Adolescent Nonfatal Firearm Injury Trends at a Level I Trauma Center in King County, WA, 2011-2021

Erika K. Marts

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Committee:

Ali Rowhani-Rahbar

Frederick Rivara

Jeanie Santaularia

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Abstract

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Erika K. Marts

Chair of the Supervisory Committee:

Ali Rowhani-Rahbar

Department of Epidemiology

Background: Firearm-related harm is a critical and growing public health problem in the United States, particularly among adolescents. Leveraging multiple data sources can provide a more complete assessment of nonfatal firearm injuries at the local-level, as national-level data may mask variations in firearm injury incidence by and within states.

Methods: This retrospective cohort study used data from a Level I Trauma Center in King County, Washington (WA) and the Gun Violence Archive (GVA) to examine adolescent nonfatal firearm injury trends and explore how well trauma registry data are captured in the GVA. We calculated incidence rates per 100,000 population for each year of the study period and by intent, race, age, and sex. Events of gun violence in the GVA were matched to trauma registry data using probabilistic linkage methods.

Results: Nonfatal firearm injury incidence rates increased among our sample from 2011 to 2021 (2.65 per 100,000 persons versus 3.38 per 100,000 persons); we observed the highest rate in 2019 (3.71 per 100,000 persons). The majority of nonfatal firearm injuries during the study period were sustained by adolescents who were aged 18-19 (51.8%), Black or African American (56.4%), and male (84.8%). Approximately 42% of trauma registry cases were probabilistically matched to cases in the GVA; assault-related cases, those involving Black adolescents, and those among patients aged 15-17 were captured at a higher proportion in the matched data.

Conclusion: The rate of nonfatal firearm injuries among King County adolescents who were captured in the trauma registry increased between 2011 and 2021. These findings indicate the need for local evidence-based policy changes and targeted interventions for adolescents at the highest risk of nonfatal firearm injury in King County, particularly individuals who are Black, male, and aged 18-19.

Introduction

Firearm-related harm is a critical and growing public health problem in the United States, particularly among adolescents. An estimated 5000 children and adolescents are injured or killed by firearms each year, with nonfatal injuries being at least twice as common as fatal injuries.[1] It is estimated that more than 80% of children and adolescents who are injured by a firearm that is not self-inflicted survive.[2] Compared to other penetrating trauma mechanisms, like cutting or piercing injuries, firearm injuries are more likely to result in greater injury severity and healthcare utilization among children and adolescents for both critical and noncritical injuries.[3] Following a firearm injury, child and adolescent survivors are significantly more likely than their non-injured counterparts to experience a subsequent injury and severe mental health impacts, such as post-traumatic stress symptoms, depression, anxiety, and suicidal thoughts.[4] Substantial increases in self-reported pain, as well as psychiatric and substance use disorders, have been noted within a year after a firearm injury and are associated with mental health impacts on a survivor's family.[2]

There is no single, comprehensive, and complete data source for ascertaining the burden of nonfatal firearm injury in the United States[5-7] and as a result, firearm injury research has primarily focused on deaths.[8] Accurate and reliable nonfatal firearm injury data is essential for informing policies and interventions to prevent firearm injury and reduce the impacts of firearm-related harm on survivors, their families, and communities. While some nonfatal firearm injury data sources do exist (e.g., the Centers for Disease Control's Web-based Injury Statistics Query and Reporting System (WISQARS)), they are typically limited in respect to detailing circumstances surrounding the firearm injury and may underestimate counts of injury.[9] Trauma registries can be a particularly useful source of nonfatal firearm injury data, as they provide

detail on patient demographics, diagnoses, intent, treatment, and outcomes.[8] Trauma facilities are required to maintain and submit these registries, and trauma registrars accurately code detailed information related to the injury.[10] Data from trauma registries have been previously used to describe nonfatal firearm injury trends among adolescent populations, both nationally[11] and within health systems.[12]

Leveraging multiple data sources to identify incidents of firearm injury can also provide a more complete assessment of nonfatal firearm injuries. For example, the Gun Violence Archive (GVA), a publicly accessible data source, can be used to identify events of both nonfatal and fatal firearm injuries that are not self-inflicted. The GVA collects gun violence incident data from thousands of sources to capture community firearm violence events, mass shootings, and unintentional firearm injuries.[13] These data may capture incidents of nonfatal firearm injury that may not appear in trauma registries but occurred in the catchment area of a trauma center.

While national-level data is vital for understanding the burden of firearm-related harm among adolescents across the United States, this data may mask variations in firearm injury incidence by region and site. Regional policies related to firearm storage, gun access, and child access protection (CAP) laws vary widely across the United States,[14] and the strength of these laws has been associated with differences in discharge rates for nonfatal firearm injuries.[15] Additionally, firearm injury trends, hospital resource utilization, patient demographics, and intent of injury differ by U.S. region.[12] Rates of firearm injury have also notably varied within states[16] and between rural and urban counties.[17]

To our knowledge, this was the first project to examine adolescent nonfatal firearm injury trends in King County, Washington (WA) and explore how well patients in trauma registry data are captured in the GVA.

Specifically, this project aimed to:

1. Investigate trends in firearm injury incidence rates among adolescents aged 10 to 19 years who presented to a Level I trauma center in King County, WA between 2011 and 2021.
2. Compare trends in firearm injury incidence rates among adolescents included in the trauma registry by intent, age, race, and sex.
3. Assess the completeness of data on nonfatal firearm injury among adolescents in the Gun Violence Archive using trauma registry data from 2014 to 2021 to explore the utility of the GVA.

Methods

Study Design

This retrospective cohort study was conducted to identify trends in firearm-related injuries among adolescents who were included in a hospital-based trauma registry in King County, WA. The exposure of interest in this study was time; we included data from January 1, 2011, through December 31, 2021. The outcome of interest was firearm injury. Firearm-related injuries were identified using the *International Classification of Diseases, Ninth Revision, Clinical Modification (ICD-9-CM)* codes for records through October 2015 and *International Classification of Diseases, Tenth Revision, Clinical Modification (ICD-10-CM)* codes for records in subsequent months/years. Firearm injury intent was classified in the registry as being one of the following: unintentional, self-inflicted, assault, legal intervention, or undetermined. This study explored the presence of effect modification in nonfatal firearm injury trends by three demographic variables: age, sex, and race. Age was categorized into three groups, 10-14, 15-17, and 18-19, based on prior evidence that injury intent differs between adolescent age categories. [1,]

[18-19] Black youth and males are disproportionately impacted by firearm-related harm, [1, 19-20] therefore this analysis also examined the presence of effect modification by sex and race.

This study received approval by the University of Washington Institutional Review Board.

Setting

King County, Washington.

Study Subjects

Subjects were identified through the trauma registry of Harborview Medical Center (HMC), a Level I trauma center in King County, WA. Participants were included if they were between the ages of 10 and 19 years old and listed King County, WA as their county of residence at the time of injury. Individuals who did not meet the eligibility criteria or sustained a fatal firearm injury were excluded from our study. Participants who were present in the trauma registry but indicated living in a different county or were residents of King County but presented to other medical centers for a nonfatal injury were not included in this sample. Participants who presented to other medical centers in King County and met the inclusion criterion may have been captured in the GVA if they had a documented injury that was not self-inflicted and were identifiable in one of the GVA's data sources. We obtained data from the GVA for incidents between January 1, 2014, and December 31, 2021, where an adolescent between the ages of 10 and 19 sustained a firearm injury in Washington State.

610 patients aged 10 to 19 were identified from the trauma registry as being treated at HMC between 2011 and 2021; 369 of these participants reported living in King County at the time of their injury, sustained a nonfatal injury, and were included in the analytical sample. 395

incidents of nonfatal injury that met the inclusion criterion for age were captured in the GVA in WA between 2014 and 2021.

Data Collection

Data from the trauma registry provided the date of the injury, victim's age at injury, county where injury occurred, state of residence, county of residence (if in WA), race, ethnicity, and sex. Census data were obtained from the American Community Survey (ACS) to ascertain the population size of adolescents aged 10 to 19 by sex and race in King County, WA during the study period. Data from the trauma registry were then probabilistically matched to person-level incidents of nonfatal injury included in GVA from 2014, when the GVA started publishing data, through 2021.

Participants who were present in the trauma registry for a subsequent injury between 2011 and 2021 were classified as having another incident firearm injury. Following probabilistic data linkage between the data from the trauma registry and incidents in the GVA, each potential match underwent manual review to ensure that they matched exactly on key identifiers (injury year, state, age group, and gender) and were likely matches on injury month, injury day, and county of injury. During the manual review process, data sources from the GVA, such as newspaper articles, were reviewed to obtain further information about the incident that would be relevant for matching.

Statistical Analysis

Data were cleaned and analyzed using R 4.3.2. Descriptive statistics were calculated to compare the distribution of nonfatal firearm injuries by age, race, sex, and intent. To examine trends in nonfatal firearm injuries from 2011-2021, we calculated incidence rates per 100,000 population for each year of the study period using counts of injury and population data for King

County by sex, race, and age. Incidence rates were calculated using the epiR package. We plotted incidence rates per year and their corresponding 95% confidence intervals to visualize temporal trends. To calculate incidence rate ratios over time, we fit a Poisson regression model using counts of nonfatal firearm injury as the outcome, year as the predictor (using 2011 as the reference group), and the population of adolescents aged 10-19 in King County between 2011 and 2021 as the offset term. To explore differences in nonfatal firearm injury incidence rates by intent and demographic factors, we calculated rates by intent, race, age category, and sex. We created plots of incidence rates over time for each variable of interest to visualize trends.

Events of gun violence identified in the GVA were matched to the trauma registry data through probabilistic linkage methods using the FastLink package in R. Pairs were classified as a match if their conditional match probability was at least 95%. We created a matching algorithm that required injury year, month, state, status, age group, gender, and county of injury to be an exact match. Injury day was considered a partial numeric match if the injury date in GVA was within 5 days of the injury date recorded in the trauma registry. The matches determined by this process were then manually validated by one of the researchers.

Results

There were 369 nonfatal firearm injuries captured among King County, WA adolescents aged 10 to 19 years in the trauma registry between 2011 and 2021. Adolescents aged 18-19 sustained the largest proportion of nonfatal firearm injuries (51.8%), followed by adolescents aged 15-17, who accounted for 38.2% of total firearm injuries during the study period (Table 1). Over half (56.4%) of all nonfatal injuries were among Black or African American youth and 84.8% of nonfatal firearm injuries were sustained by male adolescents. In our sample, the most

frequently documented intents were assault-related injuries (77.5%) and unintentional injuries (16.5%).

Table 1. Demographic characteristics of adolescents 10-19 with firearm injuries reported in the trauma registry, 2011-2021

	Assault (N = 286) n (%)	**Legal Intervention (N = 5) n (%)**	**Self-inflicted (N = 5) n (%)**	**Undetermined (N = 12) n (%)**	**Unintentional (N = 61) n (%)**	**Total (N = 369) n (%)**
Age						
10-14	20 (7.0%)	0 (0.0%)	0 (0.0%)	2 (16.7%)	15 (24.6%)	37 (10.0%)
15-17	112 (29.2%)	1 (20.0%)	4 (80.0%)	4 (33.3%)	20 (32.8%)	141 (38.2%)
18-19	154 (53.8%)	4 (80.0%)	1 (20.0%)	6 (50.0%)	26 (42.6%)	191 (51.8%)
Race						
Asian	5 (1.7%)	0 (0.0%)	0 (0.0%)	1 (8.3%)	3 (4.9%)	9 (2.4%)
Black or African American	173 (60.5%)	2 (40.0%)	1 (20.0%)	7 (58.3%)	25 (41.0%)	208 (56.4%)
Native American	3 (1.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	4 (1.1%)	4 (1.1%)
Native Hawaiian or Other Pacific Islander	6 (2.1%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	1 (1.6%)	7 (1.9%)
Not Documented	17 (5.9%)	3 (60.0%)	1 (20.0%)	0 (0.0%)	5 (8.25%)	25 (6.8%)
Multi-racial	5 (1.7%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	5 (8.2%)	10 (2.7%)
White	77 (26.9%)	0 (0.0%)	3 (60.0%)	4 (33.3%)	22 (36.1%)	106 (28.7%)
Ethnicity						
Hispanic or Latino	62 (21.7%)	0 (0%)	0 (0%)	1 (8.3%)	10 (16.4%)	73 (19.8%)
Not Documented	37 (12.9%)	2 (40.0%)	1 (20.0%)	2 (16.7%)	11 (18.0%)	53 (14.4%)
Not Hispanic or Latino	187 (65.4%)	3 (60.0%)	4 (80.0%)	9 (75.0%)	40 (65.6%)	243 (65.9%)
Sex						
Female	41 (14.3%)	0 (0.0%)	2 (40.0%)	1 (8.3%)	12 (19.7%)	56 (15.2%)
Male	245 (85.7%)	5 (100%)	3 (60.0%)	11 (91.7%)	49 (80.3%)	313 (84.8%)

Nonfatal firearm injury incidence rates increased from 2.65 per 100,000 persons in 2011 to 3.38 per 100,000 persons in 2021 (Figure 1). The highest observed rates of nonfatal firearm

injury among the sample occurred in 2019, when the incidence rate was 3.71 per 100,000 persons (Table 2). We observed lower rates of nonfatal firearm injury in our sample between 2012 and 2016, and the lowest observed incidence rate during the study period was 1.67 nonfatal firearm injuries per 100,000 persons in 2013.

Figure 1. Rates per 100,000 persons of nonfatal firearm injury among adolescents in the trauma registry, 2011-2021

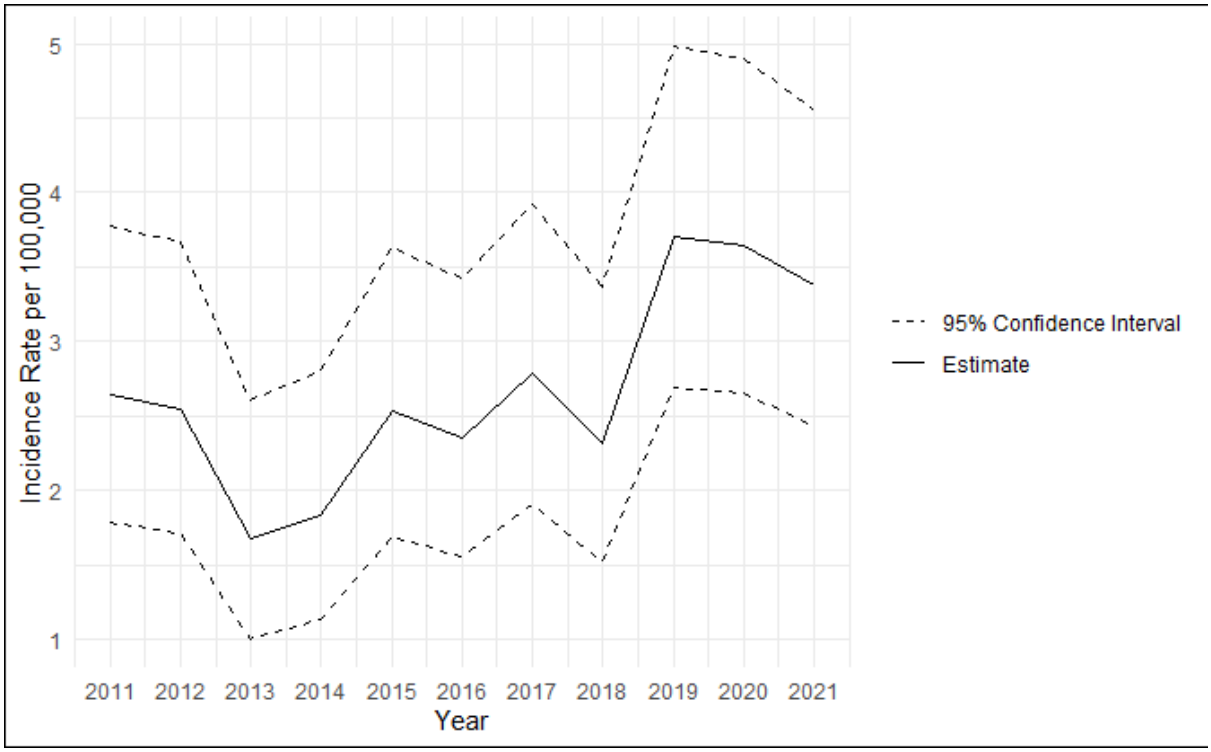


Table 2. Rates per 100,000 persons of nonfatal firearm injury among adolescents 10-19 in the trauma registry by year, 2011-2021

Year	N	Rate per 100,000 Persons	IRR	95% CI
2011	34	2.65	1.00	Reference
2012	33	2.55	0.96	0.58, 1.61
2013	23	1.67	0.63	0.36, 1.12
2014	25	1.83	0.69	0.40, 1.21
2015	34	2.53	0.96	0.57, 1.59
2016	27	2.36	0.89	0.53, 1.50
2017	34	2.78	1.05	0.64, 1.73
2018	27	2.31	0.87	0.52, 1.47
2019	44	3.71	1.40	0.88, 2.23
2020	45	3.65	1.38	0.87, 2.19
2021	43	3.38	1.28	0.80, 2.04

Assault-related injuries comprised the largest proportion of nonfatal injuries for every year of the study period (Figure 2); most of these cases were among adolescents aged 18-19 (53.8%) and Black adolescents (60.5%) (Figure 3). Approximately 21.6% of assault-related injuries were among Latinx adolescents in our sample. Among patients in our sample with self-inflicted nonfatal injuries, 80% were aged 15-17, 60% were White, and 60% were male. Approximately 86% of assault-related injuries, 92% of undetermined injuries, and 80% of unintentional injuries were among male patients. All recorded incidents of injury by legal intervention were sustained by male adolescents.

Figure 2. Rates per 100,000 persons of nonfatal firearm injury among King County adolescents in the trauma registry by intent, 2011-2021

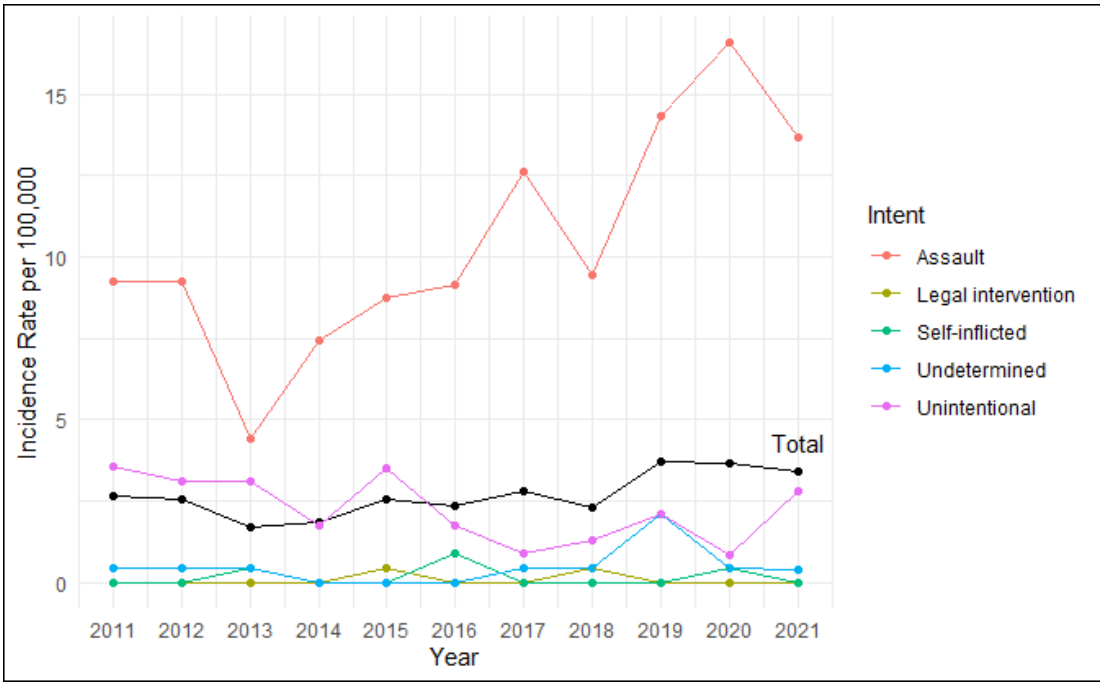
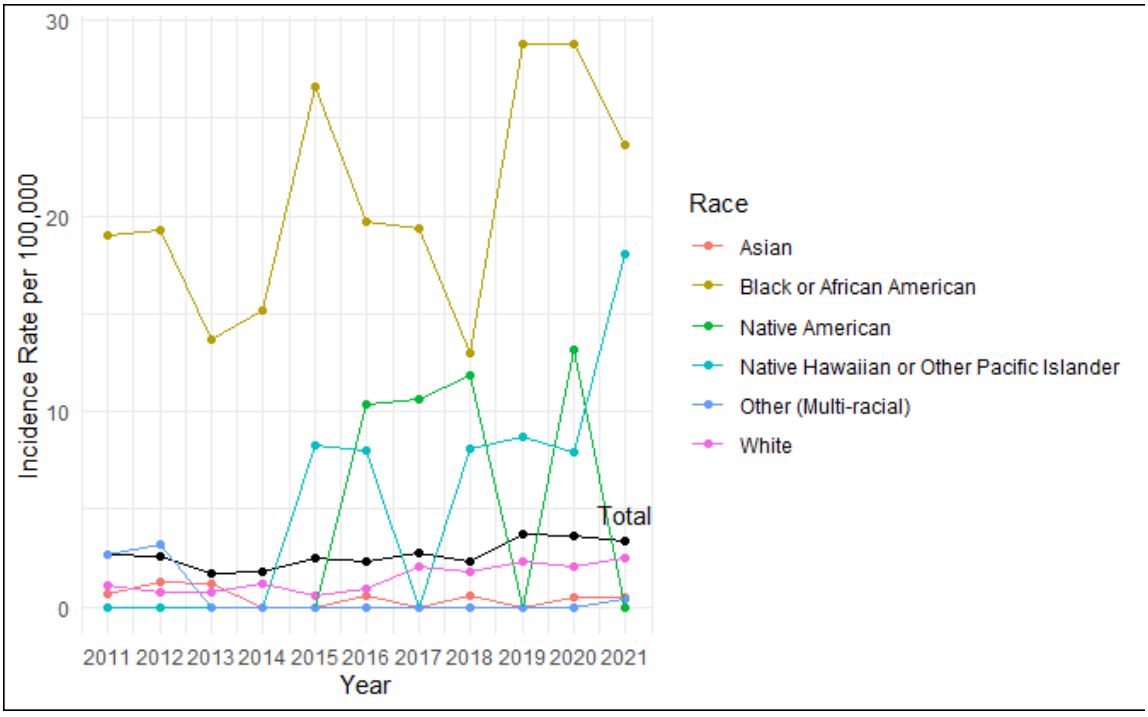


Figure 3. Rates per 100,000 persons of nonfatal firearm King County adolescents in the trauma registry by race, 2011-2021



There were 302 cases of nonfatal firearm injury captured in the trauma registry among King County adolescents between 2014 and 2021; these cases could be matched to incidents captured in the GVA in the same time period. 127 events of nonfatal injury, or approximately 42% of trauma registry cases, were probabilistically matched to cases in the GVA. Among cases present in both the trauma registry and the GVA, 86.6% were assault-related, 84.3% were among males, 59.1% were among Black adolescents, 22.8% were among Latinx adolescents, and 49.6% were among individuals aged 15-17 (Table 3). Of the cases missing in the GVA, 78.3% were assault-related, 84.6% were among males, 56.0% were among Black adolescents, 20.6% were among Latinx adolescents, and 35.4% were among individuals aged 15-17.

Table 3. Demographics of Matches and Non-Matches

Variable	**Matched (N = 127)** n (%)	**Unmatched with GVA (N = 175)** n (%)
Intent		
Assault	110 (86.6%)	137 (78.3%)
Legal intervention	3 (2.4%)	0 (0%)
Self-inflicted	0 (0%)	4 (2.3%)
Undetermined	6 (4.7%)	5 (2.9%)
Unintentional	8 (6.3%)	29 (16.6%)
Gender		
Female	20 (15.7%)	27 (15.4%)
Male	107 (84.3%)	148 (84.6%)
Race		
Asian	2 (1.6%)	4 (2.3%)
Black or African American	75 (59.1%)	98 (56.0%)
Native American	2 (1.6%)	1 (0.6%)
Native Hawaiian or Other Pacific Islander	4 (3.1%)	4 (2.3%)
Not Documented	5 (3.9%)	11 (6.3%)
White	41 (32.3%)	56 (32.0%)

Ethnicity		
Hispanic or Latino	29 (22.8%)	36 (20.6%)
Not Documented	4 (3.1%)	8 (4.6%)
Not Hispanic or Latino	94 (74.0%)	131 (74.9%)
Age Category		
10-14	9 (7.1%)	16 (9.1%)
15-17	63 (49.6%)	62 (35.4%)
18-19	55 (43.3%)	97 (55.4%)

Discussion

Our study identified an increase in the rate of nonfatal firearm injuries among King County adolescents who presented to HMC between 2011 and 2021. This finding is consistent with previous research indicating that despite overall pediatric emergency department visits declining among this age group, firearm injuries have been increasing in the past decade among children and adolescents.[19] Interestingly, the highest rate of nonfatal firearm injury was observed in 2019; nonfatal firearm injuries then decreased among this sample from 2020 to 2021. This finding contrasted with the notable increase in nonfatal firearm injuries since the start of the COVID-19 pandemic both nationally[21] and in large metropolitan areas.22

Throughout the study period, assault-related injuries accounted for the majority of all nonfatal firearm injuries, which was consistent with the distribution of intent among nonfatal firearm injuries identified in previous literature.[1] Our findings reflect those of similar work which highlight how nonfatal firearm injuries, especially those due to assault, disproportionately affect older adolescents, Black youth, and males.[1,19-20,23] Several individual, community, and structural-level risk factors have been identified in the literature to explain these findings. Economic disadvantage and structural racism have been noted as two drivers of racial disparities in firearm-related injuries.[24] Assault-related firearm injuries have been strongly associated with high levels of social vulnerability, a measure that incorporates the compounding effects of socioeconomic status, household composition and disability, minority status and language, and

housing type/transportation.[25] Firearm carrying and availability, two individual and community-level risk factors for firearm injury, also differ by age, race, and gender,[26] which may explain differences in rates of nonfatal injuries among these demographics.

Additionally, this study highlighted that self-inflicted nonfatal injuries were most common among adolescents aged 15-17 and White adolescents, which was consistent with the literature pertaining to disparities in self-harm-related injury nationally.[27] While rates of self-harm injuries have notably increased among adolescents nationally,[28] we did not observe an increasing trend in non-fatal self-injury and recorded relatively few cases by this intent over the study period. However, this finding does not indicate that rates of self-harm by firearm are lower in King County than nationally, given that the case fatality rate of suicide attempts using a firearm is approximately 90%[29] and we included only nonfatal firearm injury in this analysis.

To our knowledge, this is the first study to explore the completeness of data on nonfatal firearm injuries in the GVA compared to trauma registry data. Our study found that approximately 42% of nonfatal injury cases in the trauma registry from 2014 to 2021 could be identified in the GVA. Cases present in both the GVA and trauma registry were related to assault at a much higher proportion than any other intent. This may be explained by the fact that police department data is a more complete source of assault-related incidents than trauma registries,[30] the GVA relies on police data as a source of gun violence incident data, and the GVA has good sensitivity for capturing assault-related shooting events when compared to police department data.[7] A larger proportion of cases that were present in both the trauma registry and GVA involved injury among Black adolescents compared to cases that were missing from the GVA. This finding contrasted with previous work which compared police department data to the GVA database and found that shootings were more likely to be missing if they involved Black

individuals.[7] However, our study did find evidence to support the findings from previous work that the GVA was missing fewer incidents of gun violence among children younger than 18 compared to their older counterparts.[7]

Misclassification of intent, particularly the coding of assault-related injuries as accidental/unintentional, is greatly reduced using trauma registry data given the high sensitivity and positive predictive value associated with coding by trauma registrars for firearm injuries.[10] This study is also strengthened by its use of the GVA to examine data completeness and can provide an estimate of how many nonfatal injuries occurred in King County but were not recorded in the trauma registry because patients did not present to Harborview Medical Center. This is particularly important given that trauma registries are often missing nonfatal firearm injury cases that were treated in and discharged from the emergency department, a majority of which are assault-related and unintentional injuries.[31] This study has a few notable limitations. The GVA does not collect data on self-harm[32] and thus comparisons cannot be made between the GVA and trauma registry data for that intent. Although previous work has established that LGBTQ+ communities are disproportionately impacted by firearm violence,[33] this study used data that are not inclusive of diverse gender identities, limiting our understanding of how gender non-conforming or transgender individuals in King County, WA may be impacted by gun violence.

These findings indicate the need for local evidence-based policy changes and targeted interventions for adolescents at the highest risk of nonfatal firearm injury in King County, particularly individuals who are Black, male, and aged 18-19. Evidence-based interventions to prevent firearm injury among adolescent populations include decreasing firearm carrying and increasing safe firearm storage.[34] Given the long-term, harmful impacts associated with firearm

injury among survivors,[2] access to and connection with mental health care following a firearm injury is critical. Future research should incorporate additional sources of data to capture nonfatal firearm injuries that may not be present in the trauma registry and includes fatal firearm injuries, such as Emergency Medical Services (EMS) and death record data. Additionally, given the evidence that there is variability in rates of firearm injuries within states,[12] subsequent work could explore differences in adolescent firearm injury trends across Washington State, particularly in more rural areas where the contexts for handgun carrying and firearm injury intent often differ.[35]

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Appendix

Figure 5. Rates per 100,000 persons of nonfatal firearm injury King County adolescents in the trauma registry by age category, 2011-2021

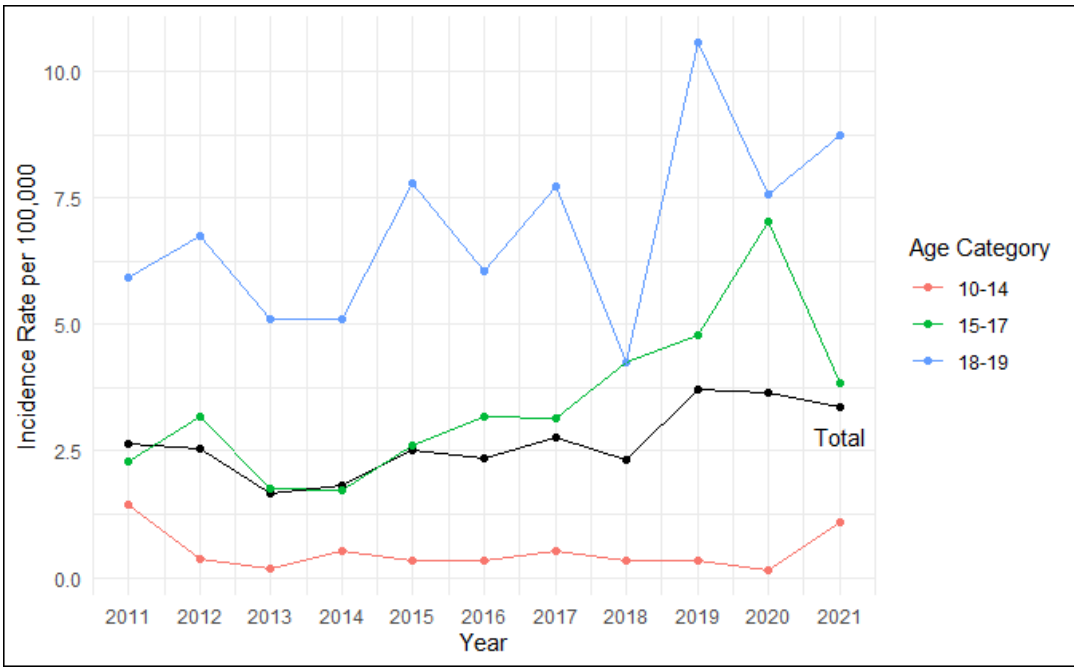

Figure 5. Rates per 100,000 persons of nonfatal firearm injury among King County adolescents in the trauma registry by sex, 2011-2021