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Mapping pediatric injuries to target prevention, education, and outreach

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ABSTRACT

Background: Initiatives exist to prevent pediatric injuries, but targeting these interventions to specific populations is challenging. We hypothesized that mapping pediatric injuries by zip code could be used to identify regions requiring more interventions and resources.

Methods: We queried the trauma registries of two level I trauma centers for children 0–17 years of age injured between 2009 and 2013 with home zip codes in our state. Maps were created to identify outlier zip codes. Multivariate linear regression analysis identified predictors within these zip codes.

Results: There were 5380 children who resided in the state and were admitted for traumatic injuries during the study period, with hospital costs totaling more than 200 million dollars. Choropleth mapping of patient addresses identified outlier zip codes in our metro area with higher incidences of specific mechanisms of injury and greater hospital charges. Multivariate analysis identified demographic features associated with higher rates of pediatric injuries and hospital charges, to further target interventions.

Conclusions: We identified outlier zip codes in our metro area with higher frequencies of pediatric injuries and higher costs for treatment. These data have helped obtain funding for prevention and education efforts. Techniques such as those presented here are becoming more important as evidence based public health initiatives expand.

Level of evidence: Type of Study: Cost Effectiveness, II.

Traumatic injuries account for significant morbidity, mortality, and economic burden in the United States. Unintentional injuries are the single greatest cause of death for individuals 1–44 years of age [1], and annual rates of non-fatal injury are as high as 13% in this age bracket [2]. These injuries are responsible for billions of dollars in annual medical care costs [3], and many of these injuries are preventable. This is especially true of children, for whom there are several proven ways to reduce both the likelihood and severity of traumatic injuries [4].

In our metro area there are numerous childhood injury prevention and outreach programs. The application of prevention efforts is, however, somewhat uneven and largely dictated by available resources and personnel in a given area. This is because no specific data exist regarding the locations of greatest need. We hypothesized that certain zip codes within our metro area would have higher frequencies of pediatric traumatic injuries and higher hospital charges for the treatment of these injuries. We further hypothesized that injury related predictors within these zip codes could be identified. To study this, we systematically examined all children treated for traumatic injuries at two level-1 trauma centers, and mapped them by zip code of residence.

1. Materials and methods

After institutional review board approval, we queried the trauma databases of two pediatric trauma centers (PTC) (Children's Hospital Colorado (PTC level 1) in Aurora, Colorado and Denver Health Medical Center (PTC level 2) in Denver, Colorado) for all children aged 0–17 years who were evaluated in the emergency department or directly admitted as an inpatient following traumatic injuries from 1/2009 to 9/2013, and had a known home zip code in the state of Colorado. Children with zip codes associated with P.O. boxes were excluded from this study (n = 8). Next, we identified children whose home zip code was in one of two adjacent cities, Denver or Aurora, Colorado, where 20% of the state's population reside. All subsequent analysis focused on this population. According to the Colorado Department of Public Health and Environment, 80% of traumatically injured children who were living in Denver or Aurora, Colorado during the study period went to one of the two hospitals in this study. Cost data were calculated using total patient charges for the hospitalization. Data were available for all categories, except where otherwise noted.

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1.1. Mapping

Choropleth maps were created to identify outlier zip codes for pediatric injuries in these cities. Choropleth maps use shading relative to the measurement of a given variable and provide a means to visualize variation across a region. Choropleth maps were created using zip code and primary and secondary road state shape files downloaded from the U.S. census bureau (2010 TIGER/Line Shapefile: Zip Code Tabulation Areas, Colorado; 2013 TIGER/Line Shapefile, Colorado, Primary and Secondary Roads). These shape file data were overlaid atop satellite imagery of the region downloaded from the Earth Science Data and Information System Project [5,6]. A computer script was written in Python by the first author to "color in" the choropleth framework with the relevant data from the trauma database using trauma codes. This computer script is available upon request to any interested party.

1.2. Theory and calculation

Zip code demographics from the 2010 census and the 2008–2012 American Community Survey were used for comparison [7]. Demographics used in our analyses included median household income, racial demographics, percent owner occupied housing, percent with some college education, percent households married with children and single parents, and total population. Demographic predictors of pediatric traumatic injuries in specific zip codes were then identified using univariate and multivariate linear models. Because of nonnormal distribution of outcome variables, all outcome variables were log-transformed (after addition of 1×10^{-11} to all values so that zero values could be log-transformed) prior to analysis. Statistical differences were considered significant if the probability of a type I error was <5% ($p < 0.05$). All analyses were performed using SAS version 9.4 (Cary, NC).

Table 1
Descriptive statistics.

Demographic	State (n = 5380)	2-city metro area (n = 2730)
Male (%)	3428 (63.7)	1755 (64.2)
Age in years (STE)	6.9 (0.1)	6.8 (0.1)
ISS (n = 5327) (STE)	7.2 (0.1)	6.6 (0.1)
Race, n (%)	5101	2596
Caucasian	3146 (58.5)	1291 (49.7)
Hispanic	1267 (23.6)	774 (29.8)
African American	305 (5.7)	271 (10.4)
Asian	117 (2.2)	67 (2.6)
Other	266 (4.9)	194 (7.5)
Insurance type, n (%)	4828	2460
Private	2746 (51.0)	1136 (46.2)
Medicaid	2007 (37.3)	1269 (51.6)
None	75 (1.4)	55 (2.2)
Length of stay (n = 4859), days (STE)	2.4 (0.1)	2.1 (0.1)
Charges/patient, dollars (STE)	$37,382 (1322)	$33,969 (1744)
Mechanism, n (%)	5040	2707
Falls	2074 (41.1)	1131 (41.8)
Motor vehicle crashes	408 (8.1)	221 (8.2)
Sports related	348 (6.9)	283 (10.5)
Bicycle related	320 (6.3)	159 (5.9)
Burns	287 (5.7)	136 (5.4)
Non-accidental	246 (4.9)	119 (4.4)
Auto-pedestrian	203 (4.0)	145 (5.4)
Trampoline related	136 (2.7)	48 (1.8)
Gunshot wounds	55 (1.0)	38 (1.4)
Fatal injuries, n (%)	58 (1.1)	37 (1.4)
Non-accidental	26 (44.8)	15 (40.5)
Motor vehicle crashes	9 (15.5)	4 (10.8)

STE = standard error; ISS = injury severity score.

2. Results

2.1. Demographics

We identified 5380 children who were Colorado residents treated for a traumatic injury during the study period (332 different zip codes). Hospital charges for this group during the study period totaled $201 million. Fifty-eight (1.1%) injuries were fatal. More deaths were related to nonaccidental (abusive) trauma than any other mechanism (26/58, 44.8%), and motor vehicle crashes accounted for the greatest proportion of unintentional deaths (9/32, 28.1%). More than half of the children identified (2730, 50.7%) lived in the immediate metro area consisting of the cities of Denver and Aurora, Colorado (53 zip codes). Demographics of these children are presented in Table 1. The majority of these children were Caucasians, males, and children with minor injuries

2.2. Maps

Choropleth maps were created to identify zip codes in our immediate metro area that had higher frequencies of pediatric traumatic injuries, including burns, nonaccidental traumas, and motor vehicle, bicycle, trampoline, and auto-pedestrian related injuries. Fig. 1 shows a sample of the maps that were created. For each injury type, there were outlier zip codes with a higher proportion of injuries. We also mapped total charges for treatment of all pediatric traumatic injuries in each zip code (Fig. 2), and identified outliers. Four out of 53 zip codes accounted for 27% of all charges in the immediate metro area; two zip codes had average charges of over one million dollars per year for the treatment of pediatric injuries.

2.3. Multivariate linear regression analysis

Multivariate linear regression analysis was used to identify predictors of pediatric injuries by zip code. Demographic data from the US census bureau were used to adjust for confounding factors. Higher rates of pediatric traumatic injuries were associated with zip codes that had larger Hispanic populations, fewer owner occupied homes, and more married couples with children (Table 2). Higher total hospital charges were associated with zip codes that had fewer owner occupied homes, more married couples with children, and higher populations (Table 3). Demographic factors that were predictive of higher rates of specific types of traumatic injury were also identified. We found that zip codes with greater populations had higher rates of burn injuries, auto-pedestrian injuries, and sports related injuries when compared to zip codes with fewer residents (Table 4).

2.4. Outcomes

Data for bicycle related injuries, auto-pedestrian accidents, and teenagers in motor vehicle crashes were presented to the state department of transportation. As a result, 5 different elementary schools located in the zip codes of greatest need were given grant awards to fund expanded bicycle and pedestrian safety education. A grant was also awarded for teen driver safety education and outreach in the metro area.

3. Discussion

We examined types, frequencies, and costs of pediatric traumatic injuries by zip code level to identify populations that would benefit most from injury prevention efforts. Several of our findings mirror those found in the CDC's Childhood Injury Report [4], including a large number of falls, and motor vehicle crashes accounting for the majority of unintentional fatal injuries. Choropleth mapping allowed the identification of outlier zip codes for both higher frequencies of specific types of pediatric injuries, and higher hospital charges for the treatment of pediatric injuries. Multivariate analysis identified predictive demographic features that were associated with higher rates and costs for pediatric injury, including zip codes that had fewer owner occupied homes, more married couples with children, and higher overall populations. This

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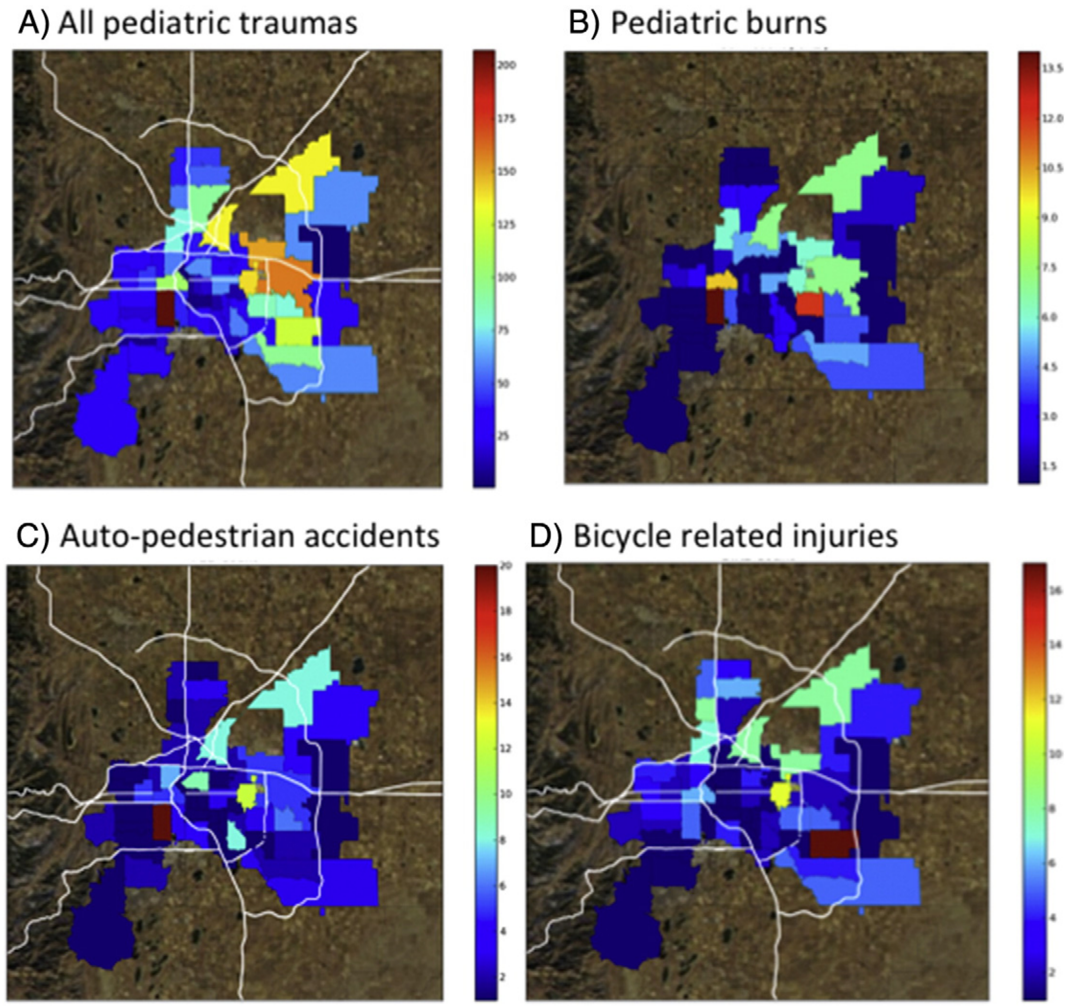

Fig. 1. Example choropleth maps showing variation in frequency and type of pediatric traumatic injuries across the 2-city metro area.

information was later used to target pediatric trauma prevention, outreach, and education efforts in the areas of greatest need. A similar mapping analysis will be performed in the future to measure the success of these interventions at decreasing the number of injuries and the overall cost of treatment. This information could then be used to help obtain additional funding for those successful interventions.

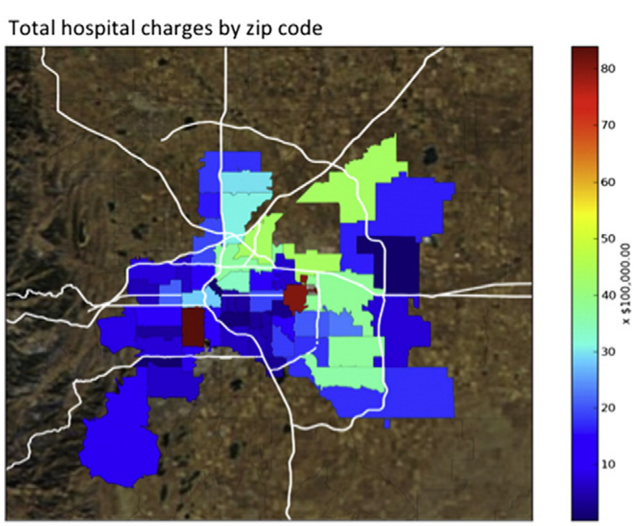

Fig. 2. Choropleth map of total hospital charges by zip code in the 2-city metro area.

As the political and economic climates shift toward price conscious medical consumerism, efforts to reduce spending are becoming more important. Funders, particularly private and governmental agencies, are mandating that preventative interventions be evidence-based, and able to measure specific outcomes [8–10]. It is known that the cost of treating pediatric traumatic injuries can be offset by increased prevention efforts [11], and savings in the billion-dollar range can be achieved with appropriate injury prevention strategies [12]. Examples of pediatric trauma prevention initiatives that have been publicized include high-visibility enforcement of child restraint laws [13,14], child restraint distribution programs [15], elementary age child pedestrian training [16,17], bicycle helmet laws [18], bicycle education for children [19], parent training programs focused on child maltreatment [20], and community education for pediatric burn prevention [21]. In a similar study, Slaughter et al. [22] used "hot spot" mapping to identify the most common locations for auto-pedestrian and auto-bicycle accidents. They determined that these were not random accidents but instead occurred at predictable and identifiable locations, thus allowing for tailored injury prevention strategies at specific locations. Our study

Table 2
Multivariate analysis for pediatric traumatic injury frequency by zip code demographic.

Predictor	Estimate	Standard error	*P*-value
Percent Hispanic	0.031	0.012	0.01
Percent married with children	0.040	0.017	0.03
Percent owner occupied housing	-0.015	0.007	0.02

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Table 3
Multivariate analysis for total hospital charges by zip code demographic.

Predictor	Estimate	Standard error	*P*-value
Percent African American	0.117	0.054	0.03
Percent Hispanic	0.062	0.024	0.01
Percent Caucasian	0.105	0.047	0.03
Percent married with children	0.130	0.039	0.002
Percent owner occupied housing	-0.031	0.014	0.03
Total population	0.0001	<0.0001	0.003

identified locations within our community with the highest rates of specific types of pediatric traumatic injuries. This choropleth mapping can help provide a "dashboard" of the disease of childhood injury in our city and can be used in combination with existing pediatric injury data to design prevention efforts that maximize effectiveness and resource utilization. Data presented in this fashion also facilitate "buy-in" from public officials, which is critical to success with public health interventions [23]. Our easily interpretable data have already helped generate additional funding for several schools in hot-spot zip codes for pediatric bicycle injuries and auto-pedestrian accidents.

There are several limitations to this study. The data presented are from children who were treated at two hospitals in the Denver metro area. While comprising 80% of injured children treated at hospitals in the metro area, this still represents a convenience sample. These data do not account for scene deaths and children who were injured but not evaluated by a medical provider or children who were injured but seen in a clinic or an emergency department at one of the many other hospitals in the city. Some of the injuries children sustained in this study may have occurred outside the home, and it might be suggest that zip code targeting cannot be applied because injuries possibly occurred elsewhere. Prevention strategies exist for the majority of pediatric injuries, however, and arguably are best applied starting in the patient's home. Further, epidemiologic studies of pediatric injuries show that the majority of injuries occur at home for children up to 5 years old [24]. Older children tend to be injured more often in sports areas or at school [24], but these are also likely to be located within the same zip code as the child's residence.

Our multivariate analysis may be skewed because one of the trauma centers included in this study is free of charge to residents of the city who are unable to pay for care, possibly attracting patients of lower socioeconomic status. This may explain why zip codes with higher populations of specific ethnic groups and lower rates of home ownership were identified as targets. Conversely, it is expected that zip codes with more people and more children would have higher rates of pediatric injuries. It is also unclear why zip codes with more pediatric injuries had higher percentages of households married with children. This is contradictory to some studies examining injury rates in children from married and single parent households [25,26], however there is a paucity of recent literature on this subject and may warrant further study.

Data presented here are also based on frequency alone, and not on rates adjusting for population density. This is because values for rates are exceedingly small and become difficult to interpret, especially when looking at specific injury types where event numbers are <20. The type of analysis presented here was done only including our metro area, and can only be performed in cities where injury numbers are high enough and zip codes are small enough to appropriately target interventions. Despite these limitations, our data remain valuable because they provide a technique to identify communities in need, and can easily be used as an adjunct to existing methods for targeting interventions.

Table 4
Multivariate analysis comparing total zip code population to specific types of traumatic injuries in children.

Predictor	Estimate	Standard error	*P*-value
Burn injuries	0.0002	<0.0001	0.005
Auto-pedestrian injuries	0.0002	<0.0001	0.005
Sports related injuries	0.0001	<0.0001	0.03

4. Conclusion

Traumatic injuries are a major source of morbidity and mortality for children. There are several proven methods for the prevention of pediatric injuries, however limited resources mandate targeting the areas in greatest need. Mapping data from trauma registries by zip code can be used to help define the communities within cities where prevention efforts should be focused. Several "hot-spots" were identified in our metro area using this technique. Statistical analysis also identified predictors of pediatric injuries. In the future, similar analyses will be performed to measure the effect of pediatric injury prevention efforts. Using this strategy with similar assessments over time will help identify the most effective methods for injury prevention. Statistical techniques, such as those presented here, are becoming more important as funding agencies are more often requiring public health initiatives to be evidence based.

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