Estimated total costs from non-fatal and fatal bicycle crashes in the USA: 1997–2013

Thomas W Gaither,1 Thomas A Sanford,1 Mohannad A Awad,1 E Charles Osterberg,1 Gregory P Murphy,1 Bruce A Lawrence,2 Ted R Miller,2,3 Benjamin N Breyer1,4

ABSTRACT

Introduction Emergency department visits and hospital admissions resulting from adult bicycle trauma have increased dramatically. Annual medical costs and work losses of these incidents last were estimated for 2005 and quality-of-life losses for 2000.


Results Approximately 3.8 million non-fatal adult bicycle injuries were reported during the study period and 9839 deaths. In 2010 dollars, estimated adult bicycle injury costs totalled $24.4 billion in 2013. Estimated injury costs per mile bicycled fell from $2.85 in 2001 to $2.35 in 2009. From 1999 to 2013, total estimated costs were $209 billion due to non-fatal bicycle injuries and $28 billion due to fatal injuries.

Conclusion Inflation-free annual costs in the study period increased by 137% for non-fatal injuries and 23% for fatal injuries. The share of non-fatal costs associated with injuries to riders age 45 and older increased by 1.6% (95% CI 1.4% to 1.9%) annually. The proportion of costs due to incidents that occurred on a street or highway steadily increased by 0.8% (95% CI 0.4% to 1.3%) annually.

INTRODUCTION

The health benefits of bicycling include increased physical activity and improved cardiovascular health.1–3 Although these positive impacts are well documented, a growing body of literature suggests potential drawbacks to bicycling due to serious and sometimes life-threatening injuries.4–7 Over the last 15 years in the USA, the incidence of hospital admissions due to bicycle crashes increased by 120%.6 Given that costs resulting from a bicycle injury are 20-fold higher for hospital-admitted patients than for patients treated in the emergency department (ED) and released, an increase in the rate of admissions has major cost implications.7

Costs associated with bicycle injuries last were reported for 2005. Estimated medical and work loss costs due to fatal and non-fatal bicycle-related trauma exceeded $5 billion in the USA in 2005.8 Estimated quality-of-life costs of bicycle injuries were $14.7 billion in 2000.9 Another study estimated medical and work loss costs of bicycle-related brain injuries at $3.9–6.0 billion in 2002.10 Motor vehicle involvement increases severity and associated costs of bicycle trauma.9–12 Males and teens/young adults have disproportionately high bicycle-related trauma costs.8 The only detailed analysis of bicycle injury costs by demographic characteristics of riders is from 2000.9 Previous studies are limited by the use of only a year’s worth of cost data. Calculation of costs over time, including non-fatal and fatal crashes, will provide a more comprehensive report of the societal burden of bicycle injuries.

We aim to estimate annual total costs (medical costs, work losses and quality-of-life losses) associated with non-fatal and fatal bicycle injuries of adults ages 18 and over in the USA over time. For non-fatal injuries, we use 1997–2013 incidence data from the National Electronic Injury Surveillance System (NEISS) and unit cost estimates from the US Consumer Product Safety Commission’s Injury Cost Model (ICM). For fatal injuries, we use 1999–2013 incidence data from the Multiple Cause of Death (MCOD) data files, with unit costs primarily from the Web-based Injury Statistics Query and Reporting System (WISQARS). We seek to understand how rider demographics (age, sex) and location of the crash predict changes in total annual costs.

METHODS

Data sources

The NEISS database is a weighted national probability sample of consumer product-related injury visits to EDs in a sample of approximately 100 US hospitals. The NEISS database provides detailed information on consumer product-related injuries, including bicycles.13 We queried the NEISS database for all bicycle-related injuries from 1997 to 2013 using NEISS product codes 5040 and 5033. This code choice excludes mopeds and cycles that do not have two wheels. Population projections of a potential doubling of bicycle ridership were used to project increased costs to 2013 using ICM cost estimates for each injury. The projections were made using the Growth Projections of the United States.3

The NEISS database provides detailed information about consumer product-related injuries, including bicycles.13 To examine the relationship between injury cost and age, sex, and other potential confounders, we calculated total costs by demographic characteristics of riders. We used unit costs primarily from the Web-based Injury Statistics Query and Reporting System (WISQARS). To examine how injury cost is distributed across different types of bicycle-related injuries, we used the Web-based Injury Statistics Query and Reporting System (WISQARS) data files, with unit costs primarily from the Web-based Injury Statistics Query and Reporting System (WISQARS). We seek to understand how rider demographics (age, sex) and location of the crash predict changes in total annual costs.

The MCOD file is maintained by the National Center for Health Statistics (NCHS). NCHS collects data from the 50 states, along with New York City and Washington, DC, which are responsible for registering deaths. It captures all deaths that occur in the USA.14 Since 1999, the MCOD has used the International Statistical Classification of Diseases and Related Health Problems 10th Revision to classify and code causes of death.15 We

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selected all cases where underlying cause of death was a pedal-cycle crash.

Miles bicycled in 2001 and 2009 from the National Household Travel Survey Data Extraction Tool (http://nhts.orl.gov) served as exposure data.

Costs
For both fatal and non-fatal bicycle injuries, we estimated medical costs, work losses and quality-of-life losses per case. When these costs are added together, they represent a total cost to society. All costs are reported in inflation-free 2010 US dollars; effects of price inflation have been removed.

Non-fatal injuries
We estimated costs resulting from non-fatal bicycle injuries using the ICM.16 17 Detailed documentation of the ICM can be found elsewhere2 but a brief overview of each component is summarised here.

The ICM’s medical and work loss costs are constructed using injury cases from two 2010 datasets of the Healthcare Cost and Utilization Project—the Nationwide Inpatient Sample (NIS) and the Nationwide Emergency Department Sample (NEDS). The Agency for Healthcare Research and Quality (AHRQ) receives the hospital inpatient and ED discharge data from participating states (45 in the NIS, 28 in the NEDS in 2010) and selects hospitals from these states whose discharges constitute representative 20% samples of US inpatient stays and ED visits. ICM developers analysed the cases from each dataset that represented injuries under the purview of Consumer Product Safety Commission (CPSC).

Medical costs for hospital-admitted injuries began with the hospital charge, which was multiplied by a facility-specific cost-to-charge ratio to obtain the cost of the initial visit. This was then multiplied by a series of factors to account for non-facility costs, readmissions and short and long-term follow-up costs. Where relevant, costs were added for rehabilitation and a nursing home stay. For injuries treated in the ED and released, cost of the initial ED visit, based on claims for outpatient services in the 2010–2011 MarketScan Commercial Claims and Encounters Database, was assigned by injury diagnosis. This was multiplied by factors representing short and long-term follow-up costs. For both hospital-admitted and ED-treated injuries, an emergency transport cost was added. Finally, claims processing cost was estimated as a percentage of the total, using a percentage specific to the expected payer.

The estimated cost of lost work included both short-term work loss and long-term disability. The diagnosis-specific expected number of days lost was multiplied by the average daily earnings and value of household production for a person of the victim’s age and sex to arrive at short-term work loss. For permanent total disability, the present value of age-and-sex-specific lifetime earnings and household production were multiplied by the diagnosis-specific probability of permanent disability. For permanent partial disability, this was multiplied by an additional factor identifying the average extent of disability resulting from that type of injury. Costs in future years were discounted to present value using a 3% discount rate. Summing short-term, total disability and partial disability costs yielded total work loss.

Lost quality of life places a dollar value on the intangible results of injury. CPSC’s ICM valued quality-of-life loss based on the amount juries awarded to injury victims for non-economic damages (losses excluding medical costs and work loss). It estimated that loss based on a log-linear regression with dependent variables including demographic, product-specific and injury-specific variables plus variables related to the legal case. Importantly, 18% of the awards analysed compensated bicycle or moped injury victims.7 As jury awards for non-fatal injury are reasonably predictable, this method offers a practical approach to estimating quality of life lost that yields estimates consistent with approaches which measure quality-adjusted life years lost.18 19 Although this method has critics,20 CPSC chose it because it grounds CPSC regulatory analyses on quality-of-life losses actually paid in product liability lawsuits. US Department of Justice regulatory analyses also base their quality-of-life loss estimates on jury verdicts.21

NEISS diagnosis and body part codes were merged onto the NIS and NEDS cases. Mean medical, work loss and quality-of-life loss costs were then estimated by NEISS diagnosis and body part, age group (0–19, 20–54, 55–69, 70+) and sex. When necessary, dimensions were collapsed to obtain reasonable cell counts. The ICM cost estimates were then merged onto the NEISS data by diagnosis, body part, age group and sex.

Fatal injuries
Our estimation of medical costs and work loss for fatal injuries follows the methods of the WISQARS Cost of Injury Module.22 We summarise the methods briefly here.

Medical costs depend on the place of death. A death at the scene of the crash incurs no medical cost. A death in a medical facility—ED, hospital, nursing home or hospice—incurs a cost that depends on the type of facility, the type of injury and the patient’s age, plus the cost of emergency transport to the facility. In addition, all deaths incur a small coroner fee, and any death that results in an autopsy incurs an autopsy cost.

Lifetime productivity loss was estimated as the discounted sum of expected annual earnings over the victim’s remaining potential working life. For a given year, expected earnings are the product of the sex-specific probability of surviving to the next year of age times sex-specific expected earnings for someone of that age. Parallel calculations valued lost household work.

WISQARS does not estimate or value quality-of-life loss. We used the average value of a year of life expectancy implicit in the jury verdict values for non-fatal quality-of-life loss.18 We multiplied this dollar amount by the discounted age and sex-specific life expectancy of each victim. This procedure produces an estimate consistent with the non-fatal quality-of-life loss costs described above.

Statistical analysis
We used linear regression to estimate the average change in inflation-free costs by year. We performed linear regression of total costs by year, and then individually by medical costs, work loss and quality-of-life loss. We then stratified our analysis and performed linear regression on the proportion of total costs in three demographic groups: age (bicycle riders ≥45 years of age vs <45 years of age), sex (male vs female) and location of injury (street incidents vs incidents that did not occur on a street). All regression coefficients were considered statistically significant if p<0.05.

RESULTS
Non-fatal injuries
Total costs
Approximately, 3.8 million non-fatal adult bicycle injuries were reported during the study period (1997–2013). Total estimated costs due to non-fatal adult bicycle injuries during this time were approximately $227 billion in 2010 US dollars. The
The number of adult cycling injuries increased by approximately 6500 (95% CI 4728 to 8287) annually. Total annual costs increased by 140% from $9.3 billion in 1997 to $22.4 billion in 2013. Each year, the total costs associated with non-fatal adult bicycle trauma increased by an average of $789 million (95% CI $647 to $930). Medical costs increased by 137% from $885 million in 1997 to $2.1 billion in 2013.

**Rider demographics**

The proportion of total adult bicycle injury costs stratified by rider demographics can be seen in figure 2. The proportion of costs due to riders age 45 and older increased an average of 1.6% (95% CI 1.4% to 1.9%) annually. In 2013, 53.9% of total

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**Table 1** Mean incidence, cost per case and total annual costs by year for non-fatal bicycle injuries, USA, 1997–2013

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<th>Year</th>
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<td>Age≥45 ($)</td>
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<td>Male ($)</td>
<td>Street or highway ($)</td>
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<td>67 147</td>
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* p<0.05 test for trend.

Costs are in 2010 dollars and include medical costs, work loss and quality-of-life loss.
costs were due to riders 45 and older, up from 26.0% in 1997 (107% increase). The proportion of costs due to incidents that occurred on a street or highway also steadily increased by 0.8% (95% CI 0.4% to 1.3%) annually. In 2013, 66.5% of total costs were due to bicycle injuries on the street, up from 46.0% in 1997 (45% increase). There was no significant linear trend by rider sex. In 2013, 77.3% of total costs were due to male riders.

Hospital versus ED admissions

Table 2 shows that adult hospital admissions increased significantly over time, with mean cost per case increasing by $2911 (95% CI $157 to $5666) annually. ED-treated adult injuries also significantly increased over time, with mean cost per case increasing by $374 (95% CI $332 to $417) annually.

Fatal injuries

Total costs

Total estimated costs due to fatal adult bicycle crashes were $39 billion from 1999 to 2013 (table 3). Total costs due to fatal injuries rose gradually by $28 million annually throughout the time period; they averaged $1.85 billion (1.5%) per year. Bicycling deaths increased by an average of 19 (95% CI 13 to 26) cases annually. Annual deaths due to bicycle crashes increased in patients age 45 and older (23 cases, 95% CI 19 to 27) and decreased in patients younger than 45 (14 cases, 95% CI 10 to 19). Cost per case steadily decreased by $28 280 (95% CI $22 086 to $34 475) annually.

Estimated adult bicycle injury costs totalled $24.4 billion in 2013. Estimated injury costs per mile bicycled fell from $2.85 in 2001 to $2.35 in 2009.

DISCUSSION

This study aimed to evaluate trends in costs associated with non-fatal and fatal bicycle injuries in the USA from 1997 to 2013 using incidence data from the federal databases and cost data based on published ICMs used in federal regulatory impact analysis. Overall, costs due to non-fatal adult bicycle injuries increased steadily since 1997 by an average of $789 million annually. In 2013, we estimate adult bicycle injury costs totalled $24 billion. For reference, this is approximately double the medical and indirect costs associated with occupational illnesses in 1 year in the USA. Injury costs of older riders and non-admitted injuries in street crashes increased disproportionately over time and raised total costs. Over time, men consistently accounted for three-quarters of total costs.

The increasing incidence of bicycle-related trauma and hospital admissions over the past 15 years only partly explained this increase in real injury costs. Costs per survivor by treatment setting also rose. Regardless of the year of injury, the ICM used the same cost by age group and treatment setting for any given injury, for example, a compound tibia fracture. Thus, the cost increase must result from more severe injuries and older bicycle riders who may require longer recovery periods. Rising injury
severity is possibly caused by changes in motor vehicle traffic, increasing commuting by bicycle, or changes in vehicle design. Older riders accounted for a greater proportion of total costs in 2001 to 0.80 in 2009. Thus, rising costs in these two age groups are driven by rising exposure. Importantly, despite the rise in total injury costs, costs per mile bicycled by adults fell by 17% from 2001 to 2009. Unfortunately data are not available to assess if this fall resulted from increasing adult helmet use.

In addition to rising exposures, the increasing prevalence of older cyclists may be increasing costs due to more severe non-fatal injuries. Others have identified age over 39 as a risk factor for bicycle injury severity among admitted patients (OR=2.2 compared with younger adult patients). Relative to younger riders, riders over age 55 have more than double the probability of dying if injured in a bicycle-MVC, an indication that this is a more vulnerable population. Analysis of head injuries from bicycle crashes found that subdural haematomas, number of contusions, intracerebral haematomas and intraventricular bleeding increased with age. With comparable injuries, age is also a risk factor for longer recovery times after injury. The mechanisms causing higher injury severity among the elderly merit future research.

Street crashes represent an increasing proportion of total costs compared with non-street incidents. These crashes often involve motor vehicles, which increase velocity of crash impact and consequently injury severity. Streets might also predispose to more injuries due to the coexisting environment with urban areas, increased population density or the presence of more unyielding street furniture. Accumulating evidence suggests that bicycle-specific facilities, such as bicycle paths, may reduce crashes and injuries on the roadway. Building such infrastructure is costly and the cost-effectiveness of such environmental health interventions often lack sufficient evidence for projects to move forward. Projected costs to rebuild an entire 274-mile bikeway network in the city of Portland are $57 million, which is about $208 000 per mile. The USA has an estimated 8 656 070 bicycle lane miles. Thus, creation of a bikeway network covering one-sixth of the entire USA would cost approximately $300 billion, which roughly equals the total costs of non-fatal and fatal bicycle injuries in the 10-year study period ($293 billion). Although such infrastructure will not prevent all injuries, costs associated with injuries must be taken into account when determining the cost-effectiveness of bicycle-specific infrastructure.

Total cost of adult bicycle fatalities steadily decreased over time. It is unclear if this resulted from shifts between age groups in frequency of bicycle use and miles bicycled. However, total cost per fatal injury is much larger in patients younger than 45 because work and quality-of-life losses fall as remaining life expectancy declines. Therefore, increasing rider age results in a falling mean cost of bicycle-related injuries. Decreased fatalities in younger riders might result from increased helmet use. Since 1980, the mortality rate due to no helmet use has decreased by estimated 40%.

The NEISS incidence data come from a sample of just 100 hospitals, which means that they might not be representative of the US population. The reliability of NEISS trend analyses, however, is enhanced because the same 100 hospitals were sampled over time. Injuries treated only in physician’s offices or ambulatory clinics are not captured in the NEISS dataset so total cost was underestimated. The cost data came from multiple sources, with each presenting the possibility of measurement error and reporting bias. We deliberately ignored any medical cost changes resulting from technological change or inflation. Injury coding in the NEISS data is coarser than in the data sets used to determine the medical cost estimates, which reduces the accuracy of the NEISS estimates and its sensitivity to severity changes.

<table>
<thead>
<tr>
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<th>Age≥45</th>
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<td>−28 280</td>
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*p<0.05 test for trends in incidence, mean cost per case and total cost. Costs are in 2010 dollars and include medical costs, work loss and quality-of-life loss.
over time. We also excluded costs of property damage, police and fire services, property insurance claims administration and injury-related litigation. We were unable to provide information about the heterogeneity of incidents or population density where bicycle injuries occur. Costs due to loss of life are challenging to estimate. The jury verdict method to value lost quality of life is imperfect and only estimates quality-of-life losses to the degree injuries in our study match those in litigation suits. Our total costs’ estimates are thus influenced by choosing this method for predicting quality-of-life loss. Future studies should examine cost–benefit analyses for best practices to prevent injury and thus costs. In particular, roadway infrastructure and vehicle design might be incorporated in this analysis.

CONCLUSION
Costs per case of bicycle injury have risen steadily since 1997. The growing costs resulted from increasing injuries among riders age 45 and older and increases in street crashes. Society bears a large direct and indirect financial burden secondary to non-fatal and fatal bicycle injuries, suggesting a policy focus on injury prevention.

What is already known on the subject

► Over the last 15 years, the incidence of bicycle trauma in adults increased by 28%.
► In 2005, estimated medical and work loss costs due to fatal and non-fatal bicycle-related trauma exceeded $5 billion in the USA.

What this study adds

► Inflation-free costs per adult bicycle crash rose steadily from 1999 to 2013.
► The growing costs resulted from increasing ridership, share of injuries among riders age 45 and older, and proportion of street crashes.
► Costs per mile bicycled by adults fell from $2.85 in 2001 to $2.35 in 2009.
► Costs associated with adult bicycle crashes exceeded $24 billion in 2013, approximately double the medical and indirect costs of occupational injuries in the USA.

Contributors TWG: data analysis, interpretation of data, manuscript writing and editing. TAS: project idea, critical review of manuscript. MA: data analysis, critical review of manuscript. ECO: interpretation of data, critical review of manuscript. GPM: interpretation of data, critical review of manuscript. BL: acquired all data, data analysis, interpretation of data, critical review of manuscript. TRM: acquired all data, data analysis, interpretation of data, critical review of manuscript. BNB: project idea, critical review of manuscript, supervision of project.

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REFERENCES


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