Intracranial Pressure Monitoring in Children With Severe Traumatic Brain Injury
National Trauma Data Bank–Based Review of Outcomes

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**IMPORTANCE** The present study is the largest on the use and effect of intracranial pressure (ICP) monitoring in pediatric trauma patients.

**OBJECTIVE** To determine the effect of ICP monitoring on survival in pediatric patients with severe head injuries using the National Trauma Data Bank.

**DESIGN, SETTING, AND PARTICIPANTS** The National Trauma Data Bank was queried (version 6.2, 2001-2006) for information on patients younger than 17 years admitted to an intensive care unit with blunt traumatic brain injury (TBI), Injury Severity Score (ISS) greater than 9, and Glasgow Coma Scale (GCS) score less than 9. Patients with incomplete medical records and those with intensive care unit length of stay of less than 24 hours were excluded from the study.

**MAIN OUTCOMES AND MEASURES** Parametric comparisons (t tests and χ² as appropriate) were performed to compare patients who received ICP monitoring with those who did not. Stepwise logistic regression methods were used to assess whether ICP monitoring in the presence of other variables (age, sex, ISS, Revised Trauma Score, and GCS score) was associated with survival.

**RESULTS** Monitoring of ICP was performed in only 7.7% of patients who met the monitoring criteria recommended by the Brain Trauma Foundation. There were no significant differences in age, sex, or GCS score. After adjustment for admission GCS score, age group, sex, Revised Trauma Score, and injury ISS, ICP monitoring was associated with a reduction in mortality only for patients with a GCS score of 3 (odds ratio, 0.64; 95% CI, 0.43-1.00). Comparison between the 2 groups showed that the ICP monitoring group had a longer hospital length of stay (21.0 days vs 10.4 days; \( P < .001 \)), longer intensive care unit stay (12.6 vs 6.3 days; \( P < .001 \)), and more ventilator days (9.2 vs 4.7; \( P < .001 \)).

**CONCLUSIONS AND RELEVANCE** Despite current Brain Trauma Foundation guidelines, ICP monitoring is used infrequently in the pediatric population. The data suggest that there is a small, yet statistically significant, survival advantage in patients who have ICP monitors and a GCS score of 3. However, all patients with ICP monitors experienced longer hospital length of stay, longer intensive care unit stay, and more ventilator days compared with those without ICP monitors. A prospective observational study would be helpful to accurately define the population for whom ICP monitoring is advantageous.
Intracranial Pressure Monitoring in Children

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raumatic brain injury (TBI) is an important public health problem in the United States. In 2003, there were an estimated 1 565 000 TBIs in the United States: 1 224 000 emergency department (ED) visits, 290 000 hospitalizations, and 51 000 deaths. Findings were similar to those from previous years in which rates of TBI were highest for young children (aged 0-4 years) and men.1 However, intracranial hypertension occurs in as many as 70% of patients and is responsible for a substantial proportion of TBI-related deaths.2-3 Published data4-7 and consensus practices since the late 1970s suggest that intensive management protocols may reduce the incidence of secondary brain injury after severe TBI (Glasgow Coma Scale [GCS] score <9) and thus improve survival and outcome. The GCS is the most widely used assessment tool for predicting the severity of TBI.

In 1995, 2000, and 2007, the Brain Trauma Foundation (BTF) published management guidelines8 that included indications for intracranial pressure (ICP) monitoring. The goal of ICP monitoring is to ensure adequate cerebral perfusion pressure through the placement of intraventricular catheters or fiberoptic monitors into the parenchyma of the brain. No randomized clinical trials to evaluate the effect of the BTF recommendation on the outcome of management of severe TBI with or without ICP monitoring have been conducted.

In 1991, a nationwide survey9 of TBI care in 219 trauma centers across the United States documented that ICP monitoring was used routinely in only 77 centers (35%) and not at all in 16 centers. A subsequent national survey10 conducted in 2000 documented only a marginal increase in ICP monitoring, from 35% to 45%, with only 16% of centers in full compliance with BTF recommendations. In light of this information, we set out to examine the National Trauma Data Bank of the American College of Surgeons between January 2001 and December 2006 to evaluate whether there has been any change in practice patterns and the outcomes of using ICP monitoring in pediatric trauma patients.

Methods

The National Trauma Data Bank of the American College of Surgeons collates data from participating trauma centers throughout the United States. Institutional review board approval was waived for this study. During the study period (2001-2006), the National Trauma Data Bank contained information on more than 1 million injured patients, which constituted the study universe. Inclusion criteria consisted of admission to a designated level I or II trauma center, blunt mechanism of injury, age younger than 17 years, admission to an intensive care unit, and an injury that met the following BTF criteria for ICP monitoring: GCS score less than 9 determined in the ED and computed tomography demonstrating TBI.

Based on these criteria, 4141 patients were identified for initial inclusion in the study. They were divided into 2 groups: those who underwent ICP monitoring (n = 318) and those who did not (n = 3823). Intracranial pressure monitoring was identified using International Classification of Diseases, Ninth Edition, codes 02.2 and 01.18.

After excluding patients with incomplete records and those with ICU lengths of stay less than 24 hours, we performed a univariate analysis to compare the 2 groups (n = 3107) using unpaired, 2-tailed t tests for continuous variables and χ2 for categorical variables, as appropriate. Variables that appeared to show a significant difference between the 2 groups were entered as covariates into a logistic regression model. These variables included the Injury Severity Score (ISS) (an anatomical measure of injury severity),11 the Revised Trauma Score (RTS) (a physiological measure of injury severity),12 the GCS score determined in the ED, and the probability of survival score (Trauma and Injury Severity Score [TRISS] analysis). The ISS is derived from the highest Abbreviated Injury Scale scores of each of the 3 most severely injured of 7 defined regions of the body (range, 1-75; the score increases with the severity of the injury). The RTS, derived from the first set of physiological data obtained from the patient, consists of the GCS score, blood pressure, and respiratory rate (range, 0-8; the score increases with the severity of the injury). The TRISS method uses a combination of anatomical (ISS) and physiological (RTS) indexes of injury severity as well as coefficients derived from the Multiple Trauma Outcome Study.11-12 An age index, and coefficients for blunt and penetrating mechanisms to calculate probability of survival. The TRISS ranges from 0 to 1, with 0 indicating no probability of survival.

Regression modeling was first applied to the entire study group to assess the relationship between ICP monitoring and mortality after adjusting for other covariates. Subsequently, regression models were completed for each GCS score group. An α level of .05 was used to determine statistical significance. Data analysis was conducted using SAS, version 8.2 (SAS Institute Inc).

The primary outcome of the study was mortality. Odds ratios (95% CIs) of mortality with ICP monitoring were calculated from the regression model variable estimates. Continuous variables are summarized as mean (SD) and categorical variables as proportions; P < .05 was considered significant for all analyses.

Results

Less than 15% of the study patients (318 of 4141 [7.7%]) underwent ICP monitoring despite meeting criteria defined by the BTF. There were no significant differences between the 2 groups in univariate analysis (n = 3107) in age, sex, or the ED-assigned GCS score (Table 1).

Monitored patients had a slightly higher ISS, a lower RTS, and similar TRISS-calculated probability of survival (Table 1). Crude survival was similar in both groups. Patients in the monitored group had significantly longer hospital stays, ICU stays, ventilator days, and overall increase in hospital charges, with no improvement compared with the unmonitored group (Table 2).

Monitoring of ICP was not associated with improvement in survival compared with the unmonitored group after adjusting for age, sex, ISS, RTS, GCS score determined in the ED, and the probability of survival score (TRISS analysis) (Table 3).
Monitoring of ICP has been used since the 1970s in the management of severe TBI and has been included in evidence-based practice guidelines for nearly a decade. However, no randomized clinical trial to evaluate the effect of ICP monitoring on outcomes in the management of severe TBI has been conducted. The obstacles to performing such a study include the ethical concern of not monitoring ICP in patients serving as a control group and the widely accepted use of ICP monitoring in major pediatric centers involved in TBI research.

Although modern, ICP-focused, intensive management protocols have almost unquestionably improved outcomes, these protocols have involved the simultaneous changes of several other major variables: improved prehospital care, cranial computed tomographic imaging for accurate diagnosis of mass lesions, increased use of tracheal intubation and controlled ventilation, more aggressive use of enteral and parenteral nutrition, more active medical management of acute injury, and more widespread availability of formal rehabilitation programs. During this period of change, ICP monitoring has emerged as an accepted practice without being evaluated in a randomized trial. Thus, it is difficult to separate the beneficial or deleterious effects of ICP monitoring—or other efforts to manage ICP—from the many other developments in the treatment of severe TBI.

Our study confirms that ICP monitoring is undertaken in few pediatric patients with severe TBI who meet the current criteria for monitoring. When it is used, ICP monitoring is associated with a decrease in mortality rate in only a small subset of the targeted population. In the present study, children who received a monitoring device in accordance with the BTF guidelines had a longer hospital stay, longer ICU stay, and more ventilator days. These findings suggest that the BTF criteria for ICP monitoring do not identify patients who are most likely to benefit from it.

The potential reason that the BTF recommendations for ICP monitoring have not been widely adopted is the lack of validation through prospective measures, and neurosurgeons may think that the level of evidence used in formulating these recommendations is insufficient and inconclusive. Although the BTF criteria have been promoted as evidence based, there is no class I evidence to address this.

Numerous studies have suggested that therapies that lower ICP, including sedation, chemical paralysis, hyperventilation, cerebrospinal fluid drainage, osmotherapy, and pentobarbital-induced coma, reduce mortality and improve the likelihood of recovery when effective. However, it remains unclear whether the association between elevated ICP and mortality is a result of the severity of the underlying injury. Only one prospective clinical trial has examined this association. Seventy-three patients whose ICP could not be controlled by conventional means were randomly assigned to receive high-dose pentobarbital or a placebo. The outcome of patients in either group whose ICP could be maintained below 20 mm Hg was better than in those whose ICP could not be controlled. A lower ICP, or one that can be lowered with therapy, might simply identify patients with less severe injuries who are likely to do well regardless of therapeutic interventions. This could explain why ICP monitoring in the study was not associated with an improved mortality rate in patients with a GCS score other than 3.

Another possible explanation for an association between ICP monitoring and increased morbidity (increased length of stay and ventilator days) in our study is that the interventions designed to reduce ICP are misapplied, harmful, or associated with complications. Hyperventilation has been shown to decrease cerebral perfusion and cause cerebral
...ICP monitoring may be beneficial.

There are several potential limitations of the study; the most important is the retrospective design. As with any large national database, we have no way of validating the information provided by individual trauma centers, including expertise in coding procedures and ability to capture all ICP-monitored patients within their facility. However, given the sample size and methods used in the present study to control the comparisons, this limitation is unlikely to invalidate the finding that there was no improvement in the mortality rate in ICP-monitored patients. In addition, this was an observational study, with no control during therapeutic interventions. Finally, we used strict inclusion criteria; hence, the results may not be extrapolated to the entire spectrum of patients with head injuries. We believe that such questions can be answered only by a prospective randomized clinical trial. Our data provide a scientific basis for conducting such a trial.

Conclusions

Monitoring of ICP in accordance with current BTF criteria is associated with limited survival benefit in pediatric patients with TBI. A prospective randomized clinical trial of ICP-guided therapy may provide further evidence for when ICP monitoring may be beneficial.


