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Factors Associated With Recurrent Pediatric Firearm Injury

A 10-Year Retrospective Cohort Analysis

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Background: Firearm injuries are the leading cause of death among children aged 0 to 17 years in the United States.

Objective: To examine the factors associated with recurrent firearm injury among children who presented with acute (index) nonfatal firearm injury in the St. Louis region.

Design: Multicenter, observational, cohort study.

Setting: 2 adult and 2 pediatric level I trauma hospitals in St. Louis, Missouri.

Participants: Pediatric patients aged 0 to 17 years presenting with an index firearm injury between 2010 and 2019.

Measurements: From the St. Louis Region-Wide Hospital-Based Violence Intervention Program Data Repository, we collected data on firearm-injured patient demographics, hospital and diagnostic information, health insurance status, and mortality. The Social Vulnerability Index was used to characterize the social vulnerability of the census tracts of patients' residences. Analysis included descriptive statistics and time-to-event analyses estimating the cumulative incidence of experiencing a recurrent firearm injury.

Results: During the 10-year study period, 1340 children presented with an index firearm injury. Most patients were Black (87%), non-Hispanic (99%), male (84%), and between the ages of 15 and 17 years (67%). The estimated risk for firearm reinjury was 6% at 1 year and 14% at 5 years after initial injury. Male children and those seen at an adult hospital were at increased risk for reinjury.

Limitation: Our data set does not account for injuries occurring outside of the study period and for reinjuries presenting to nonstudy hospitals.

Conclusion: Children who experience an initial firearm injury are at high risk for experiencing a recurrent firearm injury. Interventions are needed to reduce reinjury and address inequities in the demographic and clinical profiles within this cohort of children.

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Firearm injury is the leading cause of death among children aged 0 to 17 years in the United States (1). Children in the United States are 11 times more likely to die of a firearm injury than children in other high-income countries (2). The firearm injury epidemic among U.S. children was exacerbated during the COVID-19 pandemic, with injuries and deaths increasing since 2020 (3–5), particularly among young Black males. Recent research underscores the enduring effect of systemic racism and poverty as fundamental drivers of firearm injury disparities among Black children (6).

Although nonfatal firearm injury data in the United States are inconsistently reported, at least 20 000 children present to hospitals each year with nonfatal firearm injuries (7, 8). The current study focuses on pediatric injury in St. Louis, Missouri. Like many urban areas in the United States, St. Louis is characterized by chronic disinvestment, high levels of outmobility, a diminishing tax base, and persistent levels of racial and socioeconomic segregation (9, 10). St. Louis also has one of the highest rates of violent injury per capita in the nation and is ranked second in the country for firearm deaths within pediatric populations (5, 11). A retrospective review of pediatric, trauma registry, firearm injury patients in the St. Louis region (spanning Missouri and Illinois) between 2008 and 2013 found that most of the children younger than age 17 years treated for firearm injuries during the study period were Black males. A disproportionate number of these injuries were clustered in areas with high economic disadvantage, as indicated by an average household income of less than $25 000 annually (11, 12). Research suggests that firearm injury risk may vary by patient age, location, and community, indicating a need for coordinated regional and national efforts (13, 14).

People who survive 1 firearm injury are at an increased risk for recurrent firearm injury (15). One study reported that children with a prior firearm injury were 12 times as likely to experience a recurrent firearm injury within 5 years when compared with trauma patients whose index injury was not violence related (16). Across all ages, research indicates that males and Black people are at increased risk for recurrent firearm injury (17–19). However, limited research exists identifying predictors of recurrent injury within

the pediatric population. The identification of predictors of pediatric recurrent firearm injury beyond initial incidence is needed to guide violence intervention programming (17).

The objective of this study was to examine the factors associated with recurrent firearm injury among children who presented with acute (index) nonfatal firearm injury in the St. Louis region between 1 January 2010 and 31 December 2019. This study builds on recent work using the St. Louis Region-Wide Hospital-Based Violence Intervention Program Data Repository (STL-HVIP-DR) to track fatal and nonfatal firearm injury. This repository houses data on all patients who present to any 1 of the 4 St. Louis adult or pediatric level I trauma hospitals with a violent injury (for example, firearm injury or blunt assault) from 2010 to the present. These 4 level I trauma hospitals primarily serve the St. Louis Metropolitan Statistical Area, which was home to more than 600 000 youth under the age of 18 years in 2010. The STL-HVIP-DR is able to follow pediatric patient encounters across these 4 partner hospitals and over time (19, 20). These data address a growing need for collaborative, cross-sector data sharing. Such collaboration is essential to support violence reduction through comprehensive analysis of firearm-injured patients (8, 21–23).

METHODS

Study Design and Setting

This study is a multicenter, retrospective, observational cohort analysis of all children aged 0 to 17 years who experienced an index firearm injury and presented to 1 of the 4 St. Louis adult or pediatric level I trauma hospitals for care from 1 January 2010 to 31 December 2019. The STROBE (Strengthening the Reporting of Observational Studies in Epidemiology) statement was used to inform the study design (24). Approval for the study was granted by the institutional review board from Washington University in St. Louis, which is the umbrella institutional review board for all participating institutions.

Data Source

Our team developed and maintains the STL-HVIP-DR, which contains electronic health record data from patients presenting to any of the 4 partner adult and pediatric level I trauma hospitals in St. Louis (20). The STL-HVIP-DR was developed in parallel with Life Outside of Violence, the St. Louis region–wide, hospital-based, violence intervention program serving these 4 hospitals, which care for most violently injured patients in St. Louis (19, 20). As patients may receive care from multiple hospitals in the region, this data set is needed for a more comprehensive assessment of firearm reinjury. This data source also offers opportunity for robust reinjury analyses because it includes children treated at both adult and pediatric hospitals, and it is able to track individual patient movement across participant hospitals over time (20). This is of particular importance because the American College of Surgeons guidelines recommend that all children aged 15 years and older can be treated at either adult or pediatric trauma hospitals (25).

All 4 participating hospitals share their discharge data with the Missouri Hospital Association (MHA), a nonprofit member organization that represents all acute care hospitals in the state. The MHA then computes and provides a stable universal identifier that links patients across health systems. Through this identifier, the STL-HVIP-DR longitudinally tracks individual patients at the encounter level over time and across partner hospitals. Repository data include demographic characteristics and International Classification of Diseases (ICD) codes associated with violent injury. Methods used to construct this data set, including converting ICD, Ninth Revision (ICD-9) to ICD, Tenth Revision (ICD-10) codes using General Equivalence Mappings, have previously been published by our team (19, 20, 26). In addition, we queried National Death Index (NDI) data to identify recurrent firearm injury patients who died in the prehospital setting (27).

Participants and Classification of Index and Recurrent Firearm Injury

Inclusion criteria were all firearm-injured children aged 17 years or younger who presented for care at a partner adult or pediatric trauma hospital for an index (acute) firearm injury between 1 January 2010 and 31 December 2019. Index injury was operationally defined as the first firearm injury captured in the repository during the study period. Patients with ICD diagnostic codes in the following categories were included in the analysis: W32, W33, W34, X93, X94, X95, Y22, Y23, and Y24.

The primary outcome of interest was recurrent firearm injury. Patients were considered to have a recurrent firearm injury if they 1) returned to a partner hospital with a new firearm injury or 2) died in the prehospital setting from a new firearm injury as determined through NDI record analysis within the 10-year study period. To more accurately identify acute firearm injuries (both index and recurrent), we applied our study team's previously validated machine-learning least absolute shrinkage and selection operator classification model to this data set (19, 28). The following NDI codes were used to classify patient death by firearm in the prehospital setting: E922.0 to E922.9, E955.0 to E955.4, E965.0 to E965.4, E970, and E985.0 to E985.4. For patients who experienced 3 or more firearm injuries during the study period, only their initial and second firearm injuries were used in the analysis. Only persons who were discharged from the hospital after surviving their index firearm injury were included in the primary outcome analyses.

Recurrent firearm injury was measured as a time-to-event variable. The time to recurrent firearm injury was calculated as the number of years between the

date of the index firearm injury and the date of the recurrent fatal or nonfatal firearm injury. Nonfirearm injury deaths identified in the NDI were treated as competing risks, and people were considered censored on the date of this nonfirearm injury death. Persons with neither recurrent injuries nor nonfirearm injury deaths identified by the NDI were censored on 1 January 2020 at the end of the study period.

Variables

Variables queried from the STL-HVIP-DR included demographic information and clinical factors. Demographic variables included race (Black, White, other, and multiracial), sex (male and female), ethnicity (Hispanic and not Hispanic), age (0 to 4, 5 to 9, 10 to 14, and 15 to 17 years), and patient address of residence (used to estimate social vulnerability). Clinical factors included insurance status, treatment at a pediatric or adult hospital, and diagnostic codes (depression, drug use disorder, and alcohol use disorder). The primary method of payment was used to assess insurance status and was classified as either publicly insured, privately insured, or not insured. We used ICD codes and Centers for Medicare & Medicaid Services Chronic Conditions Data Warehouse (CMS CCW) codes to assess diagnostic information. We used the Centers for Disease Control and Prevention (CDC) Social Vulnerability Index (SVI) and U.S. Census data geocoded to patients' residential Census tracts as proxies for social determinants of health (29). The SVI was categorized as low (SVI <0.25), average (SVI between 0.25 and 0.75), and high (SVI >0.75) and corresponded to the percentile of social vulnerability represented in that tract compared with all other U.S. Census tracts.

Statistical Analysis

We reported descriptive statistics for patient-level variables and SVI (means and SD for continuous variables, frequency, and percentages for categorical variables, and medians and IQRs for skewed continuous variables). Binomial proportions and CIs were used to report information about hospital of presentation by age category, and χ^2 tests were used to compare these proportions. A time-to-event survival analysis generating the cumulative incidence function for recurrent firearm injury in the presence of competing risks was used to estimate the cumulative incidence of recurrent firearm injury over time (30). Estimated firearm reinjury incidence and associated 95% CIs were calculated. Fine and Gray's proportional subdistribution hazards models and cumulative incidence functions were used to examine the association of covariates with the risk for reinjury over time (30, 31). Mutivariable hazard ratios and 95% CIs were calculated. Children in all racial categories were included in all analyses; however, due to the limited sample sizes in race categories other than Black and White, these are the only 2 racial groups for which effect estimates and survival functions are shown. All analyses were conducted in Stata 17, SAS 9.4, and SAS Enterprise Guide 8.3.

Table. Descriptive Statistics of Pediatric Firearm Injury Cases in St. Louis ($n = 1340$), 2010 to 2019

Characteristics	Index Firearm Injury ($n = 1340$), *n* (%)	No Recurrent Firearm Injury ($n = 1118$), *n* (%)	Recurrent Firearm Injury ($n = 169$), *n* (%)
Age, *y**			
0–4	75 (6)	69 (6)	4 (2)
5–9	104 (8)	94 (8)	3 (2)
10–14	263 (20)	228 (20)	22 (13)
15–17	898 (67)	727 (65)	140 (83)
Sex			
Male	1130 (84)	931 (83)	160 (95)
Female	210 (16)	187 (17)	9 (5)
Race†			
Black	1148 (87)	940 (85)	164 (98)
White	164 (12)	154 (14)	4 (2)
Other	5 (0.4)	5 (0.4)	–
Multiracial (≥2 races)	4 (0.3)	3 (0.3)	–
Ethnicity†			
Hispanic	8 (0.6)	7 (0.6)	1 (0.6)
Not Hispanic	1330 (99)	1109 (99)	168 (99)
Insurance status			
Public	993 (74)	820 (73)	137 (81)
Private	185 (14)	162 (15)	16 (10)
No insurance	162 (12)	136 (12)	16 (10)
State†			
Illinois	221 (17)	204 (18)	10 (6)
Missouri	1114 (83)	909 (81)	159 (94)
Other state	4 (0.3)	4 (0.4)	–
Index injury intent			
Assault/homicide	777 (58)	622 (56)	122 (72)
Unintentional	471 (35)	420 (38)	34 (20)
Undetermined	92 (7)	76 (7)	13 (8)
Hospital type‡			
Pediatric	1049 (78)	908 (81)	106 (63)
Adult	291 (22)	210 (19)	63 (37)
CMS CCW codes			
Depression	16 (1)	14 (1)	2 (1)
Drug use disorder	73 (5)	60 (5)	13 (8)
Alcohol use disorder	7 (0.5)	7 (0.6)	–
SVI category†			
Low	83 (7)	80 (8)	1 (0.6)
Average	425 (33)	354 (33)	54 (33)
High	767 (60)	625 (59)	111 (67)

CMS CCW = Centers for Medicare & Medicaid Services Chronic Conditions Data Warehouse; SVI = Social Vulnerability Index.
* Age at initial injury.
† Missing values for race, ethnicity, state, and SVI category, respectively, were excluded from this table: race, 19 (1%), 16 (1%), 19 (0.6%); ethnicity, 2 (0.1%), 2 (0.2%), not applicable; state, 1 (0.1%), 1 (0.1%), not applicable; SVI category, 65 (5%), 59 (5%), 3 (2%).
‡ Treating hospital at initial injury.

Role of the Funding Source

The funders had no role in the design, data collection, or analysis, or the decision to submit the manuscript for publication.

RESULTS

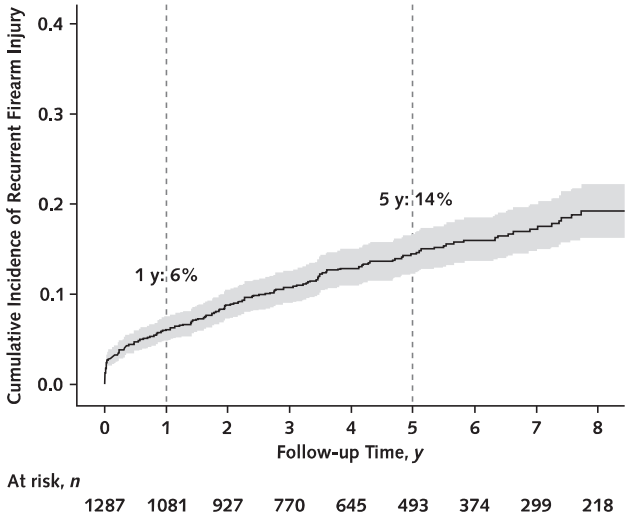
During the 2010 to 2019 study period, there were 1340 pediatric patients treated for an index firearm injury at 1 of 4 adult and pediatric partner level I trauma hospitals in the St. Louis region. Most patients were Black (87%), non-Hispanic (99%) males (84%) between the ages of 15 and 17 years (67%; **Table**). Of the 1340 patients treated for an initial firearm injury, 1287 patients (96%) were discharged from the hospital after surviving their index injury. Of this group of 1287 patients surviving their index injury, 169 (13%) experienced a recurrent firearm injury.

Nearly all patients (98%) in the study sample between the ages of 0 and 14 years were treated at a children's hospital for their initial injury, compared with 69% of children aged 15 to 17 years. Among the children aged 15 to 17 years who were treated at adult hospitals, 86% were Black males, compared with 79% Black males among those aged 15 to 17 years treated at pediatric hospitals. Of the 53 patients who did not survive their index injury, 62% were Black males and 58% were between 15 and 17 years of age. The NDI identified 6 children who survived their index injury and later died in the prehospital setting, with causes of death as follows: 1 general medical issue (seizure), 2 recurrent injuries (nonfirearm), 2 drug overdoses, and 1 firearm suicide.

Time-to-event analyses showed risk for reinjury over time (**Figure 1**). The median follow-up time for all patients was 3.8 years (IQR, 1.7 to 6.6 years). The median follow-up time for patients with recurrent firearm injuries was 1.4 years (IQR, 0.2 to 3.3 years), compared with 4.3 years (IQR, 3.9 to 71 years) for patients without recurrent injuries. For the small group of patients who died of nonfirearm injuries as identified by the NDI, the median time from index injury to death was 5.7 years (IQR, 3.9 to 7.1 years). Based on cumulative incidence estimates, the risk for firearm reinjury was 6% (95% CI, 5% to 8%) at 1 year, 14% (CI, 12% to 17%) at 5 years, and 19% (CI, 16% to 22%) at 8 years after index injury.

The associations of covariates with risk for firearm reinjury are presented in **Figure 2**. The estimated risk for firearm reinjury was highest among children who were male ($P < 0.001$), older (aged 15 to 17 years; $P = 0.034$), Black ($P < 0.001$), living in average ($P = 0.018$) or high ($P = 0.013$) SVI areas, and seen at adult hospitals ($P < 0.001$ for adult hospitals 1 and 2; **Appendix Table**). After adjusting for all covariates of interest, only males, compared with females (hazard ratio [HR], 2.7 [CI, 1.4 to 5.5]), and children presenting at adult hospitals, compared with children's hospitals (HR for adult hospital 1, 1.8 [CI, 1.2 to 2.9]; HR for adult hospital 2, 1.7 [CI, 1.0 to 2.9]), had increased risk for reinjury.

Figure 1. Cumulative incidence estimates of recurrent firearm injury for each year after pediatric index firearm injury.



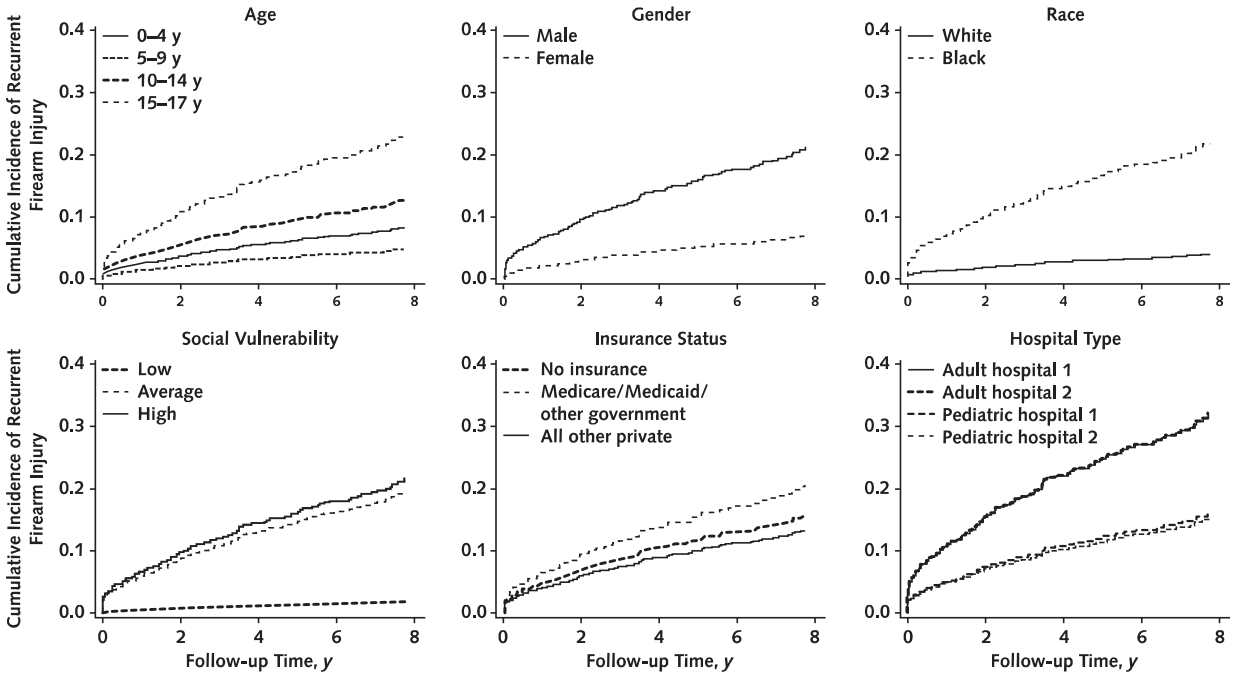
DISCUSSION

This study details the high rate of index and recurrent firearm injuries among youth and young adults in St. Louis, Missouri. This study builds on prior work conducted in St. Louis regional pediatric hospitals by also capturing children who received index firearm injury care at regional adult level I trauma hospitals. In the last decade, St. Louis level I trauma hospitals cared for 1340 children with index firearm injuries. These children were predominately non-Hispanic Black males aged 15 to 17 years. Analyses estimated that the cumulative incidence of experiencing a second firearm injury was 6% at 1 year after index injury and 14% at 5 years after index injury. These estimates are strikingly high compared with rates nationwide, which indicate a pediatric reinjury rate of 1% in the first year after initial injury (32). One comparable study in an urban setting (Seattle, Washington) found a 6% pediatric reinjury rate, with roughly 75% of these injuries occurring within 5 years of initial injury (33). The high cumulative incidence of pediatric firearm reinjury in St. Louis indicates a great need for prevention efforts in this region.

Both the index and recurrent firearm injury cohorts were disproportionately represented by Black male youths, which aligns with both regional and national trends, emphasizing a growing need for interventions tailored to this population (4, 11, 16, 34, 35). Structural racism in the United States has been implicated as a driving force of firearm injury disparities (36). There is a direct association between Black and White racial segregation in U.S. urban areas and firearm mortality (36). Structural racism may be a key contributor to the firearm injury epidemic in St. Louis: St. Louis is 1 of the 10 most racially segregated cities in the nation and is in the top 5 for firearm homicide rates (36, 37).

In addition, although children between the ages of 15 and 17 years comprised most of the study sample, we would be remiss not to highlight the fact that

Figure 2. Cumulative incidence curve of recurrent firearm injury stratified by age, gender, race, Social Vulnerability Index, insurance status, and hospital.



$P < 0.001$ for age, gender, race, hospital type. $P = 0.040$ for social vulnerability. $P = 0.149$ for insurance status.

13% of pediatric firearm injuries ($n = 179$) occurred in children under the age of 10 years. The representation of youth aged 0 to 9 years in our study sample is higher than national estimates, which indicate that roughly 7% of pediatric firearm injuries occur within this age group (38). This underscores the presence of violence in the home, school, and community contexts in which St. Louis children exist and indicates a need for additional research focused on the safety of our youngest children.

Our findings also indicated that treatment at a children's hospital was associated with lower risk for recurrent injury in the age groups of 10 to 14 years and 15 to 17 years. However, Black children in these age groups were less likely than White children in these age groups to receive index firearm injury treatment at a children's hospital. Children's hospitals often have greater social need supports than adult hospitals, which may be a protective factor for recurrent injury (39, 40). Future research will delve into which children receive treatment at adult hospitals, and if there are causal pathways linking children's hospital care to lower risk for recurrent injury.

Every child in this study interacted with a hospital system during their initial injury treatment. Hospital-based care provides a window of opportunity to reach youth and families impacted by firearm injury to identify unmet needs and risk for recurrent injury and to intervene accordingly. Public health interventions, such as hospital-based violence intervention programs, provide behavioral health care and connect families with needed economic and social resources (41–43). Connecting children and their families to violence intervention services at the time of hospital-based care is an opportunity to improve the child's physical and mental health after violent injury and may protect against future firearm injuries.

Our analyses are limited by the retrospective nature of this study design and potential misclassification bias. Identification of patients included in this cohort depended on accurate ICD coding. It is possible that we missed patients who presented with a firearm injury but did not receive a corresponding ICD diagnosis code. In addition, ICD coding misclassification of firearm injury intent is well documented, with a recent study highlighting that assaults are most often misclassified as accidental injury (44). Some patients likely sustained an index injury before 2010, which could underestimate cumulative incidence of recurrent firearm injury. We may also undercount minor firearm injuries treated only in the community setting by a nonpartner hospital, although we expect most pediatric firearm-injured patients to be transferred to regional level I trauma hospitals, and thus be captured in our data repository. It is also possible that the date of death identification in the NDI is incorrect for a small subset of people. When a death is identified in the NDI, it is highly likely that they were injured and

died that same day because their injury was too severe to indicate a need to transport them to one of the level I trauma centers in the region. However, it is possible that, for a small percentage of these children, there is a lapse between date of death and date their body was found.

In addition, our region-wide HVIP was implemented during the end of the 10-year study period. A few patients ($n = 22$) received HVIP services during the final 17 months of our study; removing these patients from the index study sample did not change cumulative incidence of reinjury among patients with recurrent firearm injuries.

We also had limited data on comorbid conditions and patient-level social determinants of health. The CCW depression and substance use disorder codes presented here are likely substantial undercounts in this non-Medicare pediatric population because it is unlikely that pediatric patients consistently received assessment for these conditions. Finally, because the median follow-up time in the sample is 3.6 years, the number of patients with larger follow-up times is limited and any conclusions related to longer follow-up times (for example, reinjury rates at 8 years and beyond) should be interpreted with caution.

In conclusion, this study highlights the high cumulative incidence of children experiencing recurrent firearm injuries in St. Louis and identifies racial and social vulnerability disparities in this group. Findings also indicate the disproportionate risk for recurrent firearm injury for children whose index firearm injury was treated at an adult hospital rather than at a children's hospital. Since the study by Choi and colleagues describing pediatric firearm injury in St. Louis was published nearly 10 years ago, rates of pediatric firearm injuries in the St. Louis region have continued to increase (11). Studies such as ours underscore the need to better detail nonfatal pediatric firearm injury and reinjury through robust data sources that can longitudinally track patient encounters across hospitals (both pediatric and adult) and health care systems. Accurate, reliable identification of firearm injury and reinjury can inform secondary prevention efforts, such as hospital-based violence intervention programs, and target them to children at greatest risk.

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Appendix Table. HRs for Risk for Firearm Reinjury for All Covariates From Univariable and Multivariable Models That Include All Covariates

Characteristics	Unadjusted HR (95% CI)	Adjusted HR (95% CI)
Gender		
Female	Reference	Reference
Male	3.28 (1.66–6.48)	2.73 (1.37–5.47)
Age		
0–4 y	Reference	Reference
5–9 y	0.57 (0.13–2.61)	0.61 (0.13–2.83)
10–14 y	1.56 (0.53–4.61)	1.28 (0.42–3.83)
15–17 y	3.01 (1.09–8.31)	1.53 (0.53–4.41)
Race*		
Black	6.60 (2.45–17.78)	3.40 (1.22–9.43)
White	Reference	Reference
Insurance		
No insurance	1.18 (0.59–2.38)	0.84 (0.41–1.73)
Medicare/Medicaid/ other government	1.58 (0.94–2.67)	1.37 (0.78–2.40)
All other private	Reference	Reference
SVI category		
High	12.16 (1.69–87.63)	6.37 (0.85–47.63)
Average	10.88 (1.50–79.12)	7.20 (0.97–53.64)
Low	Reference	Reference
Hospital		
Adult hospital 1	2.32 (1.55–3.47)	1.85 (1.19–2.88)
Adult hospital 2	2.35 (1.44–3.83)	1.74 (1.04–2.93)
Pediatric hospital 1	1.06 (0.72–1.55)	1.03 (0.70–1.52)
Pediatric hospital 2	Reference	Reference
Index injury intent		
Assault/homicide	1.96 (1.34–2.87)	1.31 (0.88–1.95)
Undetermined	1.43 (0.75–2.72)	1.47 (0.75–2.85)
Unintentional	Reference	Reference

HR = hazard ratio; SVI = Social Vulnerability Index.
* All racial categories were included in the model but due to small sample sizes in other categories, meaningful conclusions could only be drawn for the Black versus White categories.