Pediatric firearm incidents: It is time to decrease on-scene mortality

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BACKGROUND: Previous epidemiological studies on pediatric firearm mortality have focused on overall mortality rather than on-scene mortality. Despite advances in trauma care, the number of potentially preventable deaths remains high. This study used the National Emergency Medical Services Information Systems database to characterize patterns of on-scene mortality in order to identify patients who may benefit from changes to prehospital care practices.

METHODS: National Emergency Medical Services Information Systems database was searched for all pediatric firearm incidents from 2010 to 2015. Data on demographics, anatomic location of injury, intent and location of incident, and on-scene mortality were analyzed using Student's *t* test for continuous variables and χ^2 test for categorical variables. A linear regression model was used to calculate independent predictors of mortality.

RESULTS: Sixteen thousand eight hundred eight patients were identified, with a mortality rate of 6.1%. Most mortalities suffered cardiac arrest on-scene; 72.6% of these were prior to Emergency Medical Services (EMS) arrival, which carried a significantly higher mortality rate than arrest after EMS arrival. No difference was seen in anatomic location of injury in those who arrested before and after EMS arrival. Compressible injuries were most common with the lowest mortality. Noncompressible injuries together accounted for 25.8% of injuries and 23.5% of mortalities.

CONCLUSION: To our knowledge, this is the largest study of on-scene mortality in pediatric firearm injury. Cardiac arrest prior to EMS arrival was a considerable source of on-scene mortality; significantly more of these patients died than those who arrested after EMS arrival. The mortality of compressible injuries was very low, implying that use of compression and tourniquets have been effective in stopping life-threatening extremity bleeding. Noncompressible injury mortality could be decreased with education of bystanders and more aggressive on-scene intervention. Through the evaluation of on-scene mortality specifically, this study offers insight into potential areas of focus to improve prehospital care of pediatric gunshot victims. (*J Trauma Acute Care Surg.* 2019;86: 791–796.

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KEY WORDS: Pediatric firearm; prehospital mortality; on-scene.

In the United States, firearm-related injury is the third-leading cause of death in those aged 1 year to 17 years, and the second-leading cause of injury-related death in this group.[1] The morbidity and mortality of pediatric firearm injury (PFI) is substantial; the case fatality rate (proportion of cases resulting in death) of PFI is reported to be between 9% and 20%,[2–5] and up to 50% of pediatric patients hospitalized for firearm injury are discharged with a disability.[2] The most recently published, national epidemiological study on the subject found that between 2012 and 2014, 53% of pediatric firearm deaths were a result of homicide, 38% a result of suicide, and 6% unintentional. The case fatality rate for each of these types of injury during that period was 14%, 74%, and 6%, respectively.[5] Most studies on PFI use national databases which record all firearm deaths—for example, the Centers for Disease Control National Vital Statistics System, National Electronic Injury Surveillance System, National Hospital Ambulatory Medical Care Survey, and National Violent Death Reporting System. Therefore, relatively little is known about on-scene mortality in PFI.

Despite recent advances in trauma care, the number of potentially preventable deaths remains high.[6] The majority of studies on reduction of mortality from survivable injuries have focused on patient deaths during transport or after arriving to the hospital.[6–8] Our study uses the National Emergency Medical Services Information Systems (NEMSIS) database—a large, national database of Emergency Medical Services (EMS) activations that is maintained by the National Highway Traffic Safety Administration. The objective of this study was to examine *on-scene* mortality in PFI in order to identify potential areas of focus to improve pre-hospital care of pediatric gunshot victims.

MATERIALS AND METHODS

Study Design and Population

The NEMSIS database is a large convenience sample of over 30 million EMS activations from 49 US states and territories, contributed by over 10,000 EMS agencies. The database is maintained by the National Highway Traffic Safety Administration which monitors the quality of the data. These data are submitted voluntarily from EMS agencies. We performed a retrospective cross-sectional analysis of all pediatric firearm victims recorded in the NEMSIS database from 2010 to 2015. This study was exempt from institutional review board review

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and did not receive any specific funding. Pediatric (age, 0–18 years) victims of firearm injury were identified using the following "cause of injury" codes: firearm injury (accidental), firearm assault, and firearm self-inflicted.

MEASURES

Demographic information on age, gender, and race (white, African American, Asian, American Indian, and other), and insurance type was recorded. Clinical variables studied included injury intent (accidental, assault, and self-inflicted) anatomic location of injury (head, neck, chest, abdomen, back, and extremity), location of incident (home, street, public building, recreational place, and restaurant), on-scene mortality ("dead at Scene - either dead on arrival or dead after arrival with field resuscitation not successful and not transported"), and cardiac arrest on-scene ("yes, before EMS arrival" or "yes, after EMS arrival"). Injuries were further categorized as compressible (extremities) or noncompressible (chest, abdomen, and back).

Data Analysis

Univariate analysis for statistical significance was performed using Student's t test for continuous variables and χ^2 test for categorical variables. A binary logistic regression evaluated the effect of several independent variables (race, insurance status, anatomic location of injury, and intent of incident) on mortality. Data were analyzed using SPSS IBM software (version 24, Armonk, NY). A p value less than 0.05 was considered to be statistically significant.

RESULTS

A total of 16,808 patients meeting study criteria were identified, with an overall case fatality rate of 6.1%. Male children made up 82.8% of injuries and 83.5% of the mortalities (Table 1). African Americans represented 62.8% of incidents and 30.7% of deaths (Table 1). Characteristics of PFI stratified by cognitive development are listed in Table 2. Most incidents (85.4%) and deaths (86.3%) occurred in the 12- to 18-year-old age group. Most injuries in the 0 to 5 age group were a result of assault (48.1%), followed by accidental injuries (40.4%). This distribution was similar for 6- to 11-year-olds (46.9% accidental, 46.1% assault). Older children were more likely to be victims of assault than suicide or accidental injury (70.4% vs. 12.2% and 17.4%, respectively). The highest case fatality rate occurred in ages 0 year to 5 years (8.5% vs. 4.2% in 6- to 11-year-olds and 6.4% in 12- to 18-year-olds; $p < 0.001$), which also had the highest incidence of head injury (44.1% vs. 41.3% in 6- to 11-year-olds and 23.6% in 12- to 18-year-olds; $p < 0.001$). When controlling for anatomic location of injury and intention of incident, there was no difference in case fatality rates between age groups (Table 3). The majority of mortalities suffered cardiac arrest on-scene, with 72.6% of those being prior to EMS arrival; these patients had a significantly higher case fatality rate than those who arrested after EMS arrival (46.7% vs. 9.1%; $p < 0.001$, Table 4). No difference was seen in the anatomic location of injury in those who died after arrest versus those who did not (data not shown). Extremity injuries (categorized as compressible) accounted for 46.6%, head injuries for 23.8%, and chest injuries for 10.6% (categorized as noncompressible) of total firearm injuries (Table 1, Fig. 1), which carried case fatality rates of 0.1%, 16.1%, and 8.8%, respectively (Table 4). The case fatality rate for compressible injury was 0.1% versus 5.3% for noncompressible injury. The majority of deaths were a result of head injury. Noncompressible injuries together accounted for 28.6% of injuries and 26.3% of mortalities (Table 1, Fig. 1). The case fatality rate of self-inflicted gunshot was higher than assault and accidental injury (36.4% vs. 3.7% and 2.6%, respectively; $p < 0.001$; Table 4). The majority of injuries and deaths occurred at home (60.4% and 75.9%), with most of the remainder (28.7% and 14.6%) occurring on the street. Only 4.2% of injuries and 1.4% of deaths occurred in a public building, a categorization which includes schools (Table 1).

TABLE 1. Characteristics of PFI 2010 to 2015

Variables	Incidence (% of Total)	Deaths (% of Total)	Significance, p
Total	16,808	1031	
Male sex	13,844 (82.82)	898 (83.0)	< 0.001
Race, n (%)	13,490	847	< 0.001
White	4,116 (30.5)	519 (61.3)	
African American	8,222 (60.9)	268 (31.6)	
Asian	46 (0.3)	6 (0.7)	
American Indian	178 (1.3)	10 (1.2)	
Others	928 (6.9)	44 (5.2)	
Type of Firearm injuries	16,808	1092	< 0.001
Accidental	3,617 (21.5)	101 (9.2)	
Assault	11,215 (66.7)	447 (40.9)	
Self-inflicted	1,976 (11.8)	544 (49.8)	
Location of incident	13,036	949	< 0.001
Home	7,878 (60.4)	754 (79.5)	
Street	3,793 (29.1)	139 (14.6)	
Public building	596 (4.6)	13 (1.4)	
Recreational place	256 (2.0)	21 (2.2)	
Restaurant	513 (3.9)	22 (2.3)	
Anatomical location	9,698	570	< 0.001
Head	2,585 (26.7)	416 (73.0)	
Neck	276 (2.8)	13 (2.3)	
Chest	1,025 (10.6)	112 (19.6)	
Abdomen	782 (8.1)	12 (2.1)	
Back	684 (7.1)	10 (1.8)	
Extremity	4,271 (44.0)	7 (1.2)	

DISCUSSION

To our knowledge, this is the largest study of on-scene mortality in PFI to date. Through the examination of prehospital data generally, and an EMS registry specifically, this project has the potential to greatly increase our understanding of the burden of disease, injury pattern, and factors contributing to mortality in this population. Through the examination of prehospital mortality, we have identified several potential areas of improvement in the delivery of trauma care to pediatric firearm victims. Reduction of mortality from potentially survivable injury has been a hallmark of trauma research for several decades. However, a great deal of this research has focused on evaluation of care delivered once the patient arrives to the hospital; comparatively

TABLE 2. Firearms Related Injury by Age

Variables	0–5 Years	6–11 Years	12–18 Years
Incidence (% total)	917 (5.9%)	1,363 (8.7%)	13,348 (85.4%)
Deaths (% total)	78 (7.9%)	57 (5.8%)	848 (86.3%)
Case fatality rate	8.5%[a]	4.2%[b]	6.4%
Type of injury, n (% of total)	1,192	1,420	14,196
Accidental	482 (40.4)	666 (46.9)	2,469 (17.4)
Intentional	573 (48.1)	654 (46.1)	9,988 (70.4)
Self-inflicted	137 (11.5)	100 (7.0)	1,739 (12.2)
Location of incident, n (% of total)	852	1008	11176
Home	641 (75.2)[a]	787 (78.1)[a]	6,450 (57.7)[b]
Street	139 (16.3)[a]	120 (11.9)[a]	3,524 (31.6)[b]
Anatomical location	666	887	8145
Head	294 (44.1)[a]	366 (41.3)[a]	1,925 (23.6)[b]
Neck	18 (2.7)[a]	42 (4.7)[b]	216 (2.7)[a]
Chest	81 (12.2)[a]	76 (8.6)[a]	868 (10.7)[a]
Abdomen	47 (7.1)[a]	63 (7.1)[a]	672 (8.3)[a]
Back	27 (4.1)[a]	50 (5.6)	607 (7.5)[b]
Extremity	195 (29.3)[a]	287 (32.4)[a]	3,789 (46.5)[b]

Variables with different letters are statistically different from one another.

little research exists on reduction of on-scene mortality.[6] This is especially true for PFI. We found that the on-scene case fatality rate of compressible (extremity) injury was exceedingly low (0.1%), implying that the use of compression and tourniquets have been effective in stopping life-threatening bleeding. Indeed, in our study the prehospital case fatality rate was found to be considerably lower than that of a two-decades-old study which examined all prehospital firearm deaths in the United States from 1992 to 1995 (6.1% vs. 20.4%).[9] Although data in adults cannot be directly compared to data in children, it can be reasoned that improvements in prehospital care practices have resulted in improved outcomes across all age groups.

Despite improvements in prehospital trauma care, death from preventable injury continues to represent a substantial proportion of firearm deaths in both the military and the civilian population.[6,10,11] A recent analysis of prehospital deaths from potentially survivable firearm injury performed by Davis et al[6] found that upwards of 20% of deaths were potentially preventable, and that nearly 60% of these were the result of hemorrhage. Interestingly, the study also found that 28% of potentially preventable deaths were from survivable neurotrauma, and 10.3% from combined hemorrhage and neurotrauma. Also notable was that considerable proportion of patients with head injuries died from hemorrhage. Case fatality rate from noncompressible hemorrhage in our study was high (5.3% overall), and especially so for chest and neck injuries (8.8% and 4.7% for chest and neck, respectively, compared to 1.0% and 1.2% for abdomen and back, respectively). Noncompressible injuries together accounted for a considerable portion of mortalities (26.3%). The use of junctional tourniquets, injectable and topical hemostatic agents, improved resuscitative techniques, and hemoglobin-based oxygen carriers have the potential to reduce mortality from these challenging injuries.[6,12] Additionally, the feasibility of use of prehospital resuscitative endovascular balloon occlusion of the aorta (REBOA) has been demonstrated in the military and adult civilian setting.[13,14] Reva *et al* report its successful use in a swine model on a simulated battlefield during military exercises,[13] and Sadek *et al.* describe its prehospital use by London's Air Ambulance's Physician-Paramedic team in a patient who suffered blunt trauma and life-threatening hemorrhage.[14] Though very few studies on the feasibility and safety of REBOA in children have been published, one recent analysis using the Japan Trauma Data Bank found that young patients (average age 11) had similar outcomes to adult patients who underwent REBOA for uncontrolled torso hemorrhage. Of note, only 1.4% of patients in this study suffered penetrating trauma.[15]

TABLE 3. Case Fatality of PFI by Age

Age (Years)	Odds Ratio	Confidence Interval	Significance, *p*
0–5	Reference		
6–11	1.267	0.291–5.515	0.752
12–18	0.760	0.212–2.730	0.674

TABLE 4. Case Fatality Rate of PFI

Variables	Case Fatality Rate, %	Significance, *p*
Total	6.1	
Male sex	6.5	> 0.05
Cardiac arrest	40.1	< 0.001
Before EMS	46.7	
After EMS	9.1	
Type of firearm injuries		< 0.001
Accidental	2.6	
Assault	3.7	
Self-inflicted	36.4	
Anatomical location		< 0.001
Head	16.1	
Neck	4.7	
Chest	8.8	
Abdomen	1.0	
Back	1.2	
Extremity	0.1	

Cardiac arrest prior to EMS arrival was also a considerable source of on-scene mortality; significantly more of these patients died than those who arrested after EMS arrival (46.7% vs. 9.1%). This represents a potential area for improvement in the training of bystanders. There is evidence that bystander training in the correct basic life support techniques, such as high-quality cardiopulmonary resuscitation (CPR), improves outcomes.[16] Additionally, a study published in Norway in 2015 demonstrated that bystanders with documented first-aid training gave higher quality first-aid to trauma victims than those with no documented training, and that the quality of aid did not vary with the profession of the person who administered that aid.[17] Our findings highlight the importance of training bystanders in both high-quality CPR and in prehospital trauma life support.

It should be mentioned that though there have been several recent, well-publicized, tragic mass casualty events in schools, the majority of firearm injuries and deaths continue to occur in the home. We found that only 4.2% of injuries and 1.4% of deaths occurred in a public building (which includes

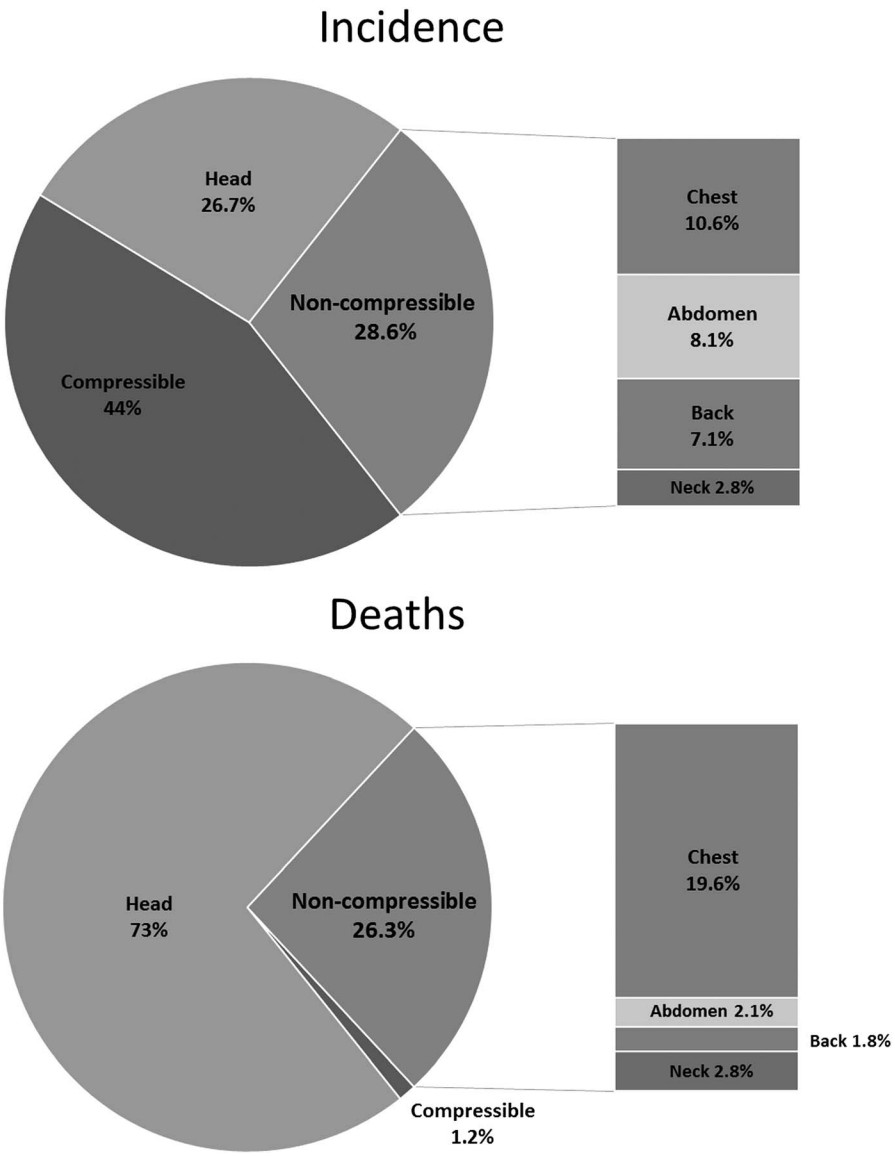

Figure 1. Incidence and deaths in PFI 2010–2015 by anatomic location of injury. Injuries are further stratified into head, compressible, and noncompressible.

schools), a finding that is consistent with other recent studies on PFI.[5] In the last five years, an initiative developed by the American College of Surgeons (Stop the Bleed®) has resulted in the education of lay bystanders of trauma (with a focus on employees of public spaces, such as schools, churches, and sports arenas) in bleeding control techniques and the stocking of these spaces with trauma first aid kits containing tourniquets and hemostatic gauze.[18] Our data and others' suggest that the education of gunowners in trauma first aid and the recommendation that gunowners keep trauma first aid kits in their homes may result in further reduction of deaths from preventable injury.

Finally, the novel use of the NEMSIS database provides a means of assessing the accuracy of studies which use vital records. It is thought that death certificate data frequently misclassifies the race of the victim[19] and the intention of the incident.[20] Particularly vulnerable to misclassification are unintentional firearm deaths which were not self-inflicted, which are reported as homicides on death certificates in up to 75% of cases.[21] Notably, despite the likely misclassification of some accidentally self-inflicted wounds as suicide attempts among 0–5 year olds (11.5% of all injuries in that age group), the rates of recorded assault, accidental injury, and self-inflicted injury in our study were similar to those reported in two recent, large epidemiological studies on PFI in the US.[5,21]

CONCLUSION

Consideration of modification of the current Traumatic Cardiac Arrest Treatment Algorithm with more aggressive on-scene interventions could be of benefit in the prehospital setting. The results of this study suggest that the use of those modalities in appropriately selected patients has the potential to further

decrease the case fatality rate of pediatric firearm injuries. Through the evaluation of on-scene mortality specifically, this study offers insight into potential areas of focus to improve prehospital care of pediatric gunshot victims.

Limitations

The NEMSIS database is a large convenience sample, consisting of data submitted by participating EMS agencies. Therefore, it likely over-represents EMS agencies with the resources needed to adopt NEMSIS standards and may not be representative of national EMS agencies. Additionally, the NEMSIS database is event-based rather than patient-based. Individual patients may have multiple EMS activations, with "frequent flyers" potentially introducing bias. States have differing criteria for including patients in statewide EMS databases, which may also lead to bias. Patient and event characteristics are assessed by first responders and may be misclassified; injuries may be missed. Not all injuries require EMS activations, so the data may be skewed by higher acuity events. And finally, though the quality of the data is monitored by the NEMSIS Technical Assistance Center (NEMSIS TAC), the database inherits the individual deficiencies originating from its contributing entities.

DISCLOSURE

No funding was provided for the completion of this project. We declare no conflicts of interest.

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DISCUSSION

L. R. TRES SCHERER III, M.D., M.B.A. (Carmel, Indiana): Good afternoon.

I would to thank the Program Committee of the AAST for inviting me to discuss this potentially provocative study concerning the pre-hospital morbidity and mortality of pediatric firearm injuries, and to Dr. Todd Maxson, who could not attend this meeting and discuss this paper. I would like to thank Dr. Friedman for providing me the manuscript well in advance of the meeting.

As many before her, Dr. Friedman and her co-authors recognize pediatric firearm injuries as a leading cause of morbidity, disability and mortality in children and teenagers.

Most studies on pediatric firearm injuries utilize national databases which record emergency department, hospital admissions or firearm deaths.

Unfortunately, this data often is incomplete as either for a population sample or a regional effort. Therefore, these researchers took a look "outside the box" at a newer nationally reported administrative and clinical registry to evaluate pre-hospital data involving children under the age of 18, the National Emergency Medical Services Information Systems database.

They presented some interesting data concerning the morbidity and mortality of pediatric firearm victims. And their data uncovers new data of previously held beliefs concerning the epidemiology and incidence of children involved with firearms injury. And we need to further evaluate some of their conclusions based on the data presented today.

From the manuscript and her presentation, I have some comments and questions concerning your methods, data analysis and conclusions.

1. First of all, in regards to the NEMSIS dataset, during your study period, there was a conversion from Version 2 to Version 3. How did this confound your data collection and your data analysis? And what was the state compliance of submission within the different states submitting data?

2. You collected six elements from the dataset, including anatomic location of injury, death, mortality, cardiac event, compressible and non-compressible injury based on anatomy. Are there any other elements/definitions that you would now consider helpful to improve the details of this study?

3. In your analysis, you determined that the victims suffering cardiac event prior to EMS arrival had a mortality of 73 percent; also, the largest location of injury and mortality is the home. And in your study, the case fatality was 76 percent and 61 percent injured.

What strategies of pre-hospital care and/or prevention would you propose from your data or others to improve mortality of victims of these situations? Does the Scandinavian study that you discussed in your paper show any benefit of bystander care in the trauma patient suffering a firearm injury?

4. With witnessed cardiac events occurring outside of the hospital with CPR and AED the best survival rate is 10 to 30 percent to discharge from the hospital.

From your data, you have remarkable survival rates of 91 percent if the arrest occurs after EMS, and even 53 percent if it occurs before EMS arrival. Do you have any insights as to their success?

5. And lastly, public and mass shootings had an injury and death rate of 4.2 and 1.4 percent of the reported EMS calls. From these data, should we reevaluate the focus of Stop the Bleed project to other groups that this study has identified?

Thank you very much.

MARIE L. CRANDALL, M.D., M.P.H. (Jacksonville, Florida): Thanks for your presentation of really important data, adding to the evidence of the scope and burden of firearm injury in the United States.

I just wanted to say that I don't quibble with your methods or your conclusions at all, and in fact, I would say that you're probably not going far enough with your suggestions of safety and accountability for Americans.

Stop and think: this is 16,000 children that have been shot and are in a database of kids who were shot. That's extraordinary. This is unique to the United States, Brazil, and Mexico, really. This is something that doesn't happen elsewhere.

So, I would argue that perhaps in your discussion, if you haven't already submitted the manuscript, that you could go further, and talk about and reference the papers that have demonstrated that states with more stringent youth-focused firearm laws — firearm access laws — have lower rates of youth suicide and youth unintentional injury; but other than that, I think it's a great paper, and thanks for sharing.

DEBORAH A. KUHLS, M.D. (Las Vegas, Nevada): I have one additional question, and that would be, given your findings, and you've made several suggestions, where do you in fact plan to go with your next steps in this research?

JESSICA FRIEDMAN, M.D. (New Orleans, Louisiana): Thank you, everybody, for your excellent comments and questions.

To address the discussant's first question about the evolving versions of the database, it is true that the database did evolve over the study period, with increased number of EMS agencies from more states reporting in later years.

However, we did not report trends over time, so we thought this might be less impactful, since we were averaging all of our data. But it is true that there were changes in the way the data was reported and which variables were collected.

That did not happen to be true for the variables that we looked at. And the quality of the data is closely monitored by the NHTSA, which is looking for both completeness and logical consistency. And if they find any errors in either of those two areas, they will flag that data and send it back to the EMS agency for correction.

Regarding collecting more information from the database and which variables we think would be important, that is an excellent question. And we actually are, and this is partly also in answer to your next question, we are in the process of expanding our study to include more variables.

The ones we're most interested in are EMS response time, transport time, which bystander interventions were performed, which is actually recorded, which EMS interventions were performed, and whether or not each of those were successful.

Unfortunately, they do not record whether it is an urban or rural environment, but they do provide the zip code, so we could extrapolate whether or not it was an urban or rural environment. And so all of those things are variables that we are looking at in order to further this study.

So, with regard to the location of injury and mortality being in the home, this is absolutely true. And some of these are accidental, so training parents or guardians in Stop the Bleed and placing trauma first aid kits in the home could be helpful.

It is true, also, a lot of these are assault, and it would be difficult to reduce those mortalities through, you know, training of the caretakers.

However, 50 percent of deaths were from suicide, so that does represent a very, very important target – also to the last questioner's point that safety and accountability is incredibly important.

And half the kids who died on the scene died from suicide. It was because they were able to obtain a gun that they should not have been able to obtain.

And then, finally, to the point of what EMS did and what bystanders should be able to do, there actually were a couple of studies that were performed demonstrating that there is improved trauma first aid delivered by people who are trained, bystanders who are trained, in both the trauma population and also the non-trauma population.

I think I'm out of time. Thank you so much, again, to everybody.