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Measuring the effects of institutional pediatric traumatic brain injury volume on outcomes for rural-dwelling children

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OBJECTIVE Rural-dwelling children may suffer worse pediatric traumatic brain injury (TBI) outcomes due to distance from and accessibility to high-volume trauma centers. This study aimed to compare the impacts of institutional TBI volume and sociodemographics on outcomes between rural- and urban-dwelling children.

METHODS This retrospective study identified patients 0–19 years of age with ICD-9 codes for TBI in the 2012–2015 National Inpatient Sample database. Patients were characterized as rural- or urban-dwelling using United States Census classification. Logistic and linear (in log scale) regressions were performed to measure the effects of institutional characteristics, patient sociodemographics, and mechanism/severity of injury on occurrence of medical complications, mortality, length of stay (LOS), and costs. Separate models were built for rural- and urban-dwelling patients.

RESULTS A total of 19,736 patients were identified (median age 11 years, interquartile range [IQR] 2–16 years, 66% male, 55% Caucasian). Overall, rural-dwelling patients had higher All Patient Refined Diagnosis Related Groups injury severity (median 2 [IQR 1–3] vs 1 [IQR 1–2], $p < 0.001$) and more intracranial monitoring (6% vs 4%, $p < 0.001$). Univariate analysis showed that overall, rural-dwelling patients suffered increased medical complications (6% vs 4%, $p < 0.001$), mortality (6% vs 4%, $p < 0.001$), and LOS (median 2 days [IQR 1–4 days] vs 2 days [IQR 1–3 days], $p < 0.001$), but multivariate analysis showed rural-dwelling status was not associated with these outcomes after adjusting for injury severity, mechanism, and hospital characteristics. Institutional TBI volume was not associated with medical complications, disposition, or mortality for either population but was associated with LOS for urban-dwelling patients (nonlinear beta, $p = 0.008$) and cost for both rural-dwelling (nonlinear beta, $p < 0.001$) and urban-dwelling (nonlinear beta, $p < 0.001$) patients.

CONCLUSIONS Overall, rural-dwelling pediatric patients with TBI have worsened injury severity, mortality, and in-hospital complications, but these disparities disappear after adjusting for injury severity and mechanism. Institutional TBI volume does not impact clinical outcomes for rural- or urban-dwelling children after adjusting for these covariates. Addressing the root causes of the increased injury severity at hospital arrival may be a useful path to improve TBI outcomes for rural-dwelling children.

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KEYWORDS neurological surgery; traumatic brain injury; institutional volume; rural; urban; trauma

Pediatric traumatic brain injury (TBI) represents a significant portion of trauma-related deaths in the United States.[1] While the clinical outcomes of a patient following TBI often depend on the severity of the injury and on decisions made in the inpatient setting, prehospital factors are increasingly being emphasized as determinants of outcome.[2] In the US, the evidence-based guidelines for prehospital management of TBI patients were established in 1995 by the Brain Trauma Foundation.[3] Although these guidelines were further updated in 2008, not all emergency response services (EMS) in the US manage the prehospital care of patients identically,[4] as access to trauma centers and transportation services can vary depending on geographic location.[5] Often, critical decisions regarding transportation of these patients must be made quickly in the field by individual EMS employ-

ABBREVIATIONS APR-DRG = All Patient Refined Diagnosis Related Groups; CDC = Centers for Disease Control and Prevention; CI = confidence interval; EMS = emergency response services; HCUP = Healthcare Cost and Utilization Project; IQR = interquartile range; LOS = length of stay; NIS = National Inpatient Sample; OR = odds ratio; SE = standard error; TBI = traumatic brain injury.

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ees, a stressful environment that can introduce unintentional error.

Furthermore, certain institutions are better equipped to treat pediatric patients with TBI than others. Although there is considerable interhospital variation in clinical outcomes for TBI, expedited transportation to an experienced center is a well-understood predictor of clinical outcomes.[6,7] Due to increased numbers of high-volume trauma centers in areas of general population concentration,[8] rural-dwelling children typically live farthest from a trauma center. Rural-dwelling children have been shown to experience worse outcomes, potentially due to unnecessary transfers and increased transportation time.[9] Unfortunately, this juxtaposes two factors potentially predictive of clinical outcome: transportation time to treatment, and treatment at a high-volume center. To better understand potential health disparities and inform prehospital protocols, this study aimed to evaluate the effects of institutional pediatric TBI volume on clinical outcomes for rural-dwelling children after adjusting for injury severity, mechanism, and hospital features.

Methods

Study Population

The authors identified pediatric patients 0–19 years of age who had been evaluated for TBI from 2012 through quarter 3 of 2015 in the National Inpatient Sample (NIS). The NIS represents a 20% stratified sample of more than 97% of the US inpatient population.[10] Only the first three quarters of 2015 were included in this study due to the switch from ICD-9 to ICD-10 coding. Traumatic brain injury was defined using the following ICD-9 codes in any diagnostic code position: 800.1–801.9, 801.1–801.9, 803.1–803.9, and 804.1–804.9 for skull fracture with intracranial injury; 850.x for concussion; 851.x for cerebral laceration or contusion; 852.x–853.x for intracranial hemorrhage; or 854.x for other intracranial injury. Admissions associated with an in-hospital birth were excluded to remove birth-associated trauma. This study was approved by the Vanderbilt University IRB and the requirement for formal patient consent was waived due to the use of a retrospective deidentified database.

Data Collection

The primary variable was annual volume of pediatric patients with TBI treated at a particular institution. This was a continuous variable calculated for each hospital for each year. Utilizing the unique hospital identifiers in the database, the total number of pediatric TBI patients from our study population associated with that hospital identifier in a given year was calculated. This total represented the pediatric TBI volume for that year at that institution. Because only the first three quarters of 2015 were included in our study, the calculated figure for 2015 was multiplied by 4 and divided by 3 to impute an annual number.

Sociodemographic information collected included urban or rural geographic residence, age, gender, race (categorized as Caucasian, Black or African American, Hispanic, Asian or Pacific Islander, Native American, or other), zip code income quartile, and private insurance payment method. Zip code income quartile represents a nationwide quartile estimate of the median household income from the patient's home zip code, with quartile 1 used as a reference category. Hospital characteristics collected were location of treating hospital (rural, urban nonteaching, or urban teaching) and hospital bed size (small, medium, or large, according to the Healthcare Cost and Utilization Project [HCUP] region-dependent categorization).[11] Geographic residence by county was categorized as urban or rural. Counties were categorized as "rural" if they were classified as micropolitan (< 50,000 population) or classified as nonmicropolitan and nonmetropolitan, following the Federal Office of Management and Budget's definition.[12]

Treatment-specific variables collected were other traumatic injury (ICD-9 codes 805–848, 860–904, 925–929, 940–959) and neurosurgical interventions: intracranial monitoring (ICD-9 codes 01.10–01.18), craniotomy or craniectomy (ICD-9 codes 01.23–01.25, 01.39), and ventriculostomy (ICD-9 codes 02.2, 02.21, 02.34). Mechanism of injury was collected and defined according to Centers for Disease Control and Prevention (CDC) E-code groupings:[13] motor vehicle injury (E81x, E958.5, E968.5, E988.5), firearm (E922.0–3, E922.8, E922.9, E955.0–4, E965.0–4, E979.4, E985.0–4, E970), fall (E880.0-E886.9, E888, E957.0–9, E968.1, E987.0–9), and nongunshot assault/abuse (E96x, E979.x, E999.1, excluding firearm). To assess injury severity, our study used the NIS-reported All Patient Refined Diagnosis Related Groups (APR-DRGs), which classifies patients based on their reason for admission, severity of illness, and risk of death. The APR-DRG mortality score is designed to quantify risk of mortality, while the APR-DRG severity score quantifies severity grade of primary illness during the hospital stay.[14]

Outcomes measured included in-hospital medical complication, in-hospital death, discharge disposition, length of stay (LOS), and cost of hospital stay. In-hospital death was a dichotomous variable. Discharge disposition was a dichotomous variable categorized as poor (death or discharge to long-term facility) or not poor (routine discharge). LOS was evaluated as a continuous variable based on the number of days from patient admission to the hospital, to patient discharge from the hospital. Cost of hospital stay was a continuous variable calculated from the reported total charge by using HCUP cost-to-charge ratios for each hospital. Medical complication was a dichotomous variable, defined as any of the following: deep vein thrombosis (ICD-9 codes 453.40, 453.41, 453.42), pulmonary embolism (ICD-9 codes 415.11, 415.12, 415.13, 415.19), occurrence of shock (ICD-9 codes 785.50, 785.51, 785.52, 785.59), coma (ICD-9 codes 780.01, 780.03), pneumonia (Clinical Classification Software overview code 112), urinary tract infection (Complication or Comorbidity overview code 159), and adverse medication reactions (Complication or Comorbidity summary codes 2613 and 2617; E-codes E850–858, E930–949).

Statistical Testing

Statistical analysis was completed using statistical software R (version 3.6.1, R Foundation for Statistical Computing). Statistical significance was set a priori at $p < 0.05$

TABLE 1. Baseline sociodemographic and hospital characteristics for the combined population as well as the rural- and urban-dwelling groups

Variable	Rural (n = 3194)	Urban (n = 16,542)	Combined (n = 19,736)	Test Statistic*
Sociodemographics				
Median age (IQR), yrs	12 (3–17)	10 (2–16)	11 (2–16)	F = 30, df = 1,19714, $p < 0.001$
Age categories, yrs				$c^2 = 37$, df = 3, $p < 0.001$
0–4	29% (928)	35% (5720)	34% (6648)	
5–9	15% (475)	14% (2246)	14% (2721)	
10–14	18% (570)	17% (2796)	17% (3366)	
15–19	38% (1220)	35% (5761)	35% (6981)	
Female gender	35% (1105)	33% (5513)	34% (6618)	$c^2 = 2$, df = 1 $p = 0.2$
Race of patient				$c^2 = 919$, df = 5, $p < 0.001$
White	78.7% (2160)	51.0% (7722)	55.2% (9882)	
Black or African American	6.4% (175)	15.9% (2404)	14.4% (2579)	
Hispanic	8.0% (219)	24.2% (3658)	21.7% (3877)	
Asian or Pacific Islander	0.9% (26)	3.2% (482)	2.8% (508)	
Native American	2.8% (78)	0.7% (101)	1.0% (179)	
Other	3.1% (86)	5.1% (776)	4.8% (862)	
Income quartile of median income for patient home zip code				$c^2 = 1488$, df = 3, $p < 0.001$
1	48% (1504)	26% (4276)	30% (5780)	
2	37% (1151)	23% (3712)	25% (4863)	
3	13% (399)	26% (4285)	24% (4684)	
4	2% (55)	25% (4018)	21% (4073)	
Payment type				$c^2 = 9$, df = 5, $p = 0.1$
Medicare	0.1% (3)	0.2% (30)	0.2% (33)	
Medicaid	42.5% (1350)	41.3% (6815)	41.5% (8165)	
Private insurance	46.4% (1475)	47.3% (7806)	47.1% (9281)	
Self-pay	5.6% (178)	5.0% (822)	5.1% (1000)	
No charge	0.2% (7)	0.2% (28)	0.2% (35)	
Other	5.2% (165)	6.1% (1006)	5.9% (1171)	
Hospital characteristics				
Median annual pediatric TBI volume of treating hospital (IQR)	16 (8–30)	16 (8–28)	16 (8–28)	F = 5, df = 1,19734, $p = 0.030$
Annual pediatric TBI volume of treating hospital, categories				$c^2 = 0.1$, df = 1, $p = 0.700$
>14	54% (1724)	54% (8986)	54% (10,710)	
1–14	46% (1470)	46% (7556)	46% (9026)	
Hospital bed size				$c^2 = 17$, df = 2, $p < 0.001$
Small	8% (267)	11% (1782)	10% (2049)	
Medium	21% (679)	21% (3452)	21% (4131)	
Large	70% (2248)	68% (11,308)	69% (13,556)	
Hospital location				$c^2 = 1085$, df = 1, $p < 0.001$
Rural	8.9% (284)	0.4% (71)	1.8% (355)	
Urban	91.1% (2910)	99.6% (16,471)	98.2% (19,381)	

df = degrees of freedom.
Data given as percentage (n) unless otherwise indicated.
* Test statistics are Kruskal-Wallis test statistic for continuous variables (F) and Pearson's chi-square value for categorical variables.

for all analyses. All effect sizes are reported with 95% confidence intervals (CIs). Univariate analysis was performed for all variables between the rural- and urban-dwelling groups using the Kruskal-Wallis rank-sum test for continuous variables and Pearson's chi-square test for categorical variables. Median and interquartile range (IQR) were presented for continuous variables, while number and frequency were presented for categorical variables.

TABLE 2. Mechanism of injury and injury severity for combined population, and segmented by rural- and urban-dwelling groups

Variable	Rural (n = 3194)	Urban (n = 16,542)	Combined (n = 19,736)	Test Statistic
Mechanism of injury				
Vehicular mechanism	31% (1000)	26% (4259)	27% (5259)	c^2 = 42, df = 1, p < 0.001
Firearm mechanism	2% (47)	2% (295)	2% (342)	c^2 = 2, df = 1, p = 0.200
Fall mechanism	22% (713)	32% (5245)	30% (5958)	c^2 = 112, df = 1, p < 0.001
Assault mechanism, except those caused by gunshot wound	4% (139)	5% (886)	5% (1025)	c^2 = 5, df = 1, p = 0.020
Injury severity				
Median APR-DRG mortality score (IQR)	1 (1–3)	1 (1–2)	1 (1–2)	F = 121, df = 1,19734, p < 0.001
Median APR-DRG severity score (IQR)	2 (1–3)	1 (1–2)	2 (1–3)	F = 140, df = 1,19734, p < 0.001
Intracranial monitor placement	6% (176)	4% (656)	4% (832)	c^2 = 16, df = 1, p < 0.001
Craniotomy intervention	6% (193)	5% (896)	6% (1089)	c^2 = 2, df = 1, p = 0.200
Ventriculostomy	3% (105)	3% (492)	3% (597)	c^2 = 0.9, df = 1, p = 0.300
Other traumatic injury	44% (1420)	35% (5741)	36% (7161)	c^2 = 110, df = 1, p < 0.001

Data given as percentage (n) unless otherwise indicated.

The first set of multivariate models was built to measure the effect of rural-dwelling status of the patient on outcomes within the entire population. The second set of models aimed to measure the effect of annual institutional pediatric TBI volume within each subset population, divided into rural- and urban-dwelling patients. Logistic regression models were built for medical complications, poor disposition, and death. Linear regression models in log scale were built for LOS and cost. The primary variable of interest in the first set of models was rural-dwelling status of the patient. The primary variable in the second set of models was annual institutional pediatric TBI volume. All models were adjusted with sociodemographics, including age, gender, race, and zip code income quartile, as well as features of injury severity, injury mechanism, and hospital type: APR-DRG mortality and severity indices, non-TBI traumatic injury, vehicular trauma, fall-related trauma, bed size of hospital, teaching versus nonteaching hospital, and urban versus rural hospital. A restricted cubic spline with three knots was used for TBI volume and age to allow for nonlinearity. Odds ratios (ORs) with 95% CIs were presented for variables in multivariable logistic regressions, while beta coefficients and standard error (SE) were presented for variables in multivariable linear regressions. For continuous variables that had nonlinear components (i.e., TBI volume and age) or categorical variables with multiple categories (i.e., race), OR or beta was not provided due to loss of linearity assumption. Instead, a graph of log odds with varying values of the variable was provided.

Results

A total of 19,736 patients were identified for inclusion in this study. The median patient age was 11 years (IQR 2–16 years), 66% were male, and 55% were Caucasian. Among these children, at the time of injury 3194 were rural-dwelling (median age 12 years, IQR 3–17 years, 65% male, 79% Caucasian) while 16,542 were urban-dwelling (median age 10 years, IQR 2–16 years, 67% male, 51% Caucasian) patients (Table 1). Overall, rural-dwelling patients had higher median APR-DRG Injury Severity Scores (2 [IQR 1–3] vs 1 [IQR 1–2], p < 0.001), more intracranial monitoring (6% vs 4%, p < 0.001), more concurrent non-TBI trauma (44% vs 35%, p < 0.001), more vehicular trauma (31% vs 26%, p < 0.001), and less fall-related trauma (22% vs 32%, p < 0.001; Table 2). There were also significant socioeconomic differences between rural- and urban-dwelling groups, trending toward rural-dwelling patients being more Caucasian (79% vs 51%, p < 0.001) and having lower incomes (2% vs 25% in highest median zip code income quartile; Table 1). A total of 16.1% (n = 2668) of the urban-dwelling patients were transfer admissions from another acute care facility, compared to 28.9% (n = 924) of the rural-dwelling patients.

Hospital Characteristics

The vast majority of neurosurgical procedures were performed in an urban hospital, including 99.5% (n = 828) of intracranial monitor placements, 99.3% (n = 593) of ventriculostomies, and 99.7% (n = 1086) of craniotomy interventions. At high-volume hospitals, defined as more than 20 cases per year, there was a slight decrease in the APR-DRG severity index (median 2 [IQR 1–2] for high volume compared to 2 [IQR 1–3] for low-volume, p = 0.009) as well as the presence of other traumatic injury (33% vs 38%, p < 0.001). However, the rate of neurosurgical procedures performed was not statistically different between high- and low-volume groups. These procedures included intracranial monitor placement (4% vs 4%, p = 0.139), craniotomy intervention (6% vs 5%, p = 0.420), and ventriculostomy (3% vs 3%, p = 1.000).

Medical Complications While an Inpatient

While rural-dwelling patients experienced increased medical complications overall (6% vs 4%, p < 0.001) compared to urban-dwelling patients (Table 3), multivariate analysis showed that rural residence of a patient (OR 1.0, 95% CI 0.8–1.3, p = 0.876) was not associated with an

TABLE 3. Outcomes for the combined population as well as rural- and urban-dwelling groups

Variable	Rural (n = 3194)	Urban (n = 16,542)	Combined (n = 19,736)	Test Statistic
Medical complication while in-hospital	6% (189)	4% (716)	5% (905)	$c^2 = 15$, df = 1, $p < 0.001$
In-hospital death	6% (194)	4% (572)	4% (766)	$c^2 = 49$, df = 1, $p < 0.001$
Bad disposition	9% (296)	7% (1196)	8% (1492)	$c^2 = 16$, df = 1, $p < 0.001$
Median LOS (IQR), days	2 (1–4)	2 (1–3)	2 (1–4)	F = 60, df = 1,19721, $p < 0.001$
Median cost (IQR), USD	8051 (3868–17,354)	7144 (3473–15,149)	7283 (3540–15,473)	F = 27, df = 1,19441, $p < 0.001$

USD = US dollars.

increased risk of medical complications after adjusting for injury severity, mechanism, hospital features, and TBI volume. TBI volume was not significantly associated with in-hospital medical complications for either rural-dwelling (nonlinear OR, p = 0.805) or urban-dwelling (nonlinear OR, p = 0.226) patients in the adjusted multivariable analysis (Fig. 1). Among rural-dwelling patients, age (nonlinear OR, p = 0.017) and female gender (OR 1.5, 95% CI 1.1–2.2, p = 0.024) were associated with increased medical complications. Similarly, for urban-dwelling patients, age (nonlinear OR, p < 0.001; Fig. 2A) and female gender (OR 1.5, 95% CI 1.2–1.8, p < 0.001) were significantly associated variables.

Discharge Disposition

Rural-dwelling children had a higher frequency of poor discharge disposition (9% vs 7%, p < 0.001) compared to urban-dwelling children. However, multivariate analysis showed that rural-dwelling status (OR 1.0, 95% CI 0.8–1.2, p = 0.971) did not increase the odds of poor disposition after adjustment. Poor discharge disposition was not associated with TBI volume for either rural-dwelling (nonlinear OR, p = 0.758) or urban-dwelling (nonlinear OR, p = 0.247) patients (Fig. 3). Increased age was associated with poor disposition in both groups (nonlinear OR, p < 0.001 for both groups; Fig. 2B). For rural-dwelling patients, zip code income quartile 2 (OR 1.8, 95% CI 1.3–2.5, p = 0.001) was associated with poor disposition. For urban-dwelling patients, private insurance (OR 1.3, 95% CI 1.1–1.5, p = 0.005) was associated with poor disposition.

Mortality

Overall, rural-dwelling patients had a higher incidence of death (6% vs 4%, p < 0.001) compared to the urban-dwelling cohort. Adjusted multivariate analysis, however, showed that rural-dwelling status (OR 1.0, 95% CI 0.8–1.3, p = 0.713) was not associated with increased mortality. In-hospital mortality was not associated with TBI volume in either the rural-dwelling (nonlinear OR, p = 0.536) or urban-dwelling (nonlinear OR, p = 0.174) group (Fig. 4). Among rural-dwelling patients, female gender (OR 1.7, 95% CI 1.1–2.6, p = 0.021) was associated with increased mortality. For urban-dwelling patients, private insurance (OR 0.8, 95% CI 0.6–1.0, p = 0.035) was associated with decreased mortality.

Length of Stay

While rural-dwelling children showed an overall longer distribution of LOS (median 2 days [IQR 1–4 days] vs 2 days [IQR 1–3 days], p < 0.001) compared to urban-dwelling children, multivariate analysis showed that rural residence (beta = 0.007, SE = 0.025, p = 0.796) was not associated with LOS after adjustment. TBI volume was associated with LOS for urban-dwelling (nonlinear beta, p = 0.008) but not rural-dwelling (nonlinear beta, p = 0.118) patients (Fig. 5). Increased age (nonlinear beta, p = 0.024) was also associated with increased LOS within the urban-dwelling group (Fig. 2C).

Cost

Rural-dwelling children had an overall higher cost of hospital stay (median $8051 [IQR $3868–$17,354] vs $7144 [IQR $3473–$15,149], p < 0.001) compared to urban-dwelling children. However, adjusted multivariate analysis showed that rural-dwelling status (beta = −0.043, SE = 0.019, p = 0.025) was inversely associated with cost after adjusting for features of injury severity, mechanism, hospital features, and TBI volume.

TBI volume was associated with increased costs for

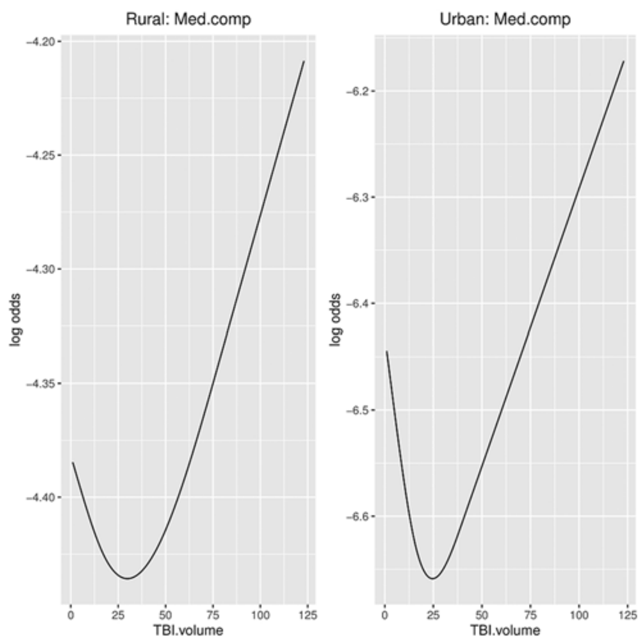

FIG. 1. Log odds of the effect of annual institutional pediatric TBI volume (TBI.volume) on medical complications (Med.comp) in rural- and urban-dwelling patients.

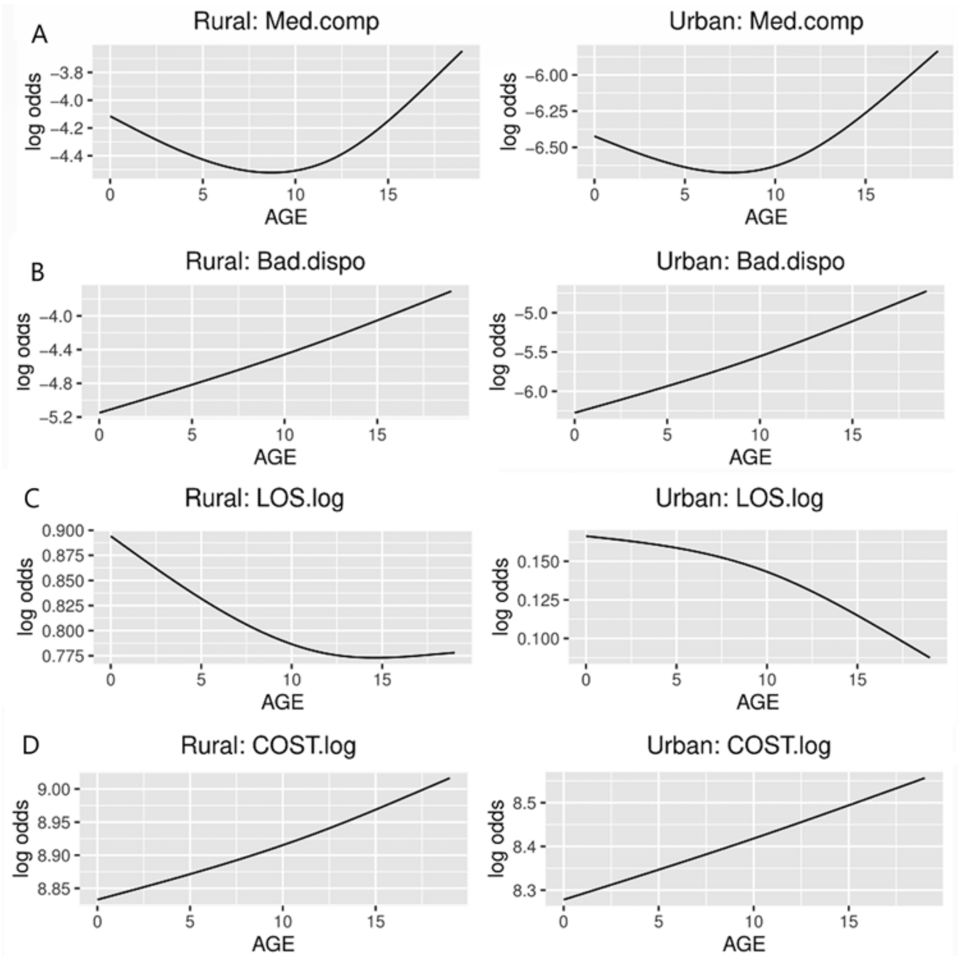

FIG. 2. Log odds representing the effects of age on medical complications (Med.comp; **A**), poor discharge disposition (Bad.dispo; **B**), hospital LOS (LOS.log, LOS in log scale; **C**), and cost of hospital stay (COST.log, cost in log scale; **D**) in rural- and urban-dwelling patients.

both the rural-dwelling (nonlinear beta, $p < 0.001$) and urban-dwelling (nonlinear beta, $p < 0.001$) populations (Fig. 5). This increasing cost showed a plateau at 40 cases/year for rural-dwelling patients but remained linear throughout for urban-dwelling patients (Fig. 5). Increased age was also associated with increased costs for both populations (rural: nonlinear beta, $p = 0.002$; urban: nonlinear beta, $p < 0.001$; Fig. 2D). For the urban-dwelling population only, increased cost was associated with Black or African American (beta = 0.053, SE 0.020, $p = 0.009$), Hispanic (beta = 0.196, SE = 0.197, $p < 0.001$), Asian/Pacific Islander (beta = 0.183, SE = 0.039, $p < 0.001$), and Native American race (beta = 0.290, SE = 0.085, $p < 0.001$).

Discussion

For pediatric patients with TBI, prompt transportation to a high-volume neurotrauma center is predictive of improved clinical outcomes.[6,7] This creates a potential outcome disparity for rural-dwelling children who often reside farther from experienced trauma centers.[8] This nationwide analysis demonstrates that volume of annual TBI cases does not influence outcomes for rural-dwelling children in the time period spanning 2012–2015, after accounting for features of injury severity, mechanism, and hospital characteristics. However, cost and hospital LOS were significantly associated with increasing pediatric TBI volume, highlighting opportunities to reduce these care burdens in future clinical management.

Disparities in pediatric TBI management for rural-dwelling children include protracted transport times, mistriage to low-volume centers,[9] healthcare avoidance,[15] and limitations in symptom education.[9,16] The CDC's "Guidelines for field triage of injured patients" and guidelines from the Brain Trauma Foundation are designed to systematize the routing of higher-severity injuries to higher-resource, high-volume trauma centers.[17,18] In this study, rural-dwelling patients had overall increased injury severity and worse clinical outcomes compared to urban-dwelling patients. However, these disparities in clinical outcomes did not persist after adjusting for injury severity. In addition, institutional pediatric TBI volume did not influence these clinical outcomes after adjustment in the rural-dwelling population specifically. This suggests that the disparities in overall clinical outcomes between rural- and urban-dwelling patients may be driven by differences

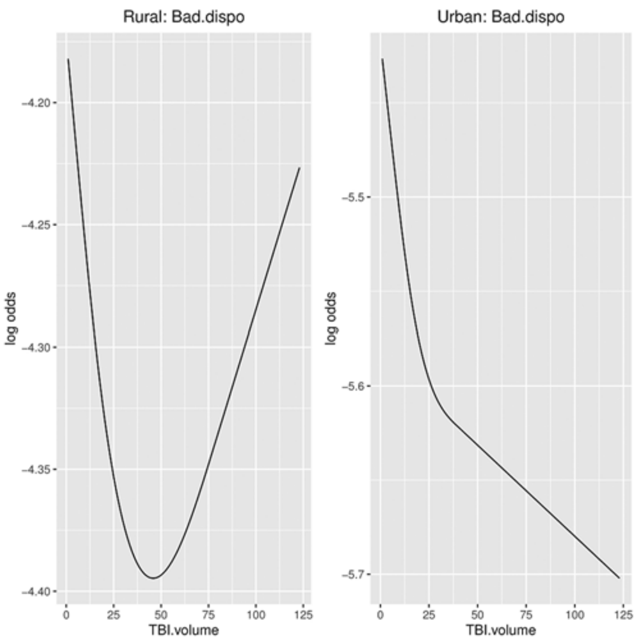

FIG. 3. Log odds of the effect of annual institutional pediatric TBI volume on poor disposition (Bad.dispo) in rural- and urban-dwelling patients.

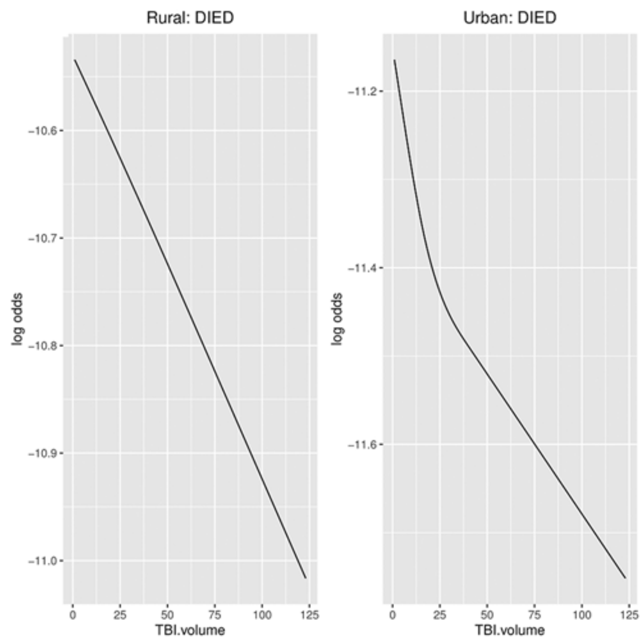

FIG. 4. Log odds of the effect of annual institutional pediatric TBI volume on in-hospital mortality (DIED) in rural- and urban-dwelling patients.

in injury severity and mechanism. Increased injury severity in the rural-dwelling population may be explained by the increased proportion of vehicular trauma, but it is important to identify alternative causes including protracted transportation time caused by geographic barriers, hospital avoidance,[15] or insufficient neurotrauma education.[16] These causes may lead to a skewed distribution of higher-severity patients presenting from rural areas,[9] and may be approached with digital or telehealth resources that can improve care access and education.[19]

Urban-dwelling patients experienced longer LOS at hospitals with low to moderate pediatric TBI volume (20 cases per year or less; Fig. 5). Longer LOS may lead to avoidable iatrogenic complications[20] as well as limited bed capacity.[21] Observational studies have identified lack of access to community discharge services and in-hospital delays as drivers of prolonged LOS.[21,22] Identifying disparities specific to urban-dwelling pediatric TBI patients at low to moderate TBI volume hospitals can inform interventions to close this care gap. Furthermore, while institutional pediatric TBI volume did not affect clinical outcomes, the cost of hospital stay showed a linear increase between low- and high-volume hospitals (Fig. 5). Decreasing costs associated with pediatric TBI management is an important priority to ensure adequate allocation of hospital resources. Notably, cost of stay decreased with increasing hospital bed size, suggesting that features specific to disease management, rather than hospital size, may be implicated.

The rural- and urban-dwelling populations had significant differences in socioeconomic distribution. It is therefore important to note differing socioeconomic outcome drivers between these groups (Fig. 2). Rural-dwelling patients saw disparities for income quartile 2 and female gender in terms of disposition and mortality, respectively. For urban-dwelling patients, private insurance was associated with poor disposition, but decreased mortality. These contradictory findings may be influenced by the imperfect nature of disposition as a measure of functional outcome. Ability to pay and broader insurance coverage in the private insurance group may lead to greater utilization of long-term care facilities. Urban-dwelling patients also saw increased LOS with increased age, and increased cost for all racial minorities. These results can inform studies aimed at defining root causes for these disparities.

In terms of study limitations, the NIS is an administrative database that creates risk for missing or misclassified data. Furthermore, long-term outcomes are not collected by the NIS. Discharge disposition is an imperfect surrogate for functional outcome and may be influenced by independent features, including ability to pay or insurance status. In addition, this study attempted to adjust analyses by features of injury severity, mechanism, and sociodemographics, but it is important to mention potential confounders of outcome that could not be controlled in this retrospective study. Notably, the absence of Injury Severity Score from this database limits the adjustments of clinical outcomes. As individual addresses were not available for this study, patients were classified as either urban or rural based on the current NIS classification standard. This classification uses the identified residential county for each patient, which is then stratified into an urban-rural designation using the county's population. As a result, a rural classification for one patient might not have the same significance as the same classification for another, as individual residences could be more or less isolated in terms of medical care access. Despite these limitations, we believe the wide representation of populations in the NIS on a national scale and the large sample size of our cohort

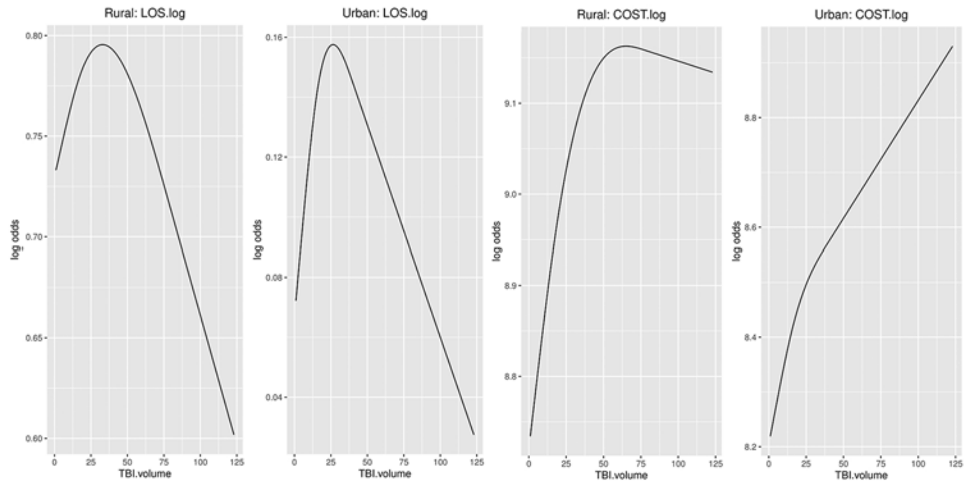

FIG. 5. Log odds of the effect of annual institutional pediatric TBI volume on hospital LOS (LOS.log, LOS in log scale) and cost (COST.log, cost in log scale) in rural- and urban-dwelling patients.

outweigh these classification issues. In addition, the inclusion of patients up to age 19 in this study may skew the generalizability of these results toward an older population. These inclusion criteria were designed to include patients in the late adolescence stage (defined as age 15–19) so that our study population paralleled those reported in large pediatric epidemiology studies.[23,24]

Conclusions

This study compared the impact of institutional pediatric TBI volume on clinical outcomes between rural- and urban-dwelling patients. TBI volume was not found to impact outcomes for either population after adjusting for injury severity and mechanism. However, both populations showed higher cost of hospital stay with higher institutional TBI volume. These results suggest that institutional TBI volume may not be the primary determinant of outcome disparities between rural- and urban-dwelling children. Addressing the root causes of rural patients' increased injury severity at hospital arrival may be a cost-effective path to improve TBI outcomes for rural-dwelling children.

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Disclosures

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Author Contributions

Conception and design: Patel, Naftel. Acquisition of data: Patel. Analysis and interpretation of data: Patel. Drafting the article: Patel, Kelly. Critically revising the article: Patel, Kelly, Greeno, Shannon, Naftel. Reviewed submitted version of manuscript: all authors. Approved the final version of the manuscript on behalf of all authors: Patel. Statistical analysis: Chen. Study supervision: Shannon, Naftel.

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