Triage of Children with Moderate and Severe Traumatic Brain Injury to Trauma Centers

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Abstract

Outcomes after pediatric traumatic brain injury (TBI) are related to pre-treatment factors including age, injury severity, and mechanism of injury, and may be positively affected by treatment at trauma centers relative to non-trauma centers. This study estimated the proportion of children with moderate to severe TBI who receive care at trauma centers, and examined factors associated with receipt of care at adult (ATC), pediatric (PTC), and adult/pediatric trauma centers (APTC), compared with care at non-trauma centers (NTC) using a nationally representative database. The Kids' Inpatient Database was used to identify hospitalizations for moderate to severe pediatric TBI. Pediatric inpatients ages 0 to 17 years with at least one diagnosis of TBI and a maximum head Abbreviated Injury Scale score of ≥ 3 were studied. Multinomial logistic regression was performed to examine factors predictive of the level and type of facility where care was received. A total of 16.7% of patients were hospitalized at NTC, 44.2% at Level I or II ATC, 17.9% at Level I or II PTC, and 21.2% at Level I or II APTC. Multiple regression analyses showed receipt of care at a trauma center was associated with age and polytrauma. We concluded that almost 84% of children with moderate to severe TBI currently receive care at a Level I or Level II trauma center. Children with trauma to multiple body regions in addition to more severe TBI are more likely to receive care at a trauma center relative to a NTC.

Key words: brain injury; pediatrics; trauma; trauma center

Introduction

TRAUMATIC BRAIN INJURY (TBI) is a leading cause of morbidity and mortality among children and youth. TBI is responsible for more than 630,000 emergency department visits, 60,000 hospitalizations, and 6000 deaths in the US each year among children and youth 0 to 19 years of age.¹ Outcomes after pediatric TBI are related to pre-treatment factors, including age, injury severity, mechanism of injury,² avoidance of secondary injury due to hypotension, hypoxia, hyperthermia or hypothermia, and uncontrolled intracranial pressure, and may be positively affected by treatment at trauma centers relative to non-trauma centers. Despite the additional resources of trauma centers to better attend to more seriously injured TBI patients, little is known about what proportion of children in the US with moderate to severe TBI

currently receive care at any trauma center or among those specifically designated to serve pediatric patients.

Many states have developed systems that include adult and pediatric trauma care designation, either through a state (or county) or by the American College of Surgeons Committee (ACS) on Trauma's verification process.³ A few reports have described where injured children receive medical care and the impact of trauma center designation on outcomes^{4–6} but studies with a specific focus on pediatric TBI are limited. Both pediatric and adult patients with private insurance and those injured far from the nearest trauma center are less likely to receive care from a trauma center.^{7,8} Mortality following severe pediatric TBI has been reported to be associated with transfers,⁹ and up to 36% of children with TBI are not treated at a trauma centers.¹⁰ Hence, it is important to examine nationally how often children with moderate to severe TBI receive

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care at trauma centers, the quality of care they receive, and the potential for more favorable outcomes relative to non-trauma centers. The main aim of this study was to provide an updated, nationally representative examination of where children with moderate to severe TBI receive care, and the demographic, injury, and geographic factors that influence where that care is received. We also examined national data available for 2003, 2006 and 2009 to determine whether referral of pediatric patients with moderate to severe TBI to trauma centers has increased over time.

Methods

Study design

This retrospective study was conducted to examine one of the goals of the Pediatric Guideline Adherence and Outcomes Study, a multisite collaboration to examine the factors associated with adherence to the “2003 Guidelines for the Acute Medical Management of Severe Pediatric Traumatic Brain Injury”¹¹ and the degree to which guideline adherence results in improved patient outcomes. This study serves to examine the degree to which pediatric TBI patients receive care at adult and/or pediatric trauma centers relative to non-trauma centers in order to gain knowledge on the first step toward guideline-adherent triage of these children who receive trauma center care.

Data source. The 2003, 2006, and 2009 Healthcare Cost and Utilization Project Kids’ Inpatient Databases (KID) were used to identify hospitalizations for moderate to severe pediatric TBI. KID is a nationally representative, weighted sample of pediatric inpatient stays at non-rehabilitation hospitals.¹² Because of our interest in classifying hospitals based on trauma designation, analyses were focused on the subset of states in KID that provide identifiable information on individual hospitals (23 states in 2003, 24 states in 2006, and 26 states in 2009). Our main analyses focused on the more recent KID data from 2006 and 2009; however, we included 2003 data to examine if a trend of increasing referral to trauma centers occurred during 2003 to 2009.

Study population. The study population consisted of 0- to 17-year-old pediatric inpatients with at least one diagnosis of TBI (International Classification of Diseases, Ninth Revision [ICD-9] diagnosis codes of 800.0–801.9, 803.0–804.9, 850.0–854.1, 959.01, 950.1–950.3, 995.55).¹ We defined moderate to severe TBI using a maximum head Abbreviated Injury Scale score (AIS) of ≥ 3 only (Glasgow Coma Scale [GCS] scores were not available in KID data) consistent with prior studies of TBI.^{13,14} This approach avoided the problems inherent with inconsistent and problematic coding of total GCS in intubated patients. We excluded patients transferred from long-term facilities and transfers from facilities other than hospitals. Transfers from other hospitals were included to allow transfers from lower level hospital emergency departments or inpatient units to trauma centers. These exclusions were performed to focus on the primary hospitalization and to avoid double counting a single unique hospitalization. Burn patients (ICD-9 diagnosis codes of 940.0–949.5) were also excluded.

Multinomial outcome. For our main analysis, trauma designation level and type served as the multinomial outcome of interest. Hospitals in the KID database were categorized into one of four levels: 1) non-trauma or lower level trauma center (Level ≥ 3); 2) Level I or II trauma centers with adult designation only; 3) Level I or II trauma centers with pediatric designation only; and 4) Level I or II trauma centers with both adult and pediatric designation. State Department of Health websites and ACS trauma verification data were used to identify pediatric and adult trauma level for the hospitals involved in our study. Trauma level and type (adult only,

pediatric only, both adult and pediatric) were defined as the highest level designation of the two sources (state and ACS verification).

Independent Variables

The first set of independent variables served to describe the study sample and was examined in bivariate analyses alone. The second set of independent variables was examined in both bivariate analyses and identified a priori as potential predictors in the multivariable, multinomial logistic regression analyses. Descriptive variables are described below.

Descriptive variables

Patient demographics. Patient demographic characteristics examined included patient race/ethnicity (White, Black/African American, Hispanic/Latino, Asian or Pacific Islander, Native American, Other) and 2006 and 2009 median income of patient residential ZIP code (in quartiles, based on year of discharge).¹⁵

Patient care and outcomes. Patient care and outcome variables examined as descriptive variables included: any procedures coded and performed during hospitalization; mean number of procedures performed; patient discharge (favorable outcome [home, outpatient care], intermediate outcome [transfer to rehabilitation, other short-term facility, home health care], and unfavorable outcome [discharge to long-term facility, hospice care, death]); patient death during hospitalization; length of hospitalization stay (continuous; in days); and total hospital charges (continuous; in 2009 U.S. dollars). Charges for patients discharged in 2006 were converted to 2009 U.S. dollars.

Mechanism of injury. Mechanism of the injury that led to patient hospitalization was categorized using ICD-9 external cause of injury codes (E codes). Indicator variables were created to identify hospitalizations with at least one E code for each of the three most prevalent classifications of mechanism of injury (the three ICD-9 E-code categories with $> 10\%$ prevalence: motor vehicle crashes, falls and assault/child abuse) within our sample.¹⁶

Potential predictors

The independent variables considered as potential predictors in our multiple regression analyses are described below.

Patient demographics. Demographic characteristics examined in our multiple regression analyses included sex (male, female), age in years (0–4, 5–9, 10–14, 15–17), primary payor status (private, private including HMO; public [Medicaid or Medicare]; other, including self-pay and no charge), and urban-rural designation of patient residence using the National Center for Health Statistics urban-rural county classification scheme (large central metropolitan areas, population ≥ 1 million and containing major most populous city; large fringe metropolitan areas, population ≥ 1 million but not central metropolitan areas; medium metropolitan, population 250,000–999,999; small metropolitan area, population 50,000–249,999; micropolitan, contains at least one urban cluster of 10,000–49,999; non-core area, less populous than micropolitan).¹⁷

Severity and extent of injuries. Stata’s ICD Programs for Injury Categorization (ICDPIC) module¹⁸ was used in conjunction with ICD-9 diagnosis codes to generate body region-specific maximum AIS (head/neck, face, chest, abdomen and pelvic contents, extremities or pelvic girdle, external), total maximum AIS, and new Injury Severity Scores (ISS). Injury severity data is often either not available or a large proportion of values are missing from patient records. A much used approach in the past has been to use

ICD-9 diagnosis codes to match diagnosis codes with severity measures as ascertained by trauma registrars. ICD-MAP, developed by researchers at Johns Hopkins^{19,20} has served this invaluable purpose for injury research for over 20 years. However, ICD-MAP has not been updated in more than 20 years, thus making its ability to map newer ICD-9 diagnosis codes problematic. ICDPIC, a newer module for assigning injury severity via diagnosis codes, was developed using similar procedures to ICD-MAP (diagnosis codes assigned to severity measures using ratings provided by trauma registrars) and the National Trauma Data Bank version 6.1.

Five indicator variables (yes, no) for the presence of AIS ≥ 1 injuries to other body regions in addition to the head/neck were created. Maximum head AIS (3, 4, 5–6), total maximum AIS scores (3, 4, 5–6), new ISS (9–15, > 15), and the five indicator variables were examined in our multiple regression analyses.

Statistical analyses

Patient and injury characteristics were examined statistically in bivariate analyses by trauma designation of facility using χ^2 and Wald tests from multinomial logistic regression of a single continuous independent variable. Statistical significance was defined as $p < 0.05$. Multivariable multinomial logistic regression was used to examine the contribution of potential predictors on trauma designation of the hospital at which definitive TBI hospitalization care was received for discharges occurring in 2006 and 2009. Multinomial logistic regression is similar to logistic regression, but is used for nominal outcomes (i.e., outcomes with greater than two non-ordered categories). The risk estimates generated are ratios of the relative risk of a given variable on one level of the outcome divided by the relative risk for that same variable on the referent level of the outcome. Thus, the risk estimate is a ratio of relative risks, otherwise referred to as a relative risk ratio (RRR). In this study, the RRR describes whether a person with a given characteristic was more, less or equally likely to receive care at one of the trauma centers than at a non-trauma center. RRRs and their respective 95% confidence intervals were calculated for all potential predictors.²¹ All analyses accounted for the complex survey design of the KID data (i.e., primary sampling unit, sampling probability weights and sampling strata).²² Data were analyzed using Stata statistical software v. 11 (StataCorp LP: College Station, Texas)²³ and Stata's subpopulation routine was used to correct weighting and calculation of standard errors on the analysis sub-sample. All potential predictor variables were included in the multivariable multinomial logistic regression model. As appropriate for multinomial logistic regression models, adjusted Wald tests were used to test the overall significance of a given predictor across all levels of the outcome relative to the referent outcome. A significant result is interpreted as any difference in any level of the outcome relative to the referent outcome level. This overall test of significance served as the primary test of significance for each predictor variable. Significance tests were also performed on the multiple regression analyses to examine the significance of the association between a given predictor variable and pair-wise comparisons between trauma center types. Due to concerns over multiple comparisons, significant pair-wise results in which the overall test is not significant should be interpreted with caution. Very few records were missing data for variables used in the regression analyses (sex was missing for 1.9%, rurality for 2.0% and payor for 0.2%, all others had no missing values), therefore, we conducted complete case analysis.

Due to strong collinearity between overall maximum AIS score and maximum head AIS score, and ISS and maximum head AIS; maximum head AIS was retained while maximum overall AIS and ISS were excluded from the model.

Trend analyses. Simple bivariate analyses were performed to examine if the proportion of patients with moderate to severe pediatric TBI has increased with time for care received at the three

trauma center types compared with non-trauma centers, and any trauma center compared with non-trauma centers.

Results

Moderate to severe pediatric TBI sample

Of the 6,538,470 (representing 14,929,015 nationally) pediatric discharges represented in 2006 and 2009 KID data, 77,680 (1.19%; 118,848 nationally) had at least one diagnosis of TBI. Of these, 39,166 (50.4%; 59,968 nationally) met the additional inclusion criteria of AIS ≥ 3 .

Of these, 17,038 hospitalizations (43.5%; 26,128 nationally) occurred in a state with identifiable hospitals, and met admission/transfer criteria. All 17,038 eligible hospitalizations were able to be classified by trauma designation of facility (since all states with identifiable hospitals met the primary criterion for a regionalized trauma system via trauma designation) and thus comprised the analytic sample. Of the 17,038 hospitalizations, 2823 (16.7%) occurred at non-trauma centers, 7751 (44.2%) occurred at trauma centers designated Level I or II for adult patients only, 2733 (17.9%) occurred at trauma centers designated Level I or II for children only, and 3731 (21.2%) occurred at trauma centers designated Level I or II for both adults and children.

Bivariate results

Study sample characteristics are presented by trauma designation level of the hospital where inpatient care was received (Table 1). Table 1 provides the number of observations in the dataset, the number this represents nationally (using survey weights), and weighted percentages (national estimates). All percentages provided in the results section of the text are also weighted percentages. Patients who received care at pediatric trauma centers were significantly younger on average than children receiving care at all other facilities. Of the youngest children (aged 0 to 4 years) with TBI, 53.0% received care at non-trauma centers or trauma centers designated for adults only. Patient sex also differed by facility type, with a slightly higher proportion of female patients seen at pediatric trauma centers, compared with other facilities. All other demographic variables were otherwise comparable across trauma designation of hospital.

All trauma centers were more likely to receive patients with greater severity of injury and with trauma to other body sites, compared with non-trauma centers. TBI patients receiving care at trauma centers were more likely to have at least one procedure performed in hospital, to have died in hospital, to have longer lengths of stays, to have unfavorable discharge dispositions, and to have higher total charges than TBI patients receiving care at non-trauma centers. Patients incurring TBI through falls were more likely to receive care at non-trauma centers and pediatric trauma centers, whereas patients incurring TBI through motor vehicle crashes were more likely to receive care at adult and adult-pediatric trauma centers than pediatric trauma centers and non-trauma centers.

Multiple multinomial logistic regression results

The results from the multiple multinomial logistic regression analyses are presented in Tables 2 and 3. Each column in Table 2 provides the relative risk ratio (RRR) and 95% confidence interval (CI) for each potential predictor after adjustment for all potential predictors when comparing hospitalization at a specific trauma center relative to a non-trauma center. Table 3 provides the same information for additional pairwise comparisons. Age, facial

TABLE 1. PATIENT DEMOGRAPHICS AND INJURY AND HOSPITALIZATION CHARACTERISTICS OF PEDIATRIC PATIENTS WITH TRAUMATIC BRAIN INJURY BY FACILITY TYPE, U.S. 2006 and 2009

	# of data observations (n) ^{††}	National estimate (N)	NTC, level ≥ 3 (n = 2823) (N = 4373) weighted %	Adult levels I/II only (n = 7751) (N = 11540) weighted %	Ped levels I/II only (n = 2733) (N = 4673) weighted %	Adult and ped levels I/II (n = 3731) (N = 5543) weighted %
Demographic Characteristics						
Patient sex*						
Male	11259	17258	68.1	67.8	64.8	67.7
Female	5450	8387	31.9	32.2	35.2	32.3
Patient age (years)***						
0 to 4	5236	8117	38.0	27.1	48.5	34.7
5 to 9	3209	4968	17.4	12.6	20.4	16.7
10 to 14	3586	5528	19.3	20.8	22.4	22.3
15 to 17	5007	7516	25.3	39.4	8.7	26.2
Patient race/ethnicity						
White	7410	11448	54.8	60.5	51.2	55.2
Black/African American	1613	2506	12.3	12.2	10.8	14.5
Hispanic/Latino	2814	4268	24.5	18.4	23.4	22.2
Asian or Pacific Islander	368	554	4.0	2.4	2.7	2.7
Native American	157	230	0.5	1.6	1.4	0.3
Other	748	1195	4.0	4.9	10.5	5.2
Patient payor						
Private	9076	13981	55.0	56.6	49.7	49.6
Public	5973	9121	34.3	31.2	38.9	40.0
Other (self-pay, no charge, other)	1961	2981	10.7	12.2	11.4	10.4
Rurality of Patient County of Residence						
Large central metropolitan areas	6156	9381	40.7	29.1	49.8	38.2
Large fringe metropolitan areas	3806	5905	21.1	25.5	20.3	21.8
Medium metropolitan areas	3075	4736	17.7	22.2	14.3	14.9
Small metropolitan area	1333	2029	8.7	7.8	6.9	8.4
Metropolitan areas	1376	2125	7.5	9.2	5.0	9.8
Non-core areas	946	1444	4.3	6.3	3.7	6.9
Median household income for patient's ZIP code†						
Lowest quartile	3915	6011	22.5	23.8	21.8	26.2
2nd lowest quartile	4191	6410	24.2	26.2	23.0	26.3
2nd highest quartile	4260	6515	25.9	24.9	28.5	25.0
Highest quartile	4162	6411	27.5	25.2	26.7	22.6
Injury characteristics						
Head AIS*						
	11396	17456	66.3	68.7	63.6	65.9
4	5227	8038	32.2	28.5	34.1	31.7
5–6	415	634	1.6	2.8	2.2	2.4
Maximum AIS*						
3	11164	17103	65.7	67.1	62.6	64.3
4	5374	8262	32.6	29.5	34.7	32.8
5–6	500	763	1.7	3.4	2.7	2.9
New ISS***						
9–15	7926	12171	53.5	45.3	47.7	42.9
> 15	9112	13957	46.5	54.7	52.3	57.1
Other body regions injured						
Facial injury***	2885	4400	12.3	19.1	12.4	19.4
Chest injury***	2668	4046	8.8	18.8	11.7	17.2
Upper/lower extremity injury***	3173	4852	13.0	21.3	14.6	20.6
Abdominal injury***	1583	2408	6.1	10.7	7.0	10.5
External injury***	5781	8811	27.7	37.5	28.9	34.8
Patient care and outcomes						
Any procedures performed***	9474	14545	43.1	57.6	51.2	65.4
Mean number of procedures (SE)*	17038	26128	1.54 (1.13, 1.94)	2.42 (2.23, 2.60)	1.85 (1.43, 2.28)	2.55 (2.16, 2.93)
Patient died in hospital***	900	1377	3.5	6.0	4.6	5.8

(continued)

TABLE 1. (CONTINUED)

	# of data observations (n) ^{††}	National estimate (N)	NTC, level ≥ 3 (n = 2823) (N = 4373) weighted %	Adult levels I/II only (n = 7751) (N = 11540) weighted %	Ped levels I/II only (n = 2733) (N = 4673) weighted %	Adult and ped levels I/II (n = 3731) (N = 5543) weighted %
Patient discharge***						
Favorable outcome	13657	20974	85.3	76.1	87.8	79.4
Moderate outcome	1904	2922	9.3	14.6	5.2	10.6
Unfavorable outcome	1439	2177	5.3	9.3	7.0	10.0
Mean length of stay in days (SE)**	17038	26128	4.31 (3.7, 4.9)	5.79 (5.5, 6.1)	5.68 (4.8, 6.6)	6.24 (5.8, 6.7)
Mean total charges in 2009 dollars (SE)*	16807	25807	40,309 (3856)	60,572 (2551)	57,453 (7533)	66,345 (6661)
Mechanism of injury						
Motor vehicle traffic crash***	4969	7592	17.8	35.1	19.1	33.9
Accidental fall***	5053	7783	37.4	25.1	36.2	28.1
Assault/child abuse	1881	2890	11.6	10.3	13.0	10.5

* p < 0.05; ** p < 0.01; *** p < 0.001.

† Median household income by quartile in 2006: \$1 – 37,999; \$38,000 – 46,999; \$47,000 – 61,999; ≥ \$62,000; and in 2009: \$1 – 39,999; \$40,000 – 49,999; \$50,000 – 65,999; ≥ \$66,000/

†† Percent missing data by variable: sex (1.9%); payor (0.2%); rurality (2.0%); race (23%); median income (3.0%); died (0.02%); E-code variables (7.8%); disposition (0.2%); all other variables have no missing data.

NTC, non-trauma center; Ped, pediatric; AIS, Abbreviated Injury Scale; ISS, Injury Severity Score; SE, standard error.

TABLE 2. MULTINOMIAL LOGISTIC REGRESSION RESULTS: FACTORS PREDICTIVE OF WHERE MODERATE/SEVERE PEDIATRIC TRAUMATIC BRAIN INJURY INPATIENTS RECEIVE CARE, TRAUMA CENTER TYPE RELATIVE TO NON-TRAUMA CENTERS

	Adult Levels I/II only: NTC	Ped Levels I/II only: NTC	Adult and ped Levels I/II: NTC
Demographic Characteristics	RRR (95% CI)	RRR (95% CI)	RRR (95% CI)
Patient sex			
Male	1.00	1.00	1.00
Female	1.07 (0.97, 1.19)	1.07 (0.97, 1.19)	1.01 (0.91, 1.13)
Patient age (years)***			
0 to 4	1.00	1.00	1.00
5 to 9	1.02 (0.88, 1.18)	0.98 (0.84, 1.14)	1.05 (0.90, 1.22)
10 to 14	1.34 (1.13, 1.59)	0.89 (0.73, 1.10)	1.17 (0.96, 1.42)
15 to 17	1.83 (1.34, 2.49)	0.25 (0.14, 0.43)	0.98 (0.72, 1.35)
Patient payor			
Private	1.00	1.00	1.00
Public	1.05 (0.81, 1.35)	1.08 (0.70, 1.68)	1.35 (0.98, 1.86)
Other (self-pay, no charge, other)	1.11 (0.83, 1.47)	1.11 (0.58, 2.14)	1.08 (0.73, 1.59)
Rurality of patient county of residence			
Large central metropolitan areas	1.00	1.00	1.00
Large fringe metropolitan areas	1.68 (0.99, 2.83)	0.80 (0.38, 1.66)	1.17 (0.60, 2.26)
Medium metropolitan areas	1.73 (0.77, 3.85)	0.67 (0.23, 1.94)	0.92 (0.37, 2.27)
Small metropolitan area	1.22 (0.61, 2.42)	0.63 (0.28, 1.38)	1.04 (0.44, 2.46)
Micropolitan areas	1.59 (0.89, 2.84)	0.50 (0.21, 1.20)	1.33 (0.63, 2.81)
Non-core areas	1.80 (1.01, 3.23)	0.67 (0.20, 2.22)	1.58 (0.72, 3.47)
Other body regions injured (in addition to head)			
Facial injury***	1.27 (1.08, 1.51)	1.12 (0.91, 1.38)	1.49 (1.23, 1.80)
Chest injury***	1.71 (1.38, 2.12)	1.51 (1.18, 1.92)	1.66 (1.33, 2.08)
Upper/lower extremity injury**	1.23 (1.06, 1.43)	1.19 (1.01, 1.41)	1.34 (1.14, 1.57)
Abdominal injury	1.05 (0.83, 1.34)	1.08 (0.81, 1.43)	1.18 (0.90, 1.56)
External injury	1.27 (1.07, 1.51)	1.14 (0.89, 1.47)	1.22 (0.99, 1.50)
Severity of Injury			
Head AIS			
3	1.00	1.00	1.00
4	0.93 (0.80, 1.08)	1.05 (0.84, 1.30)	1.03 (0.84, 1.26)
5–6	1.59 (1.11, 2.28)	1.54 (0.98, 2.44)	1.47 (0.97, 2.23)

* p < 0.05; ** p < 0.01; *** p < 0.001.

Bold = statistically significant.

NTC, non-trauma centers; Ped, pediatric; RRR, relative risk ratio; CI, confidence interval; AIS, Abbreviated Injury Scale.

TABLE 3. MULTINOMIAL LOGISTIC REGRESSION RESULTS: FACTORS PREDICTIVE OF WHERE MODERATE TO SEVERE PEDIATRIC TRAUMATIC BRAIN INJURY INPATIENTS RECEIVE CARE, ADDITIONAL PAIR-WISE TRAUMA CENTER COMPARISONS

	<i>Ped I/II only</i>	<i>adult I/II only</i>	<i>Adult and ped I/II</i>	<i>adult I/II only</i>	<i>Adult and ped I/II</i>	<i>ped I/II only</i>
Demographic characteristics	RRR (95% CI)		RRR (95% CI)		RRR (95% CI)	
Patient sex						
Male	1.00		1.00		1.00	
Female	1.00 (0.92, 1.09)		0.94 (0.86, 1.03)		0.94 (0.86, 1.04)	
Patient age (years)***						
0 to 4	1.00		1.00		1.00	
5 to 9	0.95 (0.82, 1.10)		1.05 (0.91, 1.22)		1.11 (0.94, 1.30)	
10 to 14	0.66 (0.55, 0.80)		0.88 (0.74, 1.05)		1.33 (1.08, 1.64)	
15 to 17	0.14 (0.08, 0.23)		0.54 (0.42, 0.70)		4.00 (2.37, 6.78)	
Patient payor						
Private	1.00		1.00		1.00	
Public	1.03 (0.69, 1.55)		1.29 (0.98, 1.69)		1.25 (0.80, 1.94)	
Other (self-pay, no charge, other)	1.00 (0.53, 1.90)		0.98 (0.68, 1.39)		0.97 (0.48, 1.96)	
Rurality of patient county of residence						
Large central metropolitan areas	1.00		1.00		1.00	
Large fringe metropolitan areas	0.48 (0.23, 1.00)		0.69 (0.36, 1.34)		1.46 (0.63, 3.39)	
Medium metropolitan areas	0.39 (0.16, 0.97)		0.53 (0.26, 1.10)		1.36 (0.51, 3.65)	
Small metropolitan area	0.51 (0.25, 1.08)		0.85 (0.38, 1.90)		1.65 (0.68, 4.05)	
Metropolitan areas	0.31 (0.13, 0.78)		0.83 (0.38, 1.81)		2.65 (0.96, 7.29)	
Non-core areas	0.37 (0.11, 1.21)		0.87 (0.40, 1.89)		2.35 (0.64, 8.59)	
Other body regions injured (in addition to head)						
Facial injury***	0.88 (0.75, 1.03)		1.17 (1.03, 1.32)		1.33 (1.11, 1.59)	
Chest injury***	0.88 (0.75, 1.04)		0.97 (0.85, 1.11)		1.10 (0.93, 1.31)	
Upper/lower extremity injury**	0.97 (0.85, 1.10)		1.09 (0.97, 1.22)		1.12 (0.98, 1.29)	
Abdominal injury	1.02 (0.84, 1.25)		1.12 (0.93, 1.36)		1.10 (0.88, 1.38)	
External injury	0.90 (0.72, 1.13)		0.96 (0.80, 1.15)		1.06 (0.83, 1.37)	
Severity of injury						
Head AIS						
3	1.00		1.00		1.00	
4	1.13 (0.93, 1.37)		1.11 (0.94, 1.33)		0.99 (0.79, 1.24)	
5–6	0.97 (0.68, 1.38)		0.93 (0.68, 1.27)		0.96 (0.64, 1.42)	

* $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$.

Bold = statistically significant.

Ped, pediatric; RRR, relative risk ratio; CI, confidence interval; AIS, Abbreviated Injury Scale.

injuries, chest injuries, and injuries to the extremities were the four significant independent variables associated with where pediatric TBI patients received care.

The multivariable model confirmed that, following adjustment for all other independent variables, 15- to 17-year-old pediatric TBI patients were more likely to be hospitalized at trauma centers designated for adults and less likely to be hospitalized at trauma centers designated for children relative to those seen at non-trauma centers. (Table 2)

All trauma center types were more likely to receive TBI cases with more complicated polytrauma, particularly patients presenting with facial, chest, and extremity injuries (and marginally for external injuries; $p = 0.056$), compared with non-trauma centers (Table 2). Pediatric TBI patients with facial injuries were more likely to be hospitalized at adult-pediatric trauma centers, compared with adult and pediatric trauma centers. Injuries to other body regions were comparable between trauma center types (Table 3).

No significant differences were found between patient sex, payor status, or rurality of patient residence on type of facility providing TBI care; however, these variables were retained for adjustment of confounding in the analyses conducted for Tables 2 and 3.

The proportion of pediatric patients being seen in trauma centers relative to non-trauma centers showed no significant increase over the period of 2003 to 2006 to 2009 ($p = 0.72$). The proportion of

pediatric patients with moderate to severe TBI who were hospitalized at non-trauma centers was 20.0% in 2003, 17.0% in 2006 and 16.0% in 2009. Adult trauma centers treated 44.0% of these patients in 2003, 45.0% in 2006, and 43.0% in 2009. Pediatric trauma centers treated 16.0% in 2003, 18.0% in 2006, and 19.0% in 2009, whereas adult-pediatric centers treated 20.0% in 2003, 20.0% in 2006, and 22.0% in 2009.

Discussion

The main findings of this study are that in 2006 and 2009, all three trauma center types were more likely than non-trauma centers to provide care for children with moderate to severe TBI complicated by polytrauma, particularly patients presenting with facial injuries, chest injuries, and upper or lower extremity injuries in addition to TBI. Age of patient was also an important determinant of where pediatric TBI patients received care. We found that 15- to 17-year-old children with moderate to severe TBI were more likely to receive care at adult or adult and pediatric designated trauma centers rather than non-trauma centers. We also found that 53% of children 4 and younger received care at non-trauma centers or trauma centers designated for adults only.

In 2000, Potoka reported that of 13,351 injured children (0–16 years) in the Pennsylvania trauma outcome study between 1993 and

1997, 66% of injured children were treated at either a pediatric trauma center or adult trauma center with added pediatric trauma qualifications.⁶ They found that survival for head injuries was better at pediatric trauma centers, compared with adult and adult trauma centers with pediatric qualifications, despite no apparent significant differences in ISS. In a later report on the same cohort, Potoka and colleagues also found improved functional outcome among pediatric TBI patients treated at pediatric trauma centers.⁵ Although these studies did evaluate significant differences between trauma center types and did perform some stratification to allow for the possibility of confounding, estimates of improved outcomes in injured children seen at pediatric centers by critical analysis remain equivocal. A review of studies of TBI among adults and children or adults alone collectively show mixed results on the effect of trauma center designation on patient outcomes.^{24–26} However, all but one of these studies compared trauma centers to other trauma centers. The one study comparing trauma centers to non-trauma centers found that pediatric TBI patients sent to trauma centers presented with more complex and severe injuries and after appropriate adjustment, were more likely to survive when treated at trauma centers relative to non-trauma centers.⁵ Thus, although it is unclear if trauma center types differ in terms of favorable outcomes among TBI patients, given the current best evidence, trauma center care appears to be preferential for more serious cases of TBI.

Segui-Gomez and colleagues, using hospital discharge data from the late 1990s, showed that a large proportion (47%) of severely injured children (all trauma types) received care in non-trauma centers, and 36% of children with moderate and severe TBI were treated in non-trauma centers.¹⁰ Further, fewer than half of all injured children who were treated at trauma centers received care at trauma centers with pediatric trauma designation despite the tentative suggestion that better outcomes may be obtained at pediatric trauma centers.

There are some methodologic differences between these previous reports and the current study. First, previous related studies that examined where injured pediatric inpatients received care included all trauma patients where only a subset ($n=300^6$ and $n=5396^1$) had combined head and/or neck injuries. This study examined patterns from a much larger number of moderate and severe TBI patients from a broader, more nationally representative sample of discharged children. There are additional important findings from our study compared to earlier studies. In contrast to those of Segui-Gomez, our findings showed that insurance status did not impact type of facility at which care was received. However, there was some suggestion from pair-wise comparisons that adult-pediatric trauma centers may be receiving a disproportionate number of pediatric TBI cases with public insurance relative to other facility types.

There are some other observations in hospitalization patterns worth noting. First, more injured children (47%) received care at non-trauma centers in the late 1990s, compared with earlier years, despite a larger number of designated trauma centers between the early 1990s and late 1990s, suggesting that triage of children to trauma centers lags behind development of trauma centers.¹⁰ Similar to the findings by Segui-Gomez and colleagues, we found older children (10- to 14-year-olds and 15- to 17-year-olds) with moderate to severe TBI more likely to receive care at an adult trauma facility compared to a pediatric trauma designated hospital. A substantial proportion (53.0%) of the youngest children (0 to 4 years) with moderate to severe TBI in our study received care at adult centers or non-trauma centers. If there is a benefit to receiving care at a pediatric trauma designated facility, this may not represent optimal care for children 4 and younger. This may be particularly

relevant to very young children with abuse-related TBI who may be more likely to have that abuse recognized if they are seen at a pediatric hospital.²⁷ Determining what level and type of trauma center results in better patient outcomes for pediatric TBI patients of different ages is essential in determining if the differential triage patterns we observed by age are of concern or not.

Similar to the Segui-Gomez article from the late 1990s, our study shows that children with moderate to severe TBI who receive care at adult trauma centers undergo more procedures, incur more cost, have longer hospital length of stay, and have a higher mortality rate than pediatric trauma centers and non-trauma centers. However, these results should be interpreted cautiously since they represent bivariate findings only. Although it was not the purpose of this study to examine the effect of trauma center designation on outcomes of pediatric TBI patients, there are some studies that suggest injured children do as well at adult trauma centers as they do at pediatric trauma centers.^{28–33} While we found no suggestion of an increase in the proportion of pediatric patients with moderate to severe TBI transferred to trauma centers from the period 2003 to 2009, our results show a greater proportion of children with TBI receiving care at trauma centers compared to the 36% of children with their most severe injury to the head found by Segui-Gomez in the late 1990s. However, the Segui-Gomez article included all hospitalized children and youth 0 to 15 years, whereas our study included children and youth 0 to 17 years hospitalized with a head injury of AIS ≥ 3 . A comparison of severity indicators between the two studies strongly suggests that the current study involves a more severely injured population on average than the Segui-Gomez study. This suggests that there may be more room for improvement in the triage of pediatric patients with moderate to severe TBI to trauma centers.

There are a few limitations to this study. First, we could only include states with statewide hospital discharge data sets available and provided data to identify individual hospitals. Nevertheless, we were able to generate nationally representative estimates of the proportion of pediatric TBI patients hospitalized at trauma and non-trauma centers, data that had not been available previously. Second, we relied on both state and/or ACS designation processes to classify the hospital's trauma designation level and type, which may have resulted in some variability in the definition of trauma of centers.⁴ Despite the obvious benefits of administrative data, there are limitations to their use. Injury severity variables are often not available from administrative data. For more than 20 years, a common, validated approach to solving this problem has been to match ICD-9 diagnosis codes to severity measures such as AIS and ISS, which we incorporated into our methodology to overcome this obstacle.¹⁸ Despite these limitations, our study provides critical new information on where children with moderate and severe TBI are receiving care, thereby providing insight into the current state of our nation's trauma system in attending to the needs of pediatric TBI in the United States.

In summary, although over 80% of all children with moderate to severe TBI are treated at trauma centers, many patients continue to receive care at non-trauma centers that are, by definition, not fully equipped to care for them. Future studies should examine the effect of trauma center type on outcome of pediatric TBI patients, and to determine if this effect is modified by age. Studies examining the current capacity of trauma centers to attend to a larger proportion of these children also are warranted. With the increasing understanding of the long-term consequences of TBI, our efforts to ensure that the right child gets to the right hospital at the right time must be accelerated.

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Author Disclosure Statement

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