An analysis of prehospital deaths: Who can we save?

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BACKGROUND: Since their inception in the late 1970s, trauma networks have saved thousands of lives in the prehospital setting. However, few recent works have been done to evaluate the patients who die in the field. Understanding the epidemiology of these deaths is crucial for trauma system performance evaluation and improvement. We hypothesized that specific patterns of injury could be identified and targeted for intervention.

METHODS: Medical examiner reports in a large, urban county were reviewed including all trauma deaths during 2011 that were not transported to a hospital (i.e., died at the scene) or dead on arrival. Age, sex, date of death, mechanism, and list of injuries were recorded. An expert panel reviewed each case to determine the primary cause of death, and if the patient's death was caused by potentially survivable injuries or nonsurvivable injuries.

RESULTS: A total of 512 patients were included. Patients were 80% male, died mostly of blunt (53%) and penetrating (46%) causes, and included 21% documented suicides. The leading cause of death was neurotrauma (36%), followed by hemorrhage (34%), asphyxia (15%), and combined neurotrauma/hemorrhage (15%). The anatomic regions most frequently injured were the brain (59%), chest (54%), and abdomen (35%). Finally, 29% of the patient deaths were classified as a result of potentially survivable injuries given current treatment options, mostly from hemorrhage and chest injuries.

CONCLUSION: More than one of every five trauma deaths in our study population had potentially survivable injuries. In this group, chest injuries and death via hemorrhage were predominant and suggest targets for future research and implementation of novel prehospital interventions. In addition, efforts targeting suicide prevention remain of great importance. (*J Trauma Acute Care Surg*. 2014;77: 213–218. Copyright © 2014 by Lippincott Williams & Wilkins)

LEVEL OF EVIDENCE: Epidemiologic study, level V.

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Secondary prevention has long been a major focus of trauma-related attention and research. Both prehospital and hospital-based interventions contribute to secondary prevention and together constitute a systems-based approach that is acknowledged as essential for reducing morbidity and mortality caused by traumatic injury.[1]

Civilian trauma systems have been improved by the military examples provided during the World War II, Korean War, and Vietnam War.[2] In 1966, the National Academy of Science/National Research Council released a report emphasizing that civilian trauma care was worse than the standards achieved in Vietnam.[3] One decade later, the American College of Surgeons' Committee on Trauma developed criteria for the designation of trauma centers and the establishment of regional trauma systems.[4]

Since the publication of that report, trauma systems have developed in lockstep with system self-evaluation and critique. In two landmark studies, trauma surgeons at San Francisco General Hospital surveyed trauma deaths within the city and reported 2% to 4% potentially preventable deaths.[5,6] Subsequent similar studies helped characterize region-specific trauma care and encouraged compliance with American College of Surgeons' Committee on Trauma criteria.[7] Periodically throughout the following decades, specific trauma systems have revisited the data to identify areas of improvement for evolution.[8] Reviewing trauma-related deaths has been acknowledged as the linchpin of trauma systems research, identifying new strategies for treatment, equipment, training, and technology.[9]

Despite necessary focus on the topic, certain gaps remain within the literature. The number of published reviews has diminished since the 1980s, and most recent studies concentrate on patient deaths during transport or in the hospital, without evaluating patient deaths in the field (DIFs).[10,11] The studies on civilian deaths are based in rural counties with presumably long transport times.[7,8,12] Moreover, the studies omit any data on DIF injury burden, patterns, or cause of death. We therefore studied the medical examiner reports for all trauma prehospital deaths during the course of 1 year in a large, urban county, hypothesizing that specific injury patterns could be identified and targeted for intervention.

PATIENTS AND METHODS

Medical examiner reports for Miami-Dade County in 2011 were obtained and retrospectively reviewed. Trauma DIFs and deaths on arrival to the hospital (DOAs) were identified for further analysis. A trauma was defined as a DIF if the patient was not transported to a medical facility, while DOA was defined as having nonsustainable vital signs on arrival regardless of intervention. Demographic data included age, sex, mechanism of injury, and date of death.

The reports were subsequently reviewed, and all autopsy findings were recorded. A panel of board-certified attending trauma and critical care surgeons reviewed each patient's injuries to determine primary cause of death and if the injury was nonsurvivable or potentially survivable. We chose the military nomenclature of "survivable injuries" rather than the civilian "preventable deaths" to highlight the conjectural nature of panel judgments. Nonsurvivable injuries included laceration of the heart, laceration or transection of the aorta or thoracic vena cava, massive brain hematoma, massive brain tissue trauma, brainstem herniation, and massive burns with "charring" as described on autopsy reports. Potentially survivable injuries were then determined based on the expert consensus of trauma surgeons as if optimal care were immediately available, a definition that is consistent with previously published military-based studies on the topic.[2] In addition, we erred toward inclusion to encourage discussion regarding areas of potential improvement of prehospital care.[9]

Autopsy findings were categorized by location into brain, spine, neck, chest, abdomen, pelvis, and extremity. Specific organ injuries within these anatomic locations were also recorded, such as injuries of the esophagus, trachea, and vascular structures of the

neck. Chest injuries included heart, lung, vascular structures, and chest wall injuries including the sternum and ribs. Abdominal and pelvic injuries included injuries to the spleen, liver, gastrointestinal tract and mesentery, genitourinary tract, and vascular structures. Superficial lacerations and abrasions were not recorded.

IBM SPSS Statistics for Windows version 21.0 (IBM Corp., Armonk, NY) was used for the data analysis. Descriptive statistics were calculated, and values are expressed as mean (SD) or number (percentage) as appropriate.

RESULTS

There were a total of 512 deaths during the study period. They were predominantly male (79.9%), with an mean (SD) age of 43 (20) years. Majority of the injuries were blunt (52.7%), followed by penetrating (45.9%), burns (1.2%), and other (0.2%). Approximately one in five deaths were documented as suicides (21.3%).

Patients' injury mechanisms are listed in Table 1. More than twice as many deaths were caused by gunshot wounds (42.8%) as compared with the next most common mechanism (motor vehicle collision, 19.4%). However, all types of vehicular collisions accounted for 33.7% of the deaths. Non–gunshot wound penetrating injuries constituted a mere 3.4% of the deaths. The leading cause of death was neurotrauma (35.7%), followed by hemorrhage (33.6%), combined hemorrhage and neurotrauma (15.1%), and asphyxia (14.5%). The other causes were combined asphyxia and neurotrauma (0.8%) and combined hemorrhage and asphyxia (0.2%).

The injuries documented on the medical examiners' reports by anatomic location are shown in Table 2. Although brain injuries were slightly more common, chest-related injuries were still present in more than half of all deaths, whereas only 16.4% of the patients had pelvic injuries. Thirty-four percent of the patients had a single location injured.

Table 3 details the specific organs injured among the deaths noted in this study. Injuries to the brain or skull were the most common (59.0%), followed by lungs (42.6%), chest wall (42.0%), and spine (25.4%). Vascular injuries were observed in 29.7% of all deaths.

TABLE 1. Injury Mechanism

Mechanism	n (%)
Gunshot wound	219 (42.8)
Motor vehicle collision	99 (19.4)
Hanging	55 (10.8)
Pedestrian hit by car	43 (8.4)
Motorcycle	27 (5.3)
Jump/fall	23 (4.5)
Stabbing	13 (2.6)
Other blunt	10 (2.0)
Burn	6 (1.2)
Other asphyxia	4 (0.8)
Other penetrating	4 (0.8)
Plane crash	3 (0.6)
Crush	3 (0.6)
Bicycle	2 (0.4)
Pedestrian hit by train	1 (0.2)

TABLE 2. Injury Location

Body Location	n (%)*
Brain	302 (59.0)
Chest	277 (54.1)
Abdomen	181 (35.4)
Extremity	136 (26.6)
Neck	133 (26.0)
Pelvis	84 (16.4)

*Percentages do not add up to 100%.
One hundred seventy-two patients (33.5%) with only one location injured.

Among all deaths, 146 (28.5%) were deemed to be related to potentially survivable injuries. A majority of those deaths were caused entirely by hemorrhage (54.1%), and another 10.3% were partially attributable to hemorrhage. Neurotrauma was the other major cause of deaths caused by potentially survivable injuries (Table 4). In the group of potentially survivable injuries, chest- and brain-related injuries were the most frequent (65.1% and 49.3%, respectively), while pelvic injuries were least frequent (15.8%).

DISCUSSION

This study examines the proportion of prehospital trauma deaths in Miami-Dade County which were caused by potentially survivable injuries. In this respect, it continues a decade-long exercise of reviewing trauma deaths to evaluate trauma systems and care. Such reviews are acknowledged as vital to trauma network research, identifying areas of improvement and future avenues of inquiry[2] in an attempt to minimize deaths from a potentially survivable injury in the future. This analysis found that more than 20% of injuries were potentially survivable, with death from hemorrhage and chest injuries being predominant.

TABLE 3. Organs Injured

Organ	n (%)*
Brain/skull	302 (59.0)
Lung	218 (42.6)
Sternum/ribs	215 (42.0)
Spine	130 (25.4)
Cardiac	129 (25.2)
Liver	127 (24.8)
Vascular—chest	111 (21.7)
Spleen	76 (14.8)
Gastrointestinal/mesentery	75 (14.6)
Genitourinary	61 (11.9)
Vascular—neck	22 (4.3)
Vascular—abdomen	19 (3.7)
Esophagus	13 (2.5)
Trachea	11 (2.1)

*Percentages do not add up to 100%.
One hundred forty patients (27.3%) with only one organ injured.
Three patients with autopsy reports incomplete/unavailable.

TABLE 4. Causes of Death and Anatomic Regions Injured in Potentially Survivable Patients (n=146)

Cause of Death	n (%)
Hemorrhage	79 (54.1)
Neurotrauma	41 (28.1)
Hemorrhage + neurotrauma	15 (10.3)
Asphyxia	9 (6.2)
Asphyxia + neurotrauma	2 (1.4)
Anatomic Region Injured	**n (%)***
Chest	95 (65.1)
Brain	72 (49.3)
Abdomen	63 (43.2)
Extremities	46 (31.5)
Neck	36 (24.7)
Pelvis	23 (15.8)

*Percentages do not add up to 100%.

Four studies using data from the 1990s include some regional or state-specific information on trauma deaths and suggest a potentially preventable death rate ranging from 0% to 13%.[7,8,12,13] These reported rates are far smaller than our 29%, and two explanations may play a role in this disparity. Unlike our report where we assumed rapid transport and all possible in-field capabilities, these studies described rural counties with presumably longer transport times when therapeutic options and resource distribution may be more limited. In addition, the other studies examined deaths according to the capabilities and limitations of current prehospital care standards. In contrast, our aim was to assess how increased capabilities and possible future technologies, under optimal conditions, might alter survivability. Our greater percentage of potentially preventable deaths highlights areas for potential improvement.

Civilian studies aside, 10 years of war in Iraq and Afghanistan have provided more recent opportunities for the military to conduct assessments of combat casualty care. These studies have altered category labels to account for the battlefield realities of military prehospital care, but crucially, they have explored survivability in both the hospital and prehospital settings. Holcomb et al.[2] reported that 15% of US combat casualty deaths in the field were potentially survivable, and Kelly et al.[9] arrived at a similar 19% and 28%. In each case, these percentages are closer to our 29% in Miami-Dade County. The authors concluded that improving treatment of extremity hemorrhage and noncompressible hemorrhage as well as faster evacuations might improve survival. While our data were not as complete, they also showed that nearly 60% of potentially survivable deaths were caused, at least in part, by hemorrhage.

Recognizing that battlefield trauma care entails unique challenges not necessarily present in civilian settings, the Department of Defense has developed Tactical Combat Casualty Care (TCCC), a set of trauma management guidelines customized for use on the battlefield. One of the most important lifesaving interventions that the TCCC has advocated for in the US military is prehospital tourniquet use. Despite exsanguination from extremity hemorrhage being documented as the leading cause of preventable death in the Vietnam conflict, in the mid-1990s, before the introduction of TCCC concepts, combat medics, corpsmen, and pararescuemen in the US military were taught to use tourniquets only as a last resort to control external hemorrhage. The results were predictable. A study of 2,600 combat fatalities from the Vietnam conflict had noted that the incidence of death from extremity hemorrhage was 7.4%.[14] With most of the US military using a hemorrhage control strategy that did not include tourniquets, this high incidence of death from extremity hemorrhage persisted into our more recent conflicts. A study of 982 fatalities from the early years of the wars in Afghanistan and Iraq found that the percentage of combat fatalities that died of extremity hemorrhage was essentially unchanged at 7.8%.[9]

As tourniquets became widely fielded and used by US forces in 2005, however, death from extremity hemorrhage became increasingly uncommon.[15] In the words of one combat trauma surgeon at a Role 3 combat support hospital in Kandahar in November of 2012, "Tourniquets have been very successful. In Iraq, 5 years ago, I saw casualties come in in shock and dying from single extremity injuries without tourniquets. Here, we are seeing triple and quadruple amputees come in with tourniquets applied, awake and talking to us."[16]

In contrast to the studies of Maughon and Kelly et al., the comprehensive study by Eastridge et al.[17] of 4,596 US combat fatalities from 2001 to 2011 found that the incidence of preventable deaths from extremity hemorrhage had decreased sharply to only 2.6% of the total, a reduction of 66% from the incidence reported by Kelly et al. in 2008. Tourniquets have been the signature success in battlefield trauma care in Afghanistan and Iraq. Based on the work of retired Army Colonel John Kragh and colleagues,[18–20] the number of lives saved from this single intervention has been estimated to be between 1,000 and 2,000.

Another metric of success for TCCC has been the reduction in preventable deaths in units that have trained all of their unit members in TCCC. The 2012 study by Eastridge et al.[17] documented that 87% (4,016 of 4,596) of deaths occurred before the casualty reached a medical treatment facility. A review panel also determined that 24% (976 of 4,016) of these deaths were potentially preventable.[17] In contrast, the review of Kotwal et al.[21] on 419 battle injury casualties in the 75th Ranger Regiment sustained between 2001 and 2010 found that none of their pre–medical treatment facility fatalities and only 3% of total fatalities were potentially preventable. This success in reducing preventable deaths has been mirrored in other military units that have implemented TCCC concepts.[22,23] Another perspective is provided by reviewing published preventable death analyses and noting all of the potentially preventable deaths from external hemorrhage that could potentially have been avoided had TCCC-recommended interventions been applied.[2,9,17,24]

Tourniquet use has revolutionized hemorrhage control in the military setting; however, care should be taken when translating to the civilian setting. It will become important to educate prehospital medical professionals and the public about the appropriate and effective use of tourniquets because of their potential downfalls. If used incorrectly and/or for extended periods, there may be concern for limb ischemia secondary to poor arterial blood flow, which could result in permanent nerve damage (also from direct nerve compression), skin necrosis, muscle injury, compartment syndrome, and vascular injury.[25,26] Upon

release of the tourniquet, there could be reperfusion injury.[25,26] This could result in local and systemic inflammation.[25] It has also been suggested that direct pressure (without tourniquets) may be sufficient to control the majority of external hemorrhage.[25] A variety of educational media could be used to educate prehospital medical providers and the public. Tutorials on tourniquet use could be incorporated into orientation modules and annual refresher courses for providers. In an attempt to educate the public, outreach projects such as health fairs, church associations, flyers in communities, and public service announcements could be instrumental.

Recently, all in-hospital trauma deaths at our county's only Level 1 trauma center were reviewed.[10] Approximately one fourth of all deaths were patients who arrived with no vital signs to the trauma center, further highlighting the importance of prehospital trauma care. The authors reviewed the medical examiners' reports on all patients who arrived with no vital signs and found that the most commonly injured locations were the chest (73%), abdomen (53%), and brain (44%).[10] While the injury percentages differed in our study population, the three most commonly injured locations were the same—among all deaths and potentially survivable patients only.

Clearly, an injury severity threshold exists over which advanced medical retrieval decreases time to operation and improves survival.[27] Military medical providers have noted historical lack of progress in prehospital casualty care,[14,28] but the wars in Afghanistan and Iraq have seen a remarkable transformation in battlefield trauma care and resultant dramatic decrease in preventable deaths as discussed.[15,16,18,19,21] Innovative approaches are necessary to close the persistent "en route care gap" that yet exists.[29]

As the ongoing military conflicts have drawn attention toward prehospital casualty care, several emerging technologies may hold promise for increasing survivability. Junctional hemorrhage (groin and axilla) and noncompressible hemorrhage (abdomen and chest) require a multifaceted approach including injectable hemostatic agents, junctional tourniquets, hemoglobin-based oxygen carriers, and additional blood products such as freeze-dried plasma (FDP).[30,31] In-field thromboelastography, combined with remote traumatologist telepresence, may help lower-level providers enact a high level of care.[29] Unrealized technology providing external neck compression using a noncompressible endotracheal tube has its earliest roots in neurosurgery.[32] The military success with tourniquets and hemostatic dressings may not have the same impact in civilian settings that they have had in combat, or any specific measure may not prove effective. Nevertheless, these interventions along with such advances as tranexamic acid, early use of 1:1 blood and plasma in the field, and FDP likely represent the next steps in prehospital trauma care, and their consideration conveys a concerted attempt to improve civilian prehospital trauma care.

While providing critical focus on civilian prehospital trauma care, this study is subject to certain limitations. Multiple different pathologists performed the autopsies, and their autopsy reports reflect individual approaches and documentation practices. This study used the patient population from a single, urban county and may not be generalizable to other patient populations. In addition, when determining survivability, the panel of trauma surgeons entertained the assumption that optimal care was immediately available and erred on the side of inclusion. Absent these assumptions, the survivability percentages might be quite different. Lastly, the guidelines for declaring a patient DIF or DOA may vary based on location. A different trauma system with different criteria could yield different results regarding preventability.

Ultimately, primary prevention is the most effective means for limiting trauma morbidity and mortality. Homicides and many suicides are perpetrated so as to avoid public detection, and despite the ideal next generation technology, there may be instances where no reasonable way exists for the emergency medical service (EMS) to arrive on scene quickly enough to successfully intervene. Nevertheless, given a total response time (from receipt of a 911 call to EMS arrival) of 8.05 minutes in the county[33] and average time from EMS arrival on scene to arrival at our trauma center of 39.5 minutes (local data), our study is a useful and informative exercise necessary to advance prehospital civilian trauma care.

In conclusion, more than one of every five trauma deaths in our study population had potentially survivable injuries. In this group, chest injuries and death via hemorrhage were predominant and suggest targets for future research and implementation of novel prehospital interventions. In addition, efforts targeting suicide prevention remain of great importance.

AUTHORSHIP

J.S.D., L.H.B., and C.I.S. designed this study. J.S.D., S.S.S., F.K.B., H.D., D.N., and K.J. contributed to the literature search. J.S.D., S.S.S., H.D., D.N., K.J., R.M.V.H. collected data. J.S.D. and S.S.S. performed data analysis. J.S.D., S.S.S., F.K.B., L.H.B., and C.I.S. interpreted the data. J.S.D., S.S.S., and F.K.B. wrote the manuscript, which all authors critically revised.

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DISCLOSURE

The authors declare no conflicts of interest.

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