Using Place-Based Indicators to Identify Injury Patterns and Improve Outcomes: A Statewide Review

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Introduction:

In the U.S. and worldwide, injury is the leading cause of childhood death and disability.[1] Many types of injuries affect children, including those from child physical abuse (CPA), falls, motor-vehicle crashes, and firearms. Moreover, racial and ethnic disparities in injury-related morbidity and mortality are widespread.[2-4] For example, compared to Caucasian children, African American children are nearly four times more likely to die from injuries sustained from NAT (15.2% vs. 4.0%, $p<0.005$) and two times more likely to die from traumatic brain injury (TBI; 5.3% vs. 2.2%, $p<0.05$).[2,4] Similarly, African American and Hispanic children are more likely to experience a firearm-related injury than Caucasian children (RR 2.5 for African Americans and 1.6 for Hispanics, both $p<0.001$).[5] Disparities extend beyond race and ethnicity.[5-7] Children with CPA are far more likely to have Medicaid than private insurance (78% vs. 14%, $p<0.01$).[6] Mortality is also higher among uninsured children who have been injured compared to those with private insurance (OR 2.1, 95% CI 1.2-3.6).[7]

The goal of this study was to evaluate patient- and population-level contextual factors and their impact on injury-related morbidity and mortality across our diverse state. We assessed these patterns using data from the state trauma registry. These accrued insights, and a deeper understanding of injury patterns, could then be used to systematically address those factors at the root of injury occurrences and injury-related disparities across the state.

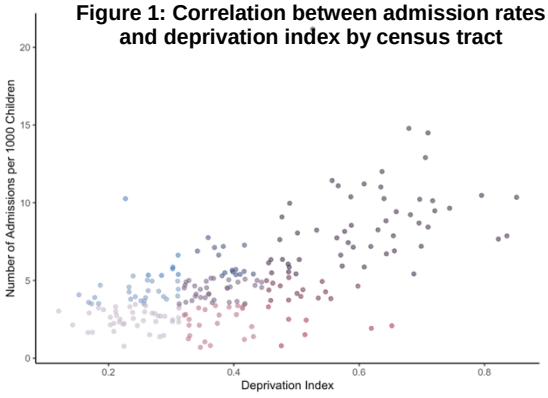
Background:

The multitude of evidence, highlighting racial, ethnic, and insurance-related differences in pediatric injury, indicates that there are broader contextual factors driving who gets injured and how severe those injuries turn out to be. We expect that many such drivers are rooted in the social determinants of health (SDH), defined, in part, as “the conditions in which people are

born, grow, work, live, and age."[8] SDH are influential at the patient level – affecting access to health-promoting resources, including food, medical care, and safe home environments – as well as at the neighborhood level, with contextual factors such as poverty, crime, traffic patterns, job access, and the availability of green spaces potentially influencing when, where, and how injuries occur. SDH may also represent targets for upstream neighborhood-based interventions to mitigate conditions that drive injuries. However, to-date, neighborhood-based research to understand population level patterns of injury has been limited.[5,7,9]

Across Greater Cincinnati, we found significant neighborhood-to-neighborhood variation in hospital admission rates for pediatric injury. We also found a significant correlation between neighborhood deprivation and injury-related admissions per 1,000 children.[10] Among 15,686 admissions for pediatric injury between 2010-2019, patients who experienced abuse had a higher length of stay (5.98 days; SD 15.71) than those who experienced assault (2.89 days; SD 5.57) or unintentional injuries (1.84 days; SD 3.65;p<0.05). Mortality rates similarly differed across intents (5.7% abuse, 2.3% assault, 0.9% unintentional, p<0.05).[10,11] We measured deprivation via an index incorporating housing, education, and poverty metrics; range 0-1, higher indicates more socioeconomic deprivation.[12-14] The mean deprivation score across census tracts was 0.38 (SD 0.14). At the neighborhood level, the deprivation index was significantly correlated with population-level injury-related admission rates (r=0.65, p<0.0001, **Figure 1**). There was a similar correlation between census tract-level crime rates and injury-related admission rates (r=0.41, p<0.0001). The bivariate map in **Figure 2** depicts geospatial variation in both deprivation index and admission rate. It

Figure 1: Correlation between admission rates and deprivation index by census tract



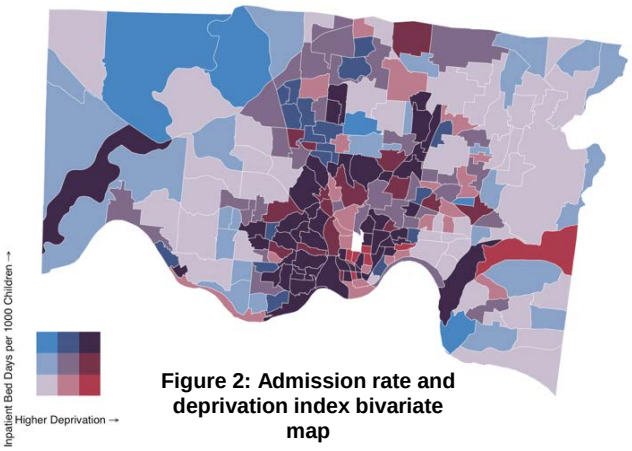


Figure 2: Admission rate and deprivation index bivariate map

demonstrates the significant neighborhood-to-neighborhood variability across our region, while also reinforcing the strong correlation between deprivation and injury-related morbidity. Specifically, census tracts with high deprivation and high admission rates are depicted in dark purple, while those with low deprivation and and low admission rates are in light purple, demonstrating that large areas with consistent correlation between deprivation and admission rates. Children living in census tracts in the highest deprivation tertile were nearly four-fold more likely than those from the lowest tertile to experience abuse, assault, and firearm-related injuries.[15]

Our **overall objective** of this study was to evaluate patterns of injury at the statewide level, to determine whether there are systematic root causes that could be addressed and to evaluate whether statewide patterns mirrored the findings from our more regional assessment in Greater Cincinnati.

Aim 1: Assess whether certain patient-level sociodemographic factors are linked to more frequent and severe injury presentations and outcomes.

Hypothesis 1: Among children evaluated in the hospital, patient-level factors, such as being insured by Medicaid and being of minority race or ethnicity, as well as primary address and neighborhood, will be associated with more frequent and severe injury presentations (e.g., PICU stay, increased injury severity score [ISS]) and outcomes (e.g., death).

Aim 2: Determine the relationship between population-level factors rooted in the social

determinants of health and population-level measures of pediatric injury across our diverse state.

Hypothesis 2a: There will be a significant, positive population-level associations between rates and severity of all-cause pediatric injury (as assessed by rates of IPBDs, hospitalizations, PICU bed-days, ED visits, and mortality) and a range of population-level factors measured at the neighborhood level (e.g., more poverty, crime, traffic exposure, unemployment; and fewer green spaces).

Hypothesis 2b: Injury patterns will vary across the state such that there will be unique "hot spots" of injury morbidity and mortality where certain mechanisms (e.g., NAT, falls, firearm-related injuries) are more common.

Methods:

Study Population and Setting

We conducted a secondary analysis of data existing in the Ohio Trauma Registry of all injured patients ages 0-16 years between 2010 and 2019. The registry includes data on mechanism of injury (e.g., NAT, falls, firearms, motor vehicle crashes), hospitalization length, injury diagnoses, severity, and outcome. This study was approved by the Cincinnati Children's Hospital Institutional Review Board.

Key Patient-Level Demographic and Clinical Characteristics:

Patient demographic and clinical information was abstracted from the registry. Our primary patient-level exposures were race/ethnicity and insurance type. These were chosen as the exposure variables as they represent SDH, such as structural racism and poverty, that are known to influence individual health. Age was treated as a continuous variable. Race/ethnicity and insurance status were evaluated as categorical variables. Race/Ethnicity was defined as Black, White, Hispanic, or other; insurance status was defined as private, public, self-pay,

other/unknown. We also abstracted data on mechanism of injury (e.g., falls, motor-vehicle crashes, etc.) and identified the intent of injury (categorized as CPA, assault, self-inflicted, unintentional, unknown). Injury severity was defined using the Injury Severity Scale (ISS), a scoring system assessing trauma severity which is known to correlate with morbidity and mortality after injury.[16] Finally, using admission and discharge dates from the hospital and ICU, we calculated hospitalization length of stay, ICU length of stay, and patient discharge disposition.

Key Neighborhood-Level Data:

To analyze injury admissions at the neighborhood level, we created a zip code level dataset. The home address for each admission event was geocoded using a custom, offline, TIGER/Line street address range geocoder.[17] Each geocoded address was then linked to its census tract. Census tract-level datasets for deprivation were then linked based on the census tract identifier, serving as exposures for the neighborhood-level analysis. To assess deprivation, we utilized a previously-validated nationwide census tract-level deprivation index.[17-19] The index uses six variables from the U.S. Census' American Community Survey (ACS): 1) % of households with income below the federal poverty level; 2) median household income; 3) % of population ≥25 years with at least high school education; 4) % of the population without health insurance; 5) % of households receiving public assistance; and 6) % of housing units that are vacant. To construct the index, we used a principal components analysis to reduce these six variables into an index that ranges from 0 to 1, with higher values indicating more deprivation.

Patient- and Neighborhood-Level Outcome Measures

Patient-level outcomes included total inpatient bed days (IPBD) per admission, ICU inpatient bed days (ICUBD) per admission, and mortality. Neighborhood-level outcome was IPBD rates

per 1000 children. We calculated the rate of each per 1,000 children in each zip code per year, using the number of children ≤16 years old from the ACS as the population denominator.

Statistical Methods

Patient-Level Analyses:

Data for patient characteristics were described as counts and percentages for categorical variables and as median and interquartile ranges for continuous variables. Group differences for categorical variables were examined using Chi-square or Fisher's exact test followed by multiple testing and for continuous variables using Kruskal Wallis test with post-hoc multiple testing. Univariate and multivariate negative binomial models were developed to examine the relationships of race/ethnicity and insurance type with IPBD and ICUBD.

Neighborhood-Level Analyses:

For neighborhood-level analyses, we quantified the zip code-level relationship between the IPBD rate and deprivation index using the Spearman correlation coefficient. Further, we created a scatterplot of the census tract-level deprivation index and admission rate per 1,000 children.

Results:

Between 2010 and 2019, 65,878 children ≤16 years were admitted for injury across the state. Patients with invalid zip code (N=1156) were excluded. Notably, out of 64,722 patients with valid zip codes, 32,061 did not have ICD codes with injury information, thus making it hard to categorize those patients on injury type. We conducted a sensitivity analysis on a subset of the cohort with ICD code data available (N=32,661) and found that our results were the same. As a result, the data presented here are for the entire cohort, including those without ICD codes. We made this decision as we did not want to exclude these patients and create bias in our results, on the presumption that these ICD data were not missing at random. Eliminating those patients

from our sample might have injected bias into our neighborhood-level analysis. Out of the total cohort, including those with ICD data, 8424 did not have an Ohio zip code as their primary home zip code and were excluded from analysis. This resulted in a final cohort of 56,298 children.

Demographic Characteristics

The median age in our cohort was 6.7 years (IQR: 2.9, 11.1) (Table 1). The cohort was 61.7% male, 74.9% white, and 50.1% of patients had Medicaid insurance. The median ISS was 4 (IQR: 2, 8). The most common mechanism of injury was falls, followed by being struck by an object and motor vehicle crashes. However, mechanism of injury was missing for nearly 50% of patients. The vast majority of injuries were unintentional (81.3%), with the remaining injuries being 0.7% self-inflicted, 1.3% CPA, 2.7% assault, and 13.5% unknown intent.

Compared to patients with other intents of injury, patients with injuries due to CPA were younger (median age 0.7 years, $p<0.05$), patients with self-inflicted injuries were more likely to be female (65.3% female; $p<0.05$), and patients who were victims of assault were more likely to be Black (35.9%; $p<0.05$). Victims of CPA were also significantly more likely to be Black compared to those with self-inflicted or unintentional injuries ($p<0.05$). Patients who experienced CPA and assault were more likely to have Medicaid insurance (76% and 61%, respectively) when compared to those experiencing self-inflicted and unintentional injuries (52% and 49%, respectively; $p<0.05$).

Table 1. Demographic Characteristics of Cohorts. *All pairwise comparisons significant with $p<0.05$ except for those denoted with *, †, §, Δ, and Ω.*

	Total Cohort (N=56298)		**CPA** (N=757)	**Assault** (N=1543)	**Self-Inflicted** (N=383)	**Un-Intentional** (N=45744)	**Unknown** (N=7867)
Median age at injury (Q1, Q3)	6.7 (3,11)		0.7 (0.3,2.3)	1.8 (0.4,9.7)	14 (13,14.5)	7 (3,11)*	6 (0.67,14)*
% Male	61.7		60.7*$^{\dagger\Delta}$	61.4$^{\Delta\Omega}$	34.7	61.9*$^{\S\Omega}$	62.4†§
Race/Ethnicity (%)							
White	74.9		65.6	55.5	83.0	75.9	73.2
Black	16.6		24.6	36.0	13.0	15.4	20.0
Hispanic	3.1		3.7	3.7	2.9	3.1	2.6
Other	5.5		6.1	4.8	1.1	5.7	4.5
% Medicaid	50.1		75.8	61.2	52.2*	48.8*	53.3
Median Injury Severity Score (Q1, Q3)	4 (2,8)		9 (3,16)	5 (2,14)	1 (1,2)	4 (2,6)	4 (1, 5)

Patient-Level Outcomes:

Black race, public insurance, older age, higher ISS, and higher home deprivation index were associated with increased IPBDs (Table 2). Median age of patients who stayed >2 days after admission was 7.5 compared to 6.7 years for those staying only one day (p<.0001). Black children made up 22% of those staying ≥2 days, compared to 17% of those staying for only one day (p<.0001). Mean ISS was higher for patients staying longer (7.6 vs 4.4, p<0.0001). Due to the significant degree of missing data, we did not feel it was appropriate to perform multivariate model as our inferences might be significantly biased. As such, we did not adjust for home zip code deprivation index or insurance status to determine how much of the increased IPBDs were due to neighborhood content and SES.

Table 2. Inpatient Bed Days (IPBD)

	IPBDs		p-value
	One (N=16538)	**≥Two** (N=8431)	
Median age at injury (Q1, Q3)	6.7 (3, 11)	7.5 (3,12)	<0.0001
% Male	60.2	61.9	0.009
Race/Ethnicity (%)			<0.0001
White	74.5	69.3	
Black	17.4	22.8	
Hispanic	3.1	3.5	
Other	5.0	4.3	
% Medicaid	48.1	53.9	<0.0001
Mean Injury Severity Score (SD)	4.4 (3.4)	7.6 (7.2)	<0.0001

Neighborhood-Level Findings:

While there was a statistically significant correlation between zip code deprivation index and the hospital length of stay, the clinical significance remains in question (rho = 0.19; p<0.0001). There was also a significant correlation between ISS and LOS (rho = 0.26, p<0.0001). However, a population level analysis of admission rate per 1000 children in a zip code did not find a significant correlation between deprivation index and admission rate (rho = -0.00058, p=.985; Figure 1).

Figure 1: Correlation between admission rates and deprivation index by zip code

Discussion:

Contrary to our regional census-tract level analysis in Cincinnati, we did not find a correlation between zip code deprivation and population level hospital admission rates for injury. We did however find a slight correlation between deprivation index and hospital length of stay. There were also notably inequities in distribution of injury intent by race and insurance status, with Black children and those on public insurance bearing a significant burden of assault and abuse injuries.

Our patient-level findings likely reflect the extent to which SDH drive inequities in pediatric injury. While we found associations between Black race and increased likelihood of abuse or assault, we do not believe that this reflects any intrinsic racial difference. Rather, these differences suggests that historical practices and structural racism likely contribute to these

findings. Practices such as redlining have forced minority communities into neighborhoods of poverty over decades, and lack of access to education and resources in a systematic fashion have resulted in higher poverty levels and increased toxic stress in these communities. Significant research has demonstrated that toxic stress and adverse childhood experiences (ACEs) have lasting impacts on neurodevelopment and health.[20-22] Due to historic structural racism, race and racial inequities are frequently colinear with socioeconomic status, creating a predominance of toxic stress and ACEs in communities of color.

Given the existing data in the literature about the association of deprivation with a number of health outcomes, and our local findings using an institutional trauma registry with far fewer missing data points, the lack of correlation between zip code deprivation index and injury admission rate in this study is surprising and gives pause as to whether the missing data and analysis at the zip code level has an unrecognized impact on our findings.

Limitations:

There were a number of significant limitations to this study. First, as noted above, there was significant missing data in the information obtained from the Ohio Trauma Registry. Sensitivity analyses suggested that our univariate findings were similar among the entire cohort and those with ICD codes for injury type; however, there were multiple other sources of missing data which may have contributed to inaccuracy and lack of generalizability of our findings. Secondly, the data from the registry does not provide a patient identifier; as a result, repeated patient visits for the same injury cannot be determined. Finally, the data available from the registry had patient home zip code, but not a more specific address that could be geocoded. Zip codes have been demonstrated to be far less accurate measure of neighborhood status. They tend to be socioeconomically and demographically heterogeneous, and rarely accurately reflect neighborhood context due to this heterogeneity that is lost in a single zip code. It is, therefore,

likely that they would bias results toward the null. In fact, area level SES measures usually underestimate the SES – mortality associations compared to individual measures, but the area level measures are more accurate at more precise geographic areas like the census block, block group, or tract.[23,24] Expected associations between deprivation and health outcomes identified at the census tract level can even disappear when examined at the zip code level.[25] As a result, the use of zip code, because it was the only available data point for geocoding, for our neighborhood level evaluation may have resulted in a type II error.

Conclusions and Recommendations:

Neighborhood-level information represents a rich opportunity for further and deeper impact by helping to identify and address factors closer to injuries' root causes. Some work has been done in this space, addressing neighborhood level factors through building playgrounds and creating bike paths for safe transport.[26] However, the findings that individual race, neighborhood deprivation, and crime rates are associated with pediatric injury suggest that much broader – and more structural – thinking is needed to have a significant impact on outcomes.[21,22] These structural interventions might focus on reducing community toxic stress, improving the built environment, and increasing economic opportunities in ways that may lift communities, and individuals within them, out of deprivation. Our lack of association identified in this study may demonstrate that there truly is no correlation, but more likely, it represents weaknesses in the quality of the data and the ability to conduct appropriate neighborhood-level analyses. Further work is needed in this space to understand true statewide impact of neighborhood-level context on injury admissions for children.

Research such as ours – identifying factors linked with inequities – must be paired with interventions to avoid what some have termed the "health disparities industrial complex," where academic productivity around health disparities flourishes, but no efforts are made to work with

communities to address these inequities. Additionally, any efforts to address community-based factors must do so in partnership and solidarity with the community itself – both to ensure the interpretation of findings is rooted in community context and to ensure the focus is on the factors of most importance to the community itself.[27-29] State health policy efforts focusing on improving neighborhood context and mitigating negative social determinants of health and augmenting positive ones have the potential to have a profound impact on child health outcomes for a number of disease areas, including injury.

Information/Qualifications – Principal and all Co-investigators:

Principal Investigator:

Meera Kotagal, MD, MPH, Assistant Professor of Pediatric General and Thoracic Surgery at CCHMC and the University of Cincinnati College of Medicine (UCCOM), will serve as the Principal Investigator of the proposed study. Dr. Kotagal's academic interests focus on improving child health in settings of poverty, including the urban core in Cincinnati as well as resource-limited settings in sub-Saharan Africa. Dr. Kotagal has a strong background in outcomes research, as a previous post-doctoral T32 research fellow at the Surgical Outcomes Research Center (SORCE) at the University of Washington and with a Masters of Public Health in clinical effectiveness from the Harvard University School of Public Health. Her focus on child health in resource-limited settings has led her to focus on addressing injury in the urban core in Cincinnati. In addition to her strong pedigree in medicine, Dr. Kotagal has previously worked as a community organizer and studied effective organizing strategies as an undergraduate. She worked as an organizer through Physicians for Human Rights and went on to join the Ohio statewide leadership team for then-Candidate Obama's presidential campaign in 2008. Additionally, Dr. Kotagal has experience building collaborative teams. As a resident, she created the *Safe and Sound* campaign within 15 hospitals in Washington State to collaboratively work to identify causes for high CT use in the diagnosis of pediatric appendicitis and then to reduce this use through system level changes across hospitals, including standardization of ultrasound reports to increase their sensitivity and specificity, as well as ultrasound training for technicians.[18] She is committed to using her skills in outcomes research, in combination with her community organizing and community engagement background, to reduce injury and improve child health in our region by identifying and tackling the social determinants of health at the root of such injuries. Dr. Kotagal is currently the Principal Investigator on a similar research proposal focused on use of place-based indicators to identify potential targets for injury prevention in Hamilton County, and the region of Ohio served by Cincinnati Children's Hospital Medical Center.

Information and Qualifications:

Richard A. Falcone, Jr., MD, MPH, Professor of Pediatric General and Thoracic Surgery at CCHMC and UCCOM will serve as a co-investigator of the proposed study. Dr. Falcone currently serves as the Director of Trauma Services at CCHMC as well as the leader of CCHMC's Comprehensive Children's Injury Center (CCIC). He has served as Dr. Kotagal's clinical and academic mentor throughout her fellowship and as she has begun her career as a member of the faculty at CCHMC. He has focused throughout his career on disparities in injury-related outcomes for children, including helping to lead, along with Dr. Victor Garcia, the Buckle Up for Life and Home Safety programs that have focused on community-based interventions to reduce injury in Hamilton County.

Andrew F. Beck, MD, MPH Associate Professor of Pediatrics at CCHMC and the University of Cincinnati College of Medicine (UCCOM), will serve as a co-investigator for the proposed study. He was PI for a K23 from NIAID to study place-based factors and health in children. His research interests include improving child health outcomes by focusing on the identification and mitigation of key social and environmental determinants of health. Dr. Beck's research experiences include quantitative, qualitative, and quality improvement studies that have focused on population-level health disparities and clinical-community collaboration. His research has been motivated by a desire to understand how place, and community, affects health outcomes. This has led him to focus on identifying ways in which geography could be used to inform clinical care delivery, developing a means through which health and non-health data could be used together to more appropriately target interventions in ways that could improve outcomes for children with chronic diseases like asthma.

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