RESEARCH ARTICLE

# Safety Factors and Patterns of Bicycle Trauma in a Tertiary Level 1 Trauma Center in Boston, Massachusetts: A Retrospective Review and Survey Study

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*Received: 17 June 2020* *Accepted: 26 August 2022*

## Abstract

**Objectives:** Increasing bicycle ridership is accompanied by ongoing bicycle-related accidents in many urban cities. There is a need for improved understanding of patterns and risks of urban bicycle usage. We describe the injuries and outcomes of bicycle-related trauma in Boston, Massachusetts, and determine accident-related factors and behaviors associated with injury severity.

**Methods:** We conducted a retrospective review via chart review of 313 bicycle-related injuries presenting to a Level 1 trauma center in Boston, Massachusetts. These patients were also surveyed regarding accident-related factors, personal safety practices, and road and environmental conditions during the accident.

**Results:** Over half of all cyclists biked for commuting and recreational purposes (54%), used a road without a bike lane (58%), and a majority wore a helmet (91%). The most common injury pattern involved the extremities (42%) followed by head injuries (13%). Bicycling for commuting rather than recreation, cycling on a road with a dedicated bicycle lane, the absence of gravel or sand, and use of bicycle lights were all factors associated with decreased injury severity ($p<0.05$). After any bicycle injury, the number of miles cycled decreased significantly regardless of cycling purpose.

**Conclusion:** Our results suggest that physical separation of cyclists from motor vehicles via bicycle lanes, regular cleaning of these lanes, and usage of bicycle lights are modifiable factors protective against injury and injury severity. Safe bicycling practices and understanding of factors involved in bicycle-related trauma can reduce injury severity and guide effective public health initiatives and urban planning.

**Level of evidence:** IV

**Keywords:** Bicycle trauma, Injury patterns, Trauma preparedness, Trauma, Urban infrastructure

## Introduction

The usage of bicycles in urban centers poses many attractive health and environmental benefits.[1] Cycling has been directly shown to reduce the public health burden of diseases such as cardiovascular disease, hypertension, obesity, and diabetes mellitus, as well as the economic burden of their management.[2-6] One model from New Zealand predicted that just an annual 5% shift in kilometers traveled from motor vehicles to cycling would translate into an annual reduction of health spending by $200 million dollars and a 0.4% reduction in national greenhouse gas emissions.[7] Additionally, a public bicycle sharing initiative in Spain demonstrated that 9.9% of the population switching their primary mode of transportation from cars to bicycles reduced carbon dioxide emissions by 9,062,344 kg over one year.[8]

Benefits notwithstanding, bicycle ridership in cities

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remains low, with only 1% of commuters across 50 major U.S. cities routinely bicycling due to multiple factors including lack of infrastructure and cycling initiatives and risk of injury.[9] Compared to motor vehicles, bicyclists face a 1.8-times higher risk of accident related injuries, a 1.3-times higher risk of death,[9,10] and a 10-times higher rate of accidents.[11] Compared to motorcyclists, cyclists have a higher mortality when sustaining comparable injuries.[12] Most bicycling fatalities occur on urban roads and involve a motor vehicle,[13] with head injuries being a leading cause of death.[14,15]

Boston, Massachusetts has seen several bicycle-promoting initiatives in recent years through the Boston Bike Network Plan and the Boston Bicycle Counts Initiative. Currently, cycling represents 2% of all transportation modes; the City of Boston has set a goal to increase this number to 10% by 2020 through investments and initiatives to increase bicycle-friendly infrastructure.[16, 17] Indeed, in Boston, bicycle commuting has increased by 82% between 2008 and 2011, accompanied by an increase in cyclist-friendly infrastructure.[18, 19]

Accompanying this increase in ridership have been cycling-related accidents and fatalities. In recent years, Boston has seen the highest number of bicycle-related fatalities compared to several comparable U.S. cities, averaging 520 cycling-related injuries annually (both fatal and non-fatal) between 2010 and 2014, with five fatalities in 2012.[17] A 2009 study by Boston Bikes estimated that 43% of bikers experienced an accident during their ridership, with 9% of 3,545 incidents serious enough to require a hospital visit.[16] The City of Boston has set a goal to reduce bicycle accidents by 50% by 2020.[16]

Improved understanding of the risks of and data regarding bicycle riding in different cities is critical in guiding important policies to improve health, the environment, and transportation. Adequate data are lacking worldwide on the rates of bicycle accidents, types of injuries, and factors contributing to these injuries.[9] additionally, correlation of injury frequency, location, and severity with the circumstances of the accident, including bicycle infrastructure and type of collision, is poorly characterized. Identifying the types of accidents, cyclist behaviors, and the relationship of infrastructural factors to injury frequency and severity will help inform and motivate interventions and city plans to lower the risk of injury. Additionally, better understanding of the types, severity, and causes of different types of injuries can guide trauma centers in planning their responses to bicycle trauma.

We conducted a retrospective study of bicycle accident-related injuries that presented to our tertiary Level I trauma center in Boston, Massachusetts in order to improve understanding of the risks of bicycle use in Boston along with the patterns and outcomes of cycling-related injury. We then sent post-injury surveys to 313 cyclists who had presented to the emergency department (ED) with injuries related to bicycle accidents, evaluating factors related to bicycle use, type of injury, and any corresponding hospitalization data with the goal of identifying opportunities for prevention and intervention.

## Materials and Methods

This is a retrospective study of bicycle accident-related injuries presenting to the ED at our Level 1 Trauma Center. Patients were identified by ICD-9CM (International Classification of Diseases) codes indicating an injury involving a bicycle. Using an Institutional Review Board (IRB)-approved protocol (Protocol #2014P000059), 313 cyclists who presented to the ED with bicycle-related injuries were contacted with surveys requesting information regarding the circumstances of the accident and the cyclists' bicycling habits and patterns. A retrospective chart review of survey respondents was then completed to gather data on demographics, medical comorbidities (diabetes, disability, psychiatric history), injury data (severity, types of injuries), diagnoses, hospital admission course (duration of stay, intensive care unit (ICU) admission, surgeries, transfusions), and discharge disposition (home vs. rehabilitation, readmission, injury sequelae, time off work, and permanent disability). Injury severity was determined retrospectively using the Injury Severity Score (ISS), a well-established score for trauma severity which accounts for multiple injuries across different anatomical regions with scores ranging from 3 (least severe) to 75 (most severe either critically ill or unsurvivable).[20, 21] Consent was obtained for the retrospective medical chart review. Written or verbal consent was obtained for subjects approached for the survey. Verbal consent was administered for phone conversations following non-deliverable mailing, or subjects contacted the study team directly.

### *Survey Components*

Cyclists seen in the ED for a bicycle-related accident completed a survey online via the Research Electronic Data Capture software (REDCap) (Vanderbilt University, Nashville, TN, USA). A letter of introduction containing a link to the online survey was sent to subjects using their mailing addresses of record. If letters were non-deliverable, the subject was then contacted at his or her phone number(s) of record. The survey queried information on cycling habits, safety behaviors, road and environmental conditions, and circumstances surrounding the accident.

### *Statistical Analysis*

Data regarding patterns of bicycle usage, accident information, and injury information were collected from survey responses. Distribution-free statistical tests were used in this study as ISS scores were not normally distributed by Shapiro-Wilk testing. The Mann-Whitney U test for significance was used when comparing two groups; the Kruskal-Wallis test was used for analyses involving three or more groups, followed by the Dunn's post-hoc test. A p-value of less than 0.05 was considered to be significant. Statistical analyses were performed using the GraphPad Prism software suite (GraphPad Software, Inc., La Jolla, CA, USA). For the section entitled Factors Associated with Injury Severity, a Bonferroni correction was applied to account for multiple comparisons.

## Results

### *Patient Demographic Factors*

There were 313 patients who presented to the emergency department (ED) of our Level 1 Trauma Center with bicycle-related injuries and who completed a survey regarding their accident and bicycle riding habits. All percentages and data are reported out of a n of 313 patients unless specifically indicated. Six cyclists were active smokers at the time of the accident. Five cyclists (2%) had diabetes and only one cyclist (0.3%) had a pre-existing disability. One bicyclist (0.3%) had a history of illicit drug use and eight (3%) had a history of psychiatric illness. Two bicyclists (0.6%) were on anticoagulation medication at the time of the accident. Almost all bicyclists were self-paying or had private insurance (n=296, 94%). Nine (3%) bicyclists were on Medicare and seven (2%) were on Medicaid.

### *Bicycle Use Patterns*

A majority of patients biked for both commuting and recreation (n=168, 54%), followed by patients biking solely for recreation purposes (n=98, 31%), and then by patients biking purely for commuting purposes (n=47, 15%) [Table 1].

Most cyclists biked on roads without bike lanes (n=183, 58%) and only 2% (n=7) of cyclists reported that they used a dedicated bike lane for a majority of their cycling. A majority of bikers were wearing a helmet at the time of the accident (n=286, 91%). The most common type of bicycle involved was a road bike (n=181, 58%). Of the bicycles involved in the accidents, 161 (52%) riders had their bicycles serviced by a professional mechanic fewer than 3 months prior to their accident. There was no significant difference in injury severity between different bicycle types. 204 riders used lights on both the front and rear of their bicycles (65%) while 77 (25%) riders had no lights on their bicycle. There was a relatively even distribution of bicyclists who wore reflective or bright clothing (n=169/308, 55%) and those that did not (n=139, 45%). The majority of bicyclists involved in accidents had more than three years of bicycling experience (n=255, 81%). After their injury, the median number of miles biked for commuting and recreation both decreased significantly ($p<0.0001$).

**Table 1. Bicycle Use Patterns**

| | | |
|---|---|---|
| **Type of Bicycle** | | |
| | Cruiser | 11(3.51%) |
| | Folding | 2 (0.64%) |
| | Hybrid | 84 (26.84%) |
| | Mountain | 35 (11.8%) |
| | Road | 181 (57.83%) |
| **Purpose of Biking** | | |
| | Commuting | 47 (15.02%) |
| | Recreation | 98 (31.38%) |
| | Both | 168 (53.67%) |
| **Types of Path Primarily Used** | | |
| | No bike lane | 183 (58.28%) |
| | Bike lane, non-painted | 59 (18.79%) |
| | Bike lane, different color than road | 15 (4.78%) |
| | Dedicated, separated bike lane | 7 (2.23%) |
| | Off road bike lane | 42 (13.38%) |
| | Sidewalk | 8 (2.55%) |
| **Percentage of Time Following Traffic Rules (Self-reported)** | | |
| | >75% | 190 (60.70%) |
| | 50-75% | 86 (27.48%) |
| | 25-50% | 28 (8.95%) |
| | <25% | 9 (2.28%) |
| **Lights on Bicycle** | | |
| | Both front and rear | 204 (65.18%) |
| | Front only | 6 (1.92%) |
| | Rear only | 26 (8.31%) |
| | None | 77 (24.60%) |
| **Percentage of Time Wearing a Helmet** | | |
| | >75% | 286 (90.79%) |
| | 50-75% | 4 (1.27%) |
| | 25-50% | 5 (1.59%) |
| | <25% | 20 (6.35%) |
| **Wearing Reflective Clothing(n=308)** | | |
| | Yes | 169 (54.87%) |
| | No | 139 (45.13%) |
| **Experience Prior to Injury** | | |
| | >3 years | 255 (81.47%) |
| | 1-3 years | 42 (13.42%) |

**Table 1. Continued**

| | | |
|---|---|---|
| | 6 months – 1 year | 6 (1.92%) |
| | 1-6 months | 4 (1.28%) |
| | <1 month | 6 (1.92%) |
| **Median Miles/Week Cycled Prior to Injury** | | |
| | For commuting | 30 miles |
| | For recreation | 20 miles |
| **Median Miles/Week Cycled After Injury** | | |
| | For commuting | 20 miles* |
| | For recreation | 10 miles* |
| **Time Since Bike Serviced by Professional** | | |
| | < 3 months | 161 (51.77%) |
| | 3-6 months | 51 (16.40%) |
| | 6 months- 1 year | 55 (17.68%) |
| | > 1 year | 44 (14.15%) |

### *Accident Information*

The types of accidents in order of decreasing frequency were collision with a motor vehicle (n=131, 41%), fall without a collision (n=130, 41%), collision with a stationary object (n=34, 11%), collision with another bicycle (n=14, 4%), and collision with a pedestrian (n=10, 3%) [Table 2] (n=319 as some survey respondents checked multiple accident mechanisms). In collisions with a motor vehicle, the most common type of vehicle involved was a sedan or small car (n=81/131, 62%).

There was one accident involving a collision with a large truck and two accidents involving collision with a bus. Based on survey results out of a n of 204, the two most common factors contributing to the accident were the presence of a pothole or other obstacle (n=69, 34%) and attempting to avoid collision with a car (n=46, 23%). Alcohol use was not involved in a majority of accidents (n=306, 98%). Only 14% (26) of cyclists self-reported that they had violated traffic rules leading up to the accident.

**Table 2. Accident Patterns**

| | | |
|---|---|---|
| Type of Accident (n=319) | Fall without collision | 130 (40.75%) |
| | Collision vs stationary object | 34 (10.66%) |
| | Collision vs other bicycle | 14 (4.39%) |
| | Collision vs motor vehicle | 131 (41.07%) |
| | Collision vs pedes trian | 10 (3.13%) |
| Type of Vehicle in Motor Vehicle (n=131) | Bus | 2 (1.53%) |
| | Large truck | 1 (0.76%) |
| | Pick-up/SUV/mini-van | 38 (29.01%) |
| | Sedan/small car | 81 (61.83%) |
| | Station wagon | 7 (5.34%) |
| | Other | 2 (1.53%) |
| Contributors to the Accident (n=204) | Equipment failure on bicycle | 15 (7.35%) |
| | Road conditions (icy or wet) | 19 (9.31%) |
| | Road conditions (gravel or sand) | 16 (7.84%) |
| | Pothole or obstacle | 69 (33.82%) |
| | Avoiding collision with a car | 46 (22.55%) |
| | Avoiding collision with a pedestrian | 15 (7.35%) |
| | Avoiding collision with other cyclist | 12 (5.88%) |
| | Avoiding collision with stationary object | 12 (5.88%) |
| Alcohol Involved (Either Party) (n=312) | Yes | 6 (1.92%) |
| | No | 306 (98.08%) |

### *Injury Information*

The most common injuries were extremity injuries (n=105, 42%) followed by head injuries (33, 13%) and facial injuries (15, 6%) [Table 3]. The median ISS score of all survey respondents was 4 (n=303 as only able to calculate for these patients). Nearly all patients had a Glasgow Coma Scale (GCS) score of 15 on arrival in the ED (n=302 of 312, 97%). Two patients required a transfusion. Most patients were not admitted to the hospital (n=204, 65%) and did not require surgery (n=256/312, 82%). 39 cyclists (12%, 39/313) required orthopedic surgical intervention; of this group, 15 (38%) had lower extremity surgery, 18 (46%) had upper extremity surgery, and 6 (15%) required spinal surgery. 18

of 312 (6%) cyclists required an ICU stay. 13 of 313 patients (4%) required hospital re-admission for injuries related to their initial bicycle accident injury. Two of 313 patients (0.6%) sustained permanent neurologic injury as a result of the bicycle accident. One patient of 313 (0.3%) sustained a permanent disability preventing return to work.

| Table 3. Injuries | | |
|---|---|---|
| **ISS Score (n=303)** | | |
| | 0-5 | 200 (66.01%) |
| | 6-10 | 71 (23.43%) |
| | 11-15 | 4 (1.32%) |
| | 15-20 | 18 (5.94%) |
| | >20 | 10 (3.3%) |
| **ISS Category** | | |
| | Head | 33 (13.10%) |
| | Face | 15 (5.95%) |
| | Chest | 26 (10.32%) |
| | Abdomen | 4 (1.59%) |
| | Extremities | 105 (41.67%) |
| | External | 69 (27.38%) |
| **GCS at Admission (n=312)** | | |
| | 10 | 0 |
| | 11 | 0 |
| | 12 | 0 |
| | 13 | 2 (0.64%) |
| | 14 | 8 (2.55%) |
| | 15 | 302 (96.7%) |
| **Length of Hospital Stay** | | |
| | Not admitted | 204 (65.18%) |
| | 1-5 days | 90 (28.75%) |
| | 6-10 days | 8 (2.56%) |
| | > 10 days | 11 (3.51%) |
| **Surgical Intervention Required (n=312)** | | |
| | Yes | 56 (17.95%) |
| | No | 256 (82.05%) |
| **Orthopedic Surgery Required (n=39)** | | |
| | Lower Extremity | 15 (38.46%) |
| | Upper Extremity | 18 (46.15%) |
| | Spine | 6 (15.38%) |
| **ICU Stay Required (n=312)** | | |
| | Yes | 18 (5.73%) |
| | No | 294 (93.63%) |
| **Transfusion Required (n=312)** | | |
| | Yes | 2 (0.64%) |
| | No | 310 (99.36%) |
| **Discharged to (n=312)** | | |
| | Home | 302 (96.79%) |
| | Rehab | 10 (3.21%) |
| **Time Off from Work Required(n=312)** | | |
| | Yes | 19 (6.09%) |
| | No | 293 (93.91%) |
| **Readmission (n=313)** | | |
| | Yes | 13 (4.15%) |
| | No | 300 (95.84%) |
| **Permanent Neurologic Injury (n=313)** | | |
| | Yes | 2 (0.6%) |
| | No | 311 (99.4%) |
| **Permanent Disability (n=313)** | | |
| | Yes | 1 (0.3%) |
| | No | 312 (99.7%) |

### *Factors Associated with Injury Severity*

Bicycle use patterns were analyzed as reported from study participants. Cyclists primarily cycling for commuting purposes had significantly less severe injury burden than those primarily cycling for recreation (median ISS score 1 vs. 8 respectively, p=0.00003) [Table 4]. Bicyclists who had any lights on their bicycles also had significantly less severe injury burden than those who did not (median ISS score 2 vs. 5, p=0.004). With regard to accident factors, the type of motor vehicle involved did not affect severity of injury. Cyclists predominantly riding their bicycles on roads without a bicycle lane also sustained more serious injuries than cyclists who predominantly rode on roads without a bicycle lane (median ISS score 4 vs. 1, p=0.0488). Sub-analyses stratifying within the group using a dedicated bicycle lane or a separated bicycle paths from the road revealed that there was no significant difference in injury severity if the bicycle lane was painted, painted a different color than other road lines, separated from the road on a separate cycle track, on an off-road bike path, or on a sidewalk. Interestingly, collisions not involving a motor vehicle were found in our study to be associated with higher ISS scores when compared with those involving a motor vehicle (median ISS score 4 vs. 2, p =0.016). Accidents during wet or icy road conditions were not associated with significant differences in median ISS score compared to those occurring on dry roads. However, accidents occurring with gravel or sand on the road were associated with higher ISS scores than those occurring on clean roads (median ISS score 9 vs. 3.5, p=0.034). Alcohol use leading up to the accident was not associated with increased ISS scores in our study. Accidents involving avoiding collision with a car, pedestrian, other cyclist, or stationary obstacle were not associated with significant differences in median ISS scores from accidents not involving avoidance of these factors. Similarly, accidents where cyclists felt they violated traffic rules were not associated with different median ISS scores than those where cyclists felt they followed traffic rules.

## Discussion

Public health efforts to improve safe bicycling practices such as using reflective clothing, lights, and wearing helmets have likely been effective.[22, 23] Indeed, nearly all bicyclists in our study used a helmet, wore reflective gear, had front and rear lights on their bicycles, and had their bicycles serviced within three months prior to the accident, suggesting the next steps in improving bicycle safety may need to center around city infrastructure and factors beyond the individual cyclist. For example, creating dedicated bicycle lanes has led to increasing bicycle use and decreased likelihood of being struck by a motorist .[18] Supporting this is the observation that over half of all survey respondents in our study predominantly rode their bicycles on roads without bike lanes and sustained significantly more severe injuries. Taken together with literature demonstrating that creating separations between bicyclists and vehicles reduces rates and severity of accidents, our data suggests cyclists in the Boston area may benefit from further infrastructural expansion of dedicated bicycle lanes.[24-26] Notably, our data showed that the type of bike lane used did not significantly influence injury severity, suggesting that simple bike lanes that are painted on roads can afford similar safety as costly physical barriers or physically separated lanes from traffic.

The most common injury pattern in our study and other studies involved the extremities.[12, 27, 28] the majority of accidents were caused by collision with a motor vehicle or a fall without a collision, with avoidance of a car or another obstacle being the most common contributors to injury, a pattern again observed in other major cities.[28]

**Table 4. Injury Distribution and Impact of Safety and Accident Factors on Injury Severity**

| | | Median ISS Score | p-value |
|---|---|---|---|
| **Safety Factors** | | | |
| Experience | | | |
| | > 3 years | 4 | >0.05 |
| | < 3 years | 1 | |
| Purpose of Biking | | | |
| | Commuting | 1 | 0.00003* |
| | Recreation | 8 | |
| Reflective Clothing | | | |
| | Yes | 4 | >0.05 |
| | No | 4 | |
| Percentage of Time Wearing a Helmet | | | |
| | >75% | 4 | >0.05 |
| | <75% | 1 | |
| Time Since Bike Serviced by Mechanic | | | |
| | < 3 months | 4 | >0.05 |
| | > 3 months | 4 | |
| Lights on Bicycle | | | |
| | Yes | 2 | 0.004* |
| | No | 5 | |
| Perceived Violation of Traffic Rules | | | |
| | Yes | 4 | > 0.05 |
| | No | 2 | |
| **Accident Factors** | | | |
| Collision with Motor Vehicle vs Other Collisions | | | |
| | Motor vehicle collision | 2 | 0.016* |
| | Other collisions | 4 | |
| Type of Motor Vehicle | | | |
| | Sedan/small car | 2 | > 0.05 |
| | Larger vehicles | 1 | |
| Type of Accident | | | |
| | Collision | 2 | > 0.05 |
| | Fall | 4 | |
| Type of Path | | | |
| | Road-bike lane without paint | 1 | > 0.05 for all combinations of comparisons |
| | Road-bike lane different color | 2 | |
| | Dedicated cycle track | 2 | |
| | Off road bike path | 3 | |
| | Sidewalk | 5 | |
| Bike Lane | | | |
| | Road without bike lane | 4 | 0.049* |
| | Road with bike lane | 1 | |
| Road Conditions | | | |
| | Wet or icy | 1 | >0.05 |
| | Dry | 4 | |
| Presence of Gravel or Sand | | | |
| | Yes | 9 | 0.034* |
| | No | 3.5 | |
| Presence of Pothole | | | |
| | Yes | 4 | > 0.05 |
| | No | 3 | |
| Alcohol Use Prior to Accident | | | |
| | Yes | 2.5 | >0.05 |
| | No | 4 | |
| Avoiding Collision with Pedestrian | | | |
| | Yes | 1 | > 0.05 |
| | No | 4 | |
| Avoiding Collision with Car | | | |
| | Yes | 2 | > 0.05 |
| | No | 4 | |
| Avoiding Collision with Other Cyclist | | | |
| | Yes | 4 | > 0.05 |
| | No | 4 | |
| Avoiding Collision with Stationary Object | | | |
| | Yes | 4 | >0.05 |
| | No | 4 | |

Most vehicle collisions involved small cars or sedans, in contrast to other larger cities that have higher rates of bicycle accidents involving freight vehicles.[29] Though one might expect non-fatal accidents involving a motor vehicle to result in more serious injuries, we found them to be associated with lower ISS than other types of collisions, and to not differ significantly from ISS scores of cyclists involved in accidents related to falls, possibly due to other factors at the time of the accident not fully elucidated by our surveys. For example, bicyclists may be more comfortable with faster speed or less likely to be mentally alert when not in immediate proximity to motor vehicles, giving them less time to appropriately react. Similarly, cyclists may exercise increased caution in wet or icy conditions but be less able to anticipate local areas of sand or gravel on the road. As the presence of sand or gravel was associated with worse injury burden, a modifiable infrastructural change may be to increase street cleaning in areas of high bicycle traffic. We note that in other studies, however, that injuries sustained in injuries involving a motor vehicle that surgical intervention was more commonly required; this study also noted that upper extremity injuries were more frequently sustained than lower extremity injuries, similar to our findings that upper extremity injuries comprised the largest proportion of injuries that required orthopedic surgical intervention.[30]

Interestingly, we found a substantial proportion of accidents involved bicyclists who bicycled for recreational purposes, a similar pattern noted in a study of emergency department bicycle injuries in Reykjavik, Iceland.[30] In our study, those cycling for recreational purposes had more severe injuries; this may be the result of commuting cyclists being more seasoned and aware of traffic, rules, and obstacles on their chosen paths. While many urban planning initiatives focus on increasing bicycling for commuting purposes,[7] it may be important to consider implementing safety measures for recreational cycling. In our study, a majority of cyclists felt that they had not violated traffic rules leading up to the accident, though this may also be subject to recall bias and any legal outcomes were not collected. Further understanding of the socioeconomic drivers of urban bicycle riding will be useful as the majority or our patients were self-paying or had private insurance.

Our study has some limitations. One inherent limitation to our design is that all data was gathered from ED visits and post-hospitalization surveys. Thus, we were unable to have a control group to analyze factors that prevented accidents from occurring, circumstances involved in near-misses, minor accidents not resulting in ED visits, and accident-related fatalities. Future collaborations between healthcare providers and urban planners are likely to be fruitful in providing this type of data for analysis. Another limitation to our study is that all surveys were sent on a non-rolling basis regardless of date of injury; thus, potential inaccuracies and recall bias may affect survey responses of patients who were involved in accidents earlier on in our study period. There was also a potential response bias with 55% of respondents replying from an accident occurring from 2011-2015 and only 11% from 2001-2005, as well as a likely bias in self-reporting of errors, such as in cases of violation of laws or alcohol use. Future studies incorporating data pertaining to fatalities will be important when considering opportunities to improve cyclist safety. Despite these limitations, our study provides important insights that merge urban and behavioral metrics with hospital correlates of injury, providing a rare opportunity to assess the relative contribution of certain behaviors or circumstances to the severity of and recovery from injury. These findings may also be generalizable to other urban centers and can also inform public health initiatives for bicyclist and transportation safety.

## Conclusion

Individual cyclists have been utilizing safety measures including helmet use and reflective gear, resulting in less severe injuries. Public infrastructure initiatives such as creation of bike lanes and support for recreational cyclists are modifiable interventions that will likely improve cyclist safety. Hospital specific data and outcomes can be of great benefit to public health and city planning organizations as there are often discrepancies between city data and hospital data that are often non-accessible to city planners.[31] Additionally, the creation and maintenance of trauma registries can guide city programs to prevent future accidents.[32] Finally, improved hospital tracking of bicycle-related injuries in combination with public health efforts to monitor bicycle accidents[33,34] may help shape programs and policies that improve safety for cyclists in cities. These efforts and initiatives can make bicycling a safer, healthier, and more environmentally conscious option for commuters and recreationalists alike.

## Acknowledgement

Not applicable

***Conflict of interest:*** The author(s) do NOT have any potential conflicts of interest for this manuscript

***Funding:*** The author(s) received NO financial support for the preparation, research, authorship, and Publication of this manuscript.

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