ORIGINAL RESEARCH

A Milwaukee Syndemic? Penetrative Injury and COVID-19

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ABSTRACT

Introduction: This study sought to evaluate injury frequency of penetrative trauma before and after stay-at-home orders were implemented due to COVID-19 in Wisconsin.

Methods: Patients who presented to a level I trauma center from January 2018 through December 2021 with a mechanism of injury of firearm or stab wound were included. The study was split into pre-COVID (January 2018-February 2020) and COVID (March 2020-December 2021) periods. Statistical analysis included chi-square tests and interrupted time series analysis.

Results: A total of 1702 patients met inclusion criteria. The COVID group had a statistically significantly higher proportion of firearm injuries (83.2%) and a significantly lower proportion of stab injuries (16.8%) compared to the pre-COVID period group (70% and 30%, respectively, $P < 0.001$). There was no change from pre-COVID to COVID periods in in-hospital mortality or length of hospital stays. There was an increase in firearm incidents in the COVID period in 72% of Milwaukee County ZIP codes and a decrease in stab incidents in 48% of ZIP codes. Interrupted time series analysis indicated a significant increase from the pre-COVID to COVID periods in monthly firearm and stab injuries. Firearm injury significantly increased from pre-COVID to COVID for Black or African American patients but no other racial group.

Conclusions: These findings are consistent with other state and national trends suggesting increasing penetrative injury during the COVID-19 pandemic. The intersection of the COVID-19 pandemic and violence pandemic may yield a "syndemic," imposing a significant burden on trauma systems. Evidenced-based public health interventions are needed to mitigate the surge of firearm injuries.

INTRODUCTION

In December 2019, the first cluster of patients with pneumonia of unknown etiology was reported.[1,2] Over the next 24 months, the novel coronavirus that causes this disease—severe acute respi-

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ratory syndrome coronavirus 2 (SARS-CoV-2), known as COVID-19—rapidly spread worldwide.[3–5] In response, local, national, and international agencies implemented measures to reduce the viral transmission. This included travel bans, stay-at-home orders, and the temporary closure of many schools and workplaces. The stay-at-home orders recommended or required that residents stay in their living quarters, with exceptions for essential activities.[6] In the United States, 43 states and the District of Columbia implemented stay-at-home orders between March 2020 and April 2020.[7] Wisconsin issued stay-at-home orders in March 2020.[8] Despite these mitigation measures, the pandemic created many challenges, and by the end of 2021, over 825 000 people had died due to COVID-19 in the United States.[9] Many individuals faced economic hardships, social isolation, and increased stress, and there were national supply chain issues and elevated sociopolitical tension.

Since the beginning of the COVID-19 pandemic, hospitals and health care systems have reported a decrease in total unintentional trauma and an increase in penetrating trauma, largely driven by firearm injuries.[10–13] In the US, gun violence has been a longstanding public health crisis and is now one of the top 5 causes of death among Americans ages 1 to 44 years.[14] In 2020, firearm-related incidents became the leading cause of death among young Americans—those ages 1 to 24 years old.[15,16] This has led to reframing the language around gun violence, recognizing it as an epidemic.[17,18] Violence also has been described as a biopsychosocial disease, requiring a comprehensive approach to prevention

and treatment.[19–22] Gun violence rates increased by approximately 30% during the first year of the COVID-19 pandemic compared to prepandemic rates in 2019, with variation across states.[13,23] Wisconsin was one of 28 states with a significant increase in gun violence during the pandemic.[13]

The impact of the COVID-19 pandemic and the increase in gun violence may represent a "syndemic."[24] A syndemic is the aggregation or convergence of two or more disease epidemics that negatively exacerbate prognosis and burden of disease.[25,26] Factors such as poverty, unequal access to health care, and underresourced neighborhoods may be important structural facilitators of both morbidity and mortality of the COVID-19 virus.[27] Similar structural factors have been associated with increased violence and firearm injuries.[28] Milwaukee County, in particular, is the largest urban area in Wisconsin, with increased demographic diversity. To evaluate the synergistic associations between the stay-at-home order implementation in response to COVID-19 and the epidemic of violence, we conducted a study to examine penetrative injury trends in the wake of the COVID-19 pandemic.

METHODS
Participants
Data were queried from the trauma registry at Froedtert Hospital, the level 1 trauma center in Milwaukee, Wisconsin. Patients were included in the study if they were adults who sustained a penetrating injury from January 2018 through December 2021 and met trauma registry inclusion criteria. For the purposes of this analysis, penetrating injuries were defined as a mechanism of injury (MOI) of either firearm or stab injuries. The trauma registry adheres to the inclusion criteria as determined by the American College of Surgeons National Trauma Data Bank's (NTDB) Data Standard.[29] The study was approved by the Institutional Review Board prior to conducting any research.

Measures
Variables of interest from the registry included patient demographics (ie, age, sex, race), MOI, injury location ZIP code, and clinical data, including injury severity score (ISS), discharge status (ie, deceased or alive), length of stay in hospital, length of stay in the intensive care unit (ICU), and number of days on a ventilator. Race was defined according to NTDB data standards: American Indian, Asian, Black or African American, Native Hawaiian or Other Pacific Islander, Other Race, Unknown, and White. Age was categorized into the following age groups: 18-24, 25-34, 35-44, 45-54, 55-64, 65+ years. Injury severity scores were grouped into low (<15), middle (16-25), and high (>25).[30,31]

Data Analysis
In Wisconsin, stay-at-home orders were implemented in March 2020. This time point was used to designate pre-COVID (26-month period from January 2018 through February 2020) versus COVID (22-month period from March 2020 through December 2021) periods. Injury counts were aggregated by month. For all analyses, firearm and stab injuries were examined separately. Demographic and clinical data were compared pre-COVID and COVID using t tests for continuous variables and chi-square tests for categorical variables. Changes in the number of incidents by injury location ZIP code also were compared pre-COVID and COVID for only injuries that occurred in Milwaukee County due to small sample sizes of incidents in other counties.

Finally, an interrupted time-series analysis was conducted via segmented quasi-Poisson regression to compare changes in level (intercept) and slope of monthly counts of penetrating injury pre-COVID to COVID periods. A quasi-Poisson model was selected due to modeling counts and to account for overdispersion by freely estimating variance as a linear function of the mean. Interrupted time series analyses were first completed for all patient firearm and stab injuries and then repeated within racial groups. Only Black or African American, White, and Other Race groups were examined in the interrupted time-series analysis due to insufficient sample sizes of remaining racial groups. Bonferroni correction was applied to adjust for multiple tests (2 MOI x 3 racial groups = 6 interrupted time-series analyses; $\alpha = .05 / 6 = .008$). All data were analyzed using R version 4.3.0 (R Core Team, 2023).

RESULTS
Overall, there were 12 262 patients recorded in the trauma registry during the study period. Of those, 1702 (13.9%) patients met inclusion criteria; 1321 (77.6%) sustained firearm injuries and 381 (22.4%) sustained stab injuries. The COVID period group included a significantly higher proportion of firearm injuries (83.2%) and a significantly lower proportion of stab injuries (16.8%) compared to the pre-COVID group (70% and 30%, respectively) ($\chi^2 = 40.99$, $P < 0.001$). When comparing pre-COVID to COVID periods, there were no differences in sex or age for firearm or stab injuries (Tables 1 and 2). A significantly higher proportion of patients within the highest ISS category was noted during the COVID versus pre-COVID period for firearm injuries only (Table 1). Overall, there was a significant difference in firearm injuries by race from pre-COVID to COVID periods; however, post-hoc tests indicated an increase among those identified as Other Race and a decrease among those whose race was Unknown or White (Table 1). Similarly, there was an overall difference by race for stab injuries, yet in post-hoc tests, only those identified as Other Race had a significant increase in stab injuries from the pre-COVID to COVID period (Table 2). Total hospital days, ventilator days, ICU days, and in-hospital mortality did not change significantly from the pre-COVID to COVID period for firearm (Table 1) or stab injuries (Table 2).

ZIP codes of injury location were reported for 97% of the sample, of which 99% were within Milwaukee County and included in the following results. An increase in firearm incidents

Table 1. Patient Characteristics During the Pre-COVID and COVID Periods Among Those Who Sustained a Firearm Injury

Variable	Pre-COVID (Jan 2018 – Feb 2020) n = 507 n (%)	COVID (Mar 2020 – Dec 2021) n = 814 n (%)	*P* value
Gender			0.99
Female	65 (12.8)	105 (12.9)	
Male	442 (87.2)	709 (87.1)	
Age, years			0.6
18 – 24	161 (31.8)	245 (30.1)	
25 – 34	184 (36.3)	322 (39.6)	
35 – 44	84 (16.6)	147 (18.1)	
45 – 54	48 (9.5)	62 (7.6)	
55 – 64	18 (3.6)	21 (2.6)	
65+	12 (2.4)	17 (2.1)	
Race			<0.001[a]
American Indian	<5	<5	ns
Asian	10 (2.0)	<5	ns
Black or African American	376 (74.2)	647 (79.5)	ns
Native Hawaiian or Other Pacific Islander	<5	<5	ns
Other Race	6 (1.2)	53 (6.5)	<0.001[a]
Unknown	<5	16 (2.0)	<0.001[a]
White	113 (22.3)	91 (11.2)	<0.001[a]
Discharge status			0.626
Alive	449 (88.6)	728 (89.5)	
Dead	58 (11.4)	85 (10.4)	
Injury Severity Score			
Low	333 (65.7)	478 (58.7)	0.212
Middle	121 (23.9)	162 (19.9)	0.777
High	49 (9.7)	151 (18.6)	<0.001[a]
Mean total hospital days	6.15 ± 7.95	6.79 ± 10.0	0.223
Mean total vent days	1.04 ± 4.03	1.48 ± 5.68	0.123
Mean total ICU days	1.77 ± 4.63	2.10 ± 5.54	0.268

[a]*P* < 0.05
n < 5 is masked for patient confidentiality.
ns = not significant (*P* > 0.05) on post-hoc tests.
Abbreviation: ICU, intensive care unit.

Table 2. Patient Characteristics During the Pre-COVID and COVID Periods Among Those Who Sustained a Stab Wound

Variable	Pre-COVID (Jan 2018 – Feb 2020) n = 217 n (%)	COVID (Mar 2020 – Dec 2021) n = 164 n (%)	*P* value
Gender			0.98
Female	45 (20.7)	33 (20.1))	
Male	172 (79.3)	131 (79.9)	
Age, years			0.36
18 – 24	42 (19.4)	30 (18.3)	
25 – 34	54 (24.9)	55 (33.5)	
35 – 44	53 (24.4)	29 (17.7)	
45 – 54	36 (16.6)	31 (18.9)	
55 – 64	21 (9.7)	13 (7.9)	
65+	11 (5.1)	6 (3.7)	
Race			<0.001[a]
American Indian	<5	<5	ns
Asian	5 (2.3)	<5	ns
Black or African American	128 (59)	98 (59.8)	ns
Native Hawaiian or Other Pacific Islander	<5	<5	ns
Other Race	<5	15 (9.15)	<0.001[a]
Unknown	<5	<5	ns
White	78 (35.9)	47 (28.7)	ns
Discharge status			0.99
Alive	211 (97.2)	160 (97.6)	
Dead	6 (2.8)	<5	
Injury Severity Score			0.072
Low	185 (85.3)	132 (80.5)	
Middle	25 (11.5)	19 (11.6)	
High	<5	9 (5.5)	
Mean total hospital days	3.55 ± 4.07	3.5 ± 4.89	0.916
Mean total vent days	0.24 ± 0.72	0.46 ± 2.17	0.148
Mean total ICU days	0.67 ± 1.31	0.67 ± 2.31	0.989

[a]*P* < 0.05
n < 5 is masked for patient confidentiality.
ns = not significant (*P* > 0.05) on post-hoc tests.
Abbreviation: ICU, intensive care unit.

occurred in 35 (72%) of the 48 Milwaukee County ZIP codes, and a decrease in stab incidents occurred in 23 (48%) of the 48 Milwaukee County ZIP codes.

Results of an interrupted time-series analysis indicated a significant increase in the level of monthly counts of firearm injuries from pre-COVID to COVID periods (ß = 0.52, z 4.71, *P* < 0.001), but no change in the slope (ß = 0.002, z = 0.31, *P* = 0.75). Similarly, there was a significant increase in the level of monthly counts of stab injuries (ß = 0.41, z = 1.99, *P* = 0.04) but no change in the slope (ß = -0.01, z = -1.17, *P* = 0.23) (Figure 1). Firearm and stab injuries observed for all patients were, on average, 32.6% and 10.2% higher, respectively, than expected during COVID. Further, the interrupted time-series analysis by race showed that from the pre-COVID to COVID periods, Black or African American patients experienced a significant increase in the level of monthly firearm injury (ß = 0.53, z = 4.56, *P* < 0.001) but no change in the slope (ß = -0.002, z = -0.28, *P* = 0.77) during COVID. Observed firearm injuries for Black or African American patients were, on average, 42.5% higher than expected during COVID (Figure 2). There were no other significant changes for firearm or stab injuries by any other racial groups that survived Bonferroni correction (all *P*s > 0.03).

DISCUSSION

This study is consistent with other literature reporting an increase in penetrating injuries from pre-COVID to COVID, with firearm injuries accounting for much of this increase. Despite the increase in penetrating injury incidents during the COVID period com-

pared to pre-COVID, the mean hospital lengths of stay, ICU days, ventilator days, and in-hospital mortality rates did not change significantly. There was a widespread geographic increase in firearm incidents across Milwaukee County, and the increase in incidents was not isolated to any one ZIP code. Further, the increase in firearm injury during the COVID period was disproportionately shouldered by Black or African Americans underscoring the disparities in the burden of firearm-related injury.

Although this study used data from a single level I trauma center in Wisconsin, it serves as a potential model for other communities to assess local or regional trends in penetrating injury in pre-COVID and COVID time periods. The results of this analysis are consistent with other reports in the literature demonstrating an overall increase in penetrating injuries during the COVID-19 pandemic, increased firearm incidents, and decreased or minimal change in rates of stab injuries. Mokhtari and colleagues completed a multicenter study and noted an increase in penetrating injuries but that they were specific to certain sites rather than attributable to the stay-at-home orders.[32] Chodos and colleagues compared the COVID period March-May 2020 to pre-COVID (March-May 2019) and noted significant increases in penetrating trauma (22.6% vs 15.1%), gunshot wounds (11.8% vs 6.8%), and stab wounds (9.2% vs 6.9%).[11] In looking specifically at intentional, violent traumatic injuries before versus after stay-at-home orders were implemented, Abdallah and colleagues noted increased penetrating trauma from 17.37% to 29.91%, stabbing from 7.0% to 7.92%, and gunshot wounds from 12.61% to 22.92%, respectively.[10] In Wisconsin, relative increases in excess firearm-related incidences, nonfatal firearm injuries, and firearm-related mortality were approximately 38.8%, 60.1%, and 39.5%, respectively.[23] Prior analyses by city or state within the US have noted significant variability, indicating that geographic location and the specific characteristics of those locations are important. In Milwaukee County, firearm injuries increased in most ZIP codes, where stab injuries decreased in nearly half of the county's ZIP codes.

The factors associated with the notable increase in firearm inci-

Figure 1. Interrupted Time Series Analysis of Penetrative Traumatic Injury Counts by Month, 2018-2021
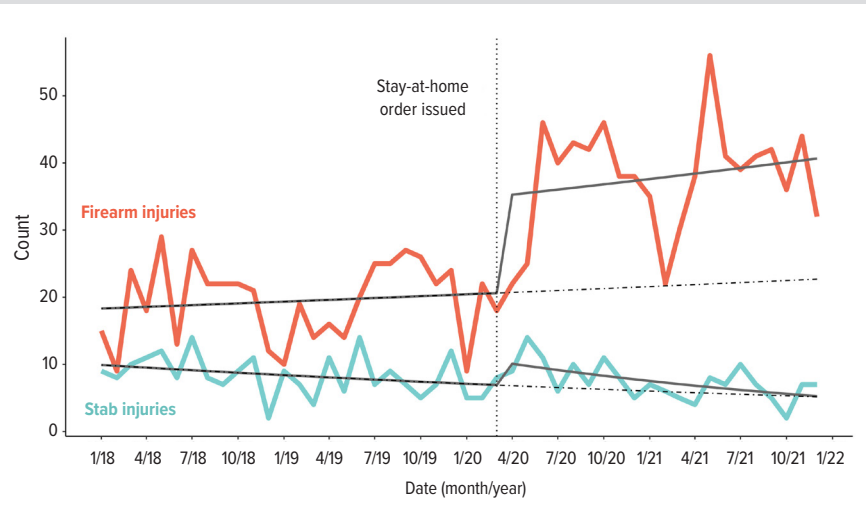
Dotted vertical line depicts March 2020 when stay-at-home orders went into effect in Wisconsin. Solid black lines depict fitted interrupted time series model for each of firearm and stab injuries. Dashed horizontal lines depict the counterfactual prediction of injury without consideration of the stay-at-home order interruption.

Figure 2. Interrupted Time Series Analysis of Firearm Injury Count by Race per Month, 2018-2021
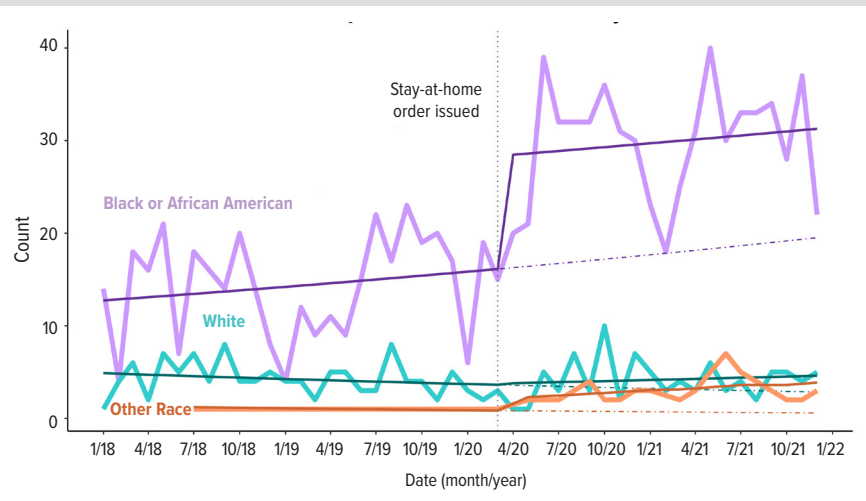
Dashed vertical line depicts March 2020 when stay-at-home orders went into effect in Wisconsin. Solid black lines depict fitted interrupted time series model for each racial group. Only Black or African American, White, and Other Race groups were examined due to insufficient sample size of remaining racial groups. Bonferroni correction was used to adjust for multiple comparisons by race (adjusted α = 0.008).

dents observed in this study and others are likely complex and varied; however, reported increases in gun purchases after the beginning of the COVID-19 pandemic may be a contributing factor.[33,34] Increased saturation of guns within communities may increase the likelihood of firearm-related incidents. In the first 2 months of the COVID-19 pandemic (March and April 2020), there were over 2 million internet searches for gun-related purchasing or removing guns from storage; this was 158% higher than what would be expected without the occurrence of the COVID-19 pandemic.[35] In a nationally representative survey sample, 6% of Americans reported purchasing a gun between March and July 2020; 34%

of those were new gun owners, resulting in an estimated 6 million new gun owners in the US.[33] In another national survey, 40% of new gun owners reported having an unlocked gun.[34] Reasons cited for purchasing a gun after the beginning of the pandemic included crime, supply chain disruptions, health, and the economy.[34]

The COVID-19 pandemic brought inequities in health, outcomes, and health care access to the forefront. Health inequities by racial and ethnic groups in COVID-19 mortality have been well documented.[36–38] Additional studies have indicated that people in the lowest socioeconomic position have experienced the highest COVID-19 mortality rates within racial and ethnic groups.[36,39] Nationally, Hispanic people had a 48% higher risk of experiencing a COVID-19 infection compared to White people.[40] Compared to White patients, those identified as Hispanic, non-Hispanic Black, or Asian or Pacific Islander had increased in-hospital mortality from COVID-19 in an adjusted model.[41] On a state level, Illinois reported that Hispanic and non-Hispanic Black patients experienced a disproportionately higher burden of COVID-19-related hospitalizations versus White patients.[42] Similar to the inequities noted in COVID-19 mortality, this study noted an increased burden of firearm injuries among Black or African American patients in the COVID period versus the pre-COVID period.

This unequal distribution of firearm injuries by race and ethnicity may be related to several contributing factors, many of which also contributed to the disparities by race for COVID-19 mortality and hospitalization rates. The social determinants of health (conditions in which one is born, lives, works, and ages) and the broader systemic factors that impact these vary geographically. Communities that experienced poverty, food insecurity, housing instability, and employment barriers at baseline were vulnerable to the changes brought about during the COVID-19 pandemic.[43] These same communities were also those vulnerable to gun violence. Increased distress, unemployment, and uncertainty brought about by the pandemic may have increased violent incidents.[10] In Milwaukee, in particular, historic redlining has contributed to significant inequities that continue to affect the social determinants of health today.[44] This intersection of racism, inequity, COVID-19, and firearm incidents is complex and cannot be ignored.

The unprecedented response to mitigate the spread of COVID-19 including, but not limited to, social distancing and self-isolation may have exacerbated the mental health crisis, contributed to the high rate of unemployment, and increased overall stress and anxiety for individuals. Many of these factors also have been linked to an increase in all types of violence – and the results of this analysis should be contextualized to the multifaceted environment of the pandemic. Further, during the COVID-19 pandemic – particularly in the early months – hospital systems were near or at capacity with COVID-19 patient admissions, while simultaneously attending to those who sustained penetrating injuries. The intersection of COVID-19 infection and penetrating injuries on the burden of hospitals should be examined – particularly with the limited availability of ICU and ventilatory care – to prevent future health crises associated with future and ongoing syndemics.

These data demonstrate a concerning increase in penetrating trauma from pre-COVID to COVID periods with increased firearm injuries. These data are an important component to inform injury prevention efforts. Despite these benefits, this study has several limitations. The data are limited to patients who met trauma registry inclusion criteria within a single level I trauma center and do not include patients who sustained minor or superficial penetrating injuries or patients with penetrating injuries who were treated at other hospitals, nor does it account for incidents where a patient died at the scene of an injury or the patient did not seek medical care. Our results may be an underrepresentation of the overall penetrating incidents in Milwaukee; however, they likely represent the most severe penetrating injuries. These data were retrospectively reviewed and therefore cannot determine any cause-effect or identify any other direct interactions between the stay-at-home orders during the COVID-19 pandemic and the changes in penetrating injury. Local and national sociopolitical events occurring over the same time period also may influence gun violence and are not accounted for in these data. We did not separate injuries by intent because data quality was insufficient, but future work should consider examining self-inflicted injuries and assaultive injuries separately during the pandemic.

CONCLUSIONS

Penetrating traumatic injuries increased during the COVID period compared to pre-COVID. Firearm injuries accounted for much of this increase, while a decrease in stab injuries was noted. The potential syndemic effect of gun violence and the COVID-19 pandemic is crucial for health care professionals, community programs, and policymakers to understand to ensure better care for patients and communities in the event of future natural disasters and disease outbreaks.

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