Hospitalizations for critically ill children with traumatic brain injuries: A longitudinal analysis*

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Objective: **This study examines the incidence, utilization of procedures, and outcomes for critically ill children hospitalized with traumatic brain injury over the period 1988–1999 to describe the benefits of improved treatment.**

Design: **Retrospective analysis of hospital discharges was conducted using data from the Health Care Cost and Utilization Project Nationwide Inpatient Sample that approximates a 20% sample of U.S. acute care hospitals.**

Setting: **Hospital inpatient stays from all types of U.S. community hospitals.**

Participants: **The study sample included all children aged 0–21 with a primary or secondary ICD-9-CM diagnosis code for traumatic brain injury and a procedure code for either endotracheal intubation or mechanical ventilation.**

Interventions: **None.**

Measurements and Main Results: **Deaths occurring during hospitalization were used to calculate mortality rates. Use of intracranial pressure monitoring and surgical openings of the skull were investigated as markers for the aggressiveness of treatment. Patients were further classified by insurance status, household income, and hospital characteristics. Over the 12-yr study period, mortality rates decreased 8 percentage points whereas utilization of intracranial pressure monitoring increased by 11 percentage points. The trend toward more aggressive management of traumatic brain injury corresponded with improved hospital outcomes over time. Lack of insurance was associated with vastly worse outcomes. An estimated 6,437 children survived their traumatic brain injury hospitalization because of improved treatment, and 1,418 children died because of increased mortality risk associated with being uninsured. Improved treatment was valued at approximately $17 billion, whereas acute care hospitalization costs increased by $1.5 billion (in constant 2000 dollars). Increased mortality in uninsured children was associated with a $3.76 billion loss in economic benefits.**

Conclusions: **More aggressive management of pediatric traumatic brain injury appears to have contributed to reduced mortality rates over time and saved thousands of lives. Additional lives could be saved if mortality rates could be equalized between insured and uninsured children. (Crit Care Med 2005; 33:2074–2081)**

KEY WORDS: traumatic brain injury; children; mortality; insurance; economic evaluation

Treating illnesses or injuries with new technologies or with more aggressive use of existing technologies has the potential to improve health outcomes, thus generating societal benefits in the form of increased years of life or improved quality of life. However, better treatment for medical conditions in most cases increases the overall cost of care and raises concerns about medical care inflation. Although some may view valuations of improved health outcomes skeptically, it is essential to investigate whether new or more aggressive treatments provide incremental benefits in excess of their incremental costs. Recent studies that have compared the cost and benefits of technology in medical care find substantial returns on investment from improved treatments (1–4). For some conditions, such as neonatal intensive care, the estimated returns are as high as 500% (2).

Evaluations as to whether treatment outcomes are improving over time are central to assessments of health care technology. Recent studies have documented improved outcomes for the treatment of acute myocardial infarction, (5) premature birth (6, 7), and hypoplastic left heart syndrome (8). Quantitative evidence is lacking on whether outcomes have improved for a number of different conditions, including traumatic brain injuries involving children.

Traumatic brain injury (TBI) is a leading cause of death for children of all ages. The societal cost of TBI is extensive and includes direct medical costs such as emergency department services, inpatient treatment, and rehabilitation, as well as indirect costs due to reductions in productivity for both the affected children and their families. Previous studies have demonstrated that aggressive management of TBI is associated with reduced mortality rates in both children and adults (9, 10), but questions remain whether these improvements generate benefits in excess of costs.

This study addresses two hypotheses to gain a better understanding of treatment benefits for critically ill children with TBI. First, we hypothesized that hos-

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***See also p. 2140.**

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pital outcomes for critically ill children have improved over time as measured by increases in hospital survival and, second, that more aggressive treatment is associated with improved outcomes. Using national estimates of the incidence of TBI hospitalizations for critically ill children, the utilization of hospital procedures, and hospital outcomes over time, this study estimates the benefits from more aggressive treatment in terms of life years saved.

METHODS

Study Design and Data. This study was based on a retrospective analysis of 12 yrs (1988–1999) of hospital discharge data using the Nationwide Inpatient Sample (NIS) database from the Healthcare Cost and Utilization Project. The Healthcare Cost and Utilization Project family of databases derives from a partnership between the Agency for Healthcare Research and Quality and statewide data organizations (11). The NIS provides longitudinal hospitalization data with information abstracted from approximately 1,000 hospitals (12). It approximates a 20% sample of United States community hospitals. Data were obtained from eight states in the initial years of the project and expanded over time to 24 states by 1999. The database contains information on diagnosis and procedure codes, hospital length of stay, insurance status, median household income for the patient's zip code of residence, and patient disposition including in-hospital death. Hospital-level data such as teaching status, ownership, region of the country, and hospital size also are included. The NIS sampling frame permits the development of national estimates of incidence, in-hospital mortality, and use of procedures for pediatric TBI and other medical conditions.

The NIS data are publicly available and exempt from human subjects review. Approval to conduct the study as exempt from human subjects review was received from the Institutional Review Board at the University of Arkansas for Medical Sciences.

Patients aged 0–21 yrs with either a primary or secondary International Classification of Diseases (ICD)-9-CM diagnosis code indicative of TBI were selected for analysis. The algorithm for patient selection follows the Center for Disease Control and Prevention case definition (13). In particular, primary or secondary ICD-9-CM diagnosis codes in the range 800.0–801.9, 803.0–804.9, and 850.1–854.1 identified cases. We further restricted the sample to a subset of patients who required endotracheal intubation or mechanical ventilation using ICD-9-CM procedure codes (93.90–93.92, 96.04, 96.70–96.72) to define a critically ill population at more than minimal risk of dying (14). This definition captures most in-hospital deaths from TBI, as few hospitalized children will die without undergoing endotracheal intubation. To avoid double counting, hospitalizations with discharge codes indicating transfer to a different acute care facility (pretransfer hospitalizations) were dropped from all analyses other than estimation of hospital charges. Such restrictions are necessary because the NIS does not contain patient identifiers to allow for the identification of multiple hospitalizations (12). Including pretransfer hospitalizations in the analysis would overestimate incidence of TBI hospitalizations and underestimate rates of mortality and procedure use (15, 16).

Injury severity was classified using ICD-MAP-90 (17), a software program that generates both the Abbreviated Injury Scale (AIS) (18) and the Injury Severity Score (ISS) (19, 20) using primary and secondary ICD-9-CM diagnosis codes. Maximal AIS scores for the head region were coded as mild (1–2), moderate (3), or severe (4–6). The AIS scoring algorithm is an anatomical score based on clinical findings and differs from the physiologic Glasgow Coma Scale that is based on clinical examination (21). The AIS and ISS have been used to assess injury severity in multiple studies (13, 22, 23), with recent work documenting the validity of the AIS and ISS measures for use in pediatric populations (24).

ICD-9-CM fifth digit subclassification codes were used to categorize consciousness as none/brief, moderate, prolonged, or unknown. Mechanism and manner/intent of injury were classified according to ICD-9-CM external cause of injury codes (E-codes) following recommended guidelines (25).

Statistical Analysis. Trends in the incidence of pediatric TBI hospitalizations over time were assessed by combining the NIS data with Current Population Survey data. Incidence estimates were developed by gender and for three age categories: 0–4 yrs old, 5–14 yrs old, and 15–21 yrs old. Age groups were based on the varied epidemiology and etiology of TBI among preschool, school-aged, and adolescent children (26–28).

To assess trends in the aggressiveness of treatment for TBI in children, ICD-9-CM procedure codes were used to identify whether hospitalized patients received an intracranial pressure (ICP) monitor (codes 01.18 and 02.2) or underwent a surgical opening of the skull (codes 01.09, 01.23–01.25, 01.39, and 01.59). These procedures were chosen because of their importance in patient management and because they are likely to be recorded in hospital claims. Patient management of TBI focuses on limiting elevations in intracranial pressure while maintaining cerebral perfusion pressure (29). We use ICP monitoring as a marker for a more aggressive approach to patient management. Previous work found ICP monitoring to be a reliable marker for a more aggressive approach to care based on significant differences in treatments received (9). Finally, patients with severe refractory intracranial hypertension may require surgical openings of the skull to improve perfusion to the brain (30).

The primary outcome measures for this study were in-hospital mortality and use of procedures. In this study, both in-hospital mortality and procedure use were modeled using individual patient-level data and hospital level structural data. Multivariate logistic regression models were used to identify the impacts of time and procedure use on in-hospital mortality after controlling for injury severity. Separate models investigated whether procedure use differed according to patient and hospital characteristics. Results are reported as odds ratios (OR) and 95% confidence intervals (CI).

All analyses used weights supplied with the data and accounted for the stratified sampling design of the NIS data (31). Stata Statistical Software (version 8) was used in all analyses.

RESULTS

Table 1 provides patient and hospital characteristics for children aged 0–21 with a TBI diagnosis and evidence of endotracheal intubation or mechanical ventilation. Data are presented as national estimates of hospitalizations over the 12-yr period with standard errors, the associated mortality rates, and rates of ICP monitoring. These data indicate that males were much more likely than females to be hospitalized and ventilated for TBI, with a gender ratio of 2.4:1. There were no differences in mortality rates or rates of ICP monitoring according to gender. Both mortality rates and rates of ICP monitoring differed significantly according to insurance status. Children with self-pay insurance (uninsured) were much more likely to die relative to either publicly or privately insured children. The 95% confidence interval for mortality rates among publicly or privately insured children was 19.7–23.3% vs. 36.5–41.4% for uninsured children. Also, uninsured children were less likely to receive ICP monitoring relative to publicly or privately insured children (16.7–21.2% vs. 22.5–27.7%).

TBI mortality rates were similar between black and white children, but rates of ICP monitoring were lower for blacks (17.3–22.5%) vs. whites (23.9–28.1%). Caution must be exercised in examining racial differences in the NIS database, because 24% of the observations lack race information and the data often are systematically missing according to the state of residence. Because of the number of missing observations on race, our multivariate analyses do not account for racial differences.

Table 1. Characteristics of critically ill children with traumatic brain injury: 1988–1999

Characteristic	No.	SE	Percent In-Hospital Death (95% CI)	Percent Use of ICPM (95% CI)
Patient characteristics				
Gender				
Male	69,150	4,629	24.3 (23.1–25.4)	23.8 (22.1–25.6)
Female	28,873	2,127	23.7 (22.3–25.2)	25.2 (23.0–27.5)
Age				
0–4	18,003	1,869	24.6 (22.8–26.4)	21.7 (18.0–25.3)
5–14	27,107	2,501	18.8 (17.6–20.1)	26.1 (23.3–28.9)
14–21	52,720	3,358	26.5 (25.3–27.7)	24.3 (22.6–26.0)
Income level				
Low	26,728	2,185	25.6 (24.2–27.1)	22.1 (19.9–24.3)
Medium	21,416	1,402	24.2 (22.6–25.8)	23.7 (21.7–25.6)
Medium high	18,269	1,474	23.3 (21.6–25.0)	25.6 (23.1–28.1)
High	24,960	2,284	22.1 (20.6–23.7)	25.9 (23.3–28.5)
Insurance status				
Public	24,378	2,495	21.8 (20.2–23.3)	25.1 (22.5–27.7)
Private	53,516	3,417	21.0 (19.7–22.2)	25.2 (23.3–27.0)
Self-pay	11,140	1,087	38.9 (36.5–41.4)	19.0 (16.7–21.2)
Other insurance	8,025	754	30.7 (27.2–34.2)	23.2 (19.7–26.7)
Race				
White	43,892	3,491	21.8 (20.6–23.0)	26.0 (23.9–28.1)
Black	12,955	1,509	24.2 (22.1–26.3)	19.9 (17.3–22.5)
Hispanic	9,970	1,383	23.1 (20.4–25.9)	27.4 (23.0–31.9)
Asian/Pacific Islander	1,421	252	23.7 (18.3–29.0)	25.0 (17.6–32.4)
Other race	3,110	466	23.6 (19.6–27.5)	27.8 (23.5–32.0)
Injury characteristics				
AIS category				
Mild	18,481	1,467	3.3 (2.3–4.3)	3.8 (3.0–4.6)
Moderate	10,062	818	6.8 (5.6–8.1)	12.8 (10.8–14.8)
Severe	67,465	4,447	32.6 (31.4–33.8)	31.9 (29.5–34.2)
ISS category				
0–16	34,878	2,569	6.6 (5.5–7.7)	12.4 (11.0–13.7)
17–29	45,185	3,059	29.3 (27.8–30.7)	28.0 (25.9–30.2)
30–75	17,874	1,258	45.3 (43.1–47.4)	37.9 (34.7–41.0)
Injury type				
Concussion	8,905	1,049	3.3 (2.4–4.3)	4.1 (1.2–7.0)
Closed fracture	31,894	2,393	22.7 (21.4–24.0)	29.4 (26.8–31.9)
Intracranial injury	53,908	3,531	24.9 (23.8–26.0)	24.6 (22.4–26.8)
Open fracture	7,222	653	47.2 (44.1–50.4)	28.0 (24.8–31.2)
Loss of consciousness				
None/brief	33,972	2,587	4.6 (3.7–5.5)	13.5 (11.9–15.1)
Moderate	5,536	400	10.6 (8.0–13.3)	17.6 (15.0–20.3)
Prolonged	34,276	2,280	56.8 (54.5–59.1)	38.2 (34.9–41.6)
Unknown	24,249	2,110	8.3 (7.0–9.6)	21.1 (19.0–23.3)
Hospital characteristics				
Region				
Northeast	17,389	2,536	21.3 (19.1–23.6)	20.1 (18.2–23.7)
Midwest	19,245	2,013	27.5 (25.6–29.4)	27.4 (23.2–31.5)
South	36,615	4,070	24.8 (23.3–26.3)	22.3 (20.1–24.5)
West	24,996	4,195	22.2 (20.2–24.2)	27.1 (22.2–31.9)
Location/teaching				
Rural	3,269	611	25.1 (21.0–29.1)	21.5 (15.0–27.9)
Urban/nonteaching	28,772	3,522	25.7 (23.4–28.1)	23.8 (19.2–28.5)
Urban/teaching	66,205	5,647	23.3 (22.1–24.5)	24.6 (22.8–26.3)
Bed size				
Small	7,654	1,977	24.4 (21.4–27.5)	22.0 (18.6–25.4)
Medium	28,086	4,031	22.5 (20.6–24.5)	26.0 (21.6–30.4)
Large	62,506	4,950	24.7 (23.4–26.0)	23.7 (21.9–25.6)

CI, confidence interval; ICPM, intracranial pressure monitoring; AIS, Abbreviated Injury Scale; ISS, Injury Severity Score.

TBI mortality rate and use of ICP monitoring differed, as expected, by the type and severity of the injury. The AIS criteria classified most injuries (70%) as severe, and children with severe injuries had mortality rates 25–29 percentage points higher than children with moderate or mild injuries. Prolonged loss of consciousness occurred in >34,000 children over the study period and was associated with an increased in-hospital mortality rate (57%).

Examination of hospital characteristics in Table 1 indicates minor differences in mortality rates and use of ICP monitoring. Although the majority of admissions (67%) occurred in urban teaching hospitals, there was no difference in outcomes between teaching and nonteaching hospitals.

Table 2 provides data on injury mechanism and intentionality for the TBI based on external cause of injury codes (E-codes) found in the secondary ICD-9-CM codes. Approximately 30% of the cases were missing E-codes, and the rate of missing observations changed over time. Thus, we did not calculate incidence estimates by the mechanism or manner of intent for the injury but indicated the percentage of total discharges with a valid E-code and the corresponding mortality rates and rates of ICP monitoring. Similar to other studies (26–28), most of the injuries (53%) involved motor vehicles, and the hospitalized children were either occupants or pedestrians. Falls were coded in 10% of the hospitalizations and firearms in approximately 8%. For most mechanisms, the proportion of children receiving an ICP monitor was substantially higher than the proportion who died, with the exception of firearms. The in-hospital mortality rate for TBI hospitalizations involving firearms was 69.2%, whereas the rate of ICP monitoring was 21.5%.

The findings on manner/intent also are similar to prior studies. Most of the hospitalizations for TBI were unintentional (86%), followed by assault (10.5%) and self-inflicted (1.8%). In contrast to unintentional injuries, children with intentional injuries had substantially higher rates of in-hospital mortality relative to the rate of ICP monitoring. There was no evidence that the patterns describing mechanism or manner/intent of the injury changed over time. For example, hospitalizations involving assaults stayed constant over the 12-yr study period.

Figure 1 provides hospitalization rates for children by age and gender over the period 1988–1999. The overall incidence increased from 5.7 to 13.0 per 100,000 children over the study period. Hospitalization rates were highest for males aged 15–21 and lowest for females aged 5–14. For all age/gender combinations, hospitalizations for critically ill children with TBI increased over time consistent with prior reports (13). For males aged 15–21, hospitalizations increased approximately

Table 2. Injury causes for critically ill pediatric patients with traumatic brain injury: 1988–1999

Injury Causes	Discharges, %	In-Hospital Mortality Rate, % (Range)	Use of ICP Monitoring Rate, % (Range)
Mechanism of injury			
Motor vehicle: occupant	39.9	19.7 (18.4–20.9)	25.3 (23.4–27.3)
Motor vehicle: pedestrian	13.2	20.7 (18.7–22.6)	27.6 (23.8–31.4)
Fall	10.0	11.9 (9.3–14.7)	18.3 (15.6–21.0)
Firearm	7.7	69.2 (65.8–72.8)	21.5 (18.3–24.7)
Other/unspecified	5.7	31.5 (28.2–34.9)	25.3 (17.7–33.6)
Motor vehicle: pedal cyclist	5.4	18.7 (15.1–21.5)	27.9 (24.2–32.6)
Struck by/against	4.1	10.8 (8.4–13.2)	17.6 (14.1–21.1)
Other transport	3.1	15.6 (11.8–19.3)	23.9 (19.0–28.7)
Motor vehicle: motorcyclist	3.0	20.4 (16.3–24.4)	26.5 (20.7–32.4)
Motor vehicle: other	2.7	26.2 (21.0–31.3)	28.2 (22.5–33.8)
Pedal cycle: other	2.0	7.4 (3.8–11.0)	16.0 (11.5–20.5)
Miscellaneous	2.4	20.3 (15.8–24.8)	23.7 (18.6–28.9)
Manner/intent of injury			
Unintentional	86.0	19.6 (18.5–20.7)	24.7 (22.8–26.5)
Assault	10.5	35.6 (33.0–38.3)	22.0 (17.2–26.8)
Self-inflicted	1.8	76.2 (70.8–81.6)	13.2 (9.1–17.2)
Other/unknown	1.8	52.9 (46.1–59.6)	26.7 (21.0–32.4)
Missing E-code	30.7	26.9 (25.2–28.5)	24.3 (21.8–26.8)

ICP, intracranial pressure.

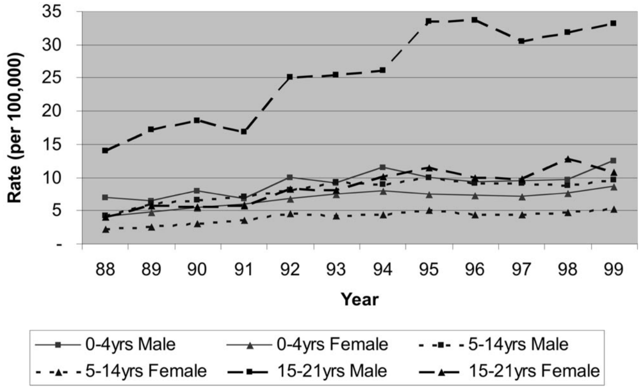

Figure 1. Incidence of traumatic brain injury requiring endotracheal intubation by age and gender.

90% from 17–18 per 100,000 children in 1988–1991 to 32–33 per 100,000 in 1995–1999. Similar increases were seen for most of the other age/gender subgroups as well.

Figure 2 provides rates of in-hospital mortality, ICP monitoring, and surgical openings of the skull in relation to the ISS scores over the study period. Figure 2 indicates a decrease in in-hospital mortality rate from approximately 30% to 22% over the study period and an increase in intracranial pressure monitoring from 17% to 28%. There were no discernable trends in surgical openings of the skull or ISS scores over the study period. Examination of specific procedures included as measures of surgical openings also failed to generate discernable trends over time.

Table 3 provides estimates from the logistic regression model predicting in-hospital mortality as a function of patient, injury, and hospital characteristics with time trend estimates and interactions for the use of ICP monitoring in moderate to severely injured children (AIS 3–6). The results in Table 3 indicate differences in in-hospital mortality rate according to age and injury severity. Age was entered in quadratic form as in-hospital mortality rate followed a U-shaped form across the age span with mortality rate higher in the youngest and oldest age groups. The odds ratio for age was calculated on a SD change (6.8) in age from the mean (13) using both terms and indicated a 30% increase in the risk of in-hospital mortality.

Table 3 indicates a large impact associated with self-pay insurance over the study period. The odds of in-hospital mortality were 2.9 (95% CI, 2.5–3.4) times those of privately insured patients after we controlled for injury type and severity. Children residing in low-income households and children with public insurance were not at increased risk of in-hospital mortality. After we controlled for injury type and severity, hospital characteristics were not associated with significant differences in in-hospital mortality.

Relative to the base years of 1988–1990, the interaction terms for use of intracranial pressure monitoring on moderate to severely injured patients indicate reductions in in-hospital mortality across the study period with odds ratios ranging from 0.72 to 0.82 (95% CI, 0.57–0.96). The residual changes in mortality rate, based on the indicator variables for the different time periods, were insignificant at the beginning of the study period and increased in size and significance over time.

Table 4 provides a similar analysis for predictors of ICP monitoring and indicates significant differences in rates of ICP monitoring according to age and injury severity but, again, little difference according to hospital characteristics. Children with prolonged loss of consciousness had higher rates of ICP monitoring with an OR of 1.5 (95% CI, 1.32–1.74). In this analysis, ISS scores were modeled in quadratic form, as the most severely injured children were less likely to receive aggressive therapy.

Evidence on whether the increased mortality rate for self-pay patients can be partially explained by less aggressive treatment appears to be supported. Across the entire study period, children without insurance were less likely to receive an ICP monitor after we controlled for injury severity and other predictors that might explain variations by insurance status. Despite having elevated risks of mortality, children with other types of insurance were not at lower risk of receiving an intracranial pressure monitor.

Table 4 also indicates the impact of time on the use of intracranial pressure monitoring for moderate to severely injured children. Relative to the base years of 1988–1990, the odds of receiving an ICP monitor increased 2.5–3.5 times (95% CI, 1.84–4.58). In contrast to the mortality estimates, the residual estimates from the time indicator variables were significant and protective (OR, 0.59–0.51; 95% CI, 0.33–0.98).

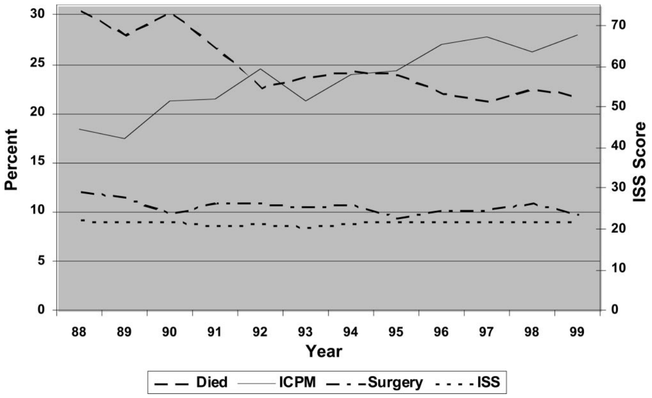

Figure 2. Rates of mortality, utilization of intracranial pressure monitoring (*ICPM*), and surgical openings of the skull in relation to Injury Severity Scores (*ISS*): 1988–1999.

Table 3. Logistic regression analysis predicting in-hospital mortality for critically ill children with traumatic brain injury

Variable	Odds Ratio	95% Confidence Interval	*p* Value
Patient characteristics			
Age[a]	1.305	(1.256–1.355)	<.001
Age squared	—	—	—
Female	0.950	(0.859–1.050)	.313
Low income	1.035	(0.919–1.166)	.565
Public insurance	0.929	(0.833–1.035)	.182
Self-pay insurance	2.917	(2.512–3.389)	<.001
Other insurance	1.488	(1.186–1.867)	.001
Injury characteristics			
Injury Severity Score	1.020	(1.012–1.028)	<.001
Prolonged LOC	10.848	(8.626–13.64)	<.001
No/brief LOC	0.471	(0.374–0.594)	<.001
Concussion	0.254	(0.190–0.338)	<.001
Open fracture	2.787	(2.397–3.241)	<.001
Hospital characteristics			
Midwest region	1.110	(0.879–1.403)	.379
South region	1.047	(0.827–1.325)	.703
West region	0.825	(0.652–1.044)	.108
Private not-for-profit	0.895	(0.772–1.037)	.141
Private investor-owned	1.109	(0.765–1.608)	.585
Medium bed size	0.853	(0.597–1.218)	.382
Large bed size	1.014	(0.718–1.431)	.938
Urban teaching	1.049	(0.891–1.235)	.566
Time/ICP Interactions			
Year = 1991–1994	0.962	(0.781–1.185)	.715
Year = 1995–1999	0.790	(0.640–0.975)	.028
ICP monitor (1991–1994)	0.720	(0.573–0.904)	.005
ICP monitor (1995–1999)	0.819	(0.700–0.959)	.013

LOC, loss of consciousness; ICP, intracranial pressure.

[a] Calculated as change in age from 13 to 20 using quadratic specification.

Finally, the in-hospital management of pediatric TBI patients may be evaluated by comparing the estimates of the lives saved due to declining mortality rate (or the lives lost due to lack of insurance) with the increases in acute care hospitalization costs over the study period (Table 5). Based on predicted mortality rates from the logistic regression model and the estimated incidence of critically ill children with TBI over the study period, an estimated 6,437 children survived a hospitalization because of more aggressive treatment that otherwise would have expired. To place this estimate in a policy context, improved technology in the treatment of TBI for critically ill children generated approximately 17 billion dollars in benefits over the study period, assuming a life expectancy of 50 additional years, a value of $100,000 per life year, and a discount rate of 3%. Because life expectancy is not known in this population, using 50 additional years of life provides a conservative estimate for life years gained. The mean age of hospitalized children was 12–13, implying 60 yrs of additional life for a normal life expectancy. Reducing TBI mortality by 1 percentage point increased the estimated lives saved by approximately 900 lives.

The study suggests that the deaths of more than 1,400 children may be related to a lack of health insurance. If insured and uninsured children had achieved similar rates of mortality, through improved prevention or treatment strategies, it would have generated approximately $3.75 billion in benefits, using the same assumptions as previously used.

Acute care costs were calculated in 2000 dollars using the hospital component of the Consumer Price Index to adjust total charges from the NIS database and then applying average cost-to-charge ratios. We calculated the increase in total costs over the study period and the average cost per patient. The average cost per patient remained relatively constant over the study period after adjusting for inflation, at approximately $67,000 per hospitalization. Total charges per year increased from $370 million to $720 million over the study period and resulted in a net cost increase of $1.5 billion over the entire study period after applying an average cost-to-charge ratio of 55%. This cost-to-charge ratio is based on findings from the most recent NIS data involving all hospital stays; cost-to-charge ratios may differ for specific hospitalizations involving TBI and over time (32).

DISCUSSION

Economic analyses typically emphasize choices and the cost of choosing among competing alternatives. Technological change in medicine produces benefits in terms of lives saved, but it costs money (33). Thus, a strict focus on reducing the cost of health care, by evaluating all cost increases as inflationary, could limit technological or other therapeutic advances and reduce the ability and potential within the current system of medical care to improve hospital outcomes over time. A cost-benefit framework to evaluate technological change in medicine frequently indicates that the benefits of medical technology greatly exceed the costs and that technological change in medicine has great value.

This study provides further evidence that improved medical technology saves additional lives. We found a large increase in the rate of ICP monitoring, a

Table 4. Logistic regression analysis predicting use of intracranial pressure monitoring for critically ill children with traumatic brain injury

Variable	Odds Ratio	95% Confidence Interval	*p* Value
Patient characteristics			
Age[a]	0.735	(0.699–0.771)	<.001
Age squared	—	—	—
Female	1.027	(0.944–1.117)	.533
Low income	0.889	(0.790–1.001)	.051
Public insurance	1.005	(0.898–1.126)	.925
Self-pay insurance	0.711	(0.614–0.823)	<.001
Other insurance	0.989	(0.846–1.158)	.894
Injury characteristics			
Injury Severity Score[b]	1.247	(1.231–1.263)	<.001
Injury Severity Score squared	—	—	—
Prolonged LOC	1.515	(1.317–1.743)	<.001
No/brief LOC	0.643	(0.565–0.732)	<.001
Concussion	0.280	(0.174–0.449)	<.001
Open fracture	0.889	(0.774–1.021)	.095
Hospital characteristics			
Midwest region	1.229	(0.908–1.663)	.181
South region	0.992	(0.786–1.252)	.946
West region	1.393	(1.022–1.899)	.036
Private not-for-profit	0.942	(0.771–1.150)	.558
Private investor-owned	0.488	(0.273–0.873)	.016
Medium bed size	1.286	(0.846–1.956)	.239
Large bed size	1.110	(0.786–1.567)	.554
Urban teaching	1.032	(0.764–1.394)	.836
Time/AIS category interaction			
Year = 1991–1994	0.594	(0.361–0.979)	.041
Year = 1995–1999	0.511	(0.333–0.784)	.002
AIS 3–6 (1991–1994)	2.539	(1.840–3.503)	<.001
AIS 3–6 (1995–1999)	3.569	(2.783–4.578)	<.001

LOC, loss of consciousness; AIS, Abbreviated Injury Scale.

[a] Calculated as change in age from 13 to 19 using quadratic specification; [b] calculated as change in injury severity score from 22 to 34 using quadratic specification.

Table 5. Acute care hospitalization costs and benefits of aggressive treatment for critically ill pediatric patients with traumatic brain injury: 1988–1999

Incremental acute care hospitalization costs	
Average cost per hospitalization in 2000 dollars	67,121
Total charges[a]	2,065
Total costs[a]	1,458
Incremental benefits of aggressive treatment over time	
Lives saved	6,437
Life years saved	321,850
Total benefit[a]	17,058
Benefits of equalizing outcomes for uninsured	
Lives lost	1,418
Life years lost	70,900
Total benefit (lost)[a]	3,758
Ratio of benefits to acute care costs	11.7

[a] In millions of (2000) dollars.

marker for treatment aggressiveness in the management of TBI, and significant decreases in mortality rate. Multivariate regression analysis indicated a reduced risk of death from more aggressive treatment among moderate to severely injured children. Multiple studies show that use of intracranial pressure monitoring is correlated with more aggressive treatment and improved survival of hospitalized TBI patients (29, 34–37). Other studies have noted the variability in the use of ICP monitoring and argued for its more aggressive use in the treatment of TBI (38–41).

Model estimates permit a quantitative assessment of the lives saved from improved treatment. Previous studies have provided anecdotal evidence for the increased survival of pediatric patients with TBI (42). Attaching a value to the lives saved provides an estimate of the benefits accruing from the more aggressive treatment of pediatric TBI over time. The estimated benefits appear substantial in relation to the increase in acute care costs over the study period. Whereas the benefits are measured in the tens of billions of dollars, the increases in acute care costs are measured in the billions of dollars. To be sure, a full assessment of the costs requires information on the need for rehabilitation services and special education, the functional health outcomes of the children who survived, and any productivity losses due to inability to work. Such information is seriously lacking and illustrates the uncertainty surrounding critical life-altering decisions facing clinicians and families of children afflicted with TBI. Still, such costs would have to be extremely large (in the order of 12:1) to overshadow the substantial benefits accruing from the increased survival found in this study.

The study also finds a large effect of being uninsured on mortality rates for critically ill children with TBI. Without adjusting for differences in injury severity, mechanism of injury, or other confounders, uninsured children had mortality rates that were 20 percentage points higher than privately and publicly insured children. After we adjusted for injury severity and other confounders, uninsured children still had three times the mortality risk of privately insured children. In an attempt to explain the large increase in mortality risk for uninsured children, we compared rates of ICP monitoring controlling for injury severity and other confounders. The findings suggest that, at most, one third of the differential mortality between insured and uninsured children can be attributed to less aggressive care. The remaining two thirds of the differential mortality between insured and uninsured children remain unexplained.

The findings are similar to recent evidence from detailed chart reviews of critically ill children. In studies from children's hospitals, uninsured children had elevated risks of mortality, but evidence of poorer quality of hospital care was not supported by these observations (43, 44), suggesting that delays in seeking treatment, diminished access to prehospital care, or unobserved factors may be responsible for their increased mortality rates. Unlike other studies, with this nationally representative database, we provide quantitative evidence of the impact of being uninsured. Equalizing mortality among insured and uninsured children over the study period would have generated almost 4 billion dollars in additional benefits. The framework used in this study follows recent work by the Institute of Medicine and adds to the accumulating evidence on the value of lives lost from being uninsured (45).

The study has a number of limitations. We control for a number of factors influencing in-hospital mortality, but we cannot fully assess mechanism or manner of injury based on ICD-9-CM external cause of injury codes (E-codes). Recording of E-codes increased considerably over the study period. Incorporating information based on E-codes into the statistical analysis would contaminate results because of correlations between the measures and study year.

Additional research is needed on whether the injury mechanism or manner/intent can explain mortality differentials between insured and uninsured children. Understanding why uninsured children hospitalized with a TBI have higher mortality rates than privately or publicly insured children is also necessary to develop a link between insurance coverage and improved health outcomes (46).

The study also is limited by availability of information used in the treatment of TBI. Some diagnostic procedures, such as computed tomography scans, are not coded reliably over time. Other relevant treatments, such as induced hypothermia, are not routinely captured in ICD-9-CM procedure codes. However, other studies have shown that ICP monitoring acts as a marker for treatment aggressiveness (9). ICP monitoring also is likely to be coded reliably as it is a high-cost billable procedure.

Finally, our data indicate a large increase in the incidence of TBI over the study period and large differentials between rates of mortality and use of ICP monitoring in the beginning of the study period. The increased incidence is consistent with previous reports using a different database (13). Concerns that the increase is an artifact of the sampling frame for the NIS database are not warranted. Although the number of participating states increased over the study period, use of weighting variables provide national estimates for each study year. Failure to incorporate weighting variables in the NIS database led to inaccurate findings on the incidence of Kawasaki syndrome (47). Appropriate weighting showed no increase in incidence over time (48). It is not clear why the incidence of severe TBI hospitalizations is increasing in this and other studies, but this may be related to improved prehospital care.

The differential rates of mortality and ICP monitoring early in the study period may be an artifact of the database design, as fewer states participated in the beginning years. However, the literature does reflect a concern about less aggressive treatment during the period of this study. One would expect to see differentials in rates of mortality and ICP monitoring that diminished over time if more aggressive treatment contributed to reduced mortality rate. Future improvements in TBI mortality rate related to recently developed guidelines for the management of pediatric TBI (49) or the use of hypothermia, if it proves beneficial in pediatric populations (50, 51), may be more difficult to detect in administrative databases.

CONCLUSIONS

More aggressive treatment of critically ill children with TBI appears to have contributed to reduced hospital mortality rates between 1988 and 1999 and saved thousands of lives. Moreover, additional life years could be gained if the mortality differential between insured and uninsured children could be reduced. Research is needed on the postacute care costs of TBI services for children and the outcomes of affected children to permit a full examination of the costs and benefits of improved treatment. Such analyses would add to the prognostic information considered by clinicians and families when making treatment decisions for critically ill children with varied risks of mortality.

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> *More aggressive treatment of critically ill children with traumatic brain injuries appears to have contributed to reduced hospital mortality rates between 1988 and 1999 and saved thousands of lives.*

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