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Geodemographic analysis of pediatric firearm injuries in Miami, FL☆

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ABSTRACT

Purpose: Firearm injuries (GSW) are a growing public health concern and leading cause of morbidity and mortality among children, yet predictors of injury remain understudied. This study examines the correlates of pediatric GSW within our county.
Methods: We retrospectively queried an urban Level 1 trauma center registry for pediatric (0–18 years) GSW from September 2013 to January 2019, examining demographic, clinical, and injury information. We used a geographic information system to map GSW rates and perform spatial and spatiotemporal cluster analysis to identify zip code "hot spots."
Results: 393 cases were identified. The cohort was 877% male, 87% African American, 10% Hispanic, and 22% Caucasian/Other. Injuries were 92% violence-related and 4% accidental, with 63% occurring outside school hours. Mortality was 12%, with 53% of deaths occurring in the resuscitation unit. Zip-level GSW rates ranged from 0 to 9 (per 1000 < 18 years) by incident address and 0–6 by home address. Statistically significant hot spots were in predominantly underserved African American and Hispanic neighborhoods.
Conclusions: Geodemographic analysis of pediatric GSW injuries can be utilized to identify at-risk neighborhoods. This methodology is applicable to other metropolitan areas where targeted interventions can reduce the burden of gun violence among children.
Type of study: Retrospective study.
Level of evidence: Level III.

Gunshot wounds (GSW) are a growing public health concern associated with significant morbidity, mortality, and cost. Compared with other high-income countries, the US has the highest incidence of pediatric firearm-related deaths and has higher overall homicide rates [1,2]. While some studies have shown that GSW are accidental and nonviolent in nature in very young children [3,4], adolescents have been found to be more likely to sustain intentional injuries [5]. Unfortunately, the rates of GSW can be significantly associated with certain geographical and demographic characteristics [6]. Children living in certain states with higher rates of gun ownership have been associated with increased risk for sustaining a firearm injury [3,7,8]. Additionally, risk factors consistently associated with firearm injury are areas with higher rates of unemployment, lower income, and minority communities [2,9,10]. Multiple studies have shown those most at risk of violent firearm injuries are young African American males, with homicide as the leading cause of death in those less than 44 years of age [2,3,11].

By identifying more granular factors associated with pediatric firearm injury risk, such as geographical hot spots, preventive strategies can be more effectively implemented as community-based interventions. Therefore, the purpose of this study was to assess the correlates of GSW injuries among the pediatric population within our county. We hypothesized that a geographic analysis would help identify hot spots and disparities in firearm violence within our county and help target future community outreach interventions.

1. Methods

1.1. Data selection

After obtaining University of Miami Institutional Research Board approval for data collection, we retrospectively queried the trauma registry of a Jackson Memorial Hospital Ryder Trauma Center in Miami, Florida for all pediatric (0–18 years) GSW treated from September

Abbreviations: GIS, geographic information system; GSW, gunshot wound; ICU, intensive care unit; IQR, interquartile range; ISS, Injury Severity Score; LOS, length of stay.

☆ How this paper will improve care: This geographical analysis of pediatric firearm injuries in Miami found low-income, minority areas at greatest risk. Violence prevention interventions by local government and community efforts, as well as further research on multilevel risk factors, can be targeted to hardest hit areas.

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2013 to January 2019. Data regarding intent of injury were examined and categorized into "accidental" (by self or other person), "violence", and "intentional self-injury". Category of "violence" included any patient who was part of an interpersonal conflict as well as any child caught in the crossfire of violence, which included drive-by shootings. While not an intentional injury, it was felt that cases of drive-by shootings would not fit the definition of an "accidental" injury as it was not the result of inappropriate gun handling or storage, which would indicate a different societal target, but rather of senseless firearm violence. Other data collected included date, age, gender, race, employment or school status, associated injuries, Injury Severity Score (ISS), home address, incident address, admission information, need for intensive care unit (ICU), operative interventions, disposition, and mortality.

1.2. Geographic analysis

We imported the 393 cases into a geodatabase using ArcGIS 10.7.1 (Esri, Redlands, CA) and were able to successfully geocode 379 cases by incident address, of which 375 occurred within Miami and 390 cases by home address, of which 365 were in Miami. The 375 incident locations and 365 home locations within Miami were aggregated by zip code and mapped as the rate of GSW injury per 1000 residents <18 years old. We then performed spatial cluster analysis using the Getis-Ord G_i^* statistic [12] to identify potential hot spots and cold spots at the zip code level. Finally, we conducted spatiotemporal cluster analysis using the *Emerging Hot Spot Analysis* geoprocessing tool, which combines the Getis-Ord G_i^* statistic with the Mann–Kendall trend test to detect temporal trends [13]. We used a space–time cube that aggregated GSW events into 30-day intervals by zip code.

1.3. Statistical analysis

Descriptive statistics were used to report demographic data. Categorical variables were compared by percentages and the χ^2 statistic was used to evaluate differences in proportions. None of the continuous variables examined were normally distributed. Therefore, continuous variables with unequal variance are reported as median [interquartile range: IQR] and examined for differences between groups using the Mann–Whitney U test, or Kruskal–Wallis test as appropriate for number of groups. All statistical analyses were performed using SPSS Version 26 (IBM Corporation, Armonk, New York) and significance was defined as $p < 0.05$.

2. Results

2.1. Study cohort

There were 393 cases of pediatric GSW age 0–18 years identified from the registry during the 5-year and 3-month study period. Baseline demographics are shown in Table 1. The median age was 16 years [IQR 15–18 years]. Males accounted for 87% of the study population. African Americans constituted 87% of the population, whereas 10% were Hispanic, and 3% Caucasian/Other. Children 15 years of age or younger comprised 32% of the study population, with the majority of the cohort being between 16 and 18 years old (68%). The overwhelming majority of injuries were because of violence (92%), followed by accidental (4%). There were 16 cases (4%) for which data on intent were not available and there were no identified cases of intentionally self-inflicted GSW in this cohort. Accidental GSW were more prevalent among Caucasian/Other race (33.3%) than African American (3%, $p < 0.001$) and Hispanic (5%, $p = 0.03$) groups, while violence was more common with African American (92%, $p = 0.02$) and Hispanic (95%, $p = 0.03$) groups than Caucasian/Other (67%) .

Table 1
Study cohort characteristics.

Total		393
Age, years[a]		16 [15–18]
Sex (%)	Female	52 (13)
	Male	341 (87)
Race/ethnicity (%)	Caucasian/other	9 (2)
	African American	343 (87)
	Latin	41 (10)
Intention (%)	Self-inflicted (intentional)	0 (0)
	Accident (self or other)	15 (4)
	Violence	362 (92)
	Unknown	16 (4)
In school/work (%)	No	84 (23)
	Yes	279 (77)
ISS[a]		5 [1–13]
ISS greater than 25 (%)	No	339 (86)
	Yes	54 (14)
ISS greater than 15 (%)	No	298 (76)
	Yes	95 (24)
Any OR (%)	No	211 (54)
	Yes	182 (46)
ICU LOS (days)[a]		4 [2–8]
Hospital LOS (days)[a]		5 [3–11]
Discharged from ER		109 (28)
Died in resuscitation unit		24 (6)
Directly to OR		98 (25)
Died in OR		13 (3)
Dispo (%)	Home	317 (81)
	Home health	11 (3)
	Rehab	9 (2)
	Died	45 (12)
	Court	9 (2)
	Other	2 (0.5)

[a] Median (interquartile range).

2.2. Injury demographics

Anatomic locations of injury most commonly included the extremities (73%) followed by the abdomen or pelvis (30%). Injury Severity Score (ISS) ranged from 1 to 75, with a median of 5 [IQR 1–13.5], which was not significantly different between age group ($p = 0.070$), gender ($p = 0.500$), or race/ethnicity ($p = 0.624$). Those considered to have a severe trauma based on ISS >25 comprised 14% of cases, or 24% of cases if using the adult definition of ISS >15. Using the Miami-Dade County Public School Systems calendar, it was found that 63% of injuries occurred on nonschool days. Twenty one percent of subjects reported not currently being enrolled in school or employed, which did not differ among gender ($p = 0.594$) or race/ethnicity ($p = 0.284$). For those who reported being in school, GSW occurred during school hours in 8% of elementary, 4% of middle school, and 4% of high school age children. Those 16–18 years old were more likely to be unemployed or not in school than those ≤15 years ($p < 0.001$). Data on school or employment were unavailable in 8%, the majority of which were patients who arrived in extremis and data collection was not possible.

2.3. Outcomes

In patients who required admission to the hospital (63%, $n = 249$), median length of stay (LOS) was 5 days [IQR 3–11 days], with a range of 0–59 days. This did not differ between age groups ($p = 0.413$), gender ($p = 0.192$), or race/ethnicity ($p = 0.179$). ICU care was required in 24% ($n = 96$) of cases, with median ICU LOS being 4 days [IQR 2–8 days] and range of 1–37 days. ICU LOS also did not differ between age groups ($p = 0.341$) or race/ethnicity ($p = 0.249$) but was significantly longer for males than females (4 vs 3 days, $p = 0.024$).

Case fatality rate was 12% ($n = 45$), with 53% ($n = 24$) of deaths occurring in the resuscitation unit and 29% ($n = 13$) occurring during emergent operation. The remaining 18% ($n = 8$) subsequently died in the ICU. In those who survived the resuscitation unit, a surgical

Table 2
Operative interventions after pediatric GSW.

Procedure	*N*	%
Any surgical intervention	182	46%
Laparotomy	64	16%
ED thoracotomy	26	7%
OR thoracotomy (emergent)	7	2%
Sternotomy	3	1%
Neck exploration	2	0.5%
Extremity exploration	17	4%
Orthopedic OR	59	15%
Other OR	62	16%

OR = operating room, ED = emergency department.

intervention, including emergent ER thoracotomy, emergent operation, or nonemergent operation during admission, was required in 46%. Operative interventions are shown in Table 2. Laparotomy was the most frequent procedure required in patients (16%), followed by orthopedic procedures (15%). Comparisons between survivors and nonsurvivors are shown in Table 3. There was no difference in mortality or need for OR between age groups, gender, race/ethnicity, or intention, although there was a significant difference in mortality for those with severe injury defined by ISS scores, regardless of definition used (ISS > 15, $p < 0.001$; ISS >25, $p < 0.001$). Mortality also differed significantly by school/employment status ($p < 0.001$). The mortality rate was higher in those with unknown school/employment history; however, this is likely because of the fact most patients died in the resuscitation unit and were in extremis on arrival, making data acquisition difficult.

2.4. Zip code level analysis

The age-adjusted morbidity rate of GSW injury for the 375 (Miami) cases with known incident location during the study period was 12.87 per 100,000 aged under-18 per year, approaching the crude morbidity rate of 15 per 100,000 previously observed for Miami [9].

Fig. 1A and B present the rate of GSW injury per 1000 residents <18 years old using incident and home addresses. The highest rates corresponded to several predominantly African American and Hispanic neighborhoods across Miami, particularly a north–south corridor of African American neighborhoods extending from Miami Gardens to downtown Miami. Panels C and D present the spatial cluster analysis and reveal statistically significant hotspots of high GSW rates in predominantly African American non-Hispanic neighborhoods centered around Liberty City. Panels E and F present sporadic clusters revealed by the spatiotemporal cluster analysis that occur in similar neighborhoods as the spatial analysis. These sporadic space–time clusters represent on-again then off-again hot spots where less than 90% of the time-step intervals were statistically significant hot spots and no intervals were cold spots. Neither the spatial nor spatiotemporal cluster analysis identified any cold spots, i.e. significant clusters of low rates. Most cases – 83% by incident location and 66% by home location – considered to have a severe trauma (ISS > 25) were located in zip codes that were part of either a spatial or space–time cluster.

3. Discussion

In this study, we aimed to describe the demographic predictors of GSW among children in our county. Miami is a very diverse city, with a population comprised of 69% Hispanics, 18% African Americans, and 13% Caucasians based on estimates from the US Census Bureau in 2018 [14]. This provides a stark contrast to this cohort, comprised of 87% African American and 10% Hispanic, with Caucasians alone accounting for only 1.5% of GSW. Other studies have had very similar findings, further highlighting the racial disparities of firearm violence [3,9,10,15–17].

Bayouth et al. examined 20 years of pediatric GSW in their community in northern Florida, finding 76% of cases were African American children. Likewise, a study from Martin et al. from Tennessee observed that 42% of children in their pediatric GSW cohort were African American, while African American residents comprise only 17% of their community [15].

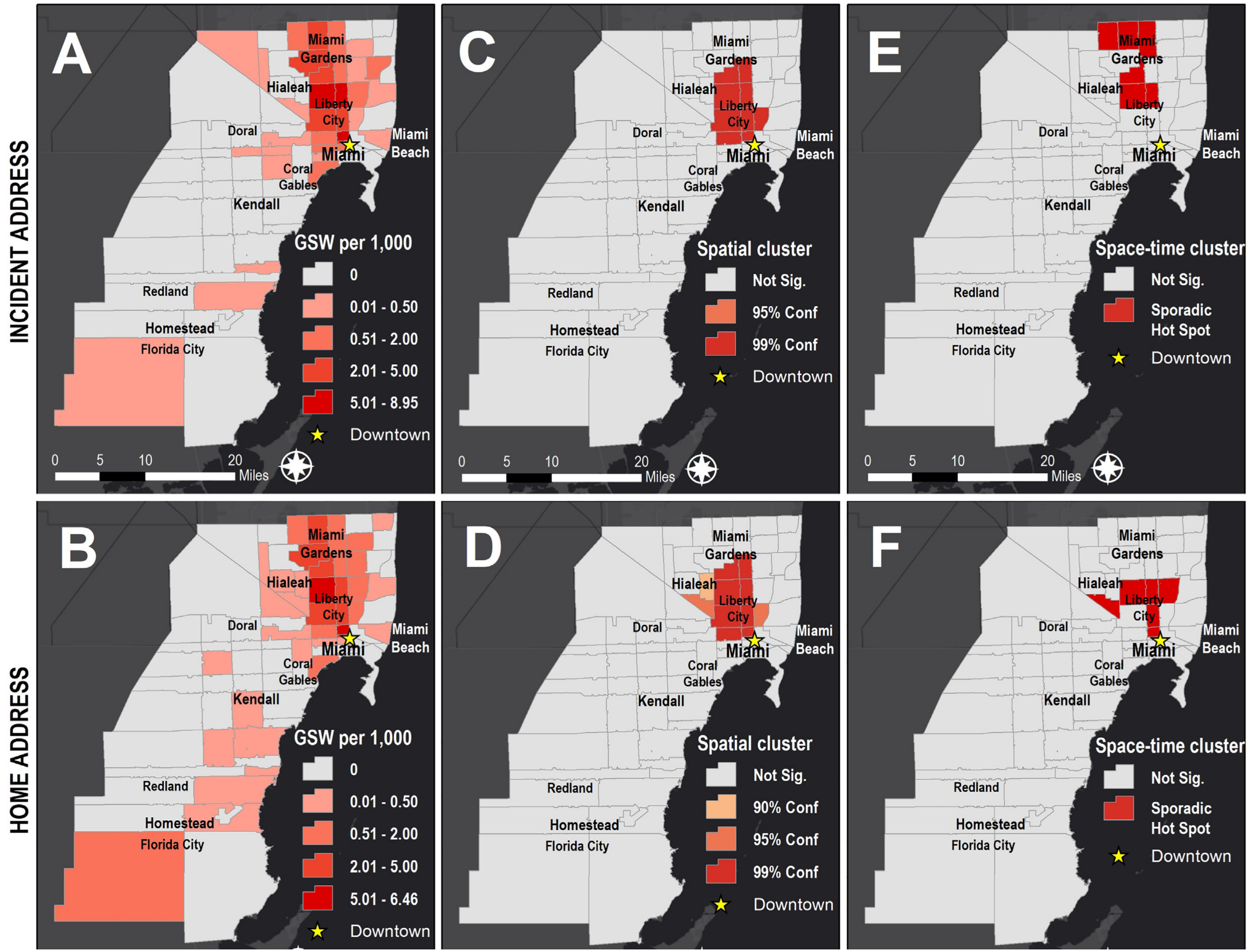
We found no difference in terms of injury severity, mortality, or operative interventions between ages, race/ethnicity, or gender. This is similar to other findings in the literature [18]. The only factors significantly associated with mortality in our cohort were unknown school/employment status and severe injury, which is defined by ISS >25 in pediatric patients [19]. School attendance is likely confounded by the fact that most patients who died did so in the resuscitation unit, making data acquisition for the social worker exceedingly difficult. The mortality rate among our cohort was nearly 12%, which is similar to estimates in other studies [2,3,15,17], but higher than other national estimates [20–22].

The devastating effects of firearms are well established and remain a growing public health concern. Costs of care continue to burden the healthcare system and injuries disproportionately affect members of minority and disadvantaged communities [4,18,22–26]. Firearms are the second leading cause of trauma-related death among children and the third leading cause of death overall [4,9,11,15,24,25,27,28]. Additionally, national estimates have found an increasing trend in deaths by firearms, with one review of the National Vital Statistics System calculating the increase as a 2.7 annual percentage change [23,29,30]. Young African American men are overwhelmingly more likely to experience GSW than other groups, which has been found in multiple studies

Table 3
Characteristics of survivors and nonsurvivors after firearm injury.

		Survivors		Nonsurvivors		
Total		348	100%	45	100%	*P*
Age group, years	16–18	236	68%	31	69%	0.885
	0–15	112	32%	14	31%	
Sex	Female	46	13%	6	13%	0.983
	Male	302	87%	39	87%	
Race/ethnicity	Caucasian/other	6	2%	3	7%	0.083
	African American	304	87%	39	87%	
	Latin	38	11%	3	7%	
Intention	Self-inflicted (intentional)	0	0%	0	0%	0.193
	Accident (self or other)	14	4%	1	2%	
	Violence	322	93%	40	89%	
	Unknown	12	3%	4	9%	
Currently employed/enrolled in school	No	74	21%	10	22%	<0.001
	Yes	262	75%	17	38%	
	Unknown	12	3%	18	40%	
Severe trauma	ISS ≤25	329	96%	10	22%	<0.001[a]
	ISS >25	19	5%	35	78%	

[a] Pearson χ^2 test.



?0,0,0,0,0,1,0,0,0,0,5;0b7]**Fig. 1.** County distribution of GSW (per 1000 residents <18 years) aggregated by zip code, treated between October 2013 and December 2018 for incident and home address (panels A and B respectively), with spatial cluster analysis revealing geographic hot spots over the entire study period (C and D), and space–time cluster analysis revealing sporadic hot spots (E and F).

and observed in our results [3,9,15,28].

A study of Miami Dade County's justice bureau found that a substantial portion of victims of homicide are 22 years old and younger [25], pointing to the problem of violence in our community. This was further demonstrated by the fact that 92% of GSW fell into the category of violence, with only 4% considered accidental. This is in contrast to most literature, which has found that between a third to half of GSW injury among children is unintentional, with rates varying by age [3,16,22,31]. Likewise, in the present study, there was no self-inflicted injury identified, which is lower than previous national estimates. Despite self-inflicted injuries having a higher case-fatality rate than accidental or violent intent [22], the case fatality rate in our cohort was higher than expected reflecting severe intentional violence in predominantly African American communities.

Our study found significant differences in intent of GSW between race/ethnicities. One third of cases of GSW in Caucasian/Other race children were because of an accident, compared to only 3% in African American and 5% in Hispanic children. Conversely, violence was the contributing factor to GSW in greater than 90% of cases in African American and Hispanic children. This is similar to findings from other studies, where Hispanic and African American children had a higher association with intentional injury than other races/ethnicity [16,17,25,32,33].

The use of georeferenced data can further elucidate the various societal, economic, and racial factors that contribute to this gun violence. Given this, our aim in this study was to define the areas of highest burden among our pediatric patients. Prior geodemographic studies in Miami described distributions of GSW patients of all ages [9]. Our findings, including the statistically significant hot spots, corroborate this prior study's findings and show very little change in the areas of most GSW clustering since 2012. This geospatial analysis very clearly delineates regions of significant economic and racial disparity within our city that continue to suffer the highest burden of firearm injuries.

This unfortunate disparity further contributes to the cycle of violence that is felt in metropolitan areas across the country. In order to effect change, an understanding of the circumstances surrounding these injuries is crucial. Children in at risk neighborhoods have a high frequency of exposure to GSW, with some estimates as high 40% [34]. This constant exposure to violence further drives practices that would expose patients to gun violence, such as carrying a firearm or being desensitized to situations with firearms present, which leads to firearm recidivism [16,33,35,36].

These findings suggest that there is a complex interplay of community and individual dynamics that leads certain groups to higher risk of violence and injury, which supports the role of targeted in-hospital psychosocial interventions for these groups.. Bayouth et al. found that the various crime prevention programs implemented during their 20-year study period, including increased policing of high crime areas, ShotSpotter microphone networks, and illegal firearm seizure programs, had little effect in incidence of pediatric GSW in Jacksonville. The authors instead advocated for family education and counseling programs, as well as legislative changes that address the many inequalities facing these communities in order to prevent the firearm violence, including access to affordable housing and better school systems [2]. This further suggests that alleviating poverty and the socioeconomic challenges that affect these communities offers the best chance at promoting change in firearm violence. Expanding our hospital-based interventions from a culturally and ethnically sensitive perspective can help decrease the injury recidivism we see in these communities. Moreover, more targeted community outreach by our trauma centers, including implementing Stop the Bleed trainings in these hotspots of injury, can potentially avoid preventable deaths.

Moving forward, these data can be used to target interventions for these neighborhoods of clustered violence, as well as support legislative change in our community. In this way, we may be a model for other large metropolitan trauma centers serving at-risk areas.

There are several limitations to this study. First, the retrospective nature of the study limited our data collection and ability to acquire certain information regarding circumstances of injury. Information on intent was limited to what was available in chart review, emergency medical services run reports, and reports by the patient or family, which could have been misinterpreted or misreported given the sensitive and legal nature of the injuries. Another limitation is the appearance of other trauma centers in the Miami area since the beginning of this study. This can lead to significant selection bias based on the catchment area, given the propensity for similar racial or socioeconomic groups to cluster in certain neighborhoods. However, our geographic results were very similar to the prior geospatial analysis of Miami's GSW injuries, which was done at a time when this institution was the only Level 1 in the area [9]. Additionally, this study only observed patients who survived to hospital arrival. Therefore, we do not capture all the patients who die on the scene, which can constitute a large portion of firearm injuries and violence in our community. This, however, is a comparable limitation to most similar studies of pediatric GSW from large trauma centers.

4. Conclusion

This is the first geodemographic study of pediatric firearm injuries in Miami, and the first to describe our patterns of injury and outcomes after pediatric GSW. Resource-poor neighborhoods in Miami bear the largest burden of interpersonal violence with firearms, disproportionately affecting our African American patients. Significant mortality is carried by this group, emphasizing the necessity for change. Distribution of injury has not changed since prior studies, reaffirming that preventative strategies and targeted interventions to stop the violence are long overdue.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jpedsurg.2020.09.032.

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