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Increased Civilian Penetrating Traumatic Brain Injury Following COVID Stay-At-Home Order: A Retrospective Cohort Study

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By

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B.S.
The University of Southern Mississippi
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An abstract of
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Abstract

Increased Civilian Penetrating Traumatic Brain Injury Following COVID Stay-At-Home Order: A Retrospective Cohort Study

By Reem Amer Dawoud

Introduction: With the COVID-19 pandemic emerging in 2020, public health measures were instituted to reduce viral transmission, including stay-at-home orders (SAHO). During this time, a record number of firearms were purchased. Nationally, increased rates of violent crime and gunshot wounds (GSW) were reported following the lifting of SAHOs. Metropolitan Atlanta is one of the epicenters of gun violence in the United States, including GSW and civilian penetrating traumatic brain injuries (pTBI). Georgia's statewide SAHO ended on April 30th. This study looks at trends in pTBI during this time.

Methods: Retrospective study from Grady Memorial Hospital, a large level 1 trauma center in downtown Atlanta, GA. All patients admitted for GSW with pTBI between January 1st 2014 to December 31st 2020 were included. Data analysis was using multivariate logistic regression, non-parametric Wilcox tests, and Fischer's analysis were used to compare variables.

Results: 407 B-TBI cases presented for evaluation, 357 (85.6%) survived initial resuscitation, and 207 (49.6%) were deemed survivable/amenable for neurosurgical intervention if needed. Cases not offered surgical intervention were based on exam (GCS of 3.6 ± 1.1 vs. 11.4 ± 3.8, $p < 0.001$) and radiographic findings consistent with global injury including bilateral trajectory, lobes traversed (2.6 vs. 1.1), and herniation (all $p < 0.001$). 107 (25.6%) patients required neurosurgical intervention with 50 ventriculostomy catheters placed and 91 craniectomy/craniotomy performed. 2020 was the only year where a significant increase in pTBI was observed from May - December (post-SAHO) compared to January - April (Pre- and SAHO) ($p = 0.0162$). A multivariate logistic regression found that post-SAHO period predicted risk of pTBI (OR=1.73, 95% CI 1.31, 2.26). No difference in pre- and post-lockdown rate of intervention (22.3 vs. 23.9%), mortality (56.8 vs. 46.2%), or outcome (Glasgow Outcome Score 2.5 vs. 2.9, $p = 0.18$) was observed.

Conclusion: Penetrating TBI represents the most extreme of brain injury and following the completion of the COVID lockdown, a substantial increase was observed. Studies are ongoing to establish predictive factors in B-TBI given this newly established, large dataset from our institution.

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LIST OF TABLES

Introduction

Traumatic brain injury (TBI) is a major preventable source of death, disability, and economic drain in the United States. In 2017, the Centers for Disease Control and Prevention reported that over 220,000 hospital admissions and over 61,000 deaths in the U.S. were a result of TBI [1]. This represented about 25% of all deaths related to injury in the U.S. and incurred costs related to treatment, rehabilitation, and lost wages of over $50 billion in 2017 [2].

Broadly, TBI can be subdivided into two pathologic mechanisms of injury: blunt and penetrating. Blunt TBI, also known as closed head injuries, are the most prevalent and are commonly caused by motor vehicle collisions (MVC) and falls [3]. In penetrating TBI (pTBI), the protective dural covering of the brain is violated and the underlying brain structures are directly exposed to the offending object, such as a bullet, shrapnel, or knife [4]. Although proportions of pTBI among adults presenting with TBI to U.S. trauma centers range from 2% to 10%, they are far more lethal representing 40-50% of all TBI deaths [5, 6].

pTBI, long thought to be the domain of the battlefield, is being studied in civilian life in increasingly sophisticated ways. The *Guidelines for the Management of Penetrating Brain Injury* published in 2001 heavily relied on observational studies and case reports of soldiers and noncombatants harmed in conflict [5,7]. This was likely done due to the relative paucity of high-quality data available on pTBI, as ethical and practical concerns preclude randomized controlled trials for this patient population. Recent large

observational studies using data from the U.S. trauma registries have shed light on clinical and prognostic factors associated with pTBI. The Survival After Acute Civilian Penetrating Brain Injuries (SPIN) score was recently validated and identified motor Glasgow Coma Scale (GCS) score, pupillary reactivity, self-inflicted injury, transfer from another hospital, sex, injury severity score (ISS), and coagulation status per admission international normalized ratio (INR) as predictors of in-hospital and 6-month survival [8,9]. However, the authors excluded radiographic findings from their model to prevent model overfitting and improve the model's performance against unseen data [8].

An important public health priority is identification of different root causes of pTBI. The currently available data indicates the vast majority of pTBI in the U.S. are self-inflicted with a small firearm, such as a handgun [10]. For the first time in 2008, firearm-related suicide became the leading cause of TBI-related death in the U.S. and over 50% of all suicides in the U.S. involved a firearm [10]. There are numerous well-documented individual, community, and societal risk factors associated with self-directed and interpersonal violence. Among them are unemployment, a history of substance use, income inequality, food insecurity, mistrust in public institutions, and access to firearms [11-14]. These risk factors are unequally distributed in the society, and especially across racial/ethnic groups [14]. The coronavirus disease 2019 (COVID-19) pandemic has provided a natural experiment within which to study these risk factors.

With the declaration that COVID-19 was a pandemic in March 2020 by the World Health Organization, U.S. state governments quickly implemented temporary stay-at-

home orders to curtail viral transmission [15]. What followed was a cascade of economic and social disruptions that instigated widespread psychological distress. Nationwide, an excess of 4.3 million firearms were purchased between March to July 2020 as compared to previous years [16]. Increased rates of intentional firearm injury soon followed [17,18]. This study seeks to evaluate the temporal variation in pTBI presenting to a large, urban, Level I trauma center in Atlanta, GA as it relates to the state of Georgia's stay-at-home order. We seek to report on our patients affected by pTBI to better to shed light on the broader impact of the COVID-19 pandemic on societal well-being and to guide policy and public health measures.

Methods

Study design and population

This retrospective cohort study reviewed patients in the Trauma Registry of Grady Memorial Hospital, an adult level 1 trauma center in downtown Atlanta, GA. Further patient data was obtained from the electronic medical record. The institutional review board approved this study with a waiver of consent owing to its retrospective design.

Inclusion and exclusion criteria

All TBI cases treated at the Grady Memorial Hospital between January 1st 2014 to December 31st 2020 were considered eligible for inclusion in the study. TBI was defined as evidence of brain injury on a clinical neurologic examination with an attributable history of traumatic mechanism. Patients pronounced dead on arrival were excluded.

Clinical Management

All patients received clinical care in accordance with published standards and guidelines by the Brain Trauma Foundation for severe TBI and the American Association of Neurological Surgeons/Congress of Neurological Surgeons for pTBI. This begins with level I activation upon arrival in the emergency department (ED). Immediate resuscitation includes ventilatory/oxygenation support with intubation and hemodynamic support to achieve a cerebral perfusion pressure $\geq$ 60 mmHg. Coagulopathies are corrected with blood products, tranexamic acid, activated factor VII, or prothrombin

complex concentrated as needed. Patients also receive a non-contrasted head CT upon stabilization. Patients are then transferred to the surgical intensive care unit (ICU) under the care of a board-certified neurosurgeon or surgical intensivist.

Data points

Demographic- and disease-specific variables under study include age, sex, race, and mechanism of TBI. Severity-based variables include admission Glasgow Coma Scale (GSC) score, calculated injury severity score (ISS), length of hospital stay (including days in ICU and on invasive ventilatory support), Glasgow Outcome Score, and survival. Intervention-based variables include placement of ventriculostomy catheters and use of craniectomy/craniotomy. Radiographic information included bullet trajectory for GSW (tangential, penetrating, perforating), injury anatomy (single lobe, multilobe/unilateral, bilateral, or posterior fossa), side of injury (neither, right, left, or both), presence of intracranial hemorrhage, intraventricular hemorrhage, subarachnoid hemorrhage, cisterns (open, compressed, absent), midline shift at the septum pellucidum, and bullet track through the ventricles.

Statistical Analysis

The primary analysis compared the incidence and proportion of TBI within each mechanism of injury prior to and after the Georgia Stay at Home Order (SAHO) (April 2nd, 2020, to April 30th, 2020). These time periods were compared with similar time frames from 2014 to 2020, accounting for annual and seasonal variation. Next, multivariate logistic regression including age, sex, and race was used to assess the

association between pTBI and time. The model was assessed for multi-collinearity using the variance inflation factor (VIF). The adjusted odds ratio (OR) for pTBI and 95% confidence intervals (CI) were calculated. C-statistics, representing the AUC in an ROC, were calculated to assess predictive strength. Secondary outcomes included trends in mortality and operative procedures over time.

Two injury mechanism subtypes were used in the analysis. The first consisted of two mechanism groups: intentional and non-intentional. Intentional injuries were further subtyped into gunshot wound (GSW) and assault. Non-intentional injuries were subtyped into fall, motor vehicle collision (MVC), and pedestrian versus auto (PVA). Race was categorized into four groups: Black, White, Hispanic, and other.

The estimates for frequency or proportion of all variables were assessed. Data are reported at mean +/- standard deviation for continuous data and as proportions for categorical data. Non-parametric Wilcox test for continuous variables and Fischer's exact test for categorical variables were used for analysis. Two-tailed significance was set at $p < 0.05$. Data analysis was conducted using R statistical software, version 4.0.4 [19]. Plots were generated using GraphPad Prism[20].

Results

During the study period, a total of 7,627 patients presented for evaluation of TBI. Tables 1, 2, and 3 summarize their demographic characteristics. The average age of the study population was 46 years. Most patients were male (68.4%), more than half were Black (53.55%). pTBI (or GSWs) represented 407 (5.5%) of all cases. Non-intentional etiologies (fall, MVC, PVA) of TBI were the most common at 86.02%.

Of the pTBI patients, most (357, 85.6%) survived initial resuscitation, and 207 (49.6%) were deemed amenable for neurosurgical intervention, if needed. 107 (25.6%) patients required neurosurgical intervention with 50 ventriculostomy catheters placed and 91 craniectomy/craniotomy performed. Decision against neurosurgical intervention was based on exam at presentation (GCS of 3.6 $\pm$ 1.1 vs. 11.4 $\pm$ 3.8, $p<0.001$) and radiographic findings consistent with global injury including bilateral trajectory, lobes traversed (2.6 vs. 1.1), and herniation (each $p<0.001$). No difference in pre- and post-SAHO rates of intervention (22.3 vs. 23.9%, $p=0.76$), mortality (56.8 vs. 46.2%, $p=0.11$), or outcome (Glasgow Outcome Score 2.5 vs. 2.9, $p=0.18$) was observed.

2020 was the only year where a significant increase in pTBI was observed post-SAHO compared to pre-SAHO ($p=0.0162$) (Figure 1). Table 4 presents the multivariate model showing that the post-SAHO period predicted risk of pTBI (OR=1.73, 95% CI 1.31, 2.26).

Discussion

To our knowledge, this is the largest study evaluating penetrating traumatic brain injury patients in the wake of the COVID-19 pandemic. We identified a significant increase in pTBI incidence in the months following the completion of the Georgia stay-at-home order in April 2020. This paralleled an increase in firearm purchasing rates [16]. In a multivariate logistic analysis identified post-SAHO time as significantly associated with pTBI. However, we did not observe a significant difference in rates of neurosurgical intervention, mortality, or outcome.

Literature has begun emerging on the pandemic's impact on TBI and firearm injury. Nationally, the risk of firearm injury increased by 30% in the first year of the pandemic [21]. At our institution, our co-investigators observed an increased frequency of firearm injury to the head and neck in the first five months of the pandemic [17]. Investigators in Pennsylvania similarly observed an increase in the proportion of penetrating neurotrauma, which includes brain and spine injury, in 2020 however, this was in the context of a 27% absolute reduction in neurotrauma [22]. The findings in Pennsylvania underscore the importance of contextualizing data on firearm injury within the social, political, and legal environment. Compared to the Pennsylvania cohort, ours is younger, more Black, and in a state with more lenient firearm legislation, all well-established risk factors for firearm injury [23-25]. Black Americans have been disproportionately affected by loss related to COVID-19, unemployment, and disruption of social support networks [25]. This was punctuated by several high-profile killings of Black individuals by law enforcement, mostly notably George Floyd. This precipitated a

summer of protests in Atlanta, GA and could have led to a further breakdown of institutional trust [12].

One limitation of this study is owning to its registry-based design. Incomplete or incorrectly coded data was excluded from analysis and the registry did not include patients who experienced recurrent trauma. This was further complicated by the single institution setting as nearly 60% of patients who experience recurrent trauma access numerous hospitals [26]. Finally, data was queried until the end of 2020 and unfortunately, consequences of the pandemic are still being felt.

Conclusion

This study evaluated patients with penetrating traumatic brain injury presenting to an adult level I trauma center in Atlanta, GA from 2015 to the end of 2020. A multivariate logistic analysis demonstrated that the time following the stay-at-home orders implemented to combat COVID-19 predicted risk of pTBI. No significant change in outcomes was observed.

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Tables and Figures

Table 1: Demographic and clinical characteristics of patients presenting to Grady Memorial Hospital (Atlanta, GA) with traumatic brain injury from January to March (prior to stay-at-home order period), 2015-2020

	Prior to Stay-At-Home Order Period (January - March)					
Characteristic	**2015 (n = 229)**	**2016 (n = 282)**	**2017 (n = 346)**	**2018 (n = 327)**	**2019 (n = 311)**	**2020 (n = 262)**
Sex, male, n (%)	165 (72.05)	182 (64.54)	251 (72.54)	227 (69.42)	210 (67.52)	174 (66.41)
Race, n (%)						
Black	128 (55.90)	153 (54.26)	170 (49.13)	163 (49.85)	170 (54.66)	132 (50.38)
White	84 (36.68)	107 (37.94)	138 (39.88)	130 (39.76)	104 (33.44)	96 (36.64)
Hispanic	8 (3.49)	12 (4.26)	18 (5.20)	24 (7.34)	28 (9.00)	15 (5.73)
Other	9 (3.93)	10 (3.55)	20 (5.78)	10 (3.06)	9 (2.89)	19 (7.25)
Age, y, mean +/- SD	44.13 +/- 20.65	46.06 +/- 20.56	43.28 +/- 20.42	47.00 +/- 21.58	47.58 +/- 21.69	50.21 +/- 22.51
Mechanism of TBI, n, (%)						
Intentional	27 (11.79)	35 (12.41)	39 (11.27)	37 (11.31)	51 (16.40)	33 (12.60)
GSW	13 (5.68)	14 (4.96)	16 (4.62)	20 (6.12)	20 (6.43)	16 (6.11)
Assault	13 (5.68)	20 (7.09)	23 (6.64)	17 (5.20)	29 (9.32)	17 (6.49)
Nonintentional	202 (88.21)	247 (87.59)	307 (88.73)	290 (88.69)	260 (83.60)	229 (87.40)
MVC	97 (42.36)	133 (47.16)	156 (45.09)	124 (37.92)	117 (37.62)	88 (33.59)
Fall	63 (27.51)	77 (27.30)	102 (29.48)	119 (36.39)	99 (31.83)	103 (39.31)
PVA	25 (10.92)	26 (9.22)	31 (8.96)	32 (9.79)	30 (9.64)	25 (9.54)
Injury Severity Scale, mean +/- SD	17.75 +/- 12.31	18.12 +/- 11.57	17.23 +/- 10.54	18.65 +/- 11.20	18.97 +/- 12.71	19.03 +/- 11.70
Glasgow Coma Scale, mean +/- SD	12.28 +/- 4.30	12.61 +/- 3.97	12.34 +/- 4.37	12.15 +/- 4.47	12.47 +/- 4.17	12.28 +/- 4.25
ICU days, mean +/- SD	9.62 +/- 15.50	9.22 +/- 12.14	6.90 +/- 9.70	6.83 +/- 8.06	9.87 +/- 25.82	8.84 +/- 9.86
Ventilator days, mean +/- SD	11.88 +/- 15.79	11.78 +/- 10.63	8.19 +/- 9.77	8.47 +/- 10.93	11.81 +/- 22.09	8.65 +/- 10.61
Hospital days, mean +/- SD	11.18 +/- 18.72	10.62 +/- 13.8	9.71 +/- 13.1	11.02 +/- 19.08	12.83 +/- 29.05	11.58 +/- 17.79
Outcome, alive, n (%)	202 (88.21)	260 (92.20)	315 (91.04)	288 (88.07)	282 (90.68)	242 (92.37)
	229	282	346	327	311	262

Table 2: Demographic and clinical characteristics of patients presenting to Grady Memorial Hospital (Atlanta, GA) with traumatic brain injury in April (during stay-at-home order), 2015-2020

	Stay-at-Home Order Period (April)					
Characteristic	**2015 (n = 90)**	**2016 (n = 114)**	**2017 (n = 117)**	**2018 (n = 124)**	**2019 (n = 119)**	**2020 (n = 78)**
Sex, male, n (%)	61 (67.78)	92 (80.70%)	78 (66.67)	85 (68.55)	85 (71.43)	56 (71.79)
Race, n (%)						
Black	50 (50.56)	64 (56.14)	61 (52.13)	52 (41.94)	68 (57.14)	33 (42.31)
White	31 (34.44)	37 (32.46)	45 (38.46)	50 (40.32)	40 (33.61)	32 (41.03)
Hispanic	7 (7.78)	5 (4.39)	9 (7.69)	11 (8.87)	9 (7.56)	6 (7.69)
Other	2 (2.22)	8 (7.02)	2 (1.71)	11 (8.87)	2 (1.68)	7 (8.97)
Age, y, mean +/- SD	41.13 +/- 20.45	47.31 +/- 19.65	42.91 +/- 20.29	44.09 +/- 20.77	44.68 +/- 21.21	52.82 +/- 20.36
Mechanism of TBI, n, (%)						
Intentional	13 (14.44)	19 (16.67)	19 (16.24)	11 (8.87)	19 (15.97)	10 (12.82)
GSW	5 (5.56)	7 (6.14)	6 (5.13)	5 (4.03)	8 (6.72)	4 (5.13)
Assault	8 (8.89)	10 (8.77)	12 (10.26)	6 (4.84)	11 (9.24)	5 (6.41)
Nonintentional	77 (85.56)	95 (83.33)	98 (83.76)	113 (91.13)	100 (84.03)	68 (87.18)
MVC	39 (43.33)	49 (42.98)	53 (45.30)	54 (43.55)	47 (39.50)	18 (23.08)
Fall	20 (22.22)	34 (29.82)	26 (22.22)	38 (30.65)	35 (29.41)	40 (51.28)
PVA	10 (11.11)	6 (5.26)	8 (6.84)	13 (10.48)	12 (10.08)	3 (3.85)
Injury Severity Scale, mean +/- SD	18.13 +/- 13.63	17.52 +/- 10.96	19.71 +/- 12.93	19.33 +/- 12.40	18.20 +/- 12.46	19.45 +/- 10.27
Glasgow Coma Scale, mean +/- SD	12.36 +/- 4.28	12.90 +/- 3.86	11.98 +/- 4.52	12.21 +/- 4.39	11.93 +/- 4.34	11.26 +/- 4.71
ICU days, mean +/- SD	8.55 +/- 12.02	9.48 +/- 11.73	8.29 +/- 13.64	8.51 +/- 10.50	11.19 +/- 13.58	8.28 +/- 9.94
Ventilator days, mean +/- SD	11.96 +/- 13.31	11.10 +/- 12.13	9.17 +/-13.97	8.56 +/- 8.43	12.82 +/- 12.67	6.46 +/- 6.62
Hospital days, mean +/- SD	11.51 +/- 17.96	11.22 +/- 15.16	9.60 +/- 14.55	12.34 +/- 18.85	15.08 +/- 34.06	11.11 +/- 14.23
Outcome, alive, n (%)	81 (90.00)	107 (93.86)	109 (93.16)	112 (90.32)	109 (91.60)	71 (90.03)
	90	114	117	124	119	78

Table 3: Demographic and clinical characteristics of patients presenting to Grady Memorial Hospital (Atlanta, GA) with traumatic brain injury from May to December (after stay-at-home order period), 2015-2020

	After Stay-At-Home Order Period (May - December)					
Characteristic	**2015 (n = 827)**	**2016 (n = 863)**	**2017 (n = 923)**	**2018 (n = 847)**	**2019 (n = 856)**	**2020 (n = 912)**
Sex, male, n (%)	587 (70.98)	615 (71.26)	637 (69.01)	567 (66.94)	560 (65.42)	626 (68.64)
Race, n (%)						
Black	461 (55.74)	458 (53.07)	508 (55.04)	459 (54.19)	454 (53.60)	500 (54.82)
White	290 (35.07)	312 (36.15)	335 (36.29)	319 (37.66)	315 (37.19)	319 (34.98)
Hispanic	52 (6.29)	55 (6.37)	46 (4.98)	46 (5.43)	57 (6.73)	55 (6.03)
Other	24 (2.90)	38 (4.40)	34 (3.68)	23 (2.72)	21 (2.48)	38 (4.17)
Age, y, mean +/- SD	43.44 +/- 19.45	43.57 +/- 20.19	45.37 +/- 20.96	45.57 +/- 21.01	49.28 +/- 20.80	48.47 +/- 21.58
Mechanism of TBI, n, (%)						
Intentional	131 (15.84)	132 (15.30)	131 (14.19)	106 (12.51)	107 (12.50)	146 (16.01)
GSW	25 (3.02)	43 (4.98)	48 (5.20)	46 (5.43)	35 (4.09)	73 (8.00)
Assault	101 (12.21)	87 (10.08)	83 (8.99)	60 (7.08)	68 (7.94)	72 (7.89)
Nonintentional	696 (84.16)	731 (84.70)	792 (85.81)	741 (87.49)	749 (87.50)	766 (83.99)
MVC	361 (43.65)	371 (42.99)	345 (37.38)	331 (39.08)	291 (34.00)	310 (33.99)
Fall	210 (25.39)	237 (27.46)	306 (33.15)	272 (32.11)	308 (35.98)	336 (36.84)
PVA	68 (8.22)	74 (8.57)	83 (8.99)	79 (9.32)	79 (9.23)	63 (6.91)
Injury Severity Scale, mean +/- SD	16.72 +/- 10.61	17.85 +/- 11.18	18.62 +/- 12.83	19.20 +/- 12.99	19.91 +/- 13.60	18.90 +/- 12.27
Glasgow Coma Scale, mean +/- SD	12.58 +/- 4.12	12.00 +/- 4.53	12.35 +/- 4.31	12.08 +/- 4.43	12.02 +/- 4.47	12.13 +/- 4.35
ICU days, mean +/- SD	9.41 +/- 14.28	8.67 +/- 11.80	8.26 +/- 16.65	8.50 +/- 11.94	9.82 +/- 11.84	7.96 +/- 11.05
Ventilator days, mean +/- SD	12.06 +/- 15.01	10.78 +/- 12.65	10.07 +/- 19.43	10.51 +/- 13.77	11.01 +/- 12.76	8.44 +/- 11.63
Hospital days, mean +/- SD	10.73 +/- 15.50	11.21 +/- 15.16	11.28 +/- 23.99	12.46 +/- 22.03	13.30 +/- 21.09	11.07 +/- 14.86
Outcome, alive, n (%)	768 (92.87)	740 (88.99)	734 (83.21)	747 (90.67)	745 (89.72)	812 (88.9)
	827	863	923	847	856	912

Table 4: Multivariate logistic analysis of the association between potential factors and pTBI among all traumatic brain injury cases, Grady Memorial Hospital (Atlanta, GA), 2015-2020

logit (penetrating TBI) = β0 + β1(age category) + β2(sex) + β3 (race) + β5(Stay at Home Order)

All VIF < 2, C-statistic 0.71

Characteristic	OR[1]	95% CI[1]	p-value
Age			
18-29	—	—	
30-54	0.61	0.49, 0.76	<0.001
55-64	0.27	0.18, 0.40	<0.001
65-74	0.19	0.10, 0.31	<0.001
75+	0.08	0.03, 0.16	<0.001
Sex			
Female	—	—	
Male	2.09	1.60, 2.76	<0.001
Race.			
White	—	—	
Black or African American	1.51	1.19, 1.92	<0.001
Other	0.79	0.51, 1.19	0.3
Stay.at.Home.Order			
Pre	—	—	
During	2.06	0.78, 4.53	0.10
Post	1.73	1.31, 2.26	<0.001

[1] OR = Odds Ratio, CI = Confidence Interval

Figure 1: Proportion of penetrating TBI secondary to firearm injury per month (1-12) with standard deviation bars. * Indicates post- stay-at-home order period