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Bicycle-related injuries among children treated in US emergency departments, 2006-2015

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ABSTRACT

Objective: One of the leading causes of non-fatal injury among children is bicycling. Past studies indicate that helmets are protective against bicycle-related injuries and involvement of motor vehicles is associated with severe injuries, but research utilizing a nationally representative data set for this population and focusing on these risk factors does not exist. The objective of this study was to describe the epidemiology of bicycle-related injuries among children treated in hospital emergency departments (EDs) in the United States (US).
Methods: A retrospective analysis was conducted with data from the National Electronic Injury Surveillance System for children 5–17 years of age who were treated in US EDs from 2006 through 2015 for a bicycle-related injury. Helmet use and motor vehicle involvement were two variables that were created and coded using keyword searches of the case narratives. Rates of injuries over time were described. Multivariate logistic regression along with 95% confidence intervals (CIs) were used to contrast types of injuries sustained among injured helmet users with non-users.
Results: An estimated 2 219 742 (95% CI: 1 871 120-2 568 363) children 5–17 years of age were treated in US EDs for bicycle-related injuries over the 10-year study period, an average of 608 injuries per day. Most injuries (45.7%) involved children 10–14 years of age. The rate of bicycle-related injuries significantly decreased from 447.4 per 100 000 children in 2006 to 321.1 per 100 000 children in 2015 ($P < 0.001$). Helmet use at the time of injury was significantly associated with lower likelihood of head and neck injuries (OR: 0.52 [95% CI: 0.40-0.59]) and hospitalizations (OR: 0.71 [95% CI: 0.54-0.94]), but there was no significant change in the rate of injury among helmet users over the study period ($P = 0.224$). Motor vehicle involvement increased the odds of bicycle-related traumatic brain injuries (TBIs) (OR: 1.98 [95% CI: 1.49–2.64]) as well as injury-related hospitalizations (OR: 4.04 [95% CI: 3.33–4.89]).
Conclusions: Despite decreasing injury rates, bicycling remains an important source of injury for children. Helmet use has demonstrated significant protective effects for TBIs, head and neck injuries, and hospitalizations. Motor vehicle involvement increased the risk of hospitalization. More efforts are needed to promote use of helmets and to reduce the possibility of bicycle-motor vehicle collisions to prevent bicycle-related injuries among children.

1. Introduction

Bicycle riding is a popular source of recreation, transportation and physical activity for children. There are many benefits of bicycling among children, including improving cardiorespiratory fitness (Oja et al., 2011) and contributing to decreasing environmentally harmful chemical emissions from motor vehicles (Komanoff et al., 1993). In 2010, 14.5 million children in the United States (US) aged 17 years and

Abbreviations: US, United States; ED, emergency department; NEISS, National Electronic Injury surveillance system; CPSC, United States Consumer Product Safety Commission; TBI, traumatic brain injury; RR, relative risk; OR, odds ratio; CI, confidence interval; SD, standard deviation

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younger were bicycle riders, accounting for 37% of all bicycle riders in the country. Of those, 2.9 million children rode their bicycle six or more times per year (Edmondson, 2011).

Bicycle riding, however, is not without risk (Bromell and Geddis, 2016). More childhood injuries are associated with bicycles than any other consumer product besides motor vehicles (Safe Kids Worldwide, 2017). One of the leading causes of non-fatal injury among children aged 5–17 years is bicycling, with approximately 160 000 children injured while bicycling in 2015 (Centers for Disease Control and Prevention, 2005; US Department of Health and Human Services Centers for Disease Control and Prevention, 2008). Children also have a higher rate of bicycle-related deaths (452 per 100 000 children) compared to adults (100 per 100 000 adults), despite the number and rate of bicycle-related deaths for children declining since 2001 (Centers for Disease Control and Prevention, 2005).

Head injuries among children bicyclists account for 60% of fatalities associated with bicycle crashes (Savage and National Conference of State Legislatures, 2002). Wearing a bicycle helmet reduces the risk of sustaining a head injury by at least 45% and fatal injury by 29% among all riders (Attewell et al., 2001). Legislation requiring children to wear a helmet while bicycling is an effective approach to reduce bicycle-related fatalities and bicycle-related head injuries among this population (Goodwin et al., 2010; Macpherson et al., 2002; Ji et al., 2006; Lee et al., 2005). Such efforts to prevent head injury risk were introduced in the early 1990 s through various local and state helmet mandates for bicycle riders and were supported by an official recommendation from the National Center for Injury Prevention and Control stating that riders of any age should use a helmet every time they ride a bicycle (National Bicycle Safety Network, 2016; Centers for Disease Control and Prevention, 2017). Further, bicycle helmets have been shown to decrease risk of traumatic brain injuries (TBIs) among children, and TBIs are more frequent among children who are non-helmet users (Sethi et al., 2015; Phillips et al., 2016a). Despite efforts to promote the use of helmets and evidence of their preventive effects, helmet use is still infrequent, with more than 87% children aged 13 to 18 years who while riding, rarely or never wear a bicycle helmet (Eaton et al., 2012). In addition, colliding with a non-stationary motor vehicle while bicycling has been associated with severe injuries among children (Rivara et al., 1997; Chen et al., 2013; Teisch et al., 2015), and children 19 years of age and younger have a higher rate of bicycle-motor vehicle non-fatal collision compared to their older age counterparts (Gerberich et al., 1994).

Previously published studies about bicycle-related injuries have been limited to a narrow focus on particular injuries (e.g., only head injuries) (Weiss, 1994; Depreitere et al., 2004), small geographic areas of study (e.g., single city) (Bromell and Geddis, 2016; Rivara et al., 1997), adult injuries (Sanford et al., 2015), or a lack of characterizing injuries by sub-group (e.g., injuries among helmet users) (Chen et al., 2013; Mehan et al., 2009; Hamann et al., 2013). To our knowledge, this is the first study to use a nationally representative data set to examine injuries among age groups known to be at increased risk for bicycle-related injuries, with particular focus on the protective effects of helmet use among riders and any motor vehicle involvement associated with these injuries. The objective of this study was to describe the epidemiology of non-fatal bicycle-related injuries among primary riders who were children 5 to 17 years of age and who were treated in US EDs from 2006 through 2015, as well as to examine the factors associated with increased risk of bicycle related TBIs and bicycle injury-related hospitalizations.

2. Methods

2.1. Data source

Data for pediatric patients who were treated in hospital EDs between January 1, 2006 and December 31, 2015 were obtained through the National Electronic Injury Surveillance System (NEISS) which is operated by the US Consumer Product Safety Commission (CPSC). The NEISS was established in 1972 and provides data on consumer product-related and sports activity-related injuries. The NEISS sample is composed of approximately 100 hospitals with a 24-hour ED and ≥6 beds, representing a stratified probability sample of over 5 000 hospitals, to estimate injuries treated in hospital EDs nationally. The database includes urban, suburban, rural, and children's hospitals. National estimates are calculated by weighting the cases by using information provided by the CPSC. Medical charts are viewed by professional NEISS coders at all sampled hospitals, and data including patient demographic characteristics (patient's age and sex), injury specific data (diagnosis, body part injured, products involved, disposition from the ED), and a brief narrative describing what the patient was doing at the time of the injury are recorded (US Consumer Product Safety Commission, 2000). Population estimates from the US Census Bureau were used to calculate injury rates per 100 000 children 5 to 17 years of age (Census Bureau, 2011a; Census Bureau, 2011b).

2.2. Case selection criteria

All NEISS cases for children aged 5–17 years identified by using NEISS product codes for bicycles (code 5040) and mountain or all-terrain bicycles (code 5033) from 2006 through 2015 were reviewed (n = 70 767). Case inclusion and exclusion criteria and variable categories were developed after reviewing a subset of narratives. An additional random subset of narratives was reviewed by > 1 author and decisions about ambiguous narratives were achieved through consensus. Cases were excluded if (1) the bicycle was not being ridden at the time of injury, such as repairing the bicycle, (2) the injury was to a passenger and not to the primary rider, (3) the injury was the result of riding a motorized bicycle or a three-wheeled product such as a tricycle, or (4) the injury was not related to operation of the bicycle, such as being shot or attacked. All fatalities (n = 12) were excluded. Fatalities were excluded from analysis as the NEISS dataset may not include cases that are not transported to the ED or fatalities that occur following inpatient admission; in addition, the focus of this manuscript was to describe non-fatal bicycle-related injuries. The number of excluded cases was 3 858, therefore a total of 66 897 cases were included in the analyses.

2.3. Variables

The following variables provided by the NEISS were recategorized for data analysis. Patient age was categorized into three groups for analysis (5–9, 10–14, and 15–17 years of age) based on the age categories of bicycle-related injuries utilized by the National Highway Traffic Safety Administration (2016). Injury diagnoses were regrouped into six categories including the following: (1) contusions and abrasions; (2) lacerations; (3) fractures (excluding fractures to the head); (4) strains and sprains; (5) traumatic brain injuries (TBI) (including concussions, fractures of the head, and internal organ injuries to the head) (Xiang et al., 2007); and (6) other (including ingesting foreign objects, all burn types, amputation, crushing, dislocation, dental injury, nerve damage, punctures, anoxia, hemorrhage, electric shock, poisoning and other or not stated diagnoses). Injured body parts were regrouped according to body region, into the following six categories: (1) head and neck; (2) face (including ear, eye and mouth); (3) upper extremity (including shoulder, arm, elbow, wrist, hand and finger); (4) lower extremity (including leg, knee, ankle, foot and toe); (5) trunk (including upper and lower trunk, hip and pubic region); and (6) other (25%–50% of the body, all parts of the body and internal injuries, except those to the head). Patient disposition was recoded into two categories including: (1) hospitalized (including cases where patients were treated and then transferred to another hospital, admitted within the same facility, or held for observation); and (2) not hospitalized (including those treated and released, or examined and released without treatment, or those who left against medical advice). The location where the injury occurred was regrouped into three categories including: (1) street; (2) home (including farm, apartments or condos and mobile homes); and (3) other (including school, sports and recreation place, industrial place and other public property).

Two additional variables were created specifically for these analyses and were coded by using keyword searches and interpretation of the case narratives. The first variable was helmet use and was coded into two categories using the following criteria: (1) narrative explicitly stated that a helmet was worn; or (2) narrative explicitly stated that a helmet was not worn. Cases where explicit helmet use could not be determined by keyword search and interpretation of the narrative were treated as missing. A variable was used to document whether a non-stationary motor vehicle was associated with the injury (yes vs. no). Since both contact with a motor vehicle and a near-miss motor vehicle collision could result in a bicycle-related injury, motor vehicle involvement was coded if the case narrative described a patient having contact with a motor vehicle (e.g., hit or struck, $n = 6\ 387$) or had a near-miss motor vehicle collision (e.g., patient jumped off bicycle to avoid collision with car $n = 60$) with any non-stationary motor vehicle (e.g., cars, trucks, sports utility vehicles, vans). Cases where a motor vehicle was stationary or parked ($n = 688$) or a motor vehicle was not indicated to be involved ($n = 58\ 762$) were coded as stationary or no motor vehicle involvement.

2.4. Statistical analysis

Data were analyzed by using SAS Enterprise Guide version 7.1 (SAS Institute, Inc, Cary, NC). A sample weight, assigned to each case by the CPSC based on the inverse probability of selection, was used to generate national estimates. The NEISS survey design was accounted for when conducting the analysis by using survey procedures in SAS. Annual injury rates were calculated as the number of injury episodes divided by US Census Bureau population estimates from 2006 to 2015, respectively (Census Bureau, 2011a; Census Bureau, 2011b). Rao-Scott design-adjusted X^2 tests were conducted for bivariate comparisons, odds ratios (ORs) assessed strength of association. ORs adjusted for age and sex were generated with survey logistic regression models to determine odds of TBI, head and neck injury, and hospitalization with helmet use exposure (Dellinger and Kresnow, 2010). Statistical significance of analysis used $\alpha = 0.05$ and results are reported with 95% confidence intervals (95% CIs). National estimates are reported unless otherwise specified as actual unweighted cases. This study was exempt from review by the Institutional Review Board at Nationwide Children's Hospital.

3. Results

3.1. Demographic features and overall injury trends

An estimated 2 219 742 bicycle-related injuries (95% CI: 1 871 120-2 568 363) sustained by children 5 to 17 years of age were treated in EDs from 2006 through 2015 (Table 1). The majority of injuries (45.7%) involved children 10 to 14 years of age and males (71.6%). The mean age at which injury occurred was 10.80 (SD: 3.34) years. The rate of bicycle-related injuries significantly decreased over the study period from 447.3 per 100 000 children ($n = 240\ 740$) in 2006 to 321.1 per 100 000 children ($n = 172\ 571$) in 2015 ($m = -14.1$; $P < 0.001$; Fig.1).

3.2. Body region injured and injury diagnosis

The most commonly injured body region was the upper extremities

Table 1
Characteristics of bicycle-related injuries treated in US EDs among children 5–17 years, 2006–2015.

Characteristic	No.		Estimated 95% CI
	Actual[a]	National Estimate[a] (%)	
Total	66 897	2 219 742	1 770 176-2 417 039
Sex			
Male	47 996	1 590 107 (71.6)	1 341 125-1 839 090
Female	18 896	629 566 (28.4)	523 045-736 087
Missing	5	67	9-125
Age, years			
5-9	26 968	832 280 (37.5)	702 897-961 662
10-14	30 123	1 013 662 (45.7)	849 117-1 178 206
15-17	9 806	373 800 (16.8)	300 543-447 058
Injury Diagnosis			
Contusion and Abrasion	17 080	609 293 (29.1)	511 003-707 581
Laceration	14 110	490 202 (23.4)	419 918-560 486
Fracture	14 568	454 933 (21.7)	371 884-537 982
Strain and Sprain	6 299	240 491 (11.5)	200 018-280 963
Traumatic Brain Injury[b]	7 996	224 566 (10.7)	175 033-274 098
Other	2 861	74 123 (3.5)	62 137-86 108
Missing	3 983	126 134	75 217-177 051
Body region injured			
Upper Extremity[c]	23 234	798 045 (36.2)	668 008-928 082
Lower Extremity[d]	15 876	549 355 (24.9)	453 896-644 812
Face[e]	10 311	338 700 (15.4)	291 300-386 099
Head and Neck	10 952	328 046 (14.9)	270 038-386 052
Trunk[f]	5 924	185 890 (8.4)	156 332-215 446
Other[g]	149	5 422 (0.2)	3 332-7 511
Missing	451	14 284	8 053-20 514
Disposition			
Not Hospitalized[h]	62 445	2 125 941 (95.8)	1 790 986-2 460 895
Hospitalized[i]	4 450	93 697 (4.2)	70 676-116 716
Missing	2	104	0-282
Location of injury			
Street	18 211	674 280 (47.9)	441 047-907 513
Home[j]	14 252	515 023 (36.6)	391 504-638 541
Other[k]	6 214	219 130 (15.6)	165 035-273 225
Missing	28 220	811 308	571 093-1 051 523
Motor vehicle involvement			
No	60 450	2 054 149 (92.5)	1 733 769-2 374 528
Yes	6 447	165 593 (7.5)	121 873-209 312
Helmet use			
Not worn	7 161	180 090 (72.8)	110 996-249 182
Worn	2 441	67 377 (27.2)	43 839-90 913
Missing	57 295	1 972 275	1 630 914-2 313 636

[a]Some categories do not total 2 219 742 or 100% because of rounding. Missing values were not included in national estimate percentage calculation.
[b]Traumatic Brain Injury includes concussion, fracture to the head and internal organ injury to the head.
[c]Upper extremity includes shoulder, arm, elbow, wrist, hand and finger.
[d]Lower extremity includes leg, knee, ankle, foot and toe.
[e]Face includes face, ear, eye and mouth.
[f]Trunk includes upper and lower trunk, hip and pubic region.
[g]Other includes 25%–50% of the body, all parts of the body and internal injuries except those to the head.
[h]Not Hospitalized includes treated and released, released without treatment, held less than 24-hours for observation or left against medical advice.
[i]Hospitalized includes treated and transferred to another hospital, transferred for hospitalization and admitted within the same facility.
jHome includes manufactured/mobile home, farm and apartment/condo.
[k]Other includes industrial place, school, sports/recreation place and other public property.

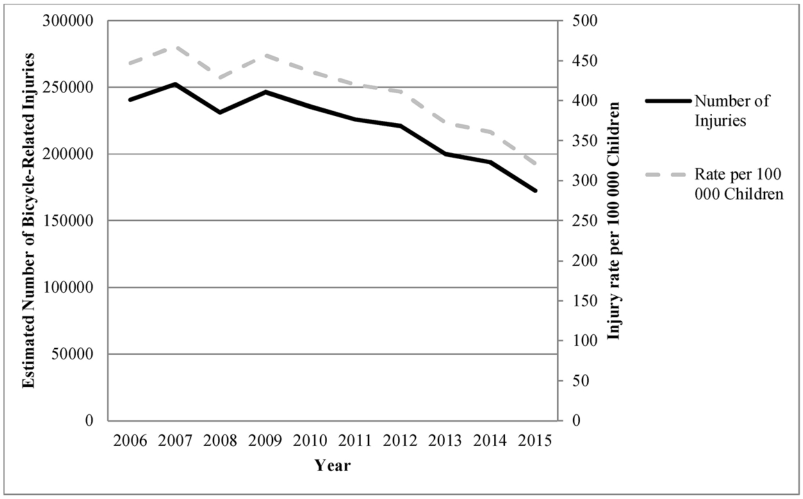

Fig. 1. Estimated number of bicycle-related injuries and rate per 100 000 children 5–17 years in US.2006–2015.

(36.2%), followed by the lower extremities (24.9%), face (15.4%) and head and neck (14.9%) (Table 1). Wrist (24.4%) and knee (34.05%) accounted for the largest proportions of upper extremity and lower extremity injuries, respectively. Excluding injuries to the upper extremities, injuries to the face were most frequent among patients 5–9 years of age (23.8%), while injuries to the lower extremities were most frequent among patients 10–14 (13.7%) and 15–17 (16.8%) years of age. The most common types of injuries were contusions and abrasions (29.1%) and lacerations (23.4%). Overall, TBIs represented 10.7% of total injuries and were most common among patients 10–14 years of age (44.1%). When compared to patients aged 5–9 years, patients aged 15–17 years had greater odds for TBIs (OR: 1.36 [95% CI: 1.17–1.57]) than patients aged 10–14 years (OR: 1.03 [94% CI: 0.95–1.13]).

3.3. Disposition and location where the injury occurred

A total of 4.2% of patients required hospitalization. Most patients were hospitalized for an injury to the head and neck (32.4%) or upper extremities (24.2%). Among hospitalized patients, 43.4% had a fracture and 31.9% sustained a TBI. Compared to patients with all other types of injuries, patients with a fracture had close to three times the odds of being hospitalized (OR: 2.92 [95% CI: 2.47–3.45]) and patients with TBIs had more than four times the odds of being hospitalized (OR: 4.32 [95% CI: 3.57–5.24]). Location at the time of injury was recorded for 63.5% of cases. Injuries most frequently occurred in the street (47.9%) or at home (36.6%). Patients 5–9 years of age were most commonly injured at home (50.6%), while patients 10–14 (51.2%) and 15–17 (62.9%) years of age were most commonly injured in the street. Injuries that occurred in the street more often resulted in TBIs (12.1%) and hospitalization (6.2%) than injuries that occurred at home (6.7% and 2.7%, respectively). Nearly one-half (45.7%) of injuries that occurred in the street and resulted in hospitalization involved a motor vehicle.

3.4. Helmet use

Helmet use or non-use was reported in 9 602 actual cases and when weighted, it represented estimated 247 467 (11.0%) injuries (Table 2). Of those, 27.2% of case narratives explicitly stated that a patient was wearing a helmet at the time of injury. Patients 5 to 9 years of age accounted for the largest percentage of helmet users (42.8%) while patients 10 to 14 years of age accounted for the largest percentage of non-helmet users (46.3%). Non-helmet users most frequently had TBI (31.9%) and injuries to the head and neck (40.1%) while helmet-users most commonly had contusions and abrasions (26.6%) and injures to the upper extremity (30.8%). Of those with known helmet use or non-helmet use, there was no significant change in the rate of patients wearing a helmet at the time of injury from 2006 (14.0 per 100 000 children) to 2015 (10.9 per 100 000 children) (m =59.4; P = 0.224; Fig. 2). After adjusting for age and sex, helmet use was associated with lower odds of head and neck injuries (OR: 0.52 [95% CI: 0.40-0.59]),

Table 2
Characteristics of bicycle-related injuries to children 5–17 years treated in US EDs by helmet use, 2006–2015.

	Helmet Use		No Helmet Use	
	Actual	Estimate (%)[a]	Actual	Estimate (%)[a]
Total[a]	2 441	67 377 (100.0)[b]	7 161	180 090 (100.0)[b]
Sex				
Male	1 752	49 051 (72.8)	5 475	138 917 (77.1)
Female	689	18 326 (27.2)	1 686	41 172 (22.9)
Age, years				
5-9	1 110	28 835 (42.8)	2 623	61 642 (34.2)
10-14	1 008	27 866 (41.4)	3 291	83 460 (46.3)
15-17	323	10 676 (15.8)	1 247	34 988 (19.4)
Injury Diagnosis				
Contusion and Abrasion	511	17 363 (26.6)	1 418	41 229 (23.5)
Laceration	445	12 922 (19.8)	1 129	30 749 (17.6)
Fracture	575	14 413 (22.1)	1 189	27 124 (15.5)
Strain and Sprain	137	4 105 (6.3)	475	12 590 (7.2)
Traumatic Brain Injury	552	13 931 (21.4)	2 376	55 864 (31.9)
Other	130	2 512 (3.8)	335	7 621 (4.4)
Body region injured				
Upper extremity	745	20 518 (30.8)	1 637	40 417 (22.6)
Lower extremity	290	8 094 (12.1)	978	23 731 (13.3)
Face	561	15 582 (23.4)	1 214	32 840 (18.4)
Head and Neck	635	17 042 (25.6)	2 873	71 714 (40.1)
Trunk	188	5 282 (7.9)	404	9 905 (5.5)
Other	6	99 (0.1)[c]	9	342 (0.2)[c]
Disposition				
Not Hospitalized	2 192	62 951 (93.6)	6 164	163 481 (90.8)
Hospitalized	248	4 337 (6.4)	997	16 609 (9.2)
Location of injury				
Street	662	23 698 (51.6)	2 579	70 102 (59.4)
Home	341	11 782 (25.7)	1 039	31 780 (26.9)
Other	384	10 451 (22.8)	545	16 070 (13.6)
Motor vehicle involvement				
No	2 163	59 410 (88.2)	5 710	150 092 (83.3)
Yes	278	7 967 (11.8)	1 451	29 998 (16.7)

[a]Some categories do not total 100% due to rounding.
[b]Total actual estimated number of all bicycle-related injury cases is 2 219 742.
[c]Estimate is based on fewer than 20 actual cases and the estimate may not be statistically valid.

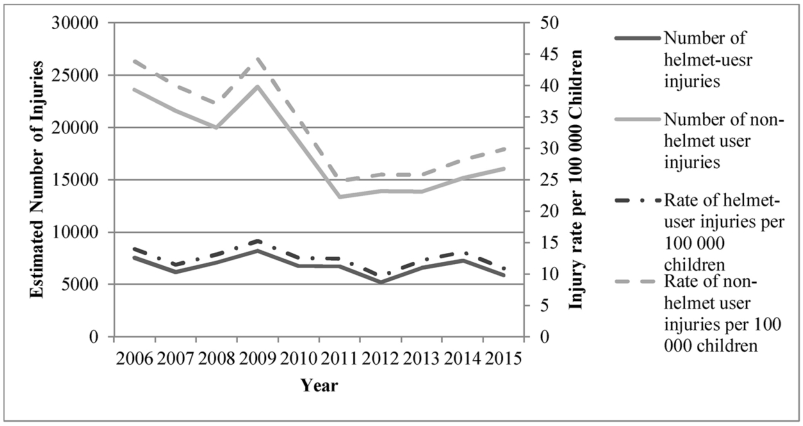

Fig. 2. Estimated number of helmet-user and non-helmet user injuries and rate per 100 000 children 5–17 years in US.2006–2015.

Table 3
Unadjusted and adjusted odds ratios with helmet use exposure for children 5–17 years treated in US EDs, 2006–2015.

Outcome	Cases: Actual	Cases: National Estimate	Unadjusted OR (95% CI)	Adjusted[a,b,c] OR (95% CI)
Injury Diagnosis				
Traumatic Brain Injury	552	13 931	**0.58 (0.43-0.78)**[c]	**0.60 (0.44-0.81)**[c]
All other diagnoses	1798	51 315	Referent	Referent
Body region injured				
Head and neck	635	17 042	**0.51 (0.39-0.67)**[c]	**0.52 (0.40-0.59)**[c]
All other body regions	1790	49 575	Referent	Referent
Disposition				
Hospitalized	248	4 337	**0.68 (0.52-0.89)**[c]	**0.71 (0.54-0.94)**[c]
Not hospitalized	2 192	62 951	Referent	Referent

[a]Models adjusted for age in years and sex.
[b]Rao-Scott Chi-Scquare Analysis.
[c]Result is significant at the P = 0.05 level.

hospitalization (OR: 0.71 [95% CI: 0.54-0.94]) and TBI (OR: 0.60 [95% CI: 0.44-0.81]) (Table 3).

3.5. Motor vehicle involvement

A total of the 6447 case narratives indicated motor vehicle involvement. When weighted, it represented estimated 165 583 (7.5%) of injuries (Table 4). Injuries involving a motor vehicle most often occurred in the street (93.9%) and were most common among children 10 to 14 years of age (45.5), although the odds of injury involving a motor vehicle was greatest for children aged 15 to 17 years (OR: 2.86 [95% CI: 2.48–3.29]) compared to all other patients. The rate of injuries associated with motor vehicle involvement significantly decreased from 2006 (35.3 per 100 000 children) to 2015 (28.6 per 100 000 children) (m = -0.83; P = 0.001). Patients with injuries associated with motor vehicle involvement more frequently sustained contusions and abrasions (47.8%) compared to patients with injuries without motor vehicle involvement (27.6%). The most commonly injured body region when a motor vehicle was involved was the lower extremity (36.8%), but when there was a stationary or no motor vehicle involvement it was the upper extremity (37.5). Motor vehicle involvement nearly doubled the odds of sustaining a TBI (OR: 1.98 [95% CI: 1.49–2.64]) and more than quadrupled the odds of hospitalization (OR: 4.04 [95% CI: 3.33–4.89]) compared to injuries without motor vehicle involvement.

Table 4
Characteristics of bicycle-related injuries to children 5–17 years treated in US EDs by motor vehicle involvement, 2006–2015.

Characteristics	Motor Vehicle Involvement: Actual	Motor Vehicle Involvement: Estimate (%)[a]	Stationary or No Motor Vehicle Involvement: Actual	Stationary or No Motor Vehicle Involvement: Estimate (%)[a]
Total[a]	6 447	165 593 (7.5)[c]	60 450	2 054 149 (92.5)[c]
Sex				
Male	5 190	130 952 (79.1)	42 806	1 459 155 (71.0)
Female	1 257	34 641 (20.9)	17 639	594 926 (29.0)
Age, years				
5-9	1 547	33 415 (20.2)	25 421	798 865 (38.9)
10-14	3 055	75 427 (45.5)	27 068	938 235 (45.7)
15-17	1 845	56 751 (34.3)	7 961	317 049 (15.4)
Injury Diagnosis				
Contusion and Abrasion	2 544	72 926 (47.8)	14 536	536 366 (27.6)
Laceration	477	12 799 (8.4)	13 633	477 403 (24.6)
Fracture	865	20 697 (13.6)	13 703	434 236 (22.4)
Strain and Sprain	472	13 919 (9.1)	5 827	226 572 (11.7)
Traumatic Brain Injury	1 310	27 855 (18.3)	6 686	196 711 (10.1)
Other	212	4 255 (2.8)	2 649	69 867 (3.6)
Body region injured				
Upper extremity	1 126	31 096 (19.2)	22 108	766 950 (37.5)
Lower extremity	2 181	59 399 (36.8)	13 695	489 956 (24.0)
Face	496	12 886 (8.0)	9 815	325 814 (15.9)
Head and Neck	1 710	38 485 (23.8)	9 242	289 561 (14.2)
Trunk	752	19 048 (11.8)	5 172	166 842 (8.2)
Other	25	693 (0.4)	124	4 729 (0.2)
Disposition				
Not Hospitalized	5 266	144 312 (87.1)	57 179	1 981 629 (96.5)
Hospitalized	1 181	21 281 (12.9)	3 269	72 416 (3.5)
Location of injury				
Street	5 553	143 018 (93.9)	12 658	531 262 (42.3)
Home	162	4 278 (2.8)	14 090	510 745 (40.7)
Other	196	4 949 (3.3)	6 018	214 182 (17.1)
Helmet use				
Not worn	1 451	29 998 (79.0)	5 710	150 092 (71.6)
Worn	278	7 967 (21.0)	2 163	59 410 (28.4)

[a]Some categories do not total to 100% due to rounding.
[b]Rao-Scott Chi-Square Analysis.
[c]Total actual estimated number of all bicycle-related injury cases is 2 219 742.

4. Discussion

From 2006 through 2015, an estimated 2 219 742 bicycle-related injuries were treated in US EDs among children 5 to 17 years of age, yielding an average of 25 cases every hour. Although both the number and rate of bicycle-related injuries significantly decreased over the 10-year study period, the mean number of bicycle-related injuries remained high at 472 injuries per day treated in US EDs in the last year of the study. The most common injury diagnosis of contusions and abrasions, most frequent body region injured of upper extremity, and most common age group injured of children aged 10 to 14 years were similar to a previous epidemiological study (Teisch et al., 2015). However, the most common location of injury differed, changing from home to street between the previous and current studies (Teisch et al., 2015).

The current study confirms associations found in previous studies that wearing a helmet at the time of injury is significantly associated with reduced odds of head and neck injuries, TBIs, and hospitalization for injured children who visit the ED (Sethi et al., 2015; Rezendes, 2006). Yet, the current study did not find a significant change in the number and rate of injury of helmet use among injured children throughout the study period (Sethi et al., 2015; Rezendes, 2006; Administration, 2016; Phillips et al., 2016b). The current study's population is injured children, and there is a possibility that helmet-using children did not visit the ED for reasons including they were not injured, or they were injured but did not go to the ED for their injury. Since previous studies and the current study agree that wearing a helmet reduces the odds of hospitalization among bicycling children, it is imperative that these children consistently wear a helmet while bicycle riding. Unfortunately, more than 85% of children aged 13–18 years rarely or never wear a bicycle helmet while riding, putting them at higher odds of hospitalization (National Bicycle Safety Network, 2016). Infrequent helmet use may be explained by both parents' and children's perceptions and attitudes regarding helmet use (Miller et al., 1996; Bernstein et al., 2003; Otis et al., 1992; Finch, 1996; Rodgers, 1996; Meehan et al., 2013a; Robertson et al., 2014). Parents perceive that their children will not wear or do not need to wear a helmet, and do not purchase a helmet due to cost (Miller et al., 1996; Bernstein et al., 2003). Children perceive helmets as uncool, uncomfortable, inconvenient, or unnecessary, and may not wear a helmet despite owning one (Otis et al., 1992; Finch, 1996; Rodgers, 1996). Other barriers to helmet use in children included poor fit of the helmet due to hairstyles, lack of knowledge regarding helmet use, and lack of access to a helmet (Pierce et al., 2014).

Despite these documented barriers around helmet use, previous evidence suggests that bicycle helmet laws have been effective in increasing helmet use among children 16 years and younger (Administration, 2016; Meehan et al., 2013a; Rodgers, 2002). Helmet laws are more efficacious with strict enforcement, supportive publicity, and educational campaigns and programs (Dellinger and Kresnow, 2010; Administration, 2016; Macpherson and Spinks, 2008; Owen et al., 2011). Helmet laws only exist in 21 states and the District of Columbia since 2007 (National Bicycle Safety Network, 2016). States without regulations should be encouraged to enact and enforce helmet laws to increase helmet use in children.

Consistent with previous findings, motor vehicle involvement increased the odds of hospitalization and the risk of TBI injury (Administration, 2016; Meehan et al., 2013a; Acton et al., 1995; Meehan et al., 2013b). Despite this current study indicating that the majority of bicycle-related injuries involving a motor vehicle occurred in the street, past studies indicate that riding bicycles in the street is safer than riding on the sidewalk for children 10 years of age or older (Alliance for Biking and Walking, 2016). The high frequency of being injured in the street could be explained by bicycle-motor vehicle collisions often leading to more serious injuries than injuries in the street that occurred without motor vehicle involvement. Bicycles are legally recognized as vehicles, which are obligated to be ridden in the street. Bicycling is one of the primary modes of transportation for children, therefore it is imperative to make roads safe for children biking and decrease bicycle-motor vehicle collisions (Alliance for Biking & Walking, 2016). Empirically supported prevention efforts to mitigate bicycle-motor vehicle collisions include "Share the Road" campaigns, increasing bicyclist visibility with bright reflective materials, and creating cycling lanes on the road, and providing bicycling education courses (Dellinger and Kresnow, 2010; Embree et al., 2016; Mulvaney et al., 2015; Haileyesus et al., 2007). Effective bicycle safety education programs for children should be grounded in child development and learning theories (Phillips et al., 2016a; Ellis, 2014).

In the present study, TBI accounted for nearly 11% of all injuries and it was the second most common injury diagnosis for hospitalized children, nearly quadrupling the risk of hospitalization. TBIs were more frequent among non-helmet users and children with injuries sustained with an involved motor vehicle. Children can decrease their risk of TBI by wearing bicycle helmets (Sethi et al., 2015; Phillips et al., 2016a; Rezendes, 2006; Sosin et al., 1996). However, consistent with other research, this study indicates that teenagers are at greatest risk of TBI which may be explained by this age group having the lowest proportion of helmet use compared to other childhood age groups (Finch, 1996; Joseph et al., 2017; Cassidy et al., 2004; O'rourke et al., 1987; Finnoff et al., 2001). Future efforts to increase helmet use among teenagers may also decrease TBIs within this age group.

This study has some limitations. Since the NEISS sampling frame only includes injuries treated in US EDs, the number of bicycle-related injuries is an underestimate. Given that helmet use and motor vehicle involvement are not variables provided by the NEISS, they were each assessed by keyword searches of case narratives and interpretation of what happened while the child was injured, and thus are subject to potential reporting error and miscoding. There may be inconsistency in the documentation of helmet use and motor vehicle involvement due to the lack of a formalized documentation process by providers in the ED to indicate these factors, making it difficult to discern the true estimate of helmet use and motor vehicle involvement. Since this study was based on data already collected by the NEISS, potential bias in reporting helmet use could exist, where it could not be determined whether those missing helmet use in the case narratives were more or less likely to have been using a helmet than those with helmet use indicated. Further, missing information on helmet use could be related to injury type, where children with injuries that are less severe or are not related to the head, such as contusions and abrasions, are less likely to be asked about helmet use than children who present with head injury in the ED. The NEISS lacked exposure information such as distance or time cycled that could impact injury outcomes. TBI case ascertainment from the NEISS is challenging because TBI is not a category within the NEISS diagnosis variable and was derived from other diagnoses and body parts injured, which may lead to the definition of TBI used in this study to overestimate the number of TBI cases (Xiang et al., 2007). Information regarding how the NEISS classifies the location of bike paths, shared paths, and pedestrian paths is unknown. Despite these limitations, the strength of this study is its large, nationally representative sample with additional analytic approaches to characterize helmet use and motor vehicle involvement with the injuries.

5. Conclusion

Although the rate of bicycle-related injuries declined, bicycles remain an important source of injury for children. Helmets are protective against TBIs, head and neck injuries and hospitalizations, yet among inured children the rate of helmet use did not change over time, and the proportion of helmet use decreased as age increased. Involvement of motor vehicles is a risk factor for hospitalization for injured children. Greater efforts are needed to promote helmet use and use of safe routes to reduce the possibility of motor vehicle involvement and to mitigate bicycle-related injuries among children.

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