Population-Based Analysis of Firearm Injuries among Young Children in the United States, 2010–2015

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Firearm violence in the United States knows no age limit. This study compares the survival of children younger than five years to children and adolescents of age 5–19 years who presented to an ED for gunshot wounds (GSWs) in the United States to test the hypothesis of higher GSW mortality in very young children. A study of GSW patients aged 19 years and younger who survived to reach medical care was performed using the Nationwide ED Sample for 2010–2015. Hospital survival and incidence of fatal and nonfatal GSWs in the United States were the study outcomes. A multilevel logistic regression model estimated the strength of association among predictors of hospital mortality. The incidence of ED presentation for GSW is as high as 19 per 100,000 population per year. Children younger than five years were 2.7 times as likely to die compared with older children (15.3% *vs* 5.6%). Children younger than one year had the highest hospital mortality, 33.1 per cent. The mortality from GSW is highest among the youngest children compared with older children. This information may help policy makers and the public better understand the impact of gun violence on the youngest and most vulnerable Americans.

The crisis of firearm violence in the United States knows no age limit as approximately 1300 children younger than 18 years die annually from firearm-related injuries.[1] These deaths are the result of widespread gun availability and associated gun violence. The United States leads all developed nations in both categories. Presently, there are approximately 120.5 civilian-owned guns per 100 United States residents.[2] The homicide mortality of firearm violence in the United States is five times greater than the rate of firearm homicides in Canada[3] and 15 times the rate in Germany.[3] As a result, in 2011, there were nearly 100,000 fatal and nonfatal firearm injuries in the United States.[4] Firearms were involved in 67.7 per cent of United States homicides in 2011.[5] Total mortality figures depict only one aspect of the complex, decades-long phenomenon of the

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firearm-related injuries and fatalities that distinguishes the United States from other nations.

More than 20 million people in the United States are younger than 20 years.[6] The goal of this study was to describe hospital survival among gunshot wounds (GSWs) victims aged 19 years or younger. In particular, we sought to characterize survival among the most vulnerable victims of gun violence, children younger than five years, who were hypothesized to have an associated higher mortality from GSW.

Methods

Data from the Healthcare Cost and Utilization Project Nationwide Emergency Department Sample (NEDS) for the years 2010–2015 were used for all analyses. Each patient record in the dataset contains a discharge sampling weight variable, which was used to calculate national estimates. GSW was identified by the external cause of injury and poisoning codes (E-Codes) for the ICD-9 or ICD-10, Clinical Modification (ICD-9-CM or ICD-10-CM, respectively) as appropriate among patients with complete vital status data (live/die) on discharge from the ED or inpatient admission. See Appendix Table 1. Patients were retained in the cohort if they were seen in the ED for a GSW and were 19 years old or younger. A maximum age of 19 was selected because the United States census categorizes population by age as follows: less than 5 years old, 5–9 years, 10–14 years, and 15–19 years. A wide age range was used to test the hypothesis that hospital survival for those injured by GSW increased with age. The different discharge variables were cross-referenced for agreement as each contains vital status data.

The Web-based Injury Statistics Query and Reporting System was referenced for the incidence of fatal and nonfatal GSW. The intention of the shooting and the type of gun used were derived from each patient's E-Codes. Injury severity was computed for each patient using the logit of the Trauma Mortality Prediction Model (TMPM),[7, 8] which is based only on their recorded anatomic injuries using injury codes in the ICD-9-CM lexicon or the ICD-10-CM lexicon by the way of the General Equivalence Mapping algorithm from the United States Centers for Medicare and Medicaid Services.[9] The TMPM was compared with the Injury Severity Score and found to have better performance predicting mortality than the Injury Severity Score.[10] The years of life lost estimate was computed using Social Security Actuarial Life Tables for 2010, 2011, 2013, 2014, and 2015.[11] The patients presenting to the ED in 2012 were randomly assigned to either the 2011 or 2013 data. Years of life lost were calculated for each patient who died in the ED or inpatient settings.

To control for clustering of patients within hospitals, multilevel mixed-effects logistic regression models for mortality were used. Model variables were selected by the method of purposeful selection. The logit transformation of the TMPM probability of mortality was used in all models rather than the probability of death as its distribution was highly skewed.[12] The logit-transformed TMPM probability of death was found to be nonlinear in the logit. To address this, it was included in the model using four spline functions that had knots at the 5th, 27.5, 50, 72.5, and 95th percentile (see Hosmer et al.).[13] Age was also found to be nonlinear in the logit. In this case, age was included in the model using a two-term fractional polynomial transformation, which was found by applying the method described by Hosmer et al.[13] Inclusion of the transformations of these two variables improved the fit of the model. In the mortality model, the ability to discriminate survivors from nonsurvivors was measured by the area under the receiver operating characteristics curve. The mortality model's goodness of fit was assessed using the Hosmer-Lemeshow test.[14]

Descriptive analysis compared categorical variables by mortality status using a chi-squared test. Continuous variables were described with medians and the IQR as most are highly skewed, and the Wilcoxon rank sum test was used to compare the medians of two groups, whereas the Kruskal-Wallis test was used for more than two groups. *P*-values less than 0.05 were considered significant. Proportions are reported with 95 per cent confidence intervals (95% CIs). All data manipulation and statistical modeling were performed using Stata version 14.2 (StataCorp, College Station, TX). The protocol was reviewed and granted exempt status by the East Valley Regional Institutional Review Board (EVR-18-135).

Results

Records from 17,615 ED visits formed the study dataset. Using the sampling weight variable, DISCWT, yielded national population-based estimates of 82,569 ED visits among children and adolescents aged 19 years or younger over the study period. In the United States, the incidence of nonfatal GSW ranged from 15.44 to 20.16 per 100,000 per year, whereas GSW resulting in death, including those who died before ED presentation, occurred between 3.00 and 3.44 per 100,000 per year in the population of children and adolescents aged 19 years or younger; see Appendix Table 1.

In the study cohort, the overall proportion of fatalities was 5.9 per cent (95% CI 5.5–6.2%). The majority of deaths were in the 15- to 19-year-old group, 83.3 per cent (95% CI 82.2–84.3%). The youngest age group, zero to four years, had the highest case fatality rate (15.3%, 95% CI 13.7–17.0%). Of those aged 5 to 19 years, hospital mortality was 5.6 per cent (95% CI 5.5–5.8%). Males accounted for the majority of the visits among the cohort, 88.0 per cent. Of note, males represented an increasing proportion of the cohort from 64.2 per cent of those less than 5 to 89.8 per cent in the 15- to 19-year-old group. Two-thirds of the GSWs were unintentional 34.1 per cent and assaults 34.0 per cent. Unintentional GSWs also represented the major intent in the three youngest age groups. However, assaults accounted for 32.8 per cent of all deaths, whereas suicides had a greater proportion of deaths than all other GSW intent categories combined; 38.9 per cent *versus* 5.2 per cent, $P < 0.001$.

The type of gun was unknown or not defined 74.5 per cent of the time by categories represented in the ICD-9 or ICD-10 lexicons. When the gun type was known, handguns were the most common type, n = 15,608 (18.9%). Handguns were associated with 27.4 per cent of GSWs in children younger than five years and decreased, as the cohort aged, to 18.6 per cent of GSWs in those aged 15–19 years. The overall median TMPM estimate of probability of death was 0.014 (IQR 0.016). Among fatalities, the median TMPM was more than 12 times higher, 0.178 (IQR 0.403). The median TMPM was higher in the youngest group, 0.018, compared with the older groups, ranging from 0.013 to 0.015, indicating the youngest patients sustained a greater burden of anatomic injury from similar types of weapons as the rest of the cohort.

Most patients were treated at a Level I trauma center (44.5%); however, the highest mortality was observed among patients treated at Level II trauma centers, 7.6 per cent (95% CI 7.1–8.2%) (data not shown). More than half (54.3%), of the study sample came from ZIP codes in the lowest median household income quartile. However, the highest mortality (9.3%) was observed among those from Zip Codes with the highest quartile of median household income. Of the 4,840 deaths among those who presented to the ED for GSW, 59.9 per cent died in the ED (95% CI 57.5–60.3%). Nearly 5,000 years of life were lost from among the nearly 14,000 children and adolescents who present to EDs because of GSW annually.

Total hospital charges for the cohort approached $2.6 billion dollars or approximately $500 million dollars per year. The median hospital charge was $2,805 (IQR $4,128) for patients in the ED and $48,773 (IQR $73,435) for those admitted as inpatients. Median hospital charges were greater for those who died compared with charges for survivors in terms of ED and inpatient charges, see Table 1.

Self-harm was identified as the GSW intent in 2.5 per cent of the children younger than five years. This likely reflects episodes when children unintentionally shoot themselves rather than purposeful suicidal gestures, although deeper investigation into this finding is beyond the scope of the NEDS dataset. Understanding the circumstances resulting in a GSW being categorized as law enforcement related is similarly beyond the reach of these data, yet they could represent innocent bystander situations.[15] Handgun involvement was most prevalent in the youngest age group (27.4%) compared with the older three age groups (see Table 2).

A mixed effect logit model was fit to estimate the strength of association among univariately significant predictors of mortality among children and adolescents presenting to the ED for GSW. Age was included in the model using two terms determined by a fractional polynomial transformation to address the considerable positive skewness (4.83). The logit-transformed TMPM probability of death was included in the model as four cubic spline terms. GSWs with intention of self-harm and hemorrhagic shock were the strongest predictors of death (odds ratio (OR) 4.61 and 2.00, respectively). Female gender was associated with decreased odds of mortality when age and severity of anatomic injury were accounted for. This model demonstrated excellent discrimination of hospital survivors from nonsurvivors, area under the receiver operating characteristics curve 0.93. The Hosmer-Lemeshow goodness-of-fit statistic was 12.2, $P = 0.14$. See Table 3. Age was a predictor of increased odds of mortality for each year younger than 13. The maximum OR of death by age compared with age 13 was 5.34 (95% CI 2.59–11.03) for those younger than one year. See Figure 1.

Discussion

The number of children under the age of five presenting to EDs because of GSW is relatively low compared with older children and adults. But, the youngest victims of gun violence are the ones most likely to die, assuming they survive to reach emergency medical and surgical care. In particular, children younger than one year are five times as likely to die compared with older children. The highest rates of mortality are seen in this age group because very young victims of gun violence possess a greater vulnerability to the injury imparted from GSWs than older cohort members leading to a higher case fatality rate despite having the lowest incidence rate in the cohort. This is supported by higher TMPM probability of death for the youngest age group than other groups signifying more severe anatomic injury in this age group. Describing the particular mechanism(s) responsible for the increased mortality before age seven are beyond the scope of this article; however, it may be explained simply by the rate of growth and

TABLE 1. *Characteristics of 82,569 United States Youths Presenting with GSW, 2010–2015*

	Lived, Number (%)	Died, Number (%)	*P* Value
Number	77,728 (94.1)	4,840 (5.9)	
Gender			0.08
Male	68,251 (94.04)	4,324 (5.96)	
Female	9,421(94.81)	516 (5.19)	
Age groups (years)			<0.001
0–4	1,543 (84.7)	279 (15.3)	
5–9	1,837 (94.2)	113 (5.8)	
10–14	7,051 (94.4)	418 (5.6)	
15–19	67,297 (84.4)	4,030 (5.7)	
Intent			<0.001
Unintentional	27,024 (96.0)	1,117 (4.0)	
Assaults	26,481 (94.3)	1,589 (5.7)	
Not specified	22,216 (93.9)	1,447 (6.1)	
Self-harm	1,026 (61.1)	653 (38.9)	
Law enforcement	976 (96.6)	35 (3.4)	
Gun type			0.27
Other/unknown	57,732 (94.1)	3,614 (5.9)	
Handgun	14,667 (94.0)	941 (6.0)	
Shotgun	3,625 (94.3)	221 (5.8)	
Hunting rifle	1,552 (96.4)	58 (3.6)	
Military style	153 (95.9)	* (4.1)	
TMPM** probability of death, median (IQR)	0.014 (0.013)	0.180 (0.403)	<0.001
Insured	57,170 (94.9)	3,100 (5.1)	<0.001
Length of stay, median days (IQR)	4 (6)	1 (2)	<0.001
Trauma center level			<0.001
Level I	34,395 (93.7)	2,331 (6.7)	
Level II	9,971 (92.4)	825 (7.6)	
Level III	4,054 (94.3)	244 (5.7)	
All other hospitals	29,309 (95.3)	1,441 (4.7)	
Year			0.85
2010	14,513 (93.7)	984 (6.4)	
2011	13,156 (94.3)	802 (5.7)	
2012	14,121 (94.0)	895 (6.0)	
2013	10,368 (94.2)	641 (5.8)	
2014	13,346 (94.2)	816 (5.8)	
2015	12,224 (94.6)	703 (5.4)	
Zip Code median income quartile			<0.001
1 ($1–$38,999)	41,509 (94.9)	2,248 (5.1)	
2 ($39,000–$47,999)	18,426 (94.1)	1,154 (5.9)	
3 ($48,000–$62,999)	11,592 (93.7)	779 (6.3)	
4 ($63,000 or more)	4,400 (90.7)	449 (9.3)	
Hospital charges, median dollars (IQR)			
ED charges	$2,745 (3,918)	$4,858 (7,678)	<0.001
Inpatient charges	$48,364 (73,749)	$55,288 (71,662)	<0.001
Died			
Died in the ED		2,853 (58.9)	
Died as inpatient		1,988 (41.1)	
Years of life lost, median (IQR)		59.9 (3.1)	

* Cell count ≤10.
** Trauma mortality prediction model.

development taking place in the first seven years of life when the median weights for boys and girls increase by approximately 650 per cent.[16] The close anatomical location of internal organs makes young children more likely to sustain multiple internal injuries from GSW than their older counterparts.

One-third of injuries in children under the age of five are self-inflicted. In 1981, the state of Missouri enacted the first of what has become known as the child access prevention (CAP) laws. Presently, 27 states and the District of Columbia have CAP legislation.[17] These are a series of laws allowing states to charge and prosecute adults for intentionally or negligently allowing children access to firearms. These statutes are intended to reduce firearm injuries and deaths among children and adolescents. The degree to which these laws have produced their intended outcomes has been widely studied. Recently, Hamilton et al., analyzed the Kids Inpatient Database from the Healthcare Cost and Utilization Project for 2006 and 2009. They distinguished strong from weak CAP laws. Strong CAP laws are those with criminal liability if a child can get access to

TABLE 2. *Characteristics by Age Group*

	<5 Years (%)	5–9 Years (%)	10–14 Years (%)	15–19 Years (%)	*P* Value
Number	1,822 (2.2)	1,950 (2.3)	7,469 (9.1)	71,328 (86.4)	
Gender					
Male	1,169 (1.6)	1,341 (1.9)	6,039 (8.3)	64,026 (88.2)	<0.001
Female	653 (6.6)	609 (6.1)	1,429 (14.4)	7,245 (72.9)	
Intent					<0.001
Unintentional	1,054 (3.7)	1,254 (4.5)	3,895 (13.8)	21,938 (78.0)	
Assaults	375 (1.3)	290 (1.0)	1,520 (5.4)	25,884 (92.2)	
Not specified	331 (1.4)	366 (1.6)	1,733 (7.3)	21,232 (89.7)	
Self-harm	45.9 (2.7)	11 (0.6)	250 (14.9)	1,373 (81.8)	
Law enforcement	16 (1.6)	30 (2.9)	70 (6.9)	895 (88.6)	
Gun type					<0.001
Other/unknown	1,215 (2.0)	1,264 (2.1)	5,015 (8.2)	53,846 (87.8)	
Handgun	499 (3.2)	402 (2.6)	1,432 (9.2)	13,275 (85.1)	
Shotgun	78 (2.0)	163 (4.3)	525 (13.7)	3,079 (80.1)	
Hunting rifle	24 (1.5)	115 (7.1)	467 (29.0)	1,004 (62.4)	
Military style	**	**	29 (18.2)	118 (74.2)	
TMPM* probability of death, median (IQR)	0.018 (0.06)	0.013 (0.01)	0.013 (0.01)	0.015 (0.02)	<0.001
Insured	1,456 (2.4)	1,675 (2.8)	6,487 (10.8)	50,647 (84.0)	<0.001
Length of stay, median days (IQR)	3 (9)	3 (5)	3 (6)	3 (5)	0.28
Trauma center level					<0.001
Level I	815 (2.2)	794 (2.2)	3,258 (8.9)	31,858 (86.8)	
Level II	202 (1.9)	163 (1.5)	581 (5.4)	9,845 (91.3)	
Level III	109 (2.5)	158 (3.7)	617 (14.4)	3,413 (79.4)	
All other hospitals	696 (2.3)	835 (2.7)	3,013 (9.8)	26,206 (85.2)	
Zip Code median income quartile					<0.001
1 ($1–$38,999)	901 (2.1)	932 (2.1)	3,602 (8.2)	38,322 (87.6)	
2 ($39,000–$47,999)	473 (2.4)	421 (2.2)	1,930 (9.9)	16,755 (85.6)	
3 ($48,000–$62,999)	228 (1.8)	421 (3.4)	1,254 (10.1)	10,469 (84.6)	
4 ($63,000 or more)	155 (3.2)	154 (3.2)	513 (10.6)	4,027 (83.1)	
Hospital charges, median dollars (IQR)					
ED charges	2,656 (4,209)	1,986 (3,199)	2,374 (3,850)	2,867 (4,169)	<0.001
Inpatient charges	42,557 (98,335)	40,546 (56,698)	43,250 (72,920)	49,660 (73,118)	0.05
Died					0.09
Died in ED	198 (71.0)	70 (61.9)	245 (58.7)	2,339 (58.1)	
Died as inpatient	81 (29.0)	43 (38.1)	173 (41.4)	1,691 (42.0)	
Died, total	279 (15.3)	113 (5.8)	418 (5.6)	4,030 (5.7)	

* Trauma mortality prediction model.
** Cell count ≤ 10.

a firearm because of careless storage. Conversely, states with weak CAP laws will only prosecute adults who knowingly or recklessly provide a firearm to a minor. Fourteen states and the District of Columbia have strong CAP laws and the laws of 13 states were considered weak. The authors found states with strong CAP laws had reduced hospitalizations for GSW injuries, including a 54 per cent decrease in self-inflicted and a 44 per cent decrease in unintentional GSWs, whereas states with no CAP laws had more such hospitalizations. Weak CAP law states were associated with 82 per cent more self-inflicted GSWs.[17] The RAND Corporation's Gun Policy in America initiative published a synthesis of available literature on this broad topic, including a thorough consideration of the effect of CAP laws. They found evidence that CAP laws reduce firearm self-injuries, including suicide attempts, unintentional firearm injuries, and deaths among children.[18] Schuster et al. analyzed the prevalence and storage pattern of firearms of households with children in the United Sates. They determined 35 per cent of homes with children had at least one firearm and 43 per cent of those homes had at least one unlocked weapon. In 1.4 million homes (4%), firearms were kept unlocked, unloaded, but stored with ammunition, thus making these guns the most accessible to children.[19] In the present study, unintentional and assault-related GSWs were the most common GSWs, accounting for more than two-thirds of this group of patients, 34.1 and 34.0 per cent, respectively. Although GSWs of undetermined intent represented most of the remaining third (28.7%).[1]

Young victims of gun violence are more likely to be female. They are also more likely to be unintentional and less likely to result from assault. Older victims are more likely to be males and their GSWs are more likely to result from assaults. These results are consistent with prior work in urban and nationwide studies showing age- and gender-related changes in violent behavior in general, as well as GSW injury and mortality.[20–22]

TABLE 3. *Multivariable Model of Hospital GSW Mortality, United States Youth, 2010–2015*

	Coefficient	OR	95% CI	*P*
Age 1	–4.54			0.003
Age 2	1.86			0.01
Female	–0.30	0.74	0.56–0.97	0.03
Hemorrhagic shock	0.69	2.00	1.53–2.61	<0.001
Self-harm intention	1.53	4.61	3.28–6.50	<0.001

Adjustment for age uses two fractional polynomial transformations: Age $1 = \sqrt{X}$, Age $2 = X$, where $X = (\text{Age} + 1)/10$. As a result, estimates of the OR for age require use of the four-step method described by Hosmer, Lemeshow, and Sturdivant[1] with results shown in Figure 1. Adjustment for injury severity, results not shown in table, used spline functions to model the logit transformation of the TMPM probability of death with knots placed at the (5, 27.5, 50, 72.5, and 95) percentiles of the distribution.

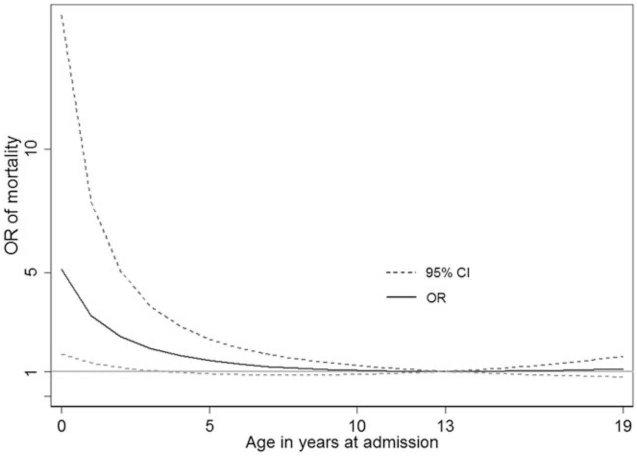

FIG. 1. OR of mortality by age *versus* the referent age of 13 among children and adolescents who present to the ED for GSW.

The mass school shootings in Columbine High School, Red Lake Senior High School, Sandy Hook Elementary School, and Marjory Stoneman Douglas High School are indelible examples of firearm violence directed at children and adolescents, yet most GSW events pass with essentially no lasting public attention. Accidental shootings of children, whether self-inflicted or by other children, are the typical scenario of this all-too-frequent tragedy.

The inferences of this study should be interpreted in light of certain limitations. First, the NEDS data are abstracted from hospital discharge records. As such, the accuracy and precision of the definitions and categorization of information likely varies from hospital to hospital and year to year. Second, the NEDS data are not gathered expressly for traumatic injury research in children and adolescents, so some meaningful clinical variables are not available to further explore this topic. Next, neither the ICD-9-CM nor the ICD-10-CM lexicons can identify multiple GSWs, although multiple GSWs are known to increase mortality.[23, 24] Fortunately, the TMPM includes all injuries for each patient, so the distinction of single *versus* multiple GSWs are unlikely to alter the results. Despite these shortcomings, using the NEDS dataset allows for generalizable inferences at the population level, including patients treated in the ED and followed into inpatient care or released to other dispositions. Finally, the gun type was unknown or not classified within the ICD-9 and ICD-10-CM lexicons in most cases. In the Federal Bureau of Investigation's Crime in the United States 2016 report, handguns are the most prevalent gun listed at a rate between 46 and 50 per cent per year. The Federal Bureau of Investigation's categories of "other guns" and "type not stated" comprise only 15 to 20 per cent of firearms used in homicides for each year listed. As such, the prevalence of handgun use in this study is likely underestimated and much of the category of other/unknown gun type may more appropriately belong to the handgun category.

Conclusion

The likelihood of mortality from GSW is highest among the youngest children compared with older children and adolescents. The high proportion of mortality in the very young is a compelling argument for public health initiatives to protect small children from firearm injury. This information may help policy makers and the public better understand the impact of gun violence on the most vulnerable members of our society.

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APPENDIX TABLE 1. *Incidence of Nonfatal and Fatal GSW by Age Group and Year (per 100,000 population)**

Age, Years	2010	2011	2012	2013	2014	2015	2010–2015
Total Nonfatal GSW in United States							
0–4	0.99	1.42	0.60	1.42	0.65	1.58	1.11
5–9	1.18	3.06	1.34	0.69	1.63	0.60	1.41
10–14	6.12	4.43	4.49	3.81	6.95	4.91	5.12
15–19	62.93	68.66	53.41	65.63	55.45	58.20	60.74
Overall	18.71	20.16	15.44	18.35	16.53	16.72	
Total GSW Mortality in United States							
0–4	0.41	0.43	0.41	0.41	0.39	0.44	0.41
5–9	0.36	0.36	0.37	0.32	0.37	0.38	0.36
10–14	1.09	1.15	1.23	1.27	1.49	1.35	1.26
15–19	10.58	10.64	10.68	9.71	9.92	11.29	10.47
Overall	3.26	3.26	3.27	3.00	3.10	3.44	

* Web-based Injury Statistics Query and Reporting System.[2, 3]