–525.
21. Mock CN, Maier RV, Boyle E, Pilcher S, Rivara FP. Injury prevention strategies to promote helmet use decrease severe head injuries at a level I trauma center. *J Trauma*. 1995;39:29–35.
22. Kraus JF, Peek C, McArthur DL, Williams A. The effect of the 1992 California motorcycle helmet use law on motorcycle crash fatalities and injuries. *JAMA*. 1994;272:1506–1511.
23. Fleming NS, Becker ER. The impact of the Texas 1989 motorcycle helmet law on total and head-related fatalities, severe injuries, and overall injuries. *Med Care*. 1992;30:832–845.
24. Muellemann RL, Mlinek EJ, Collicott PE. Motorcycle crash injuries and costs: effect of a reenacted comprehensive helmet use law. *Ann Emerg Med*. 1992;21:266–272.
25. Norvell DC, Cummings P. Association of helmet use with death in motorcycle crashes: a matched-pair cohort study. *Am J Epidemiol*. 2002;156:483–487.
26. Tsai YJ, Wang JD, Huang WF. Case-control study of the effectiveness of different types of helmets for the prevention of head injuries among motorcycle riders in Taipei, Taiwan. *Am J Epidemiol*. 1995;142:974–981.
27. Gabella B, Reiner KL, Hoffman RE, Cook M, Stallones L. Relationship of helmet use and head injuries among motorcycle crash victims in El Paso County, Colorado, 1998–1990. *Accid Anal Prev*. 1995;27:363–369.
28. Croce MA, Zarza BL, Manotti LJ, Fabian TC. Impact of motorcycle helmets and state laws on society's burden: a national study. *Ann Surg*. 2009;250:390–394.
29. Goslar PW, Crawford NR, Petersen SR, Wilson JR, Harrington T. Helmet use and associated spinal fractures in motorcycle crash victims. *J Trauma*. 2008;64:190–196; discussion 196.
30. Lin JW, Tsai SH, Tsai WC, et al. Survey of traumatic intracranial hemorrhage in Taiwan. *Surg Neurol*. 2006;66:S20–S25.
31. Eastridge BJ, Shafi S, Minei JP, Culica D, McConnel C, Gentilello L. Economic impact of motorcycle helmets: from impact to discharge. *J Trauma*. 2006;60:978–984.
32. Javouhey E, Guérin AC, Chiron M. Incidence and risk factors of severe traumatic brain injury resulting from road accidents: a population-based study. *Accid Anal Prev*. 2006;38:225–233.
33. Nakahara S, Chadbunchachai W, Ichikawa M, Tipsuntornsak N, Wakai S. Temporal distribution of motorcyclist injuries and risk of fatalities in

- relation to age, helmet use, and riding while intoxicated in Khon Kaen, Thailand. *Accid Anal Prev.* 2005;37:833–842.
34. Hundley JC, Kilgo PD, Miller PR, et al. Nonhelmeted motorcyclists: a burden to society? A study using the National Trauma Data bank. *J Trauma.* 2004;57:944–949.
 35. Brandt MM, Ahrns KS, Corpron CA, Franklin GA, Wahl WL. Hospital cost is reduced by motorcycle helmet use. *J Trauma.* 2002;53:469–471.
 36. Peek-Asa C, McArthur DL, Kraus JF. The prevalence of non-standard helmet use and head injuries among motorcycle riders. *Accid Anal Prev.* 1999;31:229–233.
 37. Petridou E, Skalkidou A, Ioannou N, Trichopoulos D. Fatalities from non-use of seat belts and helmets in Greece: a nationwide appraisal. Hellenic Road Traffic Police. *Accid Anal Prev.* 1998;30:87–91.
 38. Rowland J, Rivara F, Salzberg P, Soderberg R, Maier R, Koepsell T. Motorcycle helmet use and injury outcome and hospitalization costs from crashes in Washington state. *Am J Public Health.* 1996;86:41–45.
 39. Orsay E, Holden JA, Williams J, Lumpkin JR. Motorcycle trauma in the state of Illinois: analysis of the Illinois Department of Public Health Trauma Registry. *Ann Emerg Med.* 1995;26:455–460.
 40. Rutledge R, Stutts J. The association of helmet use with the outcome of motorcycle crash injury when controlling for crash/injury severity. *Accid Anal Prev.* 1993;25:347–353.
 41. Braddock M, Schwartz R, Lapidus G, Banco L, Jacobs L. A population-based study of motorcycle injury and costs. *Ann Emerg Med.* 1992;21:273–278.
 42. Offner PJ, Rivara FP, Maier RV. The impact of motorcycle helmet use. *J Trauma.* 1992;32:636–641; discussion 641–642.
 43. Shankar BS, Ramzy AI, Soderstrom CA, Dischinger PC, Clark CC. Helmet use, patterns of injury, medical outcome, and costs among motorcycle drivers in Maryland. *Accid Anal Prev.* 1992;24:385–396.
 44. Houston DJ, Richardson LE Jr. Motorcycle safety and the repeal of universal helmet laws. *Am J Public Health.* 2007;97:2063–2069.
 45. Coben JH, Steiner CA, Miller TR. Characteristics of motorcycle-related hospitalizations: comparing states with different helmet laws. *Accid Anal Prev.* 2007;39:190–196.