The contemporary timing of trauma deaths

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BACKGROUND: The distribution of trauma deaths was classically described as trimodal. With advances in both technology and trauma systems, this was reevaluated and found to be bimodal in the early 2000s. Over the last decade there have been continued improvements in trauma and intensive care unit (ICU) care, related to damage control techniques and evidence based ICU pathways. A better understanding of the distribution of trauma deaths may be used to improve trauma systems. This study aimed to evaluate the contemporary distribution of trauma deaths after the widespread implementation of modern trauma and critical care principles.

METHODS: This study included patients entered in the NTDB from 2008 to 2014. For dead patients, hospital length of stay was equated to time until death. Additional data was collected to include demographics, mechanism of injury, Injury Severity Score, and Abbreviated Injury Scale score. Histograms were plotted to demonstrate peaks in deaths. Survival analysis was performed with Kaplan-Meier curves and Gehan-Breslow generalized Wilcoxon tests.

RESULTS: 4,185,009 patients were analyzed. Thirty-four percent of all deaths occurred within the first 24 hours of admission. The factors most associated with death in the first 24 hours were severe abdominal trauma (73%), penetrating trauma (55%), and severe extremity trauma (58%). Among patients with penetrating trauma and an abdominal Abbreviated Injury Scale score of 4 or higher, 83% of deaths occurred within 24 hours. When plotted, the distribution of deaths was seen to fall rapidly after the first 24 hours and continued to be flat for 30 days in all subgroups analyzed.

CONCLUSION: In this study, the distribution of trauma deaths no longer appears to be trimodal. This may reflect advances in trauma and ICU care, and the widespread adaption of damage control principles. Early deaths, however, remains a significant challenge, specifically from non-compressible abdominal hemorrhage and extremity trauma. Primary prevention and early hemorrhage control must continue to be a focus of research and trauma systems. (*J Trauma Acute Care Surg.* 2018;84: 893–899. Copyright © 2018 Wolters Kluwer Health, Inc. All rights reserved.)

LEVEL OF EVIDENCE: Epidemiologic, level IV.

KEY WORDS: Trauma; deaths.

The distribution of trauma deaths was classically described as trimodal in the landmark article by Trunkey in 1983.[1] This study highlighted the causes of death in trauma patients and divided them into three groups. Immediate deaths were primarily from severe traumatic brain injury (TBI) and spinal cord injuries, or as a result of injury to the heart or great vessels. Early deaths occur within the first hours after injury, and were caused by significant hemorrhage and severe TBI. The last group was characterized as late deaths. These patients died of sepsis or multisystem organ failure. Dr. Trunkey's work pointed to the areas of trauma care that could be improved and noted that early deaths were potentially treatable if they reached a trauma center rapidly. With advances in both technology and trauma systems, this distribution of deaths was reevaluated at the turn of the century. These advances showed varying effects on mortality rates. Some centers showed the trimodal distribution was changing and reported a bimodal distribution, with a decrease in the early and late deaths.[2–4] However, many other authors have continued to demonstrate a peak several weeks posttrauma.[5–7] One large review on the topic concluded that while death from exsanguination had decreased, there was no change in mortality rate or pattern from other injuries.[8]

Over the last decade, there have been several significant improvements in trauma care, all stemming from significant research efforts and research dollars being committed. These changes include improved primary prevention, increased utilization of damage control techniques, and a focus on high-quality intensive care unit (ICU) care. Given these advancements in trauma care, the authors hypothesized that the temporal profile of trauma deaths has changed. The aims of this study were to (1) describe the contemporary distribution of trauma deaths after the widespread implementation of these modern trauma and critical care principles and (2) assess temporal differences in survival. A better understanding of the distribution of trauma deaths will assist physicians and policymakers improve trauma systems.

PATIENTS AND METHODS

This study was performed with approval from the Institutional Review Board at the University of Southern California. A retrospective analysis was performed using the American College of Surgeons National Trauma Data Bank (NTDB). All patients entered in the NTDB from 2008 to 2014 were included for analysis. Patients were excluded if burn was the mechanism of injury, if the mechanism of injury was not reported, if data on patient length of hospital stay was incomplete, or if the patient's final discharge disposition was unknown. Time of death is not a standard data point in the NTDB. The authors used length of stay (LOS) as a surrogate for time of death for all patients that died. Additional data collection included demographics, mechanism of injury (blunt, penetrating), Injury Severity Score (ISS), and Abbreviated Injury Scale (AIS) (head, chest, abdomen, extremity).

Data were divided into three epochs based on year of discharge (2008–2009, 2010–2011, and 2012–2014) to evaluate temporal differences in survival using Kaplan-Meier survival curves and Gehan-Breslow generalized Wilcoxon tests. Patients were right-censored at the end of their at-risk period (determined by length of stay). Histograms were plotted to demonstrate peaks in deaths. Analysis was conducted using R Statistical Software (Foundation for Statistical Computing. Vienna, Austria) and reviewed by a biostatistician. All p values less than 0.05 were considered significant.

RESULTS

During the study period, 5,329,246 patients were entered into the NTDB. After applying exclusion criteria, 1,144,237 (21.5%) patients were removed from analysis, 795,740 (69.5%) had an unknown discharge disposition (alive vs. dead), 85,405 (7.5%) were burn patients, 230,726 (20.2%) had an unknown mechanism of injury, and 32,366 (2.8%) had an unknown length of stay. The remaining 4,185,009 patients (133,775 deaths) were analyzed. Patient characteristics are described in Table 1. Mean age was 46 ± 25 years (range, 0–118 years), and 61% of patients were male. The majority of victims were white (71%), followed by African Americans (13%). Penetrating trauma accounted for 9% of patients and 15% of deaths. Penetrating victims were younger on average compared with blunt trauma victims (32 years vs. 47 years). Median ISS for all deaths was 25 (interquartile range, 16–33).

Injury mechanism and AIS scores among deaths are stratified by year in Table 2. Head, chest, and abdomen, and extremity AIS scores were recorded for 69%, 42%, and 28%, and 46% of deaths, respectively. Half of all deaths occurred among patients with a head AIS score of 4 or higher, and less than 10% of deaths occurred among any category of patients with an abdomen, chest, or extremities AIS score of 4 or higher. The majority of patients who died, 56% were admitted to the ICU from the emergency department, while 21% of patients who lived were admitted to the ICU. Another 24% of patients who died and 13% of patients who lived were taken directly to the operating room.

All deaths were evaluated for time of death from admission. Overall, during the first 24 hours of hospitalization, 45,753 (34%) deaths occurred. Additional details about time to death after admission by subgroup, patients with severe trauma (AIS score, ≥ 4) to the head, chest, abdomen, extremities, or multiple regions, blunt and penetrating trauma, and patients with ISS of 15 or less and ISS greater than 15 are provided in Tables 3A and 3B. The percentage of deaths over the first 24 hours was highest in severe abdominal trauma (73%), penetrating trauma (55%), and severe extremity trauma (58%). The

TABLE 1. Patient Characteristics

	Died Before Discharge	Alive at Discharge	All
	n = 133,775	n = 4,051,234	n = 4,185,009
	n (%)	n (%)	n (%)
Race			
American Indian	767 (1%)	32,926 (1%)	33,693 (1%)
Asian	2,775 (2%)	67,079 (2%)	69,854 (2%)
Black or African American	15,560 (12%)	519,295 (13%)	534,855 (13%)
Native Hawaiian or other Pacific Islander	262 (0.2%)	7,991 (0.2%)	8,253 (0.2%)
White	96,955 (72%)	2,858,455 (71%)	2,955,410 (71%)
Other race	10,405 (8%)	363,973 (9%)	374,378 (9%)
Multiple races	46 (0.03%)	1,603 (0.04%)	1,649 (0.04%)
Unknown/not reported	7,005 (5%)	199,912 (5%)	206,917 (5%)
Hispanic ethnicity			
Hispanic or Latino	11,774 (9%)	426,455 (11%)	438,229 (10%)
Not Hispanic or Latino	88,328 (66%)	2,609,286 (64%)	2,697,614 (64%)
Unknown/not reported	33,673 (25%)	1,015,493 (25%)	1,049,166 (25%)
Sex			
Female	44,405 (33%)	1,570,944 (39%)	1,615,349 (39%)
Male	89,316 (67%)	2,478,702 (61%)	2,568,018 (61%)
Unknown/not reported	54 (0.04%)	1,588 (0.04%)	1,642 (0.04%)
Injury type			
Blunt	114,197 (85%)	3,702,620 (91%)	3,816,817 (91%)
Penetrating	19,578 (15%)	348,614 (9%)	368,192 (9%)
Year of discharge			
2008	16,426 (12%)	458,169 (11%)	474,595 (11%)
2009	17,681 (13%)	516,754 (13%)	534,435 (13%)
2010	17,949 (13%)	546,604 (13%)	564,553 (13%)
2011	19,211 (14%)	589,082 (15%)	608,293 (15%)
2012	20,774 (16%)	639,428 (16%)	660,202 (16%)
2013	20,565 (15%)	640,747 (16%)	661,312 (16%)
2014	21,169 (16%)	660,450 (16%)	681,619 (16%)

	Died before discharge		Alive at discharge		All	
	Mean ± SD	Median (IQR)	Mean ± SD	Median (IQR)	Mean ± SD	Median (IQR)
Age at injury*	57 ± 24	61 (35–79)	45 ± 25	45 (24–66)	46 ± 25	46 (24–66)
ISS**	26 ± 15	25 (16–33)	10 ± 8	9 (4–13)	10 ± 8	9 (4–13)

*Age at diagnosis was unknown/not reported for 3% of all patients (died before discharge, 6%; alive at discharge, 3%).
**Injury severity score was unknown/not reported for 3% of all patients (died before discharge, 3%; alive at discharge, 3%).
SD, standard deviation; IQR, interquartile range (lower quartile-upper quartile).

TABLE 2. Mortalities by Year, Mechanism, and AIS Scores

		Mechanism		AIS ≥ 4*				
		Blunt	Penetrating	Head [a]	Chest [b]	Abdomen [c]	Extremities [d]	Multiple
Years	Total	n (%)	n (%)	n (%)	n (%)	n (%)	n (%)	n (%)
2008	16,426	13,805 (84%)	2,621 (16%)	8,106 (49%)	961 (6%)	779 (5%)	56 (0%)	1,853 (11%)
2009	17,681	14,989 (85%)	2,692 (15%)	8,948 (51%)	1,053 (6%)	745 (4%)	62 (0%)	1,764 (10%)
2010	17,949	15,237 (85%)	2,712 (15%)	9,044 (50%)	1,095 (6%)	790 (4%)	86 (0%)	2,099 (12%)
2011	19,211	16,433 (86%)	2,778 (14%)	9,584 (50%)	1,183 (6%)	778 (4%)	115 (1%)	2,269 (12%)
2012	20,774	17,794 (86%)	2,980 (14%)	10,334 (50%)	1,280 (6%)	876 (4%)	116 (1%)	2,594 (12%)
2013	20,565	17,593 (86%)	2,972 (14%)	10,119 (49%)	1,304 (6%)	834 (4%)	111 (1%)	2,544 (12%)
2014	21,169	18,346 (87%)	2,823 (13%)	10,391 (49%)	1,297 (6%)	801 (4%)	109 (1%)	2,657 (13%)
All years	133,775	114,197 (85%)	19,578 (15%)	66,526 (50%)	8,173 (6%)	5,603 (4%)	655 (0.5%)	15,780 (12%)

Percentages reflect proportion of all mortalities from corresponding year.

percentage of 24-hour deaths was lowest in severe TBI (34%), blunt trauma (29%), and ISS ≤ 15 (20%). Compared with severe chest or abdominal trauma, severe TBI patients were noted to have the lowest rate of death over the first 12 hours of admission, but saw an increased between hours 12 and 24. Among patients with penetrating trauma, an abdominal AIS of 4 or higher, and no other AIS score of 4 or higher, 83% of deaths occurred within 24 hours.

The distributions of death were plotted in histograms to compare severely injured systems (head vs. chest vs. abdomen vs. extremities vs. multiple; AIS, ≥ 4) (Fig. 1), and to compare mechanism of injury (Blunt vs. Penetrating) (Fig. 2). The distribution falls rapidly after the first 24 hours and continues to be flat for 30 days in all subgroups analyzed. The Kaplan-Meier figure suggests differences in deaths by year (graphed as biennium/triennium) (Fig. 3). However, the log-rank test could not be applied due to violations of the proportional hazards assumption ($p < 0.01$) as observed in the crossover pattern from the Kaplan-Meier plot. Gehan-Breslow generalized Wilcoxon tests indicated differences in survival between 2008 to 2009 and 2010 to 2011 ($p < 0.01$) and between 2008 to 2009 and 2012 to 2014 ($p < 0.01$) but not between 2010 to 2011 and 2012 to 2014 ($p = 0.92$).

The majority of excluded patients (n = 795,740, 69.5%) were excluded solely because their final disposition was unknown. To understand potential bias introduced by the exclusion of these patients, we conducted sensitivity analysis. Of the 795,740 patients with an unknown disposition, 707,088 (88.9%) had a valid length of stay and met inclusion criteria. We considered two extreme scenarios to assign dispositions to these patients: (1) assuming all patients with unknown disposition died at the end of their LOS and (2) assuming all patients with unknown disposition were alive at the end of their LOS. Under scenario 1, we observed decreased proportions of dead patients with AIS > =4 and an increased proportion of deaths within the first 24 hours. We also observed a difference in survival analysis results under scenario 1: no significant difference in survival for 2008 to 2009 versus 2010 to 2011 ($p = 0.25$), significant differences in survival for 2008 to 2009 versus 2012 to 2014 ($p < 0.01$) and for 2010 to 2011 versus 2012 to 2014 ($p < 0.01$). Scenario 2 did not impact dead participants (no changes to proportions of dead patients with AIS score of 4 or higher or proportion of deaths within the first 24 hours), nor did the results of survival analysis in scenario 2 differ from the survival analysis results in the original analysis. We believe scenario 2 is the most realistic because of the low ISS (median = 4) observed among the 707,088 additional patients included in sensitivity analysis, this suggests most of those patients would have survived.

DISCUSSION

The temporal distribution of death after traumatic injury was highlighted by Trunkey in a landmark 1983 article.[1] This

TABLE 3A. Time to Mortality After Admission by Mechanism and Injury Severity

		Mechanism		Injury Severity	
	All Mortalities	Blunt	Penetrating	ISS ≤ 15*	ISS > 15*
Time to Mortality	n (%)	n (%)	n (%)	n (%)	n (%)
<1 h	3,129 (2%)	1,332 (1%)	2,621 (13%)	1,697 (5%)	5,666 (5%)
1–4 h	12,110 (9%)	7,729 (7%)	2,692 (14%)	1,443 (4%)	13,177 (11%)
4–12 h	15,725 (12%)	11,758 (10%)	2,712 (14%)	2,011 (5%)	16,261 (13%)
12–24 h	14,789 (11%)	11,870 (10%)	2,778 (14%)	2,245 (6%)	14,779 (12%)
Total in 24 h	45,753 (34%)	32,689 (29%)	10,803 (55%)	7,396 (20%)	49,883 (41%)
Total mortalities	133,775 (100%)	114,197 (100%)	19,578 (100%)	37,593 (100%)	120,858 (100%)

*ISS recorded for 97% of mortalities.

TABLE 3B. Time to Mortality After Admission by AIS Scores

		AIS ≥ 4				
	All Mortalities	Head	Chest	Abdomen	Extremities	Multiple
Time to Mortality	n (%)	n (%)	n (%)	n (%)	n (%)	n (%)
<1 h	3,129 (2%)	488 (1%)	675 (8%)	488 (9%)	32 (5%)	392 (2%)
1–4 h	12,110 (9%)	3,221 (5%)	1,599 (20%)	2,130 (38%)	157 (24%)	2,725 (17%)
4–12 h	15,725 (12%)	8,342 (13%)	1,006 (12%)	1,191 (21%)	144 (22%)	2,640 (17%)
12–24 h	14,789 (11%)	10,241 (15%)	379 (5%)	285 (5%)	46 (7%)	1,782 (11%)
Total in 24 h	45,753 (34%)	22,292 (34%)	3,659 (45%)	4,094 (73%)	379 (58%)	7,539 (48%)
Total mortalities	133,775 (100%)	66,526 (100%)	8,173 (100%)	5,603 (100%)	655 (100%)	15,780 (100%)

Head, chest, abdomen, and extremity AIS scores are missing for some mortalities. Percentages in table above reflect proportion of all mortalities with available data meeting criterion listed in column header. A patient with only one AIS score of at least 4 is included in the category corresponding to the score. A patient with multiple AIS scores of at least 4 is included in the multiple category.

study identified three peaks for traumatic deaths. Immediate deaths occurred within 1 hour of injury, early deaths occurred between 1 hours and 4 hours postinjury, and late deaths occurred greater than 1 week postinjury. The development of trauma systems, and emergency medical services, have grown from these observations, as rapid transport to a trauma center was believed to be associated with improved outcomes. Numerous other advances in trauma care have occurred, with data supporting an association with increased survival. The widespread adaption of damage control surgery has decreased the number of patients dying from acute hemorrhage and coagulopathy.[9,10] This, coupled with the development of damage control resuscitation, the use of balanced transfusions, and a reduction in crystalloid infusion, has decreased hemorrhagic deaths and improved survival.[11–13] Significant changes in ICU medicine have also occurred. Evidence based critical care bundles are now routinely used to provide best practice at the bedside, and have mitigated the impact of conditions such as sepsis and acute respiratory distress syndrome.[14–16]

As progress has been made, numerous authors have reevaluated this pattern of deaths, and come to varying conclusions. These differing patterns of death may be seen due to single center experiences, with regional differences in traumatic injuries and trauma resources. One comparable study from

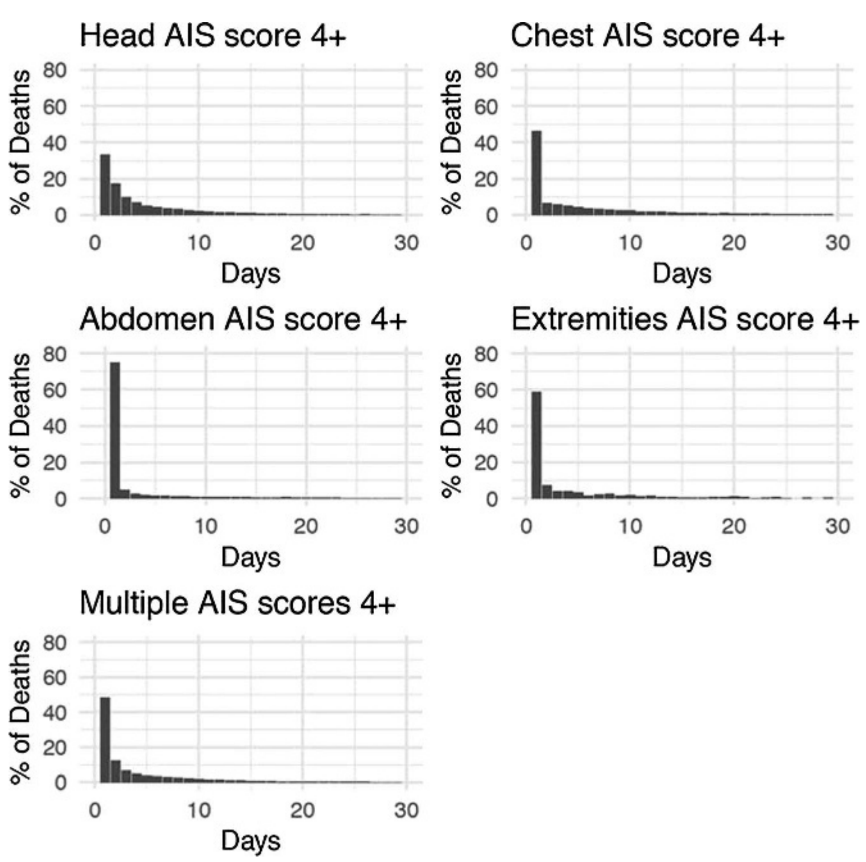

Figure 1. Distribution of deaths by severely injured system (AIS ≥ 4).

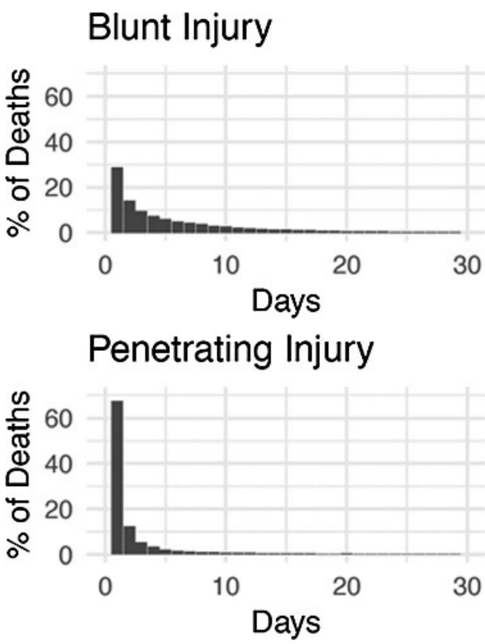

Figure 2. Distribution of deaths by mechanism of injury.

Valdez et al.[17] did evaluate the NTDB from 2002 to 2006. These researchers identified a similar rate of early deaths, 41% within 24 hours. They also found a gradual decline in deaths after the first 24 hours; however, their data continue to show an increase in mortality rates between days 11 and 20 after injury. In this study, we evaluated the contemporary timing of death after traumatic injury using a larger dataset from this same national data repository. An up-to-date understanding of these severely injured patients is necessary to evaluate the changes made in trauma care delivery, as well as to direct areas of future research, further funding, and areas for primary prevention.

Overall, this study demonstrated an early peak of deaths within 24 hours of injury. The histograms then demonstrated a rapid flattening of the mortality curve. There did not appear to be the increase in deaths that have traditionally occurred 2 weeks after injury. This would suggest that the widespread adoption of contemporary trauma resuscitation and ICU principles may be decreasing the incidence of multisystem organ failure and sepsis related deaths. These data does identify several areas for further investigation. Of patients that ultimately died, within 24 hours of injury, 73% of severe abdominal trauma, 55% of penetrating trauma, and 58% of severe extremity trauma have died. These injuries are associated with life threatening hemorrhage. Subgroup analysis of penetrating trauma with severe intra-abdominal injuries found that over 80% of the deaths in this group occurred within the first 24 hours. These patients most likely died from noncompressible hemorrhage and is an area that warrants further investigation. These results suggest continued advances in this field may lead to a significant reduction in traumatic deaths.

The number of deaths in patients with severe extremity injuries stands out as an area for further improvements in care. These are largely preventable hemorrhagic deaths, yet 58% occurred with 24 hours. This rate appears high, and could relate to differences in tourniquet use over the study period, compared to contemporary practice and the resurgent interest in civilian tourniquet use. The American College of Surgeons Committee on Trauma has launched a new national bleeding control campaign, and this will be an area for follow-up research.[18]

The large number of deaths seen after a severe head injury (50%) in this study is similar to prior studies.[8] These data demonstrate that many of these patients do survive their initial trauma, with only 34% dying during the first 24 hours. The remainder dies at a slow rate over a considerable length of time. These TBI patients impart a unique strain on the medical system, as they frequently require prolonged ICU care, often for an injury with poor recovery potential. This calls for continued efforts in primary prevention. Programs designed to combat substance abuse and impaired driving and improve seatbelt and helmet use may be beneficial in decreasing these injuries. Beyond prevention is the need for further research on the early management of TBI. Advances in this field are crucial to reducing the burden these injuries place on the health system.

This study does have several limitations. Like any large database study, the proportion of missing data can be high, in this study 21.5% of patients were excluded for missing information. We attempted to control for this by performing a sensitivity analysis. Year-to-year comparisons demonstrated differing results; this does limit the conclusions about year-to-year survival. This will be an area for further research and monitoring for performance improvement in the future. While the use of the NTDB does provide evidence at the national level, it does not provide information on the actual cause of death. The study can only hypothesize the causes of death based on timing and AIS scores. Likewise, this large database study cannot firmly establish any specific causation for the change in the mortality curves. Additionally, the NTDB does not include data on immediate deaths and out of hospital late deaths. Immediate deaths likely continue to account for a large percentage of traumatic deaths and will impact decisions about primary prevention strategies.

One additional limitation that must be considered is the changing culture within our ICUs, with regard to withdrawal

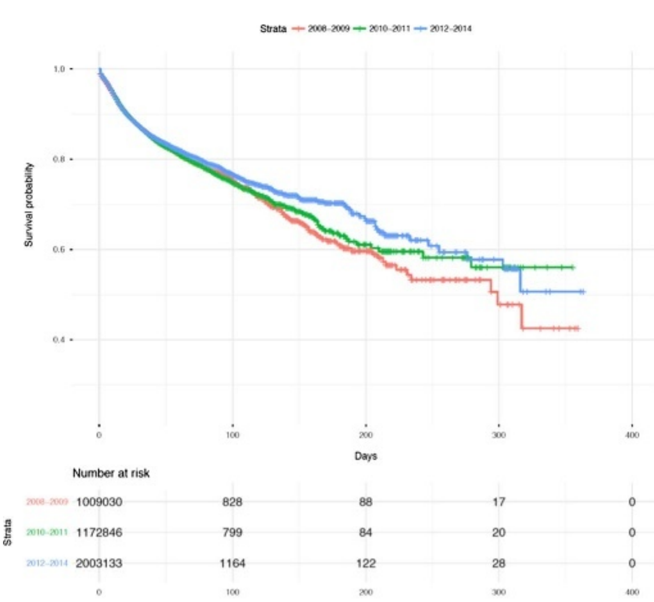

Figure 3. Survival by biennium/triennium.

of life-sustaining measures and the transition to comfort as a goal. A secondary analysis of data from the Resuscitation Outcomes Consortium evaluated deaths that had occurred within two randomized trials on hypovolemic shock and TBI.[19] This analysis found 46% of TBI deaths and 82% of shock deaths occurred with 24 hours. Survival analysis showed a similar pattern of decreasing mortality rates, as this study. Of interest, these authors were able to show that 62% of patients had a withdrawal of life-sustaining care. Our study was unable to identify patients in which deaths were related to family decisions about goals of care, because this information is not collected in the NTDB. As future research occurs on the changing distribution of trauma deaths, information on these decisions would be beneficial.

In this study, the distribution of trauma deaths no longer appears to be trimodal. The historical third peak of late deaths, at approximately 1 week to 3 weeks posttrauma has disappeared. This may reflect advances in blood product resuscitation, limiting crystalloid use, damage control surgery, and the uniform implementation of evidence based critical care management principles. This study does identify several challenges that still remain, challenges that should be seen as the critical areas to direct trauma research going forward. Traumatic brain injury continues to cause a large proportion of deaths, however, at a much slower rate. Continued research on TBI management may improve death and recovery rates. Early deaths are mainly from noncompressible hemorrhage, with high percentages from abdominal and extremity trauma. Similar to the advent of the golden hour, or early defibrillation for cardiac arrest, rapid correction of the acute disease state, or hemorrhage in this case, will likely lead to the greatest impact on outcomes. Traumatic brain injury management and early hemorrhage control must continue to be a focus of research and trauma system development.

AUTHORSHIP

Study design performed by J.B., K.I., M.S. Literature review conducted by J.B. Data collection performed by J.B. and M.S. Data analysis by J.B. and N.B. Data interpretation by J.B., K.I., and N.B. Writing performed by J.B. and K.I. All authors contributed to critical revision.

DISCLOSURE

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The data in this article are the original work of the authors. It will be presented as a Quick Shot at the 2017 Annual Meeting of the AAST.

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