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Association of Emergency Department Pediatric Readiness With Mortality to 1 Year Among Injured Children Treated at Trauma Centers

Craig D. Newgard, MD, MPH; Amber Lin, MS; Jeremy D. Goldhaber-Fiebert, PhD; Jennifer R. Marin, MD, MSc; McKenna Smith, MPH; Jennifer N. B. Cook, GCPH; Nicholas M. Mohr, MD, MS; Mark R. Zonfrillo, MD, MSCE; Devin Puapong, MD; Linda Papa, MD, MSc; Robert L. Cloutier, MD, MCR; Randall S. Burd, MD, PhD; for the Pediatric Readiness Study Group

Supplemental content

IMPORTANCE There is substantial variability among emergency departments (EDs) in their readiness to care for acutely ill and injured children, including US trauma centers. While high ED pediatric readiness is associated with improved in-hospital survival among children treated at trauma centers, the association between high ED readiness and long-term outcomes is unknown.

OBJECTIVE To evaluate the association between ED pediatric readiness and 1-year survival among injured children presenting to 146 trauma centers.

DESIGN, SETTING, AND PARTICIPANTS In this retrospective cohort study, injured children younger than 18 years who were residents of 8 states with admission, transfer to, or injury-related death at one of 146 participating trauma centers were included. Children cared for in and outside their state of residence were included. Subgroups included those with an Injury Severity Score (ISS) of 16 or more; any Abbreviated Injury Scale (AIS) score of 3 or more; head AIS score of 3 or more; and need for early critical resources. Data were collected from January 2012 to December 2017, with follow-up to December 2018. Data were analyzed from January to July 2021.

EXPOSURES ED pediatric readiness for the initial ED, measured using the weighted Pediatric Readiness Score (wPRS; range, 0-100) from the 2013 National Pediatric Readiness Project assessment.

MAIN OUTCOMES AND MEASURES Time to death within 365 days.

RESULTS Of 88 071 included children, 30 654 (34.8%) were female; 2114 (2.4%) were Asian, 16 730 (10.0%) were Black, and 49 496 (56.2%) were White; and the median (IQR) age was 11 (5-15) years. A total of 1974 (2.2%) died within 1 year of the initial ED visit, including 1768 (2.0%) during hospitalization and 206 (0.2%) following discharge. Subgroups included 12 752 (14.5%) with an ISS of 16 or more, 28 402 (32.2%) with any AIS score of 3 or more, 13 348 (15.2%) with a head AIS of 3 or more, and 9048 (10.3%) requiring early critical resources. Compared with EDs in the lowest wPRS quartile (32-69), children cared for in the highest wPRS quartile (95-100) had lower hazard of death to 1 year (adjusted hazard ratio [aHR], 0.70; 95% CI, 0.56-0.88). Supplemental analyses removing early deaths had similar results (aHR, 0.75; 95% CI, 0.56-0.996). Findings were consistent across subgroups and multiple sensitivity analyses.

CONCLUSIONS AND RELEVANCE Children treated in high-readiness trauma center EDs after injury had a lower risk of death that persisted to 1 year. High ED readiness is independently associated with long-term survival among injured children.

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Author Affiliations: Author affiliations are listed at the end of this article.

Group Information: Members of the Pediatric Readiness Study Group appear at the end of the article.

Corresponding Author: Craig D. Newgard, MD, MPH, Center for Policy and Research in Emergency Medicine, Department of Emergency Medicine, Oregon Health & Science University, 3181 SW Sam Jackson Park Rd, Mail Code CR-114, Portland, OR 97239-3098 (newgardc@ohsu.edu).

Emergency department (ED) pediatric readiness refers to the resources, equipment, expertise, protocols, and oversight required to adequately care for acutely ill and injured children.[1] There is large variability of ED pediatric readiness across EDs[2] and trauma centers.[3] Two studies have shown that high ED pediatric readiness is associated with improved in-hospital survival.[4,5] One study included critically ill children in 5 states[4] and the other included injured children admitted to trauma centers in 50 states.[5] Whether the benefit of treatment in a high-readiness ED extends to injured children classified as dead on arrival (DOA) and beyond hospital discharge remains unknown.

Because injury remains the leading cause of death and years of potential life lost among children in the US,[6,7] changes are urgently needed to improve survival. Short-term (in-hospital) survival is higher for children treated at pediatric trauma centers[8-10] and at trauma centers with high ED pediatric readiness.[5] Studying survival beyond hospitalization and the need for research linking long-term outcomes to the early management of trauma patients was highlighted in a 2016 national report[11] and is highly relevant for children to decrease the long-term morbidity and mortality of injury.

In this study, we evaluated the association between ED pediatric readiness from the initial trauma center ED and days to death to 1 year among injured children from 8 states receiving care in 146 trauma centers. This study was a follow-up to previous research demonstrating the association between high ED pediatric readiness and improved in-hospital survival in US trauma centers.[5]

Key Points

Question Is high emergency department (ED) pediatric readiness associated with long-term survival in US trauma centers?

Findings In this cohort study of 88 071 injured children from 8 states cared for in 146 EDs of trauma centers in 15 states, receiving initial care in an ED in the highest quartile of readiness was associated with 30% lower hazard of death to 1 year. The findings were consistent after removing children who died early.

Meaning Results of this study indicate high ED readiness is independently associated with long-term survival among injured children.

Methods

Study Design

We performed a retrospective cohort study that was reviewed and approved by Institutional Review Boards at Oregon Health & Science University and the University of Utah School of Medicine, which waived the requirement for informed consent. We used the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) reporting guideline.[12]

Study Setting

We included 146 trauma centers (levels 1 to 4) in 15 states and the District of Columbia that participate in the National Trauma Data Bank (NTDB). The NTDB data are collected using the National Trauma Data Standard,[13] which use standardized data fields to capture information from the initial ED presentation and hospitalization. We limited our analysis to EDs that treated at least 50 children during the study period (about 10 pediatric trauma patients per year) to decrease the effect of small samples, increase stability in the estimates, and allow model convergence.

Patient Population

We included injured children younger than 18 years who were residents of 8 states (based on home zip code) and met standardized NTDB inclusion criteria (an injury diagnosis and hospital admission, interhospital transfer, or injury-related death in a participating trauma center[14]) from January 1, 2012, through December 31, 2017, with follow-up through December 31, 2018. The cohort was based on state residency to assure eligibility for matching to vital statistics records in these states, including deaths occurring outside of the home state. The 8 states included Arizona, California, Florida, Iowa, Maryland, North Carolina, New Jersey, and Utah. We included all children arriving to an ED, including those who were DOA, to evaluate the frequency and timing of mortality for all injured children arriving to an ED. Study dates were aligned with the 2013 National Pediatric Readiness Project (NPRP) assessment. For children transferred to another trauma center, we linked available records from the second hospital. We excluded children missing information from the initial ED, transferred to another hospital without a second hospital record, and receiving care in an ED without a matched NPRP assessment (eFigure in Supplement 1).

We prespecified high-risk subgroups of children likely to be affected by the quality of care provided in the initial ED: those with an Injury Severity Score (ISS) of 16 or higher[15-17]; any Abbreviated Injury Scale (AIS) score of 3 or higher[16]; a head AIS score of 3 or higher (serious brain injury); and those requiring early critical resources.[18] Early critical resources was based on a consensus definition for children[18] and included critical interventions and surgical procedures performed within 24 hours of the initial ED presentation.

National Pediatric Readiness Survey

The primary exposure was ED pediatric readiness for the initial ED, measured using the weighted Pediatric Readiness Score (wPRS) from the 2013 NPRP assessment.[2] The NPRP assessment was a national 55-question assessment of EDs providing 24-hour emergency care, based on national guidelines.[19] The assessment was completed from January 1 through August 31, 2013, and has been described in detail elsewhere.[2] The wPRS is a weighted score from 0 to 100 based on questions in 6 domains (pediatric care coordination, ED personnel, quality improvement, patient safety, policies and procedures, and equipment[2]), with a score of 100 representing complete guideline compliance and the highest level of ED pediatric readiness. The weighted score was developed by a national work group using a modified Delphi process, with focus on questions of moderate to high clinical importance.[20] We linked the

Table 1. Characteristics of Injured Children Presenting to 146 US Trauma Center Emergency Departments (EDs) by Quartile of ED Pediatric Readiness

Characteristic	No. (%)				
		ED pediatric readiness, quartile			
	Overall (N = 88 071)	First (wPRS, 32-69) (n = 10 081)	Second (wPRS, 70-87) (n = 11 285)	Third (wPRS, 88-94) (n = 18 246)	Fourth (wPRS, 95-100) (n = 48 459)
Demographic characteristics					
Age, median (IQR), y	11 (5-15)	15 (8-16)	14 (8-16)	12 (5-16)	9 (4-14)
Age group, y					
0-4	21 487 (24.4)	1449 (14.4)	1829 (16.2)	3898 (21.4)	14 311 (29.5)
5-12	28 873 (32.8)	2344 (23.3)	2634 (23.3)	5530 (30.3)	18 365 (37.9)
13-15	17 640 (20.0)	2234 (22.2)	2508 (22.2)	3792 (20.8)	9106 (18.8)
16-17	20 071 (22.8)	4054 (40.2)	4314 (38.2)	5026 (27.5)	6677 (13.8)
Sex					
Female	30 654 (34.8)	3292 (32.7)	3689 (32.7)	6138 (33.6)	17 535 (36.2)
Male	57 417 (65.2)	6789 (67.3)	7596 (67.3)	12 108 (66.4)	30 924 (63.8)
Race[b]					
Asian	2114 (2.4)	255 (2.5)	195 (1.7)	615 (3.4)	1050 (2.2)
Black	16 730 (19.0)	1844 (18.3)	2379 (21.1)	2820 (15.5)	9687 (20.0)
Other/multiple[c]	19 731 (22.4)	2172 (21.5)	1931 (17.1)	4248 (23.3)	11 381 (23.5)
White	49 496 (56.2)	5811 (57.6)	6780 (60.1)	10 563 (57.9)	26 342 (54.4)
Any comorbidities	7255 (8.2)	844 (8.4)	990 (8.8)	1736 (9.5)	3685 (7.6)
Mechanism of injury					
Gunshot wound	3630 (4.1)	720 (7.1)	566 (5.0)	963 (5.3)	1382 (2.9)
Stabbing	2720 (3.1)	383 (3.8)	457 (4.0)	557 (3.1)	1323 (2.7)
Assault	9499 (10.8)	1047 (10.4)	1264 (11.2)	2038 (11.2)	5150 (10.6)
Fall	31 218 (35.4)	2826 (28.0)	3352 (29.7)	6076 (33.3)	18 964 (39.1)
Motor vehicle	17 764 (20.2)	2513 (24.9)	2702 (23.9)	3688 (20.2)	8862 (18.3)
Bicycle	5292 (6.0)	711 (7.1)	786 (7.0)	1266 (6.9)	2530 (5.2)
Pedestrian	7789 (8.8)	878 (8.7)	1023 (9.1)	1764 (9.7)	4124 (8.5)
Other	10 159 (11.5)	1003 (9.9)	1136 (10.1)	1896 (10.4)	6123 (12.6)
Arrival by ambulance	58 810 (66.8)	7099 (70.4)	8249 (73.1)	12 276 (67.3)	31 187 (64.4)
Ground transport	49 134 (55.8)	6420 (63.7)	7547 (66.9)	10 544 (57.8)	24 623 (50.8)
Helicopter	8837 (10.0)	591 (5.9)	605 (5.4)	1438 (7.9)	6203 (12.8)
Fixed wing	19 (0.02)	3 (0.03)	1 (0.01)	6 (0.03)	9 (0.02)
Unknown	820 (0.9)	85 (0.8)	96 (0.9)	288 (1.6)	352 (0.7)
Initial hospital adult trauma level					
1	32 103 (36.5)	2651 (26.3)	2355 (20.9)	10 496 (57.5)	16 601 (34.3)
2	26 596 (30.2)	5311 (52.7)	7389 (65.5)	7423 (40.7)	6473 (13.4)
3 or 4	3987 (4.5)	2119 (21.0)	1541 (13.7)	327 (1.8)	0
Pediatric trauma centers only	25 385 (28.8)	0	0	0	25 385 (52.4)
Initial hospital pediatric trauma level					
1	38 265 (43.4)	1195 (11.9)	1259 (11.2)	2558 (14.0)	33 253 (68.6)
2	13 320 (15.1)	0	120 (1.1)	5033 (27.6)	8167 (16.9)
Adult trauma level only	36 486 (41.4)	8886 (88.1)	9906 (87.8)	10 655 (58.4)	7039 (14.5)
ED physiology					
Age-adjusted hypotension	1781 (2.0)	244 (2.4)	279 (2.5)	379 (2.1)	879 (1.8)
GCS score					
13-15	81 650 (92.7)	9404 (93.3)	10 382 (92.0)	16 803 (92.1)	45 060 (93.0)
9-12	2222 (2.5)	213 (2.1)	282 (2.5)	499 (2.7)	1228 (2.5)
≤8	4200 (4.8)	464 (4.6)	622 (5.5)	944 (5.2)	2171 (4.5)

(continued)

Table 1. Characteristics of Injured Children Presenting to 146 US Trauma Center Emergency Departments (EDs) by Quartile of ED Pediatric Readiness (continued)

Characteristic	No. (%)				
		ED pediatric readiness, quartile			
	Overall (N = 88 071)	First (wPRS, 32-69) (n = 10 081)	Second (wPRS, 70-87) (n = 11 285)	Third (wPRS, 88-94) (n = 18 246)	Fourth (wPRS, 95-100) (n = 48 459)
Injury severity					
ISS					
Median (IQR)	4 (4-9)	4 (3-9)	5 (4-9)	5 (4-10)	4 (4-9)
0-8	57 495 (65.3)	6812 (67.6)	7247 (64.2)	11 584 (63.5)	31 852 (65.7)
9-15	17 824 (20.2)	1932 (19.2)	2431 (21.5)	3812 (20.9)	9649 (19.9)
16-24	7920 (9.0)	784 (7.8)	934 (8.3)	1783 (9.8)	4419 (9.1)
≥25	4832 (5.5)	553 (5.5)	673 (6.0)	1067 (5.8)	2539 (5.2)
AIS score ≥3					
Head	13 348 (15.2)	1234 (12.2)	1722 (15.3)	2847 (15.6)	7545 (15.6)
Chest	7096 (8.1)	957 (9.5)	1109 (9.8)	1740 (9.5)	3290 (6.8)
Abdominal-pelvic	3434 (3.9)	422 (4.2)	528 (4.7)	821 (4.5)	1663 (3.4)
Extremity	9931 (11.3)	1057 (10.5)	1268 (11.2)	2062 (11.3)	5543 (11.4)
Hospitalization					
Emergent airway/mechanical ventilation	7955 (9.0)	853 (8.5)	1061 (9.4)	1836 (10.1)	4205 (8.7)
Blood transfusion	2965 (3.4)	340 (3.4)	460 (4.1)	691 (3.8)	1475 (3.0)
Nonorthopedic surgery[a]	7915 (9.0)	854 (8.5)	1028 (9.1)	1832 (10.0)	4201 (8.7)
Orthopedic surgery	25 234 (28.7)	2397 (23.8)	2829 (25.1)	5055 (27.7)	14 954 (30.9)
Interhospital transfer					
None	86 243 (97.9)	9585 (95.1)	10 604 (94.0)	17 801 (97.6)	48 253 (99.6)
From the ED	1720 (2.0)	480 (4.8)	638 (5.7)	421 (2.3)	181 (0.4)
From inpatient	108 (0.1)	16 (0.2)	43 (0.4)	24 (0.1)	25 (0.1)
Length of stay, median (IQR), d	1 (0-2)	1 (0-2)	1 (0-2)	1 (1-3)	1 (1-2)
Mortality					
In-hospital	1768 (2.0)	240 (2.4)	299 (2.6)	414 (2.3)	815 (1.7)
3 d	1478 (1.7)	213 (2.1)	266 (2.4)	333 (1.8)	666 (1.4)
7 d	1664 (1.9)	225 (2.2)	296 (2.6)	389 (2.1)	754 (1.6)
30 d	1796 (2.0)	244 (2.4)	303 (2.7)	419 (2.3)	830 (1.7)
90 d	1847 (2.1)	256 (2.5)	309 (2.7)	430 (2.4)	852 (1.8)
365 d	1974 (2.2)	288 (2.9)	329 (2.9)	454 (2.5)	903 (1.9)

Abbreviations: AIS, Abbreviated Injury Scale; GCS, Glasgow Coma Scale; ISS, Injury Severity Score; wPRS, weighted Pediatric Readiness Score.

[a] Nonorthopedic surgery included brain, spine, thoracic, abdominal, or neck procedures.

[b] Race data were abstracted from medical records in the National Trauma Data Bank.

[c] Includes American Indian, Native Hawaiian or other Pacific Islander, and other race.

NPRP assessment data to the initial ED using hospital name, address, and zip code (eFigure in Supplement 1).

Variables

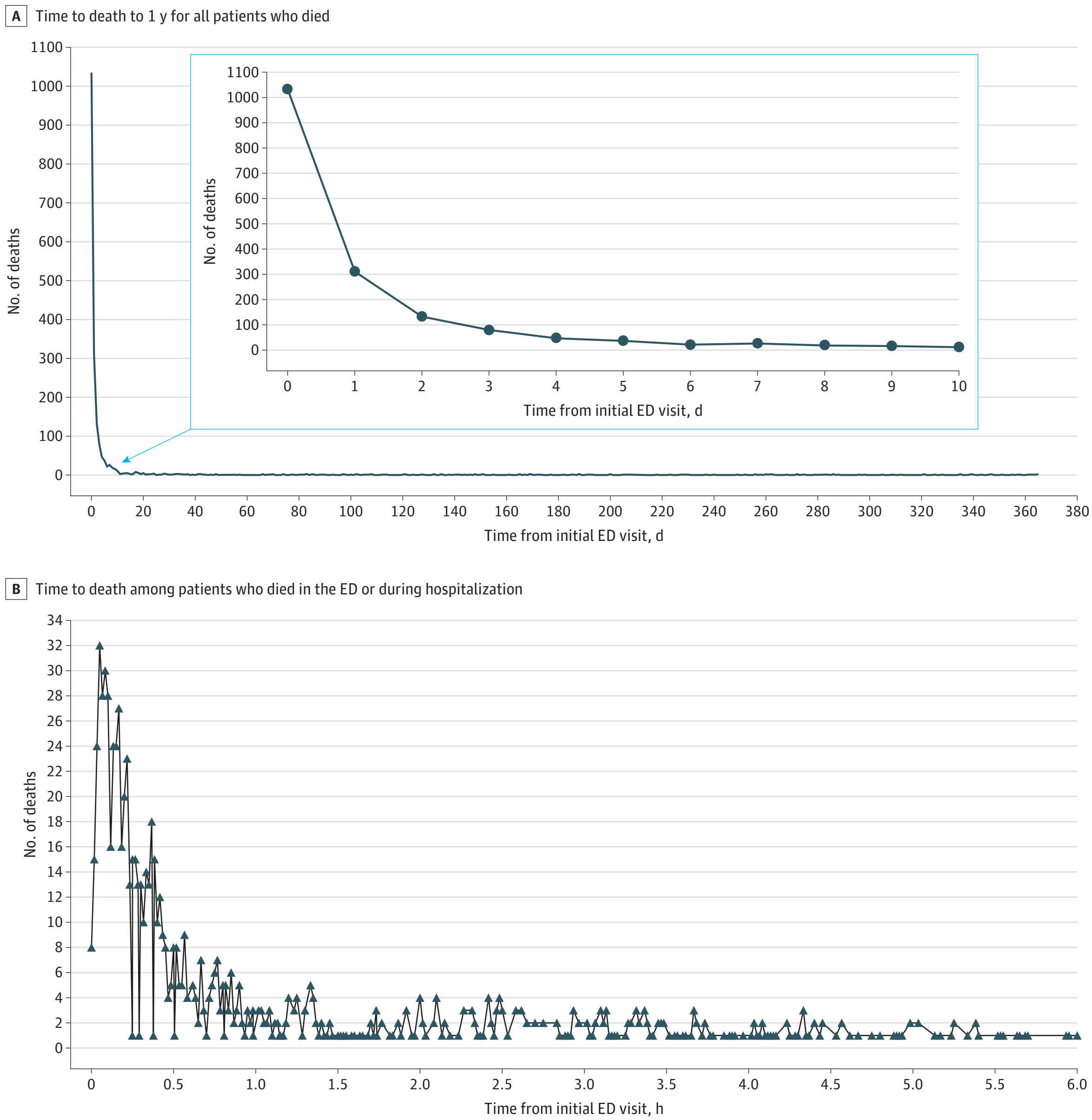
Patient-level variables in the analyses included demographic characteristics, comorbidities, initial ED systolic blood pressure, initial ED Glasgow Coma Scale score, emergent airway intervention, blood transfusion, mechanism of injury, mode of arrival, AIS scores,[16] ISS,[15,16] surgical procedures, interhospital transfer, and length of hospital stay. We identified ED and hospital procedures using *International Classification of Diseases, Ninth Revision* (*ICD-9*) and *ICD-10* procedure codes, categorized using the Agency for Healthcare Research and Quality Clinical Classifications Software.[21] We then mapped Clinical Classifications Software categories to standardized surgical categories, emergent airway intervention, and blood transfusion.

To define trauma center level (1 to 4) and type (adult and pediatric) when multiple data sources existed, we used the following hierarchy: American College of Surgeons verification status, state-level designation, NPRP assessment, and the annual American Hospital Association survey.[22] We also collected hospital region, year of admission, annual ED pediatric volume, and annual pediatric trauma volume.

Outcomes

The primary outcome was time to death, tracked from the date of ED arrival to 365 days using deaths recorded in NTDB and matched to state vital statistics records. For children with matched vital statistics records, we characterized the cause and location of death. We used probabilistic linkage[23] (LinkSolv version 9 [Strategic Matching]) and previously validated linkage routines[24-26] to match state vital statistics records to NTDB

Figure 1. Time to Death Among Injured Children Who Died After Arriving to an Emergency Department (ED)



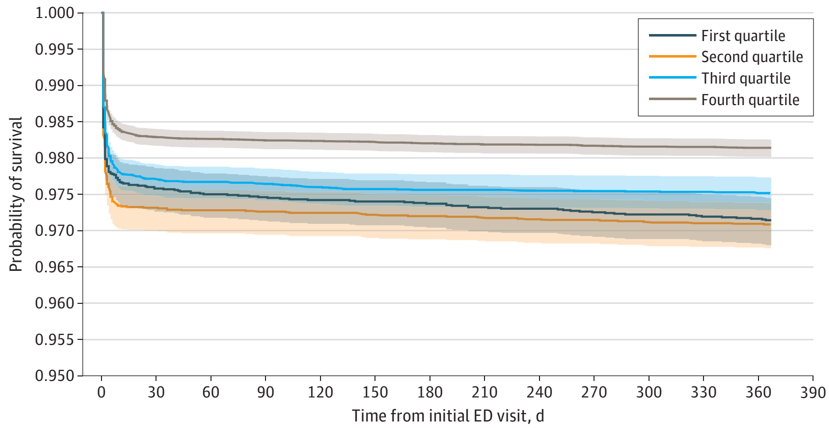
For in-hospital deaths, the median (IQR; range) time to death was 3.1 (0.3-36.5; 0-3244) hours. Panel B is truncated at 6 hours to reflect the most common time period for death and to illustrate increments less than 1 hour.

records using date of birth, home zip code, sex, race, and ethnicity. State-by-state validation of the matching process is included in eTable 4 in Supplement 1.

Statistical Analysis

We used descriptive statistics to characterize children and hospitals by quartile of ED pediatric readiness. We then used Kaplan-Meier curves to examine the unadjusted time to death by quartile of ED readiness. To evaluate the adjusted association between ED readiness and time to death, we used a flexible parametric model with restricted cubic splines for censored survival data[27] and variance adjustment based on clustering by the initial ED[28] (implemented by the stpm2 package in Stata version 16 [StataCorp]). This method allowed for risk adjustment of patient-level characteristics and adjusted hazard ratios (HRs) without the assumption of constant hazards over time. The flexible spline model provided good fit of the distribution of deaths over time, with spline knots selected by testing centiles of days to death. We selected covariates for the model based on a standardized risk-adjusted model for trauma.[29] In addition to ED pediatric readiness, the model included patient demographic characteristics, comorbidities, Glasgow Coma Scale score, age-adjusted hypotension,[30] emergent airway intervention, blood transfusion, mechanism, ISS, interhospital transfer, and year of visit. We

Figure 2. Kaplan-Meier Survival Curve by Quartile of Emergency Department (ED) Pediatric Readiness



No. at risk													
First quartile	10081	9837	9829	9825	9821	9819	9816	9811	9809	9804	9801	9798	9795
Second quartile	11285	10982	10978	10976	10974	10971	10969	10967	10964	10963	10959	10958	10957
Third quartile	18246	17828	17821	17816	17808	17803	17801	17801	17799	17798	17797	17796	17793
Fourth quartile	48459	47630	47617	47608	47604	47596	47588	47580	47578	47572	47566	47564	47558

The shaded areas represent 95% CIs. Compared with injured children treated in the first (lowest) quartile of emergency department pediatric readiness, the hazard ratios for death were 0.73 (95% CI, 0.57-0.94) for the fourth (highest) quartile, 0.97 (95% CI, 0.73-1.27) for the third quartile, and 0.99 (95% CI, 0.75-1.32) for the second quartile.

evaluated ED pediatric readiness as a categorical variable by quartile of wPRS at the ED level, using the lowest quartile as the reference group. We used separate models to analyze high-risk subgroups and conducted stratified analyses by transfer status and age group. We assessed model fit using Akaike information criterion, deviance, and martingale residuals. To test the robustness of our results, we added hospital-level variables to the model. To examine the role of ED readiness beyond early deaths, we sequentially removed children who died within 2 days, 3 days, 5 days, 7 days, and all in-hospital deaths, modeling subsequent deaths to 365 days. Significance was set at a *P* value less than .05, and all *P* values were 2-tailed and generated from multivariable models.

To further evaluate survival at different time points using a different analytic approach, we used a hierarchical mixed-effects logistic regression model and a dichotomous outcome of death, with a random intercept to account for clustering by the initial ED (PROC GLIMMIX procedure in SAS version 9.4 [SAS Institute]). In these models, we tested mortality at the following time points: in-hospital, 30 days, 90 days, and 365 days. We previously developed and used this risk-adjustment model to study ED readiness and in-hospital mortality.[5]

Missingness for individual variables ranged from 0% to 7.5%. There were no missing values for mortality. To decrease bias and preserve the study sample, we used multiple imputation[31,32] to handle missing values. We have validated the use of multiple imputation for missing values in trauma data.[24,33,34] We generated 10 multiply imputed data sets[35] via chained equations, as implemented by Stata's mi impute chained command,[36,37] then combined the results using Rubin rules to account for within-data and between-data set variance.[32]

Results

Of the 96 198 children presenting to EDs with pediatric readiness information, 6086 were transferred to another hospital without a matching record and 2041 received care at very low-volume hospitals (eFigure in Supplement 1). Of 88 071 children included in the primary cohort, 30 654 (34.8%) were female; 2114 (2.4%) were Asian, 16 730 (10.0%) were Black, and 49 496 (56.2%) were White; and the median (IQR) age was 11 (5-15) years. A total of 1974 (2.2%) died within 1 year of the initial ED visit, including 1768 (2.0%) during hospitalization and 206 (0.2%) following discharge. The 7-, 30-, 90-, and 365-day mortality rates were 1.9% (1664 deaths), 2.0% (1796 deaths), 2.1% (1847 deaths), and 2.2% (1974 deaths), respectively. Among the 732 children classified as DOA, 630 (86%) died. Subgroups included 12 752 (14.5%) with ISS of 16 or more, 28 402 (32.2%) with any AIS score of 3 or more, 13 348 (15.2%) with a head AIS score of 3 or more, and 9048 (10.3%) requiring early critical resources. The most common mechanism of injury was fall (31 218 [35.4%]), and the median (IQR) ISS was 4 (4-9). The study population is characterized in **Table 1**. Among the 146 trauma center EDs, the median (IQR; range) wPRS was 88 (70-95; 32-100). Hospital characteristics by quartile of ED pediatric readiness are included in eTable 1 in Supplement 1.

Among the 1974 children who died within 1 year of ED presentation, the median (IQR) time to death was 1 (1-4) day. For 1598 children who died in-hospital and had detailed time information available, the median (IQR; range) time to death was 3.1 (0.3-36.5;0-3244) hours. **Figure 1** illustrates the days to death (ie, all deaths; Figure 1A) and hours to death (ie, in-hospital deaths; Figure 1B). The unadjusted survival curve by quartile of ED readiness (**Figure 2**) shows that children initially treated in EDs in the highest quartile of readiness had higher survival to 1 year than children treated in EDs in the lowest quartile (HR, 0.73; 95% CI, 0.57-0.94). The causes and locations of death among 1378 of 1974 pediatric deaths (69.8%) with a matched death certificate are included in eTable 2 in Supplement 1. While injury was the most common cause of death overall (1076 [78.1%]), the distribution changed over time. The proportion of deaths from unintentional injury decreased from 85.0% (950 of 1118 deaths) at 0 to 7 days to 69.8%

(60 of 86 deaths) at 8 to 30 days, 36.7% (18 of 49 deaths) at 31 to 90 days, and 38.4% (48 of 125 deaths) at 91 to 365 days. While numbers for individual categories were small, the number of deaths from self-harm, neoplasms, circulatory diseases, neurologic conditions, and congenital malformations increased over time.

After accounting for ED case mix, the instantaneous risk of death (rate of mortality) to 1 year was lowest among children initially treated in EDs in the highest readiness quartile (highest vs lowest quartiles of ED readiness: aHR, 0.70; 95% CI, 0.56-0.88) (**Table 2**; **Figure 3**). Compared with children in the first quartile of ED readiness, there was no association with mortality among children treated in the second readiness quartile (aHR, 1.10; 95% CI, 0.86-1.40) or third quartile (aHR, 0.82; 95% CI, 0.62-1.06). The best-fit model had spline knots at 0 and 1 day. After removing deaths occurring within the first 2 days (1478 [74.9%] of all deaths), the association between initial ED pediatric readiness and survival persisted (aHR, 0.75; 95% CI, 0.56-0.996). Additional sensitivity analyses excluding deaths within 3 days, 5 days, 7 days, and all in-hospital deaths showed consistent findings (eTable 3 in Supplement 1).

Among high-risk subgroups of injured children, there was a similar association between high ED readiness and lower mortality rates to 1 year among those with an ISS of 16 or more (aHR, 0.69; 95% CI, 0.54-0.88), those with an AIS score of 3 or more (aHR, 0.70; 95% CI, 0.56-0.88), and those with a head AIS score of 3 or more (aHR, 0.69; 95% CI, 0.52-0.90) but not among those requiring early critical resources (aHR, 0.79; 95% CI, 0.60-1.04) (eTable 5 in Supplement 1). In models stratified by transfer status, high ED readiness was associated with decreased mortality among nontransfers (aHR, 0.71; 95% CI, 0.56-0.89) but not among transfers (aHR, 0.73; 95% CI, 0.20-2.71) (eTable 6 in Supplement 1). Among age strata, the benefit of high ED readiness persisted through 15 years of age but was not evident for children aged 16 to 17 years (aHR, 0.84; 95% CI, 0.65-1.08) (eTable 7 in Supplement 1). In sensitivity analyses, the association between ED readiness and mortality remained after adding overall trauma level, adult trauma level, ED pediatric annual volume, and hospital region but was diminished when we added pediatric trauma level and annual hospital trauma volume to the model (eTable 8 in Supplement 1). The results were unchanged after removing outlier patients, influential values, and using time-dependent versions of emergent airway management and blood transfusion. The findings were similar when modeling mortality at fixed time points. The adjusted odds ratios of mortality comparing the highest vs lowest quartiles of ED pediatric readiness were 0.61 (95% CI, 0.42-0.89) for in-hospital mortality, 0.64 (95% CI, 0.45-0.92) for 30-day mortality, 0.64 (95% CI, 0.45-0.89) for 90-day mortality, and 0.60 (95% CI, 0.44-0.81) for 1-year mortality.

Table 2. Adjusted Flexible Parametric Spline Model for Mortality to 1 Year Among 88 071 Injured Children Treated in 146 Trauma Centers

Variable	Hazard ratio (95% CI)	*P* value
Weighted Pediatric Readiness Score, quartile		
First (least ready)	1 [Reference]	<.001
Second	1.10 (0.86-1.4)	
Third	0.82 (0.62-1.06)	
Fourth (most ready)	0.70 (0.56-0.88)	
Sex		
Female	0.86 (0.78-0.96)	.005
Male	1 [Reference]	
Age group, y		
0-4	1.42 (1.22-1.65)	<.001
5-12	1 [Reference]	
13-15	0.88 (0.75-1.02)	
16-17	1.01 (0.87-1.19)	
Race[a]		
Asian	1.03 (0.71-1.49)	.91
Black	1.02 (0.89-1.17)	
Other[b]	1.05 (0.92-1.21)	
White	1 [Reference]	
Any comorbid condition	0.76 (0.62-0.93)	.009
Injury mechanism		
Gunshot wound	5.74 (4.30-7.66)	<.001
Stabbing	3.56 (2.31-5.47)	
Assault	1.42 (0.99-2.02)	
Fall	1 [Reference]	
Motor vehicle	1.79 (1.34-2.39)	
Bicycle	1.59 (1.10-2.30)	
Pedestrian	2.47 (1.85-3.28)	
Other	2.20 (1.64-2.96)	
Arrival by ambulance	1.33 (1.08-1.65)	.007
Interhospital transfer to another hospital	0.64 (0.48-0.86)	.003
Initial ED physiology		
Hypotension	6.62 (5.79-7.58)	<.001
GCS score		
13-15	1 [Reference]	<.001
9-12	3.08 (2.13-4.46)	
≤8	41.78 (31.64-55.16)	
Injury Severity Score		
0-8	1 [Reference]	<.001
9-15	1.94 (1.50-2.50)	
16-24	1.97 (1.49-2.59)	
≥25	3.08 (2.35-4.02)	
Emergent airway intervention	1.29 (0.95-1.75)	.11
Blood transfusion	1.09 (0.97-1.23)	.16
Year visit	1.00 (0.97-1.03)	.97

Abbreviations: ED, emergency department; GCS, Glasgow Coma Scale.

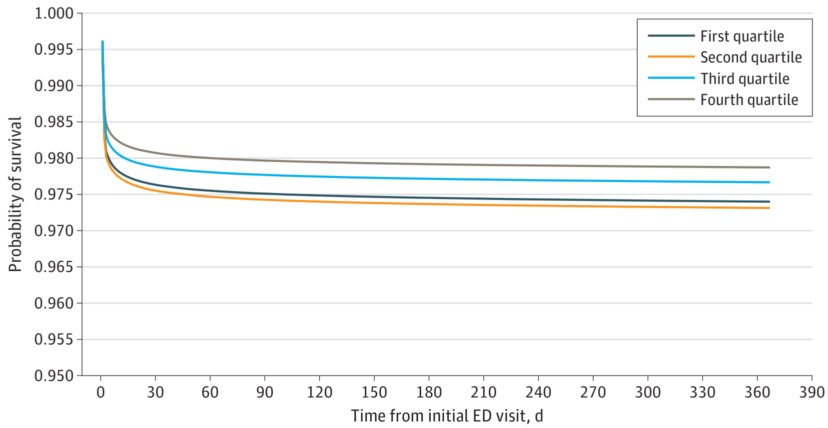
[a] Race data were abstracted from medical records in the National Trauma Data Bank.

[b] Includes American Indian, Native Hawaiian or other Pacific Islander, and other race.

Discussion

In this study, we demonstrate the timing of death among injured children reaching a trauma center and the durable survival benefit of receiving initial trauma care in a high-readiness ED. Among children who died after injury, three-fourths of deaths occurred within the first 2 days, and few deaths occurred after hospital discharge. The association between high ED readiness and survival to 1 year was evident even

Figure 3. Adjusted Time-to-Death Analysis Among 88 071 Injured Children Presenting to 146 Trauma Centers by Emergency Department (ED) Pediatric Readiness



In addition to quartiles of ED pediatric readiness, the model included sex, age group, race, comorbidities, mechanism of injury, arrival by ambulance, interhospital transfer, hypotension, Glasgow Coma Scale score, Injury Severity Score, need for emergent airway, and blood transfusion.

after excluding early deaths. These findings suggest that high-quality ED care has benefits that extend beyond the acute care period. While 2 previous studies have demonstrated the association of high ED pediatric readiness and improved in-hospital survival,[4,5] to our knowledge, this is the first study to link high ED readiness and long-term survival.

Our results show that most children who die after injury do so early in their clinical course, making early clinical care a key target to decrease preventable mortality. The survival curves show that the benefit of care in high-readiness EDs was evident within the first several days and persisted to 1 year, illustrating the impact that adequately prepared EDs can have on pediatric survival. While the benefit of high ED readiness was evident well beyond the acute care period, it is likely that this association is driven by reducing early preventable deaths in children. The finding also highlights the importance of hospital selection (eg, by emergency medical services or family), as the location of initial care has a pronounced impact on the likelihood of survival.

Although ED pediatric readiness is being incorporated into the American College of Surgeons trauma center verification criteria, the level of readiness is critically important. We show that improvements in survival were limited to children cared for in EDs in the highest quartile of readiness (wPRS of 95 to 100), which is consistent with a previous in-hospital evaluation of ED pediatric readiness in US trauma centers.[5] Our results also demonstrate that the benefit of high ED readiness is not limited to major (level 1 and 2) trauma centers. Having high pediatric readiness in all trauma center EDs, regardless of level, would align ED readiness with the field triage algorithm and further optimize pediatric survival.

In addition to the timing of death, we also examined the causes of death. Unintentional injury dominated within the first week, but there was a shift in causes over time. Deaths from self-harm, congenital conditions, neoplasms, and circulatory and neurologic conditions increased after the first month. While the number of children in individual categories was relatively small and we do not know if these deaths were related to the initial injury event, the findings highlight the importance of maintaining vigilance after hospital discharge. It is possible that hospitals with high-readiness EDs also have greater attention to and resources to address noninjury conditions during and after an injury-related admission.

Limitations

This study has several limitations. The findings are restricted to injured children from 8 states cared for in 146 trauma centers. Inclusion of more hospitals and additional states could have changed the results. Our findings do not apply to children with noninjury conditions. The data spanned 2012 through 2017, matched to ED readiness data from 2013. It is possible that ED readiness has changed over time or its association with survival is different in the current period. Reassessing these relationships using the 2021 repeated national assessment of ED pediatric readiness will be important.

There was the potential for bias in different aspects of the study. We excluded children from hospitals that cared for less than 50 children during the study period. While inclusion of lower-volume hospitals could change these findings, our data suggest that such hospitals have lower ED readiness scores and that the findings could be more pronounced with their inclusion. Unmeasured confounding and inadequate risk adjustment could have introduced bias, but model fit diagnostics indicated good fit, we used an established risk-adjustment model for trauma centers,[29] and multiple sensitivity analyses yielded similar findings. Our linkage processes did not identify all children who died, which could have biased characterization of causes of death and the number of children who died after discharge. Additionally, reasons that high ED readiness may decrease deaths later in a hospital course or following hospital discharge are not clear from our data and will require further study.

Conclusions

In summary, this study showed that high ED readiness was associated with lower mortality to 1 year among injured children. These findings further support the importance of ED pediatric readiness and the imperative for US trauma centers to meet the high level of ED readiness required to reduce pediatric mortality after injury.

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Author Affiliations: Center for Policy and Research in Emergency Medicine, Department of Emergency Medicine, Oregon Health & Science University, Portland (Newgard, Lin, Cook, Cloutier); Centers for Health Policy, Primary Care and Outcomes Research, Department of Medicine, Stanford University School of Medicine, Palo Alto, California (Goldhaber-Fiebert); Departments of Pediatrics, Emergency Medicine, and Radiology, University of Pittsburgh School of Medicine, Pittsburgh, Pennsylvania (Marin); Department of Pediatrics, The University of Utah School of Medicine, Salt Lake City (Smith); Department of Emergency Medicine, The University of Iowa Carver College of Medicine, Iowa City (Mohr); Departments of Emergency Medicine and Pediatrics, Alpert Medical School of Brown University, Providence, Rhode Island (Zonfrillo); Department of Pediatric Surgery, Kapiolani Medical Center for Women and Children, Honolulu, Hawaii (Puapong); Department of Surgery, University of Hawai'i John A. Burns School of Medicine, Honolulu (Puapong); Department of Emergency Medicine, Orlando Regional Medical Center, Orlando, Florida (Papa); Division of Trauma and Burn Surgery, Department of Surgery, Children's National Hospital, Washington, DC (Burd).

Author Contributions: Dr Newgard had full access to all of the data in the study and takes responsibility for the integrity of the data and the accuracy of the data analysis.
Study concept and design: Newgard, Zonfrillo, Burd.
Acquisition, analysis, or interpretation of data: All authors.
Drafting of the manuscript: Newgard, Lin.
Critical revision of the manuscript for important intellectual content: Newgard, Goldhaber-Fiebert, Marin, Smith, Cook, Mohr, Zonfrillo, Puapong, Papa, Cloutier, Burd.
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