Facility Characteristics and Inhospital Pediatric Mortality after Severe Traumatic Brain Injury

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Abstract

More than 500,000 children sustain a traumatic brain injury (TBI) each year. Previous studies have described significant variation in inhospital mortality after pediatric TBI. The aim of this study was to identify facility-level characteristics independently associated with 30-day inhospital mortality after pediatric severe TBI. We hypothesized that, even after accounting for patient-level characteristics associated with mortality, the characteristics of facilities where patients received care would be associated with inhospital mortality. Using data from the National Trauma Data Bank from 2009–2012, we identified a cohort of 6707 pediatric patients hospitalized with severe TBI in 391 facilities and investigated their risk of 30-day inhospital mortality. Pre-specified facility-level characteristics (trauma certification level, teaching status, census region, facility size, nonprofit status, and responsibility for pediatric trauma care) were added to a Poisson regression model that accounted for patient-level characteristics associated with mortality. In multivariable analyses, patients treated in facilities located in the Midwest (risk ratio [RR] = 1.42; 95% confidence interval [CI] 1.12–1.81) and South (RR = 1.39; 95% CI: 1.12–1.72) regions had higher likelihoods of 30-day inhospital mortality compared with patients treated in the Northeast. Other facility-level characteristics were not found to be significant. To our knowledge, this is one of the largest investigations to identify regional variation in inhospital mortality after pediatric severe TBI in a national sample after accounting for individual and other facility-level characteristics. Further investigations to help explain this variation are needed to inform evidence-based decision-making for pediatric severe TBI care across different settings.

Key words: hospital mortality; facility characteristics; National Trauma Data Bank; pediatrics; regional variation; TBI

Introduction

MORE THAN 500,000 CHILDREN sustain a traumatic brain injury (TBI) each year in the United States, and more than 2000 die as a result of their injuries.¹ These injuries and deaths are not uniformly distributed nationally. Data from the Centers for Disease Control and Prevention (CDC) show large variation in TBI-related mortality by state.² Likewise, a retrospective cohort study using Healthcare Cost and Utilization Project data found nearly a two-fold difference between states in inpatient mortality after pediatric TBI.³

While some of the observed variation in mortality is attributable to differences in sociodemographic characteristics, injury mechanisms, and severity between children with severe TBI, variation in how facilities treat those children may also explain mortality differences. The Guidelines for the Acute Medical Management of Severe Traumatic Brain Injury in Infants, Children, and Adolescents,⁴ originally published in 2003 and revised in 2012, aim to facilitate uniform, evidence-based treatment of those with pediatric

severe TBI nationally. A recent study comparing implementation and adherence to those guidelines among five geographically dispersed trauma centers found substantial variation in overall guideline adherence and mortality. Importantly, guideline adherence was associated with better discharge survival.⁵

Facility type (e.g., pediatric vs. adult center, trauma level certification) may also be an important predictor of survival, although studies comparing pediatric trauma outcomes between different types of facilities are limited. Previous investigations suggest that severely injured children (particularly those with head injuries) have improved discharge outcomes and lower mortality when treated at pediatric trauma centers compared with adult trauma centers,⁶ and that this may be related to differences in treatment (e.g., approach to operative vs. nonoperative management, frequency of neurosurgical intervention by pediatric specialists).⁷ Studies on adult trauma populations have shown mixed results when comparing trauma mortality outcomes between Level I and Level II trauma centers. Using National Trauma Data Bank

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(NTDB) data from 1994–2003, one group found significantly lower mortality among patients age 14 or older treated for severe traumatic injuries at Level I trauma centers compared with patients treated at Level II centers.^{8,9} These findings were consistent with several smaller, state-specific studies, which found significantly lower risk of mortality among all adult trauma patients treated at Level I centers in Pennsylvania¹⁰ and Ohio¹¹ compared with those treated at Level II centers. Conversely, one study focused on isolated patients with severe TBI of all ages in the NTDB found no significant difference in mortality between American College of Surgeons (ACS) Level I and II trauma centers.¹²

While differences between hospitals in pediatric severe TBI mortality may be explained by differences in their patient populations, characteristics of the hospitals themselves might also affect outcomes. The aim of this study was to identify facility-level characteristics independently associated with 30-day in-hospital mortality after pediatric severe TBI. We hypothesized that, after accounting for patient-level characteristics that affect mortality, the characteristics of facilities where patients received care would be associated with in-hospital mortality.

Methods

Study setting and population

Using data from the NTDB for admission years 2009–2012, we identified a cohort of pediatric patients hospitalized with severe TBI. The NTDB, maintained by the ACS, is the largest aggregation of US trauma data,¹³ containing more than 5 million patient discharge records from more than 800 trauma centers across the United States.¹⁴

Patients were included in the analysis if they were under 18 years of age at admission, were in the intensive care unit (ICU) for a minimum of 2 calendar days, and were treated for a severe TBI. In line with previous work,^{5,15} severe TBI was identified based on: (1) an Abbreviated Injury Scale (AIS) score of ≥ 3 and specific to head trauma (predot code beginning with 1), (2) a Glasgow Coma Scale (GCS) score < 9 , and (3) a TBI-specific *International Classification of Diseases* (ICD-9 code on their discharge abstract (800.0–801.9, 803.0–804.9, 850.0–854.1, 950.1–950.3, 959.01, or 995.55)). We restricted our cohort to patients treated in Level I and II hospitals to focus on facilities that provide the majority of care for severe TBI injuries as both direct admissions and transfers from lower level trauma centers. We excluded patients with missing inclusion criteria ($n = 3870$), mechanism of injury ($n = 236$), hospital discharge status (i.e., main outcome, $n = 38$), those patients with penetrating injuries ($n = 301$), non-survivable injuries (AIS = 6, $n = 241$), and those who arrived without vital signs ($n = 61$).

Exposure, outcome and confounders

We developed a list of pre-specified facility-level characteristics as exposures of interest based on available data from the NTDB, including facility size (< 200 beds, 201–400, 401–600, > 600), trauma level (pediatric level I, pediatric level II, adult level I, adult level II), teaching status (university, community, nonteaching), nonprofit status (for profit, nonprofit), responsibility for pediatric trauma care (sole provider of care, shared responsibility/no pediatric services), and census region (Northeast, Midwest, South, West, shown in Fig. 1¹⁶). The outcome of interest was 30-day in-hospital mortality (yes/no) identified using hospital discharge status and length of stay.

Statistical analysis

To control for confounding because of differences in patient populations between facilities, patient-level characteristics were

FIG. 1. United States census regions.

included in a “baseline” model of pediatric severe TBI mortality risk. This baseline model was constructed using a previously validated mortality risk-adjusted model for the adult NTDB population.¹⁷ This model, a parsimonious predictive set of variables among severely injured patients in the NTDB, was developed to identify and standardize the minimum set of covariates researchers should adjust for when performing a risk-adjustment analysis of mortality as an outcome in subsets of trauma populations. Variables not included in this minimum set may be associated with trauma mortality, but adding such variables to a model that includes the minimum set may not improve the model’s ability to predict mortality. Because the validated model was developed for an adult population, we chose to expand the minimum set of variables and include other important predictors of mortality identified in the pediatric TBI literature. The definition of each covariate in our baseline model was modified for use in a pediatric population. As such, the baseline model included age, race, insurance source, transfer status, hypotension on arrival (based on American Heart Association guidelines for pediatric age groups¹⁸), heart rate on arrival, mechanism of injury, GCS score, injury severity score calculated from AIS (ISSAIS), head AIS score, and requirement for mechanical ventilation. Age and mechanism of injury were included as categorical variables. Transfer status, the presence of in-hospital complications, the presence of comorbidities, requirement for mechanical ventilation, and hypotension were included as binary variables. Heart rate on arrival, GCS, head AIS, and ISSAIS were included as continuous variables. A full description of variable definitions for the baseline model can be found in Supplementary Table 1 (see online supplementary material at ftp.liebertpub.com).

We used Poisson regression with clustered sandwich estimators of variance to calculate risk ratios (RR) and 95% confidence intervals (CI) for 30-day in-hospital mortality. Clustering by facility was used to account for correlation between patients seen at the same hospital. To determine independent associations between our exposures of interest and in-hospital mortality, we added the facility-level characteristics of interest to our baseline model individually and as a group. All analyses were conducted using Stata statistical software version 12 (Statacorp LP: College Station, TX).¹⁹

This study did not require Institutional Review Board approval by the University of Washington Human Subjects Division, because the previously collected de-identified data used for this investigation do not meet the federal regulatory definition of human subjects research.

Results

Patient characteristics

A total of 6707 patients met inclusion criteria for the study. Key patient and facility characteristics of the cohort are shown in Tables 1 and 2, respectively. Overall 30-day in-hospital mortality for the cohort was 12.5%. Patients who died in the hospital within 30 days were on average younger, more severely injured, more likely to have hypotension on arrival, and spent a greater pro-

TABLE 1. CHARACTERISTICS OF PEDIATRIC PATIENTS WITH SEVERE TRAUMATIC BRAIN INJURY^a

	<i>Discharged alive^b</i>		<i>Died within 30 days in-hospital</i>	
	N = 5870		N = 837	
<i>Patient characteristic</i>				
Mean total GCS score (range)	4.2 (3–8)		3.4 (3–8)	
Mean head Abbreviated Injury Score (range)	3.7 (3–5)		4.0 (3–5)	
Mean length of stay in hospital (range)	16.5 (2–197)		5.7 (2–29)	
Mean days in ICU (range)	10.5 (2–196)		5.1 (2–29)	
Mean days on ventilator (range)	7.6 (1–197)		5.1 (1–28)	
Mean Injury Severity Score (range)	24.2 (4–75) ^c		31.2 (1–75) ^c	
Mean heart rate at admission (range)	114.6 (10–247)		119.1 (19–230)	
	N	% ^d	N	% ^d
Age group, years				
0–4	1672	28.5	384	45.9
5–9	876	14.9	87	10.4
10–14	1264	21.5	106	12.7
15–17	2058	35.1	260	31.1
Male	3823	65.1	536	64.0
Transfer from another facility	2523	43.0	371	44.3
Hypotension at admission	204	3.5	95	11.4
Race				
White	3672	62.6	486	58.1
African American	840	14.3	164	19.6
Asian/PI/NA ^e	168	2.9	28	3.4
Other	779	13.3	96	11.5
Missing	411	7.0	63	7.5
Insurance source				
Private	2686	45.8	294	35.1
Public	2178	37.1	364	43.5
Self-pay	376	6.4	72	8.6
Missing	630	10.7	107	12.8
Mechanism of injury				
Motor vehicle	3183	54.2	374	44.7
Fall	747	12.7	60	7.2
Transport, other	661	11.3	56	6.7
Struck by/against	362	6.2	40	4.8
Other, specified and classifiable	513	8.7	237	28.3
Other	404	6.9	70	8.4

GCS, Glasgow Coma Scale; ICU, intensive care unit.

^aVariables presented as included in analytic models.

^bIncludes 16 patients who died in-hospital after >30 days.

^cInjury severity score is based on AIS as provided by each facility, and includes additional, less severe injuries outside our inclusion criteria.

^dPercentages may not sum to 100 because of rounding.

^eAsian, Pacific Islander or Native Hawaiian, and American Indian.

TABLE 2. CHARACTERISTICS OF FACILITIES CARING FOR PEDIATRIC PATIENTS WITH SEVERE TRAUMATIC BRAIN INJURY

	<i>Facility N = 391</i>		<i>Patient N = 6707</i>	
	N	%	N	%
Trauma level				
Pediatric level I	86	22.0	2990	44.6
Pediatric level II	50	12.8	1075	16.0
Adult level I	111	28.4	1922	28.7
Adult level II	144	36.8	720	10.7
Teaching status				
Community	166	42.5	1746	26.0
Nonteaching	51	13.0	380	5.7
University	174	44.5	4581	68.3
Region				
Northeast	71	18.2	845	12.6
Midwest	121	30.9	1571	23.4
South	110	28.1	2841	42.4
West	89	22.8	1450	21.6
# of beds				
≤ 200	24	6.1	225	3.3
201–400	143	36.6	1990	29.7
401–600	117	29.9	2111	31.5
> 600	107	27.4	2381	35.5
Nonprofit status				
Nonprofit	358	91.6	6357	94.8
For-profit	33	8.4	350	5.2
Sole responsibility for pediatric trauma care				
Yes	249	63.7	5861	87.4
No/shared responsibility	142	36.3	846	12.6

portion of their hospital stay in the ICU. Mechanisms of injury varied between discharge groups, with a greater proportion of deceased patients treated for injuries falling under the blanket term “Other, specified and classifiable,” 95% of which had an external cause of injury (e-code) for child abuse (E967) documented on their discharge abstract. Similar proportions of both groups were transferred from other facilities. Among patients who were treated in facilities that reported on data on complications, the presence of complications was reported more frequently among those who died in the hospital than among patients discharged alive (Supplementary Table 2; see online supplementary material at ftp.liebertpub.com).

Facility characteristics

Patients included in the analysis were treated at 391 facilities across the country (Table 2). Each facility treated between 1 and 141 patients, with a mean of 17.1 patients per facility. Almost half of the cohort was treated at facilities in the South (42.4%, vs. 23.4% in the Midwest, 12.6% in the Northeast, and 21.6% in the West). The largest proportion of facilities represented was from the Midwest (30.9%, vs. 18.2% in the Northeast, 28.1% in the South, and 22.8% in the West). A majority (60.6%) of patients were treated at facilities with a specific pediatric certification, although such facilities represented only 34.8% of all the facilities in this cohort. Similarly, 68.3% of patients were treated at university hospitals, but only 44.5% of hospitals in the cohort were university-affiliated. The highest proportion of facilities represented in the cohort were adult level II (36.8%), university-affiliated (44.5%), located in the Midwest

(30.9%), with between 200 and 400 beds (36.6%), nonprofit (91.6%), and solely responsible for treating pediatric trauma cases (63.7%). In comparison, the highest proportion of patients in the cohort were treated in facilities that were pediatric level I (44.6%), university-affiliated (68.3%), located in the South (42.4%), with more than 600 beds (35.5%), nonprofit (94.8%), and solely responsible for providing care to pediatric trauma cases (87.4%).

Multivariable analyses

Census region was found to be significantly associated with risk of 30-day in-hospital mortality in a multivariable analysis adjusting for both patient characteristics and all other facility characteristics (Fig. 2). Patients treated in facilities located in the Midwest (RR=1.42; 95% CI 1.12–1.81) and South (RR=1.39; 95% CI: 1.12–1.72) were more likely to die during their hospitalization compared with patients treated in the Northeast region. Patients in the West were also at greater risk of in-hospital mortality compared with patients in the Northeast, but this estimate did not reach statistical significance (RR=1.19; 95% CI 0.91–1.56).

Having identified region as significantly associated with in-hospital mortality, we conducted several sensitivity analyses to examine potential confounding by factors not considered in our initial models. We added type of transport to the hospital (e.g., ground vs. air transport), and time between dispatch of emergency medical services (EMS) and hospital arrival to an expanded multivariable analysis, and limited the study sample to patients who were not transferred from other facilities. The results of these analyses were not meaningfully different from the main results (not shown). We also explored how several patient- and facility-level characteristics not included in our original analytic model varied between census regions (Supplementary Table 3; see online supplementary material at ftp.liebertpub.com).

The majority of the variables we considered did not vary substantially between regions. No single variable we examined explained the observed association between region and mortality. The Northeast had the fewest subjects in our cohort and the lowest mean number of subjects per facility. Although public insurance and self-pay for treatment were less common among patients in the

Northeast, the greater proportion of missing data on insurance status makes it difficult to assess. While the presence of both reported complications and reported comorbidities varied (between 34.1 and 45.5% for complications and 16.8 and 23.0% for comorbidities), the Northeast did not have the lowest reported prevalence of comorbidities, and the reported prevalence of complications in the Northeast (34.1%) was very similar to the reported prevalence in the Midwest (34.1%). For both complications and comorbidities, the most common category reported was “Other,” highlighting the limitations of interpreting these categories in the NTDB.

Discussion

To our knowledge, this is one of the first investigations to identify regional variation in 30-day in-hospital mortality after pediatric severe TBI in a large national sample while accounting for individual, injury, and facility-level characteristics. We identified 6707 pediatric patients with severe TBI treated in level I or level II trauma centers from 2009–2012. Thirty-day in-hospital mortality for these patients was 12.5%, and children treated in the South and Midwest had a 39% to 42% increased risk of mortality compared with children treated in the Northeast. None of the other facility characteristics examined in this investigation had a significant association with mortality after adjusting for patient- and other facility-level characteristics.

Our results are in line with CDC estimates of TBI-related mortality in children under age 18, which in 2010 were lowest in the Northeast (2.4 per 100,000), compared with the West (3.2 per 100,000), Midwest (3.9 per 100,000), and South (4.3 per 100,000).² Other studies of TBI have found regional variation in in-hospital mortality, as well as variation in the use of neurosurgical procedures²⁰ and the delivery of potentially unnecessary or ineffective care.²¹ Regional variation in broader child health indicators²² and disease-specific treatments (e.g., pediatric ICU treatment for asthma²³) have also been described.

Regional variation in 30-day survival may be attributable to differences in hospital care, including the management of patients' comorbidities and in-hospital complications. Pre-existing comorbidities and treatment and injury complications may be strongly associated with mortality risk. Complication and comorbidity data as collected and defined by the NTDB, however, present a substantial challenge for researchers seeking to address this important question. These data are not recorded by all facilities, with percentages of trauma cases including complications data at Level I trauma centers varying between 0 and 40%.²⁴

Our analyses are subject to other limitations. While 95% of Level I trauma centers and 80% of Level II centers report their data to the NTDB,²⁵ the NTDB is not a population-based sample.¹⁴ The facilities contributing data to this cohort may not be representative of all facilities in their regions or across the country. As such, that other facility characteristics were not associated with mortality may be because of selection bias,²⁴ because facilities with poorer outcomes may not participate in the NTDB. Because data in the NTDB do not distinguish between primary diagnoses and other diagnoses, we defined TBI using diagnoses codes present in any position. Thus, this cohort includes both isolated TBI injuries and poly-trauma cases. We also excluded patients from our analyses with missing inclusion or exclusion criteria data, and this increases the potential for bias²⁶ if the reason data are missing is related to a subject's risk of in-hospital mortality (for example, if vitals data are less well-captured among the severely injured).

FIG. 2. Association between facility characteristics and in-hospital 30-day mortality. *Multivariable model adjusted for age, race, insurance source, transfer status, hypotension on arrival, heart rate on arrival, mechanism of injury, injury intent, Glasgow Coma Scale score, Injury Severity Score, head Abbreviated Injury Score, and mechanical ventilation requirement.

We did not include all the individual-level factors that may impact in-hospital mortality in our models. Differences in pre-hospital factors, such as patient care by EMS personnel, transport method (e.g., air vs. ground), and facility transfer time may have a substantial impact on TBI victims given that half of those who die do so within the first 2 h after injury.²⁷ The importance of these factors has been demonstrated in other studies pertaining to survival after trauma.^{28,29} Research into out-of-hospital cardiac arrest patients suggests that time of day³⁰ and race³¹ may play a role in survival. Our sensitivity analyses found that adding individual-level variables to our model did not affect the risk estimates associated with facility-level factors. Indeed, the risk estimates associated with the individual-level variables included in our base model were not meaningfully changed by the inclusion of facility-level variables in our multivariate model. We adjusted all analyses for patient characteristics (including race, age, mechanism of injury, and intent of injury) to ensure our results were not the result of case-mix differences. Many variables, however, are not completely captured in the NTDB. Staffing levels during patient care and time of day of patient arrival are not part of NTDB data, and this type of dynamic facility characteristics may also play a role in trauma outcomes.

There are several potential explanations for the observed regional variation in mortality in this cohort of pediatric patients with severe TBI. In addition to differences in data collection, there may be important differences in the population of pediatric TBI injuries or differences in treatment and practice. It is possible facilities in the Northeast are better organized, or that pediatric patients with TBI in that region have better access to care. State-level variation in outcomes after pediatric severe TBI³ suggests a more fine-grained geographic breakdown may provide greater insight into the association between geography and mortality, including what role state-level organization of trauma systems might play in improving patient outcomes. Regional differences in 30-day mortality may also be attributable to variation in the aggressiveness and duration of care provided for patients with little chance of recovery.

Future research regarding regional variation in in-hospital mortality should aim to examine differences in pre-hospital care and in-hospital treatment, including a more fine-grained geographic breakdown. Focused research on the interaction between important individual-level characteristics and geographic region may also help explain important regional disparities in treatment and outcome by race or socioeconomic status. An enhanced understanding of the extent to which this geographic association stems from variation in (a) the characteristics of pediatric patients with TBI, including preexisting conditions, (b) pre-hospital management, including availability and resources of EMS personnel, and (c) treatment during hospitalization, including adherence to guidelines of care, can inform evidence-based practices and may reduce the burden of mortality among this patient population.

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Author Disclosure Statement

No competing financial interests exist.

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