

Burden of hospitalizations for bicycling injuries by motor vehicle involvement: United States, 2002 to 2009

Cara Hamann, PhD, MPH, Corinne Peek-Asa, PhD, MPH, Charles F. Lynch, PhD, Marizen Ramirez, PhD, and James Torner, PhD, Iowa City, Iowa

BACKGROUND:	Bicycling and bicycling injuries have increased during the past decade in the United States, but research on the extent and outcomes of injuries has lagged behind. This study aimed to estimate the current burden of injury from bicycling injury hospitalizations by motor vehicle crash (MVC) and non-MVC in the United States.
METHODS:	We included patients with primary or secondary diagnosis e-codes corresponding to MVC or non-MVC bicycle injury, drawn from the US Nationwide Inpatient Sample (2002–2009). Descriptive statistics, linear regression, and logistic regression were used to examine patient and hospital characteristics (length of stay, total charges, nonroutine discharges, and demographics) associated with hospitalizations for bicycling injuries by motor vehicle involvement.
RESULTS:	On average, from 2002 to 2009, there were an annually estimated 6,877 MVC and 18,457 non-MVC bicycle injury hospitalizations nationwide. This translates to more than \$1 billion of hospital charges overall, \$425 million for MVC and \$588 million for non-MVC per year. After controlling for covariates, MVC bicycling injury hospitalizations had an average length of stay that was 2 days longer (95% confidence interval [CI], 1.8–2.3) and an average hospitalization charge of \$23,424 more (95% CI, \$21,360–\$25,538) than non-MVC. Those with MVC bicycling injuries were more than two times as likely to have a nonroutine hospital discharge than non-MVC (odds ratio, 2.22; 95% CI, 2.06–2.39).
CONCLUSION:	The burden of injury from bicycle crashes is large overall, and MVC-related bicycling injuries result in longer hospital stays, higher costs, and more nonroutine hospital discharges than non-MVC, despite the fact that non-MVC hospitalizations are more frequent and result in higher total charges, overall. To have the greatest impact on reducing the burden of injury from bicycle crashes, educational interventions, policy, and infrastructure changes should include all age groups and prioritize reducing bicycle–motor vehicle collisions. (<i>J Trauma Acute Care Surg.</i> 2013;75: 871–877. Copyright © 2013 by Lippincott Williams & Wilkins)
LEVEL OF EVIDENCE:	Epidemiologic study, level III.
KEY WORDS:	Traffic injury; bicycle; vulnerable road users; crash.

Bicycling in United States has increased during the past two decades for both recreational and transportation purposes.^{1–3} The proportion of people who bike to work increased by 64% from 1990 to 2009, and the number of bicycle facilities (such as bicycle lanes) per square mile increased by 29% in the 2 years from 2010 to 2012.⁴ These changes can be attributed to increasing individual and community priorities of physical fitness and environmentally conscious transportation.⁴

Bicycle crashes and injuries are a public health priority because they are preventable, there are a large number of injuries and fatalities each year, and the number of vulnerable road users is increasing because bicycling is increasing. Bicyclists are identified as vulnerable road users owing to a lack of protection within a vehicle and differences in mass and speed compared with motor vehicles,^{5,6} which leads to fatality and injury rates that are higher than passenger car occupants.^{2,5} For example, one nationally representative study found that bicyclists had 2.3 times as many fatalities and 1.8 times

as many nonfatal injuries as the motor vehicle occupants, per 100 million person trips,⁵ while others have reported bicyclists have up to 11 times the number of fatalities per billion kilometers traveled than passenger vehicle occupants.²

The existing evidence regarding bicycle-related injuries has many shortcomings when attempting to estimate the current national burden. Much of the a priori research has focused on children, helmet use, limited geographic regions, and areas outside the United States or was conducted more than a decade ago.^{7–12} Previous studies showed that children and males were at the highest risk for injury and death from bicycle crashes.^{8,10} However, the bicyclist fatality rates have changed considerably since 1975, when 67% of deaths were those 16 years or younger. In 2000, this age group represented 28% of deaths, and, in 2010, represented only 11%.¹³ Past research findings may not be generalizable to current bicycling populations, particularly given the bicycle-specific roadway infrastructure changes implemented in the United States throughout the past decade. Current research is needed to identify the incidence, burden, and characteristics of modern bicycling-related injuries.

One of the most important and established factors associated with bicycle crash severity is whether the bicyclist collides with a motor vehicle (MVC) or not (non-MVC). US studies have shown that bicycle MVCs are more severe and result in more deaths than non-MVCs,^{8,11,14} although these

Submitted: May 28, 2013, Revised: July 5, 2013, Accepted: July 9, 2013.

From the University of Iowa, Iowa City, Iowa.

Address for reprints: Cara Hamann, PhD, MPH, Injury Prevention Research Center, The University of Iowa, 200 Newton Rd, 2186 WL, Iowa City, IA 52242; email: cara-hamann@uiowa.edu.

DOI: 10.1097/TA.0b013e3182a74a3f

findings are either limited in scope, dated, or strictly descriptive. For example, Rivara et al.⁸ found increased risk of fatalities and severe injuries when bicycle crashes involved motor vehicles, but this study was restricted to the city of Seattle, Washington, and was conducted 15 years ago. A recent report examined bicycle-related hospitalizations and also found worse outcomes for MVCs, but they only looked at 1 year of data (2009) and did not adjust for potential confounding variables.¹⁴

With increases in bicycling miles traveled and changes in the bicycle roadway infrastructure, it is important to understand the current burden and outcomes from bicycling injuries to support injury prevention efforts. Therefore, the aim of the current study was to estimate the recent national burden of injury (length of stay [LOS], hospital charges, and nonroutine discharges) from bicycle crashes resulting in hospitalizations for all ages, stratified by crash type (MVC and non-MVC). We hypothesized that the burden is large overall and larger for MVC compared with non-MVC.

PATIENTS AND METHODS

Study Design and Setting, Data Source

The data source for this retrospective study was the Nationwide Inpatient Sample (NIS), years 2002 through 2009. The NIS is a nationally representative database of all-payer inpatient care in the United States and is part of the Healthcare Cost and Utilization Project, maintained by the Agency for Healthcare Research and Quality.¹⁵ The NIS uses an algorithm that takes into consideration five different hospital characteristics (ownership/control, bed size, teaching status, urban/rural location, and region) to create a weight variable, available in the data set, which can be used to estimate the total number of hospitalizations nationally.

Top procedures and diagnoses were aggregated by using Clinical Classifications Software (CCS), which takes the thousands of diagnosis and procedure codes from DRG International Classification of Diseases—9th Rev.—Clinical Modification (ICD-9-CM) and collapses them into more meaningful and useful categories for describing the data.¹⁶ Hospitalizations with primary or secondary external cause of injury CCS e-codes 2607 and 2608 associated with pedal cyclist injuries were used to identify the study sample. The CCS e-code 2607 relates to crashes involving motor vehicles, and the following ICD-9-CM e-codes within 2607 that include bicyclists are E810.6, E811.6, E812.6, E813.6, E814.6, E815.6, E816.6, E817.6, and E818.6. CCS e-code 2608 relates to bicyclist crashes that do not involve motor vehicles and includes the following ICD-9-CM codes: E800.3, E801.3, E802.3, E803.3, E804.3, E805.3, E806.3, E807.3, E820.6, E821.6, E822.6, E823.6, E824.6, E825.6, E826.1, and E826.9.

Main Outcome Measures

The main outcomes of interest were LOS (in days), total hospital charges (in US dollars), and nonroutine discharge. Hospital charges were adjusted for inflation to the year 2009 inflation rates for in-hospital care.¹⁷ Nonroutine discharge included death and transfer to nursing facility, short-term hospital, or home health care.

Patient and Hospital Characteristics

Patient characteristics included age, race, sex, insurance type, and Injury Severity Score (ISS). ISS ranges from 0 (least severe) to 75 (most severe) and is based on a scoring system that accounts for multiple injuries to a patient, divides them among six body regions, and then creates a total score based on the three most severely injured regions.¹⁸ ISS for this study was obtained using a software program called ICDMAP-90,¹⁹ which derived ISS from the primary and secondary ICD-9-CM diagnoses.

Because of missing values on race/ethnicity, 22% of cases were coded as unknown and retained for that variable, to avoid dropping them from the regression models. Missing values for all other variables were left out of analyses, with little impact because all had 2% or less missing.

Hospital characteristics serving as covariates included bed size, region, and hospital location (urban/rural). Before 2004, all metropolitan statistical areas were categorized as urban, while all non-metropolitan statistical areas were rural.²⁰ From 2004 to present, classifications were categorized by core-based statistical areas, where metropolitan was considered urban and micropolitan (population of 10,000 to 50,000) or noncore was considered rural, which resulted in slightly fewer rural designations for hospitals.²⁰

Analysis

Actual counts and national estimates of frequencies and percentages were tabulated for patient and hospital characteristics. National estimates were calculated using discharge-level weights that are provided by the Healthcare Cost and Utilization Project and available in the NIS data set.¹⁵ A Rao-Scott χ^2 test, which is a version of the Pearson χ^2 test that corrects for the clustered sample design, was conducted to test for an association between MVC and year.²¹

Unadjusted logistic and linear regression models were used to evaluate the impact of motor vehicle involvement and potential confounders (sex, age, race/ethnicity, source of payment, hospital location, hospital bed size, and hospital region) on outcomes (LOS, total charges, and nonroutine discharge). ISS was not included as a covariate in any of the models because it is considered an intermediate in the causal pathway between the exposure (MVC/non-MVC) and the outcomes, and therefore, inclusion would prevent the detection of the relationship between exposures and outcomes.

Multiple linear regression was used to examine the impact of motor vehicle involvement on LOS and total hospital charges. These adjusted models estimated LOS (in days) and hospital charges (in US dollars) for MVC- and non-MVC-related injury hospitalizations. The total hospital charges model included LOS as a covariate to determine the difference in total charges between MVC and non-MVC that were not a result of the LOS itself. Multivariable logistic regression was used to examine the impact of MVC involvement on the risk of nonroutine hospital discharge.

Log transformations were performed on hospital charges and LOS to address the skewness of the data and to stabilize the variability of residuals in the models. Cook's D statistics were used to identify influential observations in model diagnostics. A cutoff of $D_i > 4/n$ (where n = sample size) was used to remove

TABLE 1. Characteristics of Bicycling Injury Hospitalizations by Motor Vehicle Traffic Involvement, NIS, 2002 to 2009, United States (n = 41,469)

	NIS			National Estimate*				
	Total	MVC	Non-MVC	Total	MVC		Non-MVC	
	n = 41,469	n = 11,260	n = 30,209	n = 202,674	n = 55,018		n = 147,656	
	n	n	n	n	n	%	n	%
Year								
2002	4,918	1,345	3,573	23,724	6,560	11.9	17,164	11.6
2003	5,370	1,615	3,755	26,133	7,831	14.2	18,301	12.4
2004	5,430	1,484	3,946	26,102	7,091	12.9	19,011	12.9
2005	4,936	1,249	3,687	24,014	6,041	11.0	17,973	12.2
2006	4,913	1,381	3,532	24,124	6,743	12.3	17,381	11.8
2007	4,944	1,328	3,616	24,191	6,581	12.0	17,610	11.9
2008	5,445	1,430	4,015	26,576	6,933	12.6	19,644	13.3
2009	5,513	1,428	4,085	27,810	7,238	13.2	20,572	13.9
Sex**								
Male	32,332	9,466	22,866	157,994	46,247	84.1	111,746	75.7
Female	8,347	1,678	6,669	40,759	8,204	14.9	32,555	22.0
Age**								
0–10	5,620	1,204	4,416	27,393	5,851	10.6	21,542	14.6
11–17	8,024	2,358	5,666	39,243	11,529	21.0	27,714	18.8
18–30	5,260	1,849	3,411	25,845	9,105	16.5	16,740	11.3
31–50	11,292	3,400	7,892	55,087	16,589	30.2	38,498	26.1
51–70	8,754	1,995	6,759	42,843	9,757	17.7	33,086	22.4
≥71	2,269	427	1,842	11,012	2,054	3.7	8,958	6.1
Race/ethnicity								
White	22,299	5,249	17,050	108,814	25,617	46.6	83,198	56.3
Black	3,383	1,475	1,908	16,414	7,132	13.0	9,282	6.3
Other	6,531	2,519	4,012	31,923	12,335	22.4	19,589	13.3
Unknown	9,256	2,017	7,239	45,523	9,935	18.1	35,588	24.1
Discharge disposition								
Routine or discharge alive	33,883	8,598	25,285	165,636	42,040	76.4	123,596	83.7
Skilled nursing facility/home health care/other facility	5,913	1,960	3,953	28,879	9,579	17.4	19,299	13.1
Short-term hospital	692	226	466	3,395	1,100	2.0	2,294	1.6
Died	508	347	161	2,454	1,675	3.0	778	0.5
Against medical advice/unknown	473	129	344	2,312	623	1.1	1,689	1.1
Payer information**								
Medicare and Medicaid	10,970	2,576	8,394	53,660	12,569	22.8	41,091	27.8
Private, including HMO	21,771	5,720	16,051	106,660	28,073	51.0	78,587	53.2
Self-pay/no charge	6,063	2,080	3,983	29,498	10,113	18.4	19,385	13.1
Other	2,545	836	1,709	12,270	4,027	7.3	8,242	5.6
Hospital location**								
Rural	16,139	3,178	12,961	77,940	15,213	27.7	62,727	42.5
Urban	25,244	8,057	17,187	124,329	39,688	72.1	84,642	57.3
Hospital bed size**								
Small	4,071	839	3,232	19,107	3,851	7.0	15,255	10.3
Medium	9,044	2,155	6,889	44,032	10,512	19.1	33,520	22.7
Large	28,268	8,241	20,027	139,130	40,538	73.7	98,592	66.8
Hospital region								
Northeast	8,457	2,640	5,817	43,589	13,692	24.9	29,897	20.2
Midwest	6,754	1,535	5,219	33,871	7,691	14.0	26,180	17.7
South	12,903	3,797	9,106	60,651	17,693	32.2	42,958	29.1
West	13,355	3,288	10,067	64,564	15,942	29.0	48,622	32.9

*Weighted to discharges from all US community nonrehabilitation hospitals.

**Sums that do not total 41,469 for NIS sample are due to missing data, and sums that do not add to 202,674 for national estimate are due to rounding off. HMO, health maintenance organization.

observations that did not fit with the regression models. The LOS and hospital charges linear regression models were based on reduced samples, with 5.17% and 5.88% of influential observations removed, based on model diagnostics. SAS Survey Procedures (e.g., PROC SURVEYLOGISTIC) in version 9.2 were used to account for the complex study design by taking into account clustering variables and sample weights.²²

This study was reviewed and approved by the University of Iowa Institutional Review Board. All data were deidentified.

RESULTS

Hospitalization Characteristics Stratified by MVC Involvement

For 2002 through 2009, the NIS captured 11,260 MVC and 30,209 non-MVC-bicycling injury hospitalizations (Table 1). This translates to a nationwide estimate of 6,877 MVC-related and 18,457 non-MVC-bicycle injury hospitalizations annually. The highest number of MVC-related hospitalizations occurred in 2003 (national estimate, 7,831), while the most non-MVC

hospitalizations were in 2009 (national estimate, 20,572). There was not a significant difference in frequency between years (Rao-Scott χ^2 $p = 0.24$).

Males made up a majority of the hospitalizations overall (78.0%) and had more MVC-related (84.1%) than non-MVC-related hospitalizations (75.7%). A majority of hospitalizations, overall, were adults (≥ 18 years, 66.5%) and non-MVC (72.8%). The youngest (0–10 years) and oldest (51–70 years and ≥ 71 years) age groups made up larger proportions of non-MVC than MVC (43.1% vs. 32%), while the older children (11–17 years) and middle-age groups (18–30 years and 31–50 years) were opposite, with larger proportions of MVC than non-MVC (67.7% vs. 56.2%).

For all races, a majority of hospitalizations were caused by non-MVCs, with whites making up the largest proportions across both categories. Black and “other” (includes Hispanic, Asian, and Pacific Islander) made up 13.0% and 22.4% of MVC but only 6.3% and 13.3% of non-MVC bicycling hospitalizations. Conversely, whites accounted for a greater proportion of MVC than non-MVC (56.3% vs. 46.6%).

TABLE 2. Injury Characteristics for Bicycle-Related Injury Hospitalizations by Motor Vehicle Collision Involvement, NIS, 2002 to 2009

	MVC (n = 55,018)*		Non-MVC (n = 147,656)*	
	National Estimate*		National Estimate*	
	n	95% CI	n	95% CI
Mean ISS	10.41	10.10–10.72	Mean ISS	7.8 7.66–7.97
	n	%	n	%
Top 10 Principal Diagnoses			Top 10 Principal Diagnoses	
Fracture of the lower limb	12,982	23.60	Fracture of the upper limb	26,236 17.77
Other intracranial injury	10,169	18.48	Fracture of the lower limb	20,533 13.91
Other fractures	5,270	9.58	Crushing injury or internal injury	16,199 10.97
Concussion	4,598	8.36	Other intracranial injury	17,498 11.85
Crushing injury or internal injury	3,958	7.19	Fracture of the neck of femur	11,923 8.07
Fracture of the upper limb	3,705	6.73	Other fractures	10,490 7.10
Skull and face fractures	3,123	5.68	Skull and face fractures	8,906 6.03
Other injuries and conditions due to external causes	1,881	16.12	Concussion	8,661 5.87
Open wounds of the head, neck, and trunk	1,635	2.97	Open wounds of the head, neck, and trunk	3,185 2.16
Superficial injury; contusion	1,617	16.8	Other injuries and conditions due to external causes	2,981 2.02
Top 10 Principal Procedures			Top 10 Principal Procedures	
Treatment of fracture or dislocation of the lower extremity (other than the hip or femur)	8,223	14.95	Treatment of fracture or dislocation of the lower extremity (other than the hip or femur)	14,335 9.71
Suture of skin and subcutaneous tissue	4,277	7.77	Treatment of fracture or dislocation of the hip or femur	12,958 8.78
Treatment of fracture or dislocation of the hip or femur	4,049	7.36	Treatment of fracture or dislocation of the radius or ulna	12,602 8.53
Other fracture and dislocation procedure	1,934	3.52	Other fracture or dislocation procedure	11,210 7.59
CT scan	1,755	3.19	Suture of skin and subcutaneous tissue	5,749 3.89
Debridement of wound; infection or burn	1,294	2.35	Closed chest drainage	3,093 2.09
Continuous mechanical ventilation less than 96 h	1,194	2.17	Treatment of facial fracture or dislocation	3,022 2.05
Treatment of fracture or dislocation of the radius or ulna	1,138	2.07	Hip replacement, total or partial	2,285 1.55
Traction, splints, or other wound care	1,112	2.02	Debridement of wound; infection or burn	2,280 1.54
Other OR therapeutic nervous system procedures	1,011	1.84	CT scan	2,342 1.59

*Weighted to discharges from all US community, nonrehabilitation hospitals. Sums that do not add to total are due to rounding off.

A majority of both MVC (76.4%) and non-MVC (83.7%) hospitalizations were routine discharge or discharge alive, but more MVC patients were dead at discharge than non-MVC patients (3.1% vs. 0.5%). More than half of the hospitalizations were paid via private insurance for both MVC (51.0%) and non-MVC (53.2%). A larger proportion of MVC hospitalizations were self-pay or no charge (18.4%) compared with non-MVC (13.1%). Conversely, Medicare/Medicaid as payers made up a smaller proportion of MVC than non-MVC (22.8% vs. 27.8%).

In terms of hospital characteristics, most of the bicycle-related injuries were seen at large urban hospitals. MVC-related hospitalizations were 72.1% urban, and 73.7% had a large number of beds, compared with 57.3% and 66.8% for non-MVC, respectively. The South and West regions of the United States had the largest proportions of crashes overall (29.9% and 31.9%). The South accounted for a larger proportion of MVC (32.2%) than non-MVC (29.1%), while the West had the reverse, with 29.0% MVC and 32.9% non-MVC.

Injury Characteristics: Injury Severity, Procedures, and Diagnoses

MVC-related hospitalizations were more severe than non-MVC-related hospitalizations, with a mean ISS of 10.41 (95% confidence interval [CI]: 10.10–10.72) versus 7.80 (95% CI, 7.66–7.97) (Table 2). Among the diagnoses and procedures, there were indications of increased severity for MVC hospitalizations. For example, 35% of diagnoses of MVC-related hospitalizations involved injuries to the head and face, compared with 26% among non-MVC. MVC-related hospitalizations had larger proportions of computed tomographic (CT) scans (3.19% MVC vs. 1.59% non-MVC) and

continuous mechanical ventilation less than 96 hours (2.17% MVC vs. 1.04% non-MVC). Crushing injuries or internal injuries were more commonly listed as the principal diagnosis among non-MVC (10.97% non-MVC vs. 7.19% MVC), and closed chest drainage was one of the top 10 procedures among non-MVCs, but not among MVCs.

Total Hospital Charges, LOS, and Nonroutine Discharge

Annually, there are an estimated \$1 billion (95% CI, 0.9–1.1) of total hospital charges, 103,058 days of stay (95% CI, 91,850–114,267), and 4,341 nonroutine hospital discharges (95% CI, 3,938–4,744) resulting from bicycling injury hospitalizations (Table 3). During the 8-year study period, 27% of the hospitalizations were MVC related, but they made up 42% of the total annual hospital charges at a national estimate of \$3.4 billion (95% CI, 2.8–3.9).

The average total hospital charges per visit were \$62,214 (median, \$32,015) for MVC-related hospitalizations and \$32,884 (median, \$20,577) for non-MVC-related hospitalizations. After adjusting for covariates including LOS, which is one of the main drivers of total charges, the average hospital charges were 38% more for MVC compared with non-MVC. The average LOS for MVCs was also longer than that for non-MVC at 5.88 days (median, 2.44) versus 3.39 days (median, 1.73). Adjusted LOS for MVC-related hospitalizations were on average 2.02 days (95% CI, 1.76–2.29) longer than non-MVC. Twenty-two percent of MVC-related hospitalizations resulted in nonroutine discharge versus 15% of non-MVC-related hospitalizations. Adjusted odds of nonroutine discharge for MVC-related injuries were 2.22 (95% CI, 2.06–2.39) times higher than non-MVC-related injuries.

TABLE 3. Regression Models Predicting Hospital LOS, Hospital Charges, and Nonroutine Discharge for Bicyclists Involved in Motor Vehicle Traffic and Non-Motor Vehicle Traffic Crashes, NIS, 2002 to 2009 (n = 41,469)

	Total	MVC*	Non-MVC*
Hospital charges, US dollars***			
Total charges, US billion dollars (95% CI)†	8.1	3.4 (2.8–3.9)	4.7 (4.3–5.2)
Mean, per visit	40,903	62,214	32,884
Median, per visit	23,032	32,015	20,577
Predicted difference in average charges (95% CI)		23,424 (21,360–25,538)‡	Reference
LOS, days*§			
Mean, per visit	4.06	5.88	3.39
Median, per visit	1.86	2.44	1.73
Predicted difference in average LOS (95% CI)		2.02 (1.76–2.29)‡	Reference
Nonroutine discharge*†¶			
Total	34,727	12,355 (22.4%)	22,372 (15.2%)
OR (95% CI)		2.22 (2.06–2.39)‡	Reference

*Weighted to discharges from all US community, nonrehabilitation hospitals.

**The model for hospital charges was based on 39,030 observations after 2,439 potentially influential observations were removed. Total charges were adjusted for inflation to the year 2009 inflation rates for in-hospital care. This model was adjusted for race, sex, year, age, hospital bedsize, hospital location, payer, and LOS.

†Nonroutine discharge includes discharge to skilled nursing facility, short-term hospital, home health care, or other facility.

‡Statistical significance at $p < 0.01$.

§The model for LOS was based on 39,326 observations after 2,143 potentially influential observations were removed. This model was adjusted for race, sex, year, age, hospital bedsize, hospital location, and payer.

¶The model for nonroutine discharge was based on 40,007 observations due to 1,462 cases with missing values. This model was adjusted for race, sex, year, age, hospital bedsize, hospital location, and payer.

||Total numbers are for the entire 8-year study period.

DISCUSSION

During the 8-year study period, 2002 to 2009, more than 25,000 bicycling-related hospitalizations occurred annually. These hospitalizations accounted for a national estimate of \$1 billion total hospital charges per year. Although not all bicycle crashes result in hospitalization, those that do carry a large financial burden on the health care system and the individuals involved. This study estimates the burden of bicycling-related hospitalizations, stratified by motor vehicle involvement, owing to inherent differences in injuries with the increased energy transfer from the weight and velocity of a motor vehicle.

Although less frequent than non-MVC hospitalizations, bicycle crashes that involved motor vehicles carried a larger burden of injury with increased injury severity leading to more nonroutine discharges (including death). Crashes involving motor vehicles accounted for only 27.2% of all bicycle crashes but 42% of total hospital charges. Average hospital charges per hospitalization and average LOS were also longer for MVC hospitalizations. These results are consistent with previous studies. For example, one prospective cohort study reported that 36% of admitted and 12.8% of not admitted injured bicyclists were involved in crashes with motor vehicles.⁸ They also found that bicycle crashes that involved motor vehicles were 4.6 times (95% CI, 3.3–6.3) more likely to result in severe injury and 14.1 (95% CI, 4.1–53.5) times more likely to result in death.⁸ However, that study was published more than 15 years ago and showed a different distribution in age of hospitalized rider: they found that 60% were 19 years and younger, while we found that 33% were 17 years or younger. In addition, our study is nationally representative, while the study of Rivara et al.⁸ focused on the city of Seattle, Washington.

A more recent study of trauma hospitalizations in Israel was also consistent with our results of poorer outcomes of bicycle crashes involving MVCs.⁹ They found that crashes involving motor vehicles had 10 times higher risk of death in hospital for adults (95% CI, 1.8–34.3) and 8 times for children 1 year to 17 years (95% CI, 1.2–85.3). They also found that MVC-related crashes had higher odds of LOS of 7 or more days (odds ratio [OR]_{children}, 1.3; 95% CI, 1.0–1.7) (OR_{adults}, 1.6; 95% CI, 1.3–2.1), which is consistent with our results.⁹ However, demographically, our results differed somewhat from those of Siman-Tov et al.⁹ in terms of sex and age as our study had fewer males (78% vs. 87%) and fewer adults (28% vs. 37%) involved in MVC-related bicycle crashes than the Israel study. This highlights the importance of proceeding with caution when generalizing results across national borders.

Findings from this study inform the development and evaluation of prevention approaches to reduce bicycle–motor vehicle (BMV) crashes. Existing injury prevention approaches include helmet policies and promotion programs as well as the growing implementation of bicycle-specific infrastructure as part of the built environment, such as the installation of bicycle lanes and paths, which has been rapidly growing in the United States in the past decade.^{4,23} The use of information from this study, such as the impact of age and sex as well as the increased burden from BMV crashes, can help to target and strengthen the impact of prevention efforts to reduce serious injuries and fatalities resulting from BMV crashes. Our results can also be

used to explain the extent of the burden resulting from bicycle crashes in the United States, overall, which can help bring this issue to the forefront and drive policy change. This is especially true given the existing knowledge that bicycling has been increasing in the United States and continues to grow, leading to increased exposure and potential risk of crashes and injuries.⁴

Limitations

This study used hospital charges to estimate financial burden, but the use of hospital charges does not capture the full cost to an individual and society in terms of long-term impacts. In addition, the NIS provides weights, which allow for calculation of national estimates; however, these weights are based on a sample of hospitals nationwide, so we cannot be certain that the national estimates are a reflection of true numbers.

The use of e-codes to identify bicycle-related hospitalizations likely underestimates the actual number of cases. One study of the completeness of e-codes in the NIS database reported that 14% of injury cases were missing e-codes,²⁴ so we cannot be certain that our results speak to all bicycling crashes resulting in hospitalizations. We also cannot generalize our results beyond bicycle crashes resulting in hospitalizations. Our results are best generalized to like injuries, which do not include the least severe or most severe, because crashes resulting in deaths before hospitalization or emergency department visits and ones that did not require advanced medical care were not included in this study.

CONCLUSION

The NIS provides important and useful data. Our findings show that the burden of injury from bicycle MVCs outweigh those from non-MVC crashes by resulting in longer stays, more charges, and poorer outcomes. This is especially important because of the increases in the frequency of exposure between bicycles and motor vehicles in recent years. To have the greatest impact on reducing the burden from bicycle crashes, educational interventions, policies, and environmental changes should consider all age groups and place an emphasis on reducing collisions between bicycles and motor vehicles.

AUTHORSHIP

C.H. contributed in the literature search, study design, data collection, data analysis, data interpretation, writing, and critical revision. C.P.-A. contributed in the study design, data interpretation, writing, and critical revision. C.F.L. contributed in the data interpretation, writing, and critical revision. M.R. contributed in the data interpretation and critical revision. J.T. contributed in the study design and critical revision.

ACKNOWLEDGMENT

We thank Gang Cheng for his assistance with the data acquisition and management.

DISCLOSURE

The authors declare no conflicts of interest.

REFERENCES

- National Highway Traffic Safety Administration. *National Survey of Bicyclist and Pedestrian Attitudes and Behavior, Volume I: Summary Report*. 2008. Available at: <http://www.nhtsa.gov/Driving+Safety/Research+&+Evaluation/National+Survey+of+Bicyclist+and+Pedestrian+Attitudes+and+Behavior>. Accessed September 5, 2013.
- Pucher J, Dijkstra L. Making walking and cycling safer: lessons from Europe. *Transport Q*. 2000;54(3):25–50.
- League of American Bicyclists. Facts and figures. Available at: <http://www.bikeleague.org/media/facts/#sold>. Accessed May 21, 2013.
- Alliance for Biking & Walking. *Bicycling and walking in the United States: 2012 benchmarking report*. Available at: www.peoplepoweredmovement.org/benchmarking. Accessed May 21, 2013.
- Beck LF, Dellinger AM, O'Neil ME. Motor vehicle crash injury rates by mode of travel, united states: using exposure-based methods to quantify differences. *Am J Epidemiol*. 2007;166(2):212–218.
- Elvik R, Høy A, Vaa T, Sørensen M. *Handbook of Road Safety Measures*. 2nd ed. Bingley, UK; Emerald Group Publishing Limited. 2009:1–1124.
- Puranik S, Long J, Coffman S. Profile of Pediatric Bicycle Injuries. *South Med J*. 1999;91(11):1033–1037.
- Rivara FP, Thompson DC, Thompson RS. Epidemiology of bicycle injuries and risk factors for serious injury. *Inj Prev*. 1997;3(2):110–114.
- Siman-Tov M, Jaffe DH, Peleg K, Grp IT. Bicycle injuries: a matter of mechanism and age. *Accid Anal Prev*. 2012;44(1):135–139.
- Shah S, Sinclair SA, Smith GA, Xiang H. Pediatric hospitalizations for bicycle-related injuries. *Inj Prev*. 2007;13(5):316–321.
- Powell EC, Tanz RR. Cycling injuries treated in emergency departments: need for bicycle helmets among preschoolers. *Arch Pediatr Adolesc Med*. 2000;154(11):1096–1100.
- Mehan TJ, Gardner R, Smith GA, McKenzie LB. Bicycle-related injuries among children and adolescents in the United States. *Clin Pediatr*. 2009;48(2):166–173.
- Insurance Institute for Highway Safety. *Fatality facts 2010: bicycles*. Available at: <http://www.iihs.org/research/fatality.aspx?topicName=Bicycles&year=2010>. Accessed May 21, 2013.
- Healthcare Cost and Utilization Project. *Statistical Brief #135. Healthcare Cost and Utilization Project (HCUP)*. Agency for Healthcare Research and Quality. Available at: <http://www.hcup-us.ahrq.gov/reports/statbriefs/sb135.jsp>. Accessed May 21, 2013.
- Agency for Healthcare Research and Quality. *Healthcare Cost and Utilization Project (HCUP). HCUP Databases*. Available at: <http://www.hcup-us.ahrq.gov/nisoverview.jsp>. Accessed May 21, 2013.
- Healthcare Cost and Utilization Project. *Clinical classifications software for ICD-9-CM*. Available at: <http://www.hcup-us.ahrq.gov/toolssoftware/ccs/ccs.jsp>. Accessed May 21, 2013.
- Bureau of Labor Statistics. *Inflation rate for in-hospital care*. Available at: <http://www.bls.gov/cpi/data.htm>. Accessed May 21, 2013.
- Baker SP, Oneill B, Haddon W, Long WB. Injury Severity Score—method for describing patients with multiple injuries and evaluating emergency care. *J Trauma*. 1974;14(3):187–196.
- Center for Injury Research and Policy of the Johns Hopkins University School of Public Health. *ICD-9-CM Software*. Baltimore, MD: The Johns Hopkins University and Tri-Analytics; 1997.
- Healthcare Cost and Utilization Project. *NIS description of data elements: HOSP_LOCATION - (urban/rural) of hospital*. Available at: http://www.hcup-us.ahrq.gov/db/vars/hosp_location/nisnote.jsp. Accessed May 21, 2013.
- Rao JNK, Scott AJ. On simple adjustments to chi-square tests with sample survey data. *Ann Stat*. 1987;15(1):385–397.
- SAS Institute Inc. *Version 9.3*. Cary, NC: SAS Institute Inc.; 2002–2010.
- Pucher J, Buehler R, Seinen M. *Bicycling renaissance in North America? An update and re-appraisal of cycling trends and policies*. *Transport Res A-Pol*. 2011;45(6):451–475.
- Coben JH, Steiner CA, Barrett M, Merrill CT, Adamson D. Completeness of cause of injury coding in healthcare administrative databases in the United States, 2001. *Injury Prev*. 2006;12(3):199–201.