Access Delayed Is Access Denied: Relationship Between Access to Trauma Center Care and Pre-Hospital Death

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BACKGROUND: Timely access to trauma center (TC) care is critical to achieve "Zero Preventable Deaths after Injury." However, the impact of timely access to TC care on pre-hospital deaths in each US state remains unknown. We sought to determine the state-level relationship between the proportion of pre-hospital deaths, age-adjusted mortality, and timely access to trauma center care.

STUDY DESIGN: We analyzed state-level analysis of adult trauma deaths reported to the CDC Wide-ranging Online Data for Epidemiological Research (WONDER) (1999 to 2016). Correlation between the state-level pre-hospital:in-hospital death ratio (PH:IH), the proportion of population with access to Level-I/II TC, and the age-adjusted mortality rate (AAMR) was determined. Population proportion with timely access to TC care was compared between states with a high pre-hospital death burden vs all other states. National estimates of potentially preventable pre-hospital deaths were calculated.

RESULTS: There were 1,949,375 trauma deaths analyzed. Overall, 1.19 times more deaths occurred pre-hospital (49%, n = 960,554) than in-hospital (42%, n = 810,387). States with better TC access had a lower AAMR ($r = -0.71$, $p < 0.05$) and relatively fewer pre-hospital deaths ($r = -0.64$, $p < 0.05$); states with higher AAMR had relatively more pre-hospital deaths ($r = 0.70$, $p < 0.05$). States with a high pre-hospital death burden had a lower proportion of population with access to Level-I/II TC within 1 hour vs all other states (63.2% vs 90.2%, $p < 0.001$). If all states had the same PH:IH death ratio as those among the best quartile for access, 129,213 pre-hospital deaths may potentially have been averted.

CONCLUSIONS: States with poor TC access have more pre-hospital deaths, which contribute to higher overall injury mortality. This suggests that in these states, improving TC access will be critical to achieve "Zero Preventable Deaths after Injury." (J Am Coll Surg 2019;228:9–20. © 2018 by the American College of Surgeons. Published by Elsevier Inc. All rights reserved.)

According to recent estimates, between 200,000 and 300,000 trauma deaths in the US are potentially preventable over a 10-year period, given optimal, high-quality trauma care.[1,2] Although these estimates include only in-hospital preventable deaths, it is likely that a substantial proportion of pre-hospital deaths may also be preventable, underscoring the importance of addressing gaps in pre-hospital care. To reduce this immense burden, the National Academies of

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Abbreviations and Acronyms

AAMR	= age-adjusted mortality rate
ACS	= American College of Surgeons
CDC WONDER	= CDC Wide-ranging Online Data for Epidemiological Research
EMS	= Emergency Medical Services
HCUP	= Healthcare Cost and Utilization Project
MCD	= Multiple Cause of Death database
NASEM	= National Academies of Sciences, Engineering and Medicine
PH:IH	= pre-hospital to in-hospital death ratio

Sciences, Engineering and Medicine (NASEM) have outlined a number of recommendations to achieve "Zero Preventable Deaths after Injury," with an emphasis on improving the quality of pre-hospital care and timely access to definitive trauma center care.[3]

Over the last few decades, the establishment of trauma centers and data-centric performance improvement has resulted in a significant reduction of in-hospital trauma mortality.[4-6] However, it is unclear if similar progress has been made in the pre-hospital setting, given variations in state-level emergency medical services (EMS) systems and lack of standardized data collection to inform process improvement.[3,7] Additionally, large areas of the country remain without timely access to definitive care due to geographic misalignment of US trauma centers with population densities.[8-10] Although these factors are known to contribute to significant geographic disparities in overall and in-hospital injury mortality, the impact of timely access to trauma center care on the burden of pre-hospital deaths has not been elucidated.

The relationship between pre-hospital death and access at the state level is critical to understand the potential of pre-hospital trauma quality improvement and inform policy decisions. Specifically, several key questions remain unanswered; for example, it is unknown if state-level pre-hospital deaths are associated with timely access to trauma center care and contribute to overall injury mortality. It is also unclear how many potentially preventable trauma deaths occur in the pre-hospital setting due to differential access to timely trauma center care. Cumulatively, these questions will help elucidate whether some US states would benefit more readily than others from improving pre-hospital care. Therefore, the primary objective of this study was to determine the state-level relationship between the relative proportion of pre-hospital to in-hospital deaths, overall age-adjusted mortality, and timely access to trauma center care. The secondary objective was to determine the number of potentially preventable pre-hospital deaths due to differences in timely access to trauma center care. We hypothesized that states with poor trauma center access will have relatively more pre-hospital deaths, resulting in higher overall injury mortality.

METHODS

Study Design

This was a retrospective cohort study of adult trauma deaths in the US between 1999 and 2016. This study was approved by the institutional review board at the Brigham and Women's Hospital.

Data source and sample selection

Our primary data source was the state-level Multiple Cause of Death (MCD) data, 1999 to 2016, produced by the Division of Vital Statistics, National Center for Health Statistics, Centers for Disease Control and Prevention, United States Department of Health and Human Services.[11] The MCD 1999 to 2016 data comprises national/sub-national mortality and population data available from the CDC Wide-ranging Online Data for Epidemiological Research (CDC WONDER), an online, public-access, searchable repository of multiple nationwide health and environmental data.[12] The MCD mortality data are based on death certificates reported through the Division of Vital Statistics, National Center for Health Statistics; the population data are based on standardized 2010 US Census Bureau estimates.[11]

Our secondary data sources were state-level estimates of proportion of population with timely access to trauma center care, which were obtained from Branas and colleagues'[8] previously published analysis. As part of the Trauma Resource Allocation Model for Ambulances and Hospitals, the authors combined data from multiple national databases to determine state-level estimates of the proportion of population with access to Level I/II and Level I/II/II TCs within 45 and 60 minutes by land and/or air transportation.[8,13] We used these data because these estimates are the only publicly available estimates of state-level timely access to definitive trauma care.

Data for supplemental analysis assessing state-level variation in early in-hospital trauma deaths were obtained from the Healthcare Cost and Utilization Project (HCUP) National Inpatient Sample (NIS) 2011.[14] Data on state-level trauma and emergency medical services (EMS) structural variables were collated from annual reports published by the National Conference of State Legislatures, United States Department of Transportation, and National Association of State EMS Officials.[15-17] The number of American College of Surgeons (ACS)-verified and state-designated trauma centers within each state were obtained from the American Trauma Society Trauma Information Exchange Program 2017.[17] Data

on rural population percentage and population density by state were obtained from the US Census Bureau.[18]

We queried the MCD data for adult (≥15 years old) trauma deaths between 1999 and 2016, recorded in all 50 US states and the District of Columbia. Although the adult trauma population is traditionally defined as 16 years old or older, we chose the ≥15 years cut-off to align with census and population-level age categories. Trauma-related deaths were identified using ICD-10 diagnosis codes as defined by the National Trauma Data Standard 2017 trauma definitions.[19] Importantly, we excluded deaths due to late effects of injuries, foreign bodies, and superficial injuries. We additionally restricted the query to only blunt and penetrating injuries, using the underlying cause of death mechanisms qualifier. Therefore, deaths resulting from the following injury mechanisms were not included: drowning, fire/flame, hot object/substance, natural/environmental, overexertion, poisoning, suffocation.

Definitions and variables

Variables obtained from the MCD 1999 to 2016 query included total number of trauma deaths, crude and age-adjusted mortality rates, place of death, and total population for each US state. The MCD reports place of death as the following categories: medical facility-inpatient, medical facility-outpatient or emergency room, medical facility-dead on arrival, medical facility-status unknown, decedent's home, hospice facility, nursing home/long-term care, other, and unknown. Deaths occurring at a decedent's home, other, or unknown were categorized as "pre-hospital deaths"; deaths occurring at medical facility-inpatient, medical facility-outpatient or emergency room, and medical facility-status unknown were categorized as "in-hospital deaths." We treated dead-on-arrivals separately for 2 reasons leading to uncertainty in classifying them as pre-hospital or in-hospital deaths. First, there are regional variations in regulations governing the pronouncement of out-of-hospital deaths by EMS providers. For example, until recently, the state of Maryland had no formal guidelines for pronouncing deaths in the field, and consequently clearly unsalvageable and/or deceased patients were being transported to hospitals to be pronounced as dead-on-arrival. Since 2013, the state has begun to implement the "Termination of Resuscitation and Pronouncement of Death in the Field" protocols to guide EMS decision making.[20] Second, the MCD lacks clinically relevant data such as transport times, estimated duration of out-of-hospital arrest, initial Glasgow Coma Scale, pulse rate, or blood pressure to more accurately classify dead-on-arrivals as pre-hospital or in-hospital deaths. We also treated deaths at hospice facility and nursing home/long-term care separately due to challenges in accurately discerning treatment intents and trajectories.

Timely access to a trauma center was defined as the proportion of population with access to a Level I/II trauma center within 1 hour by land or air transportation.[8] For supplemental analyses, access to a Level I/II trauma center within 45 minutes and access to a Level I/II/III trauma center within 45 minutes to 1 hour were also considered.

The primary variable of interest was the state-level ratio of pre-hospital to in-hospital deaths (PH:IH).

Statistical analysis

We used descriptive statistics and generated state-level maps to report the geographic variation in PH:IH death ratio, proportion of population with access to Level I/II trauma center within 1 hour, and age-adjusted mortality rate. Multiple scatter plots were generated to ascertain the relationship between PH:IH death ratio, trauma center access, and age-adjusted mortality rate. Pearson's correlation coefficient was calculated where data were normally distributed, and Spearman's rank correlation was used for nonparametric distributions. A subset analysis was performed to explore the relationship within urban and rural populations. States with higher than national average PH:IH and age-adjusted mortality rate were classified as "high pre-hospital burden" states. This cumulative cutoff was chosen to identify states in which a relatively higher number of pre-hospital deaths may be contributing to higher overall age-adjusted mortality rate over and above the national average. These "high pre-hospital burden" states were then compared with the rest of the states, using a *t*-test, to determine the proportion of population with access to a Level I/II and/or I/II/III trauma center within 45 to 60 minutes.

We then sought to determine a national estimate of potentially preventable pre-hospital trauma deaths using previously published methods.[1,21] States were classified into quartiles of proportion of population with Level I/II trauma center access within 1 hour. The average PH:IH death ratio at the best quartile for access (reference quartile) was compared with each subsequent access quartile using ANOVA with Bonferroni correction for multiple comparisons. The expected number of pre-hospital deaths in each quartile was calculated if all states had the same PH:IH death ratio as those among the best quartile for access. Potentially preventable pre-hospital trauma deaths were then calculated as a difference between observed and expected deaths at each access quintile.

Last, we explored structural differences among state trauma and EMS systems, including presence of legislation mandating statewide advisory committees, establishment of trauma registries, and pre-hospital injury

data linkage with trauma registry. The number of ACS-verified and state-designated Level I/II trauma centers per million population was also compared between high pre-hospital burden states vs rest of the states.

We performed 2 supplementary analyses to assess if better trauma center access was associated with a higher number of dead-on-arrivals and early in-hospital deaths. Using data from the MCD 1999 to 2016, we compared the rate of dead-on-arrivals among high pre-hospital burden states vs rest of the states, using a *t*-test. A scatter plot of timely access to a trauma center and state level dead-on-arrival rate was also generated, and a correlation coefficient was calculated. To determine the association between improved trauma center access and early in-hospital mortality, we used the HCUP National Inpatient Sample 2011 data with similar inclusion/exclusion criteria, as described previously. Early in-hospital mortality was defined as deaths occurring within 24 hours of admission. A multivariate logistic regression analysis was performed with early in-hospital mortality as the outcome, adjusting for age, sex, mechanism of injury, and anatomic injury severity (using Trauma Mortality Prediction Model).[22,23] The state-level, early in-hospital mortality rate was calculated and the difference between average mortality rate among high pre-hospital burden states vs rest of the states was ascertained using a *t*-test.

All analyses were performed using Stata 14/MP statistical software package (StataCorp). A 2-sided $p < 0.05$ was considered statistically significant.

RESULTS

We included and analyzed 1,949,375 adult trauma deaths between the years 1999 and 2016. The national age-adjusted mortality rate was 44.4 (±SD 1.63) per 100,000 population. Figure 1A describes the state-level variation in age-adjusted mortality rate; there was a 2.8-fold difference between the states with lowest (Massachusetts, 25.2 per 100,000 population) vs highest mortality (Mississippi, 71.3 per 100,000 population). Nationally, 960,544 (49.3%) deaths were classified as pre-hospital and 810,387 (41.6%) as in-hospital; the remainder of the deaths occurred at nursing home/long-term care (4.5%, n = 88,478), were dead-on-arrival (3.0%, n = 57,656), or died at a hospice facility (1.7%, n = 32,300). The national average PH:IH death ratio was 1.19. Figure 1B describes the state-level variation in PH:IH death ratio; there was a 4.6-fold difference between the state with the lowest (District of Columbia, 0.49) vs the highest (Alaska, 2.24) PH:IH ratio. Nationally, 84.1% of population had access to a Level I/II trauma center within 1 hour. Figure 1C describes the state-level variation in Level I/II trauma center access; there was a 16.4-fold difference between the states with the lowest (Arkansas, 6.1%) vs highest (Connecticut, New Jersey, Rhode Island, District of Columbia, 100%) access. Table 1 summarizes the state-level PH:IH death ratios, AAMR, percentage of rural population and population density in rural areas.

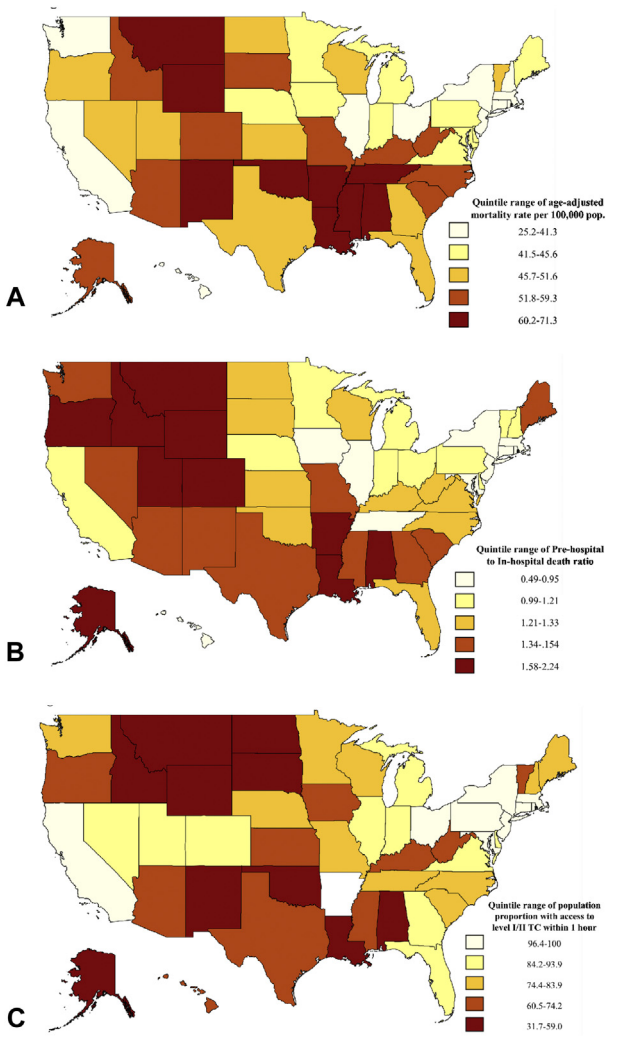

Figure 1. State-level variation in (A) age-adjusted mortality rate per 100,000 population, (B) the ratio of pre-hospital to in-hospital deaths, and (C) access to Level I/II trauma center within 1 hour. Arkansas was a significant low-outlier, with 6.1% of population with access to Level I/II trauma center within 1 hour.

Figure 2 describes the relationship between PH:IH death ratio, age-adjusted mortality rate, and timely access to Level I/II trauma center care. As the state-level proportion of population with access to a Level I/II trauma center increased, both the overall age-adjusted mortality rate ($r = -0.71$, $p < 0.05$) and the ratio of PH:IH deaths

Table 1. State-Level Distribution of Ratio of Pre-Hospital to In-Hospital Death, Age-Adjusted Mortality Rate, Percent Rural Population, and Rural Population Density (in Ascending Order with Respect to Pre-Hospital:In-Hospital Death Ratio)

State	Ratio of pre-hospital to in-hospital death	Age-adjusted mortality rate, per 100,000 population	Percent rural population, %*	Population density of rural areas, persons per square mile*
District of Columbia	0.49	51.8	0	n/a
Massachusetts	0.51	25.2	8.03	109.2
Rhode Island	0.52	32.1	9.27	154
Connecticut	0.59	31.8	12.01	142.3
Hawaii	0.60	30.7	8.07	18.2
New York	0.72	28.5	12.13	54.6
New Jersey	0.77	28.4	5.32	105.5
Illinois	0.81	37.1	11.51	28.6
Tennessee	0.82	60.2	33.61	55.6
Maryland	0.90	41.9	12.8	96
Iowa	0.95	42.3	35.98	20
New Hampshire	0.99	37.3	39.7	62.9
Vermont	1.03	48.6	61.1	42.2
Ohio	1.05	41.3	22.08	69.9
Pennsylvania	1.06	42.5	21.34	67.7
Michigan	1.07	42.6	25.43	47.5
Delaware	1.09	42.0	16.7	97.3
Nebraska	1.11	44.3	26.87	6.4
Minnesota	1.17	42.7	26.73	18.2
California	1.17	35.3	5.05	12.7
National average	**1.18**	**44.4**	**19.3**	**17.4**
Indiana	1.21	45.6	27.56	53.7
Florida	1.21	48.2	8.84	35.9
North Carolina	1.21	53.3	33.91	73.5
Virginia	1.24	43.4	24.55	53.3
West Virginia	1.28	59.1	51.28	40.6
Kansas	1.28	49.8	25.8	9.1
Kentucky	1.29	57.3	41.62	47.4
South Dakota	1.29	55.2	43.35	4.7
Oklahoma	1.30	62.6	33.76	18.8
Wisconsin	1.30	47.7	29.85	32.5
North Dakota	1.33	48.8	40.1	3.9
Missouri	1.34	55.1	29.56	26.6
Maine	1.36	41.5	61.34	26.7
Texas	1.43	47.5	15.3	15.2
Arizona	1.43	58.7	10.19	5.8
Washington	1.45	41.2	15.95	16.7
Georgia	1.45	51.6	24.93	45.8
South Carolina	1.45	59.3	33.67	56.3
Mississippi	1.47	71.3	50.65	32.8
Nevada	1.53	51.0	5.8	1.4
New Mexico	1.54	69.9	22.57	3.9
Arkansas	1.58	61.5	43.84	25.1
Louisiana	1.60	62.1	26.81	29.5
Utah	1.62	45.7	9.42	3.2
Colorado	1.63	52.5	13.85	6.8

(Continued)

Table 1. Continued

State	Ratio of pre-hospital to in-hospital death	Age-adjusted mortality rate, per 100,000 population	Percent rural population, %*	Population density of rural areas, persons per square mile*
Alabama	1.67	63.9	40.96	40.4
Oregon	1.79	46.9	18.97	7.7
Idaho	1.86	53.4	29.42	5.6
Wyoming	1.92	68.2	35.24	2
Montana	1.92	67.9	44.11	3
Alaska	2.24	59.3	33.98	0.4

Bold text identifies national averages.
*Data from the US Census Bureau 2010 Census.

decreased ($r = -0.64$, $p < 0.05$), demonstrating a moderate to strong negative correlation (Figs. 2A and 2B). Additionally, the PH:IH death ratio and age-adjusted mortality rate demonstrated a strong positive correlation ($r = 0.70$, $p < 0.05$); states with a relatively higher proportion of pre-hospital deaths also had higher overall age-adjusted mortality rate. This relationship persisted for both urban ($r = 0.67$, $p < 0.05$) and rural population subsets ($r = 0.62$, $p < 0.05$) (Figs. 3A and 3B). Additionally, states with higher percentages of rural population had higher PH:IH death ratios ($r = 0.38$, $p < 0.05$); those with higher rural population density had significantly lower PH:IH death ratios ($r = -0.70$, $p < 0.01$).

States with a higher than national average PH:IH death ratio and age-adjusted mortality rate also demonstrated significantly worse trauma center access compared with the rest of the states (Fig. 4). This difference was greatest in the proportion of the population with Level I/II trauma center access within 60 minutes (63.2% in high pre-hospital burden states vs 90.2% among rest of the states, $p < 0.01$).

Table 2 describes the national estimates of potentially preventable pre-hospital trauma deaths. States within the best quartile for timely trauma center access had significantly lower age-adjusted mortality rate and PH:IH death ratio vs each subsequent quartile. If all states

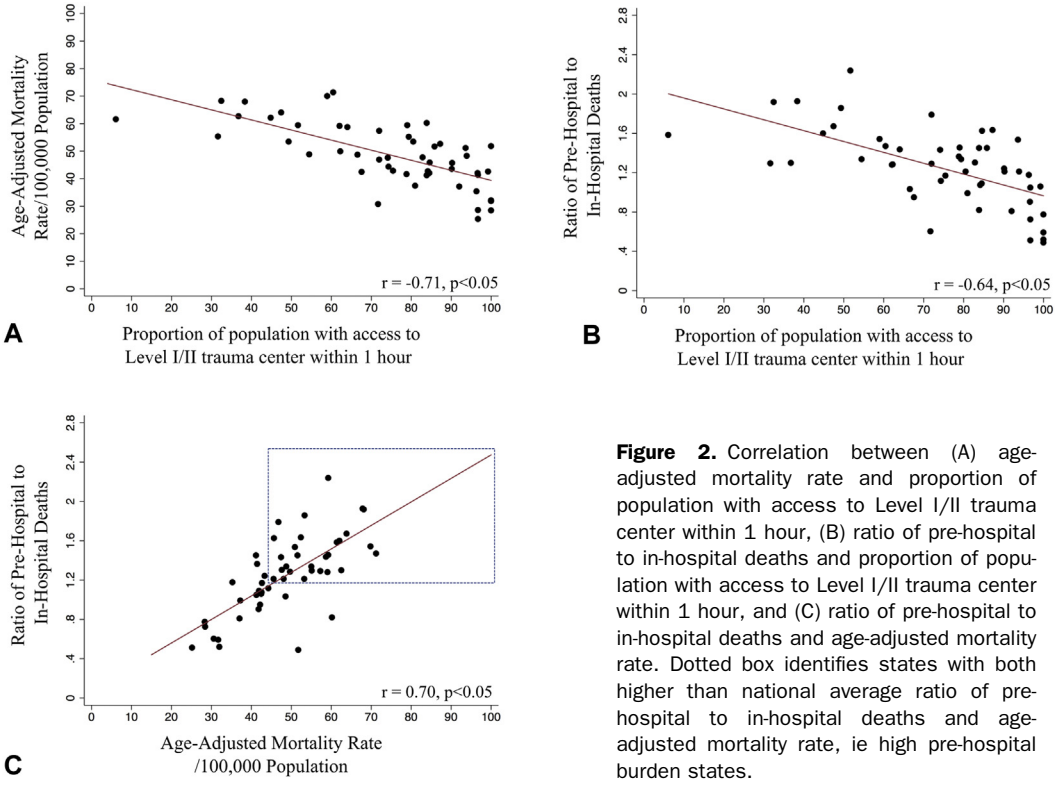

Figure 2. Correlation between (A) age-adjusted mortality rate and proportion of population with access to Level I/II trauma center within 1 hour, (B) ratio of pre-hospital to in-hospital deaths and proportion of population with access to Level I/II trauma center within 1 hour, and (C) ratio of pre-hospital to in-hospital deaths and age-adjusted mortality rate. Dotted box identifies states with both higher than national average ratio of pre-hospital to in-hospital deaths and age-adjusted mortality rate, ie high pre-hospital burden states.

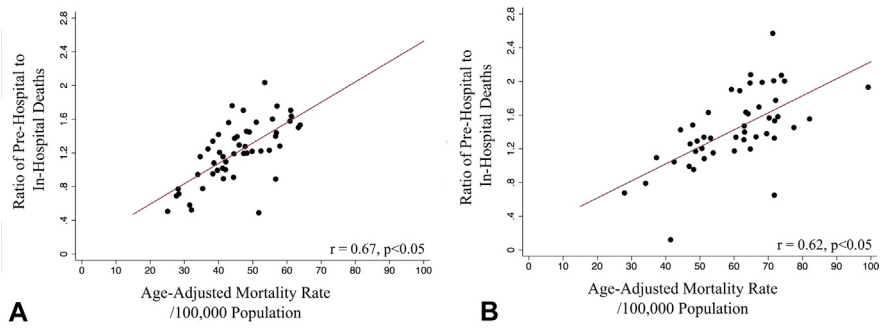

Figure 3. Correlation between ratio of pre-hospital to in-hospital deaths and age-adjusted mortality rate for (A) urban deaths and (B) rural deaths. Each point on the scatter plot represents a US state.

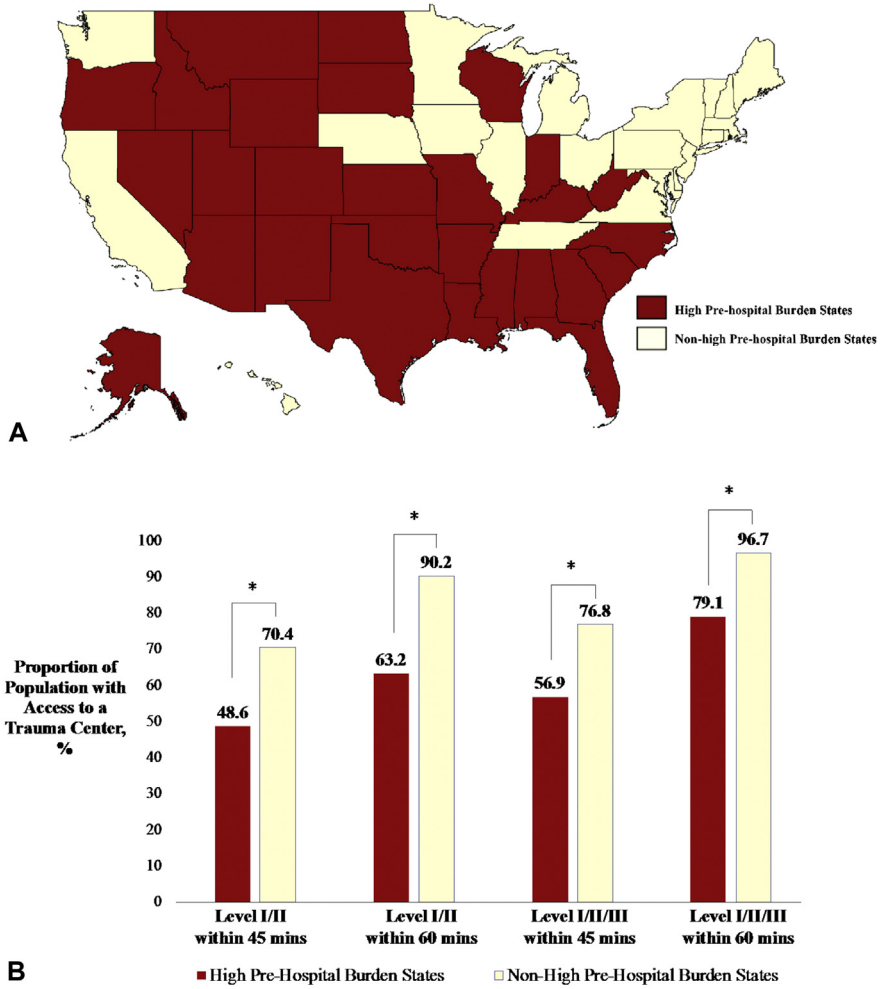

Figure 4. (A) Map depicting states with high pre-hospital burden of trauma deaths (defined as those with higher than national average pre-hospital to in-hospital death ratio, and age-adjusted mortality rate). (B) Proportion of population with access to a trauma center in high pre-hospital burden states vs all other states. States with both higher than national average ratio of pre-hospital to in-hospital deaths and age-adjusted mortality rate were classified as high pre-hospital burden states. *$p < 0.01$.

Table 2. National Estimate of the Number of Potentially Preventable Pre-Hospital Trauma Deaths

Population proportion with Level I/II trauma center access within 1 hour		Age-adjusted mortality rate per 100,000 population	Average pre-hospital: in-hospital death ratio*,†	Observed pre-hospital death, n	Expected pre-hospital death, n	Potentially preventable pre-hospital death, n	Percentage of potentially preventable pre-hospital death
Quartile	Average proportion						
Q1	97.5	38.2	0.88	319,125	Ref	Ref	Ref
Q2	85.5	46.2	1.22	261,041	218,783	42,258	16.2
Q3	72.2	48.1	1.25	238,333	187,647	50,686	21.3
Q4	44.2	61.8	1.61	141,982	105,713	36,269	25.5
Total						129,213	

*Ratio of pre-hospital to in-hospital deaths.
†Pre-hospital:in-hospital ratio for quartile 1 was significantly different vs quartiles 2, 3, and 4 (Bonferroni corrected $p < 0.05$).

had the same PH:IH death ratio as those among the best quartile for access, 129,213 pre-hospital deaths (7,601 per year) may potentially have been averted. At the worst quartile for trauma center access, 25.5% (n = 36,269) of all pre-hospital deaths were deemed potentially preventable.

Table 3 describes the structural difference between state trauma and EMS systems. Apart from the unexpected finding that more states with high pre-hospital death burden had a legislatively mandated statewide trauma registry, no other state-level structural differences were seen. Importantly, pre-hospital and injury data integration with trauma registry and the number of Level I/II centers per million population were not significantly different between the 2 groups of states.

Results of the supplemental analysis suggested that there was no difference between dead-on-arrival rates between high pre-hospital burden states and rest of the states (1.10 vs 1.74 per 100,000 pop., p = 0.15) and no correlation between dead-on-arrival rate and proportion of population with access to Level I/II trauma center within 1 hour (r = 0.08, p = 0.56). Additionally, there was no difference between rate of early deaths between the 2 groups of states (0.79 vs 0.80, p = 0.55).

DISCUSSION

This nationally representative study of more than 1.9 million trauma deaths demonstrates that states with poor trauma center access have relatively more pre-hospital deaths, which may contribute toward a higher overall injury mortality rate. If all states had the same, relatively low proportion of pre-hospital deaths as states with the best access, nearly 130,000 pre-hospitals deaths could potentially have been averted over a 17-year period. Additionally, improved state-level trauma center access did not inflate the rate of dead-on-arrivals or early deaths. Together, these data suggest that in some states, improving pre-hospital care and access to definitive trauma care will be critical in order to achieve the "Zero Preventable Deaths after Injury" mandate.[3]

Dedicated efforts in the last few decades have profoundly improved the care of the injured patient.[4,24,25] Since the 1970s, multiple legislative efforts have resulted in the funding, development, and evolution of the modern trauma system.[26-28] In 1976, the American College of Surgeons published its first *Resources for the Optimal Care of the Injured* manual to help standardize trauma care and became the basis for trauma center verification nationwide.[29] Concurrently, improvements in surgical critical care, hemorrhage control, resuscitation science, trauma education, and the institution of trauma center

Table 3. Structural Differences among State Trauma and Emergency Medical Services Systems

Structural variable description*	High pre-hospital burden state, n = 28, n (%)	Non-high pre-hospital burden state, n = 23, n (%)	p Value	States with a lower pre-hospital:in-hospital death ratio† (1st-50th percentile), n = 26, n (%)	States with a higher pre-hospital:in-hospital death ratio† (51st-100th percentile), n = 25, n (%)	p Value
Presence of a statewide trauma advisory committee	14 (50.0)	12 (52.2)	0.87	12 (46.2)	14 (56.0)	0.58
Presence of a statewide EMS advisory committee	14 (50.0)	12 (52.2)	0.87	13 (50.0)	13 (52.0)	1.00
Statewide trauma registry mandated by statute	26 (92.9)	14 (60.9)	0.01‡	16 (61.5)	24 (96.0)	<0.01‡
Statute mandates trauma registry integration with pre-hospital data	11 (39.3)	8 (34.8)	0.78	10 (38.5)	9 (36.0)	1.00
State trauma program located within/ accountable to state EMS office	14 (50.0)	11 (47.8)	0.87	12 (46.2)	13 (52.0)	0.78
EMS data linked with the trauma registry	12 (42.9)	8 (34.8)	0.58	11 (42.3)	9 (36.0)	0.78
EMS patient injury data monitored by state	9 (32.1)	13 (56.5)	0.09	13 (50.0)	9 (36.0)	0.40
Number of ACS-verified Level I/II trauma centers per million population	1.55	1.21	0.36	1.24	1.56	0.39
Number of state-designated Level I/II trauma centers per million population	2.01	1.94	0.85	1.92	2.03	0.77

*Data collated from National Conference of State Legislatures, United States Department of Transportation and National Association of State EMS Officials reports (cited in text).
†Ratio of pre-hospital to in-hospital deaths.
‡Statistically significant.
ACS, American College of Surgeons; EMS, emergency medical services.

care led to a significant decline in in-hospital mortality, from more than 20% to 4% among the severely injured.[4,24,29-33] Data-driven performance feedback, made possible through dedicated trauma registries and care improvement initiatives, such as the ACS Trauma Quality Improvement Program, is now driving future gains via continuous quality improvement.[5] Although in-hospital trauma mortality has decreased substantially, evidence from recent military experiences demonstrate that most preventable deaths occur in the pre-hospital setting.[34-36] However, little is known about the magnitude of and factors influencing pre-hospital trauma deaths in the civilian sector.

Our study demonstrates that nationwide, more deaths occur in the pre-hospital setting, and there is a large state-level variation in the ratio of pre-hospital to in-hospital deaths. This suggests that although state-level in-hospital trauma mortality has improved, the number of pre-hospital deaths remains high in certain states. These findings corroborate with Champion and colleagues'[37] recent analysis evaluating 1.6 million vehicle-associated deaths between 1978 and 2013, reported by the National Highway Traffic Safety Administration. The authors found that between 1978 and 2013, the proportion of in-hospital deaths decreased from nearly 70% to 44%, while the proportion of pre-hospital deaths increased from 23% to 56%; every year since the year 2000, more trauma deaths occurred in the pre-hospital setting than in-hospital. Our study builds on this previous work and found that certain US states have substantially more pre-hospital deaths than others. Several studies demonstrated that proximity and access to trauma center care are associated with improved overall survival after injury.[38,39] However, our study provides the first direct evidence to suggest that states with poor access to definitive trauma center care have more pre-hospital deaths, which contributes toward higher overall injury mortality. This effect is further magnified in rural population clusters, in line with previous work documenting the "rural risk" after injury.[40,41]

Although the optimum ratio of pre-hospital to in-hospital deaths remains to be defined, an aim to achieve parity through improved access to care may be a reasonable initial target for states with a high pre-hospital death burden. This may include measures such as improving quality of pre-hospital care, improving pre-hospital times through air-medical transportation, and optimizing placement of trauma centers. Overall, the ratio of pre-hospital to in-hospital deaths can serve as an actionable metric to benchmark state and regional trauma system performance.

Recent civilian studies have estimated that between 20,000 and 30,000 in-hospital trauma deaths may be potentially preventable each year.[1,2] Our results provide the first nationwide estimates of potentially preventable pre-hospital deaths and suggest that approximately 7,600 deaths per year may be averted through improved access to definitive care. We believe that this estimate captures only a fraction of the true burden of civilian preventable pre-hospital deaths as it relates to overall access to Level I/II trauma center care. Importantly, this estimate does not account for patients who were delayed in transit but ultimately died in-hospital due to progressive time-sensitive physiologic derangements, and it does not consider the impact of quality of pre-hospital treatment (time to extrication, timely hemorrhage control, blood product administration, etc) on individual patients. However, this estimate also suggests that improving timely access to trauma center care alone may be an opportunity to save thousands of lives each year.

Lastly, our study found no significant structural differences among state trauma and EMS systems to explain the variation in pre-hospital deaths. Additionally, the number of trauma centers per million population were not associated with the burden of pre-hospital deaths. The fact that disparities in pre-hospital deaths exist despite similarities in legislative and policy-level provisions seems to suggest the role of more granular aspects of pre-hospital care delivery and the overall importance of timely transport to definitive trauma center care.

This study has several important limitations. Pre-hospital deaths were defined as those occurring at the decedent's home, other, or unknown. Although this classification is not validated, we based this on several reasonable assumptions. Deaths after injury can occur either pre-hospital, in-hospital, or post-discharge. Deaths occurring at a medical facility are likely to be accurately certified as such on the death certificate. Therefore, pre-hospital deaths must be distinguished from post-discharge deaths. To ensure this, we excluded all deaths occurring at nursing home/long-term care and hospice facilities because they may potentially represent post-discharge deaths. Additionally, we excluded deaths due to "late effects of injuries," which may also contribute toward post-discharge deaths. Therefore, it is reasonable to suggest that all or the vast majority of the remainder of deaths likely occurred in the pre-hospital setting.

Another limitation pertains to the use of year 2005 estimates of state-level proportion of population with timely trauma center coverage, as reported by Branas and associates.[8] Due to the passage of time and institution of newer trauma centers, these data may slightly underestimate current trauma center access. However, we chose to include these data for 2 reasons. First, these data represent the best publicly available estimates of state-level trauma

center access, including the contribution of trauma resources of neighboring states. Second, a recent follow-up analysis by the same group of authors demonstrated that although timely access to trauma centers improved nationwide, state-level geographic disparities still persisted. Therefore, although these data may somewhat underestimate the true population proportion with timely access to a trauma center, the relative differences between states appear well-preserved, rendering the relationships described in this study applicable.

Another limitation of this work is the lack of adjustment of year or assessment of temporality due to MCD data use restriction, which suppresses queries with cell sizes ≤ 9. Therefore, state-level data queries for each individual year had several missing death counts, rendering a temporally directed analysis impossible. Last, the MCD database lacks patient-level and clinical data such as demographics, injury-specific information, and details regarding pre-hospital timing and care. Therefore, the impact of delays in access to definitive trauma care on individual patient outcomes cannot be determined. In this context, we were unable to specifically account for prolonged "discovery time" in injuries occurring in more remote regions; while this may reduce the opportunity for EMS to intervene in time and yet increase the pre-hospital death rate, it ultimately highlights a systems-level deficiency in timely access to definitive care. We were also unable to ascertain the quality of interventions performed, especially in the pre-hospital setting. The latter highlights one of the recommendations of the recently published NASEM report to collect nationally representative trauma data across the entire continuum of care in order to improve pre- and post-trauma care in addition to on-going in-hospital quality improvement initiatives.

CONCLUSIONS

This study demonstrates that states with poor trauma center access have a higher burden of pre-hospital deaths, which may contribute toward their higher overall injury mortality. A discussion on how to reduce pre-hospital deaths is beyond the scope of this study. However, we strongly believe that establishment of an integrated trauma data repository that can track individual patient outcomes across the entire continuum of trauma care (pre-hospital, in-hospital, and post-discharge care) will enable states with poor access to trauma center improve their outcomes. By identifying system-level deficiencies within a regional trauma system, these data will allow a needs-based assessment to guide the establishment of EMS care and definitive trauma center care. For example, in certain remote regions, longer discovery and transport times may need to be addressed; in other regions, the quality of pre-hospital care may need to be improved. The American College of Surgeons Committee on Trauma recently convened a conference to establish the Needs Based Assessment of Trauma Systems (ACS NBATS) tool centered around a grounding principle that trauma center designation within a geographic region must be based on population trauma needs.[42,43] An integrated trauma data repository will greatly supplement this effort by providing clinically relevant data to guide whether a state/county needs additional EMS resources, improvement in the quality of existing pre-hospital care, or establishment of more trauma centers. Ultimately, our work suggests that improvements in pre-hospital care and access to definitive care are essential and should be prioritized in order to achieve "Zero Preventable Deaths after Injury."

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