Intracranial Pressure Monitoring in Brain-Injured Patients is Associated With Worsening of Survival

Shahid Shafi, MD, MPH, Ramon Diaz-Arrastia, MD, PhD, Christopher Madden, MD, and Larry Gentilello, MD

Background: The Brain Trauma Foundation (BTF) recommends intracranial pressure (ICP) monitoring in traumatic brain injury (TBI) patients with Glasgow Coma Scale (GCS) of 8 or less, and an abnormal brain computed tomography. However, benefits of ICP monitoring have not been documented. We hypothesized that BTF criteria for ICP monitoring in blunt TBI do not identify patients who are likely to benefit from it.

Methods: The National Trauma Data Bank (1994–2001) was analyzed. Inclusion criteria were blunt TBI, head-abbreviated injury score (AIS) 3 to 6, age 20 to 50 years, GCS ≤8, abnormal brain computed tomographic scan, and intensive care unit admission for 3 days or more. Early deaths (<48 hours) and delayed admissions (>24 hours after injury) were excluded. Patients who underwent ICP monitoring (n = 708) were compared with those did not (n = 938). Multivariate logistic regression was used to determine the relationship between ICP monitoring and survival, while controlling for overall injury severity, TBI severity, craniotomy, associated injuries, comorbidities, and complications.

Results: ICP monitoring was performed in only 43% of patients who met BTF criteria. There were no group differences in age, gender, or GCS. After adjusting for multiple potential confounding factors including, admission GCS, age, blood pressure, head AIS, and injury severity score (ISS), ICP monitoring was associated with a 45% reduction in survival (OR = 0.55; 95% CI, 0.39–0.76; p < 0.001).

Conclusions: ICP monitoring in accordance with current BTF criteria is associated with worsening of survival in TBI patients. A prospective randomized controlled trial of ICP-guided therapy is needed. Until then, the use of ICP monitoring should not be used as a quality benchmark.

Key Words: Traumatic brain injury, Intracranial pressure monitoring, Outcomes.

Exclusion criteria were developed to isolate the population most likely to benefit from ICP monitoring. Patients with minor brain injury (abbreviated injury score [AIS] of <3) were excluded. The AIS is an anatomic scoring system that ranks injury severity on a 1 to 6 scale; a score of 3 represents serious, 4 severe, 5 critical, and 6 a nonsurvivable injury. Patients who died within 48 hours of admission were excluded because these patients were assumed to have non-survivable injuries, with death because of uncontrollable hemorrhage or massive brain injury. Those who were admitted to a trauma center >24 hours after sustaining the injury were also excluded.

Based on these criteria, 1,646 patients were included in the study. They were divided into two groups: those who underwent ICP monitoring (n = 708), including 325 ventriculostomies (46%), and those who did not undergo ICP monitoring (n = 938). ICP monitoring was identified using ICD 9 codes 02.2 and 01.18.

To adjust for differences in mortality risk between the two groups, we first undertook a univariate analysis to compare the two groups using t tests for continuous variables, and χ² or Fisher’s exact test for categorical variables, as appropriate. Variables that were significantly different between the two groups were entered as covariates in a logistic regression model. These included the injury severity score (ISS, an anatomic measure of injury severity), the revised trauma score (RTS, a physiologic measure of injury severity), head AIS, motor component of the GCS in the emergency department, craniotomy, injuries to the spinal column, preexisting cardiac disease, and complications during hospitalization (pneumonia, renal failure, and infections).

The ISS is derived from the highest AIS scores of each of the three most severely injured of seven defined regions of the body, and ranges from 1 to 75. The RTS is derived from the first set of physiologic data obtained from the patient, and consists of the GCS, blood pressure, and respiratory rate, and ranges from 0 to 8. TRISS methodology uses a combination of anatomic (ISS) and physiologic (RTS) indices of injury severity, and uses coefficients derived from the Multiple Trauma Outcome Study, an age index, and coefficients for blunt and penetrating mechanism to calculate probability of survival, ranging from 0 to 1. However, TRISS was not included in the regression model as its primary components (ISS and RTS) were already included as covariates.

The resulting regression model was first applied to the entire study group to assess the relationship between ICP monitoring and survival after adjusting for differences between the two groups. Subsequently, the model was applied separately to each head AIS severity category (AIS = 3–5) except AIS 6 injuries, as those are universally fatal by definition. The validity of the model as a mortality predictor was confirmed using the Hosmer–Lemeshow goodness-of-fit statistic (3.676; p = 0.885), and by calculating the area under the receiver operating characteristic curve (0.742; 95% CI, 0.705–0.779).

The primary outcome of interest was survival. Odds ratios of survival with ICP monitoring, with 95% confidence intervals, were calculated using the regression models, with survival as the dependent variable and ICP monitoring as the independent variable. The secondary outcome of interest was functional independence. Functional outcome at discharge was measured using the modified functional independence measure (FIM). The modified FIM scores range from 1 (completely dependent) to 4 (completely independent) for each of the three functions assessed (feeding, expression, and locomotor) for a total ranging from 3 to 12. It is widely used by trauma registries and is considered useful in comparing patient groups and trends.

Continuous variables are summarized as mean ± SEM, and categorical variables as proportions. A p value of <0.05 was considered significant for all analyses.

RESULTS

Less than half of the study patients underwent ICP monitoring, despite meeting criteria defined by the BTF (708 of 1646, 43%). There was no difference between the two groups in age, gender distribution, mechanism of injury, systolic blood pressure, core temperature, base deficit, or teaching status of the hospitals (Tables 1 and 2). There was no difference in presence or severity of associated injuries, including chest, abdominal or extremity injuries, except spine injuries, which were less common in the ICP monitoring group (Table 3). Also, there was no difference in the presence of preexisting conditions such as coagulopathy, diabetes, obesity, drug and alcohol abuse, pulmonary disease and liver disease, except those monitored patients who were more likely to have preexisting cardiac disease (52% vs. 32%, p < 0.001).

Patients in the monitored group had a lower scene GCS, but there was no difference in emergency department GCS, except for a slightly lower motor component (Table 4). Monitored patients had a higher head AIS, and were more likely to undergo craniotomy (Table 4). Patients in the monitored group had a slightly higher ISS, a lower RTS, and lower TRISS calculated probability of survival (Table 1).

Crude survival was worse in the monitored group (Tables 1 and 5). In the entire study group, ICP monitoring was associated with an approximately 45% reduction in survival after adjusting for severity of brain injury, overall injury severity, associated injuries, preexisting conditions, and complications (Table 5). When analyzed by severity of head injuries, ICP monitoring was associated with a significant reduction in survival in those with AIS 4 and 5 head injuries. There was no effect of monitoring on survival of AIS 3 head injuries. Monitoring was also associated with a significant increase in complications including pneumonia (37% vs. 23%, p < 0.001), renal failure (2.7% vs. 1.1%, p = 0.02), and infections (39% vs. 24%, p < 0.001). There was no difference in adult respiratory distress syndrome (4.6% vs. 3.9%, p = NS), myocardial infarction (0.6% vs. 0.2%, p = NS), or venous thromboembolism (3.8% vs. 2.7%, p = NS). Func-
tional outcome was significantly worse in patients who underwent ICP monitoring (FIM 5.9 ± 0.16 vs. 7.9 ± 0.14, p < 0.000, n = 876, Table 6).

**DISCUSSION**

ICP monitoring has been used since the 1970s in the management of severe traumatic brain injuries, and has been included in evidence-based practice guidelines for nearly a decade. However, a prospective, randomized clinical trial on the effectiveness of this modality in improving outcomes has never been performed. The current study confirms that ICP monitoring is undertaken in only a minority of patients with severe head injuries who meet the current criteria for monitoring, and when used, ICP monitoring is associated with a decrease in survival. Despite controlling for multiple potential confounders that were associated with mortality, those who received a monitoring device in accordance with the BTF guidelines did not seem to benefit. These findings suggest that BTF criteria for ICP monitoring do not identify patients who are likely to benefit from it.

There are several potential reasons why BTF recommendations for ICP monitoring have not been widely adopted. First, ICP monitoring has not been prospectively validated, and neurosurgeons may think that the level of evidence used in formulating these recommendations is insufficient and inconclusive. Although these criteria have been promoted as evidence-based, there is no class I evidence to address this

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**Table 1** General Characteristics

<table>
<thead>
<tr>
<th></th>
<th>No ICP Monitoring</th>
<th>ICP Monitoring</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>All patients</td>
<td>1,646</td>
<td>708</td>
<td></td>
</tr>
<tr>
<td>Age (yr)</td>
<td>1,646</td>
<td>708</td>
<td></td>
</tr>
<tr>
<td>Survival (unadjusted)</td>
<td>1,646</td>
<td>708</td>
<td></td>
</tr>
<tr>
<td>Female gender</td>
<td>1,645</td>
<td>708</td>
<td></td>
</tr>
<tr>
<td>Teaching hospital</td>
<td>1,602</td>
<td>708</td>
<td></td>
</tr>
<tr>
<td>Drug screen positive</td>
<td>927</td>
<td>708</td>
<td></td>
</tr>
<tr>
<td>Alcohol screen positive</td>
<td>999</td>
<td>708</td>
<td></td>
</tr>
<tr>
<td>First ED systolic blood pressure</td>
<td>1,636</td>
<td>708</td>
<td></td>
</tr>
<tr>
<td>ED temperature</td>
<td>1,085</td>
<td>708</td>
<td></td>
</tr>
<tr>
<td>ED base deficit</td>
<td>1,140</td>
<td>708</td>
<td></td>
</tr>
<tr>
<td>Injury severity score</td>
<td>1,637</td>
<td>708</td>
<td></td>
</tr>
<tr>
<td>Length of stay (days)</td>
<td>1,636</td>
<td>708</td>
<td></td>
</tr>
<tr>
<td>Revised trauma Score</td>
<td>1,457</td>
<td>708</td>
<td></td>
</tr>
<tr>
<td>TRISS probability of survival</td>
<td>1,504</td>
<td>708</td>
<td></td>
</tr>
</tbody>
</table>

* Number of patients with available information.

ED, emergency department.

**Table 2** Mechanism of Injury (p = NS)

<table>
<thead>
<tr>
<th></th>
<th>No ICP Monitoring (%)</th>
<th>ICP Monitoring (%)</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fall</td>
<td>172</td>
<td>10.1</td>
<td>10.9</td>
</tr>
<tr>
<td>Motor vehicle occupants</td>
<td>898</td>
<td>56</td>
<td>52.7</td>
</tr>
<tr>
<td>Motorcycle riders</td>
<td>181</td>
<td>11.1</td>
<td>10.9</td>
</tr>
<tr>
<td>Bicycle riders</td>
<td>29</td>
<td>1.9</td>
<td>1.6</td>
</tr>
<tr>
<td>Pedestrians</td>
<td>126</td>
<td>6.8</td>
<td>8.8</td>
</tr>
<tr>
<td>Struck by or against an object</td>
<td>122</td>
<td>7.2</td>
<td>7.6</td>
</tr>
<tr>
<td>Other transport related</td>
<td>118</td>
<td>6.8</td>
<td>7.6</td>
</tr>
</tbody>
</table>

**Table 3** Associated Injuries

<table>
<thead>
<tr>
<th></th>
<th>No ICP Monitoring (%)</th>
<th>ICP Monitoring (%)</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Face</td>
<td>815</td>
<td>49.8</td>
<td>49.2</td>
</tr>
<tr>
<td>Neck</td>
<td>33</td>
<td>2.3</td>
<td>1.6</td>
</tr>
<tr>
<td>Chest</td>
<td>804</td>
<td>48.3</td>
<td>49.6</td>
</tr>
<tr>
<td>Abdomen</td>
<td>410</td>
<td>26.3</td>
<td>23</td>
</tr>
<tr>
<td>Spine</td>
<td>418</td>
<td>28.7</td>
<td>21</td>
</tr>
<tr>
<td>Upper extremity</td>
<td>620</td>
<td>38.1</td>
<td>37.1</td>
</tr>
<tr>
<td>Lower extremity</td>
<td>670</td>
<td>39.1</td>
<td>42.8</td>
</tr>
<tr>
<td>Others (unspecified)</td>
<td>155</td>
<td>9</td>
<td>10</td>
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</tbody>
</table>

**Table 4** Severity of Head Injuries

<table>
<thead>
<tr>
<th></th>
<th>No ICP Monitoring (%)</th>
<th>ICP Monitoring (%)</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scene GCS (n = 958)</td>
<td>5.4 ± 0.13</td>
<td>4.7 ± 0.13</td>
<td>0.000</td>
</tr>
<tr>
<td>Craniotomy (n = 1,552)</td>
<td>16%</td>
<td>27%</td>
<td>0.000</td>
</tr>
<tr>
<td>GCS groups in ED:</td>
<td>938</td>
<td>708</td>
<td>NS</td>
</tr>
<tr>
<td>GCS 3 and 4</td>
<td>65%</td>
<td>68%</td>
<td></td>
</tr>
<tr>
<td>GCS 5 and 6</td>
<td>16%</td>
<td>17%</td>
<td></td>
</tr>
<tr>
<td>GCS 7 and 8</td>
<td>19%</td>
<td>15%</td>
<td></td>
</tr>
<tr>
<td>Highest Head AIS:</td>
<td>935</td>
<td>707</td>
<td>0.000</td>
</tr>
<tr>
<td>AIS 3</td>
<td>34%</td>
<td>17%</td>
<td></td>
</tr>
<tr>
<td>AIS 4</td>
<td>33%</td>
<td>30%</td>
<td></td>
</tr>
<tr>
<td>AIS 5</td>
<td>33%</td>
<td>53%</td>
<td></td>
</tr>
<tr>
<td>AIS 6</td>
<td>0%</td>
<td>0%</td>
<td></td>
</tr>
<tr>
<td>GCS in emergency department</td>
<td>4.3 ± 0.06</td>
<td>4.2 ± 0.06</td>
<td>NS</td>
</tr>
<tr>
<td>Eye</td>
<td>1.1 ± 0.01</td>
<td>1.1 ± 0.02</td>
<td>NS</td>
</tr>
<tr>
<td>Verbal</td>
<td>1.1 ± 0.01</td>
<td>1.1 ± 0.01</td>
<td>NS</td>
</tr>
<tr>
<td>Motor</td>
<td>2.1 ± 0.05</td>
<td>1.9 ± 0.05</td>
<td>0.04</td>
</tr>
</tbody>
</table>

ED, emergency department.
threshold value that predicted an adverse outcome.3 An ICP
confounding variables, an ICP of 20 mm Hg was identified as
lected observational data, and after controlling for potential
The largest study of ICP monitoring used prospectively col-
mortality is a result of the severity of the underlying injury.
remains unclear if the association between elevated ICP and
recovery when effective at reducing ICP.3,4,14–21 However, it
though numerous studies have suggested that therapies that
One explanation is that ICP monitoring is not helpful even
account for a higher mortality in the monitored group.
There may be several reasons for a higher mortality and
clinical question. Another potential reason for low compli-
cance with recommendations is that the clinicians prefer to
rely on their clinical judgment based on the severity of head
injury as seen on the CT scan or the motor component of the
GCS, which may be followed reliably even in intubated
patients. It is possible that neurosurgeons may have chosen to
perform ICP monitoring in patients who, in their clinical
judgment, were at greater risk for mortality. Although the
measured characteristics of unmonitored and monitored pa-
patients were similar in our study, neurosurgeons may have
been adept at identifying patients likely to have worse out-
comes despite similar indications for monitoring, which may
account for a higher mortality in the monitored group.
There may be several reasons for a higher mortality and
worse functional outcome observed in the monitored group.
One explanation is that ICP monitoring is not helpful even
though 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 at reducing ICP.3,4,14–21 However, it
remains unclear if the association between elevated ICP and
mortality is a result of the severity of the underlying injury.
The largest study of ICP monitoring used prospectively col-
lected observational data, and after controlling for potential
confounding variables, an ICP of 20 mm Hg was identified as
a threshold value that predicted an adverse outcome.7 An ICP
greater than 20 mm Hg that is refractory to treatment may
simply be a marker of brain injury severity, and identifies pa-
patients with a worse prognosis. The only prospective, controlled
trial contained 73 patients whose ICP could not be controlled by
conventional means, who were randomly assigned to receive a
high-dose pentobarbital or a placebo. The outcome of patients in
either group whose ICP could be kept below 20 mm Hg was
better than those whose ICP could not be controlled.16 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 irrespective of therapeutic interventions.
Another possible explanation for association between
ICP monitoring and increased mortality is that the inter-
ventions designed to reduce ICP are misapplied, are harm-
ful, or are associated with complications. Hyperventilation
has been shown to decrease cerebral perfusion and cause
cerebral ischemia.22–24 Osmotic diuresis with Mannitol
may cause hypovolemia and result in episodes of hypoten-
sion, which have been shown to significantly increase
mortality in head-injured patients.25,26 There is also a small
amount of risk associated with the placement of an
ICP monitor.27,28 Other interventions to reduce ICP or to
increase cerebral perfusion pressure may result in fluid
overload, inappropriate use of vasopressors, excessive use
of paralytics and sedatives, and delay in liberation from the
ventilator, all of which may contribute to increased mortal-
ity.29–31 At least one study has shown that efforts to
maintain an elevated cerebral perfusion pressure are asso-
ciated with an increased risk of adult respiratory distress
syndrome.32 In the present study, ICP monitoring was
associated with an increase in complications, including
pneumonia, renal failure, and infections (but not with adult
respiratory distress syndrome), which may have contrib-
uted to increased mortality. Finally, it is possible that ICP
monitoring does not improve survival because appropriate
interventions to reduce an elevated ICP are not undertaken in
a timely fashion.
Irrespective of which explanation for our results eventu-
ally bears out, we cannot escape the conclusion that the BTF
guidelines do not identify patients who benefit from ICP
monitoring. All patients included in this study should have
had ICP monitors placed according to the current guidelines
and yet we were not able to find any subgroup of patients
defined by AIS or GCS score that seemed to benefit from ICP
monitoring. Specifically, emergency department GCS was a
poor discriminant for efficacious use of ICP monitoring. This
analysis strongly suggests that the indications for ICP mon-
itoring should be reevaluated.
The similarity between our results and those reported on
the use of right heart catheterization (RHC) for invasive
hemodynamic monitoring of critically ill patients bears con-
sideration. Like ICP monitoring for TBI, RHC was adopted
widely for use in critically ill patients in the early 1970s
before performance of randomized controlled trials to define
its benefits. Several observational studies challenged its use

Table 5 Impact of ICP Monitoring on Survival
(Multivariate Logistic Regression Model)

<table>
<thead>
<tr>
<th></th>
<th>N</th>
<th>OR for Survival</th>
<th>95% C.I.</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unadjusted or</td>
<td>1,646</td>
<td>0.549</td>
<td>0.421–0.716</td>
<td>0.000</td>
</tr>
<tr>
<td>Adjusted</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>All patients</td>
<td>1,313</td>
<td>0.545</td>
<td>0.39–0.763</td>
<td>0.000</td>
</tr>
<tr>
<td>Patients with</td>
<td>344</td>
<td>0.569</td>
<td>0.214–1.511</td>
<td>NS</td>
</tr>
<tr>
<td>head AIS 3</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Patients with</td>
<td>423</td>
<td>0.329</td>
<td>0.158–0.688</td>
<td>0.003</td>
</tr>
<tr>
<td>head AIS 4</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Patients with</td>
<td>545</td>
<td>0.606</td>
<td>0.394–0.933</td>
<td>0.023</td>
</tr>
<tr>
<td>head AIS 5</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Adjusted for ISS, RTS, head AIS, craniotomy, motor component of GCS in the emergency department, spine injuries, preexisting cardiac disease, complications of pneumonia, renal failure and infections.
N, number of patients in the model; OR, odds ratio.

Table 6 Functional Outcomes Using FIM Scores

<table>
<thead>
<tr>
<th></th>
<th>N*</th>
<th>FIM feed</th>
<th>FIM locomotor</th>
<th>FIM expression</th>
<th>FIM total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>No ICP Monitoring</td>
<td>ICP Monitoring</td>
<td>p</td>
<td></td>
</tr>
<tr>
<td></td>
<td>881</td>
<td>2.7 ± 0.06</td>
<td>1.9 ± 0.06</td>
<td>0.000</td>
<td></td>
</tr>
<tr>
<td></td>
<td>883</td>
<td>2.4 ± 0.05</td>
<td>1.8 ± 0.05</td>
<td>0.000</td>
<td></td>
</tr>
<tr>
<td></td>
<td>879</td>
<td>2.9 ± 0.05</td>
<td>2.2 ± 0.06</td>
<td>0.000</td>
<td></td>
</tr>
<tr>
<td></td>
<td>876</td>
<td>7.9 ± 0.14</td>
<td>5.9 ± 0.16</td>
<td>0.000</td>
<td></td>
</tr>
</tbody>
</table>

* Number of patients with available information.
after noting increased mortality associated with use of the RHC, even after adjusting for confounding variables. Subsequent randomized, controlled trials have confirmed a lack of benefit to therapy directed by RHC in high-risk surgical patients. The current study is the first observational study of its size in a national sample that similarly questions the use of ICP monitoring in head-injured patients, and suggests a need for prospective examination of BTF criteria.

There are several potential limitations of the study, most importantly, the retrospective nature of the analysis. As with any large national database, we have no way of validating the data provided by individual trauma centers, their expertise in coding procedures, and their ability to capture all ICP monitored patients in their center. Although we are confident that our analysis is robust and supports our conclusions, it must be emphasized that the presence of a statistical association does not establish a causal relationship. There may be unmeasured variables that explain why ICP monitoring was associated with an increase in mortality. This is most likely attributable to clinicians’ judgment, and does not invalidate the conclusion that BTF guidelines for monitoring do not identify patients who benefit from such monitoring. An additional limitation is that the cause of death was not known, and patients may have died of something other than their brain injury. Given the size of the sample and methodologies used to control for injury severity and mortality risk, this is unlikely to invalidate the finding of increased mortality risk in monitored patients. Additionally, this was a purely observational study, with no control during therapeutic interventions. Finally, we used strict inclusion and exclusion criteria; hence, the results may not be extrapolated to the entire spectrum of head-injured patients. We think that such questions can only be answered by a prospective randomized controlled trial. Our data provide a scientific basis for conducting such a trial.

In conclusion, our data suggest that ICP monitoring is associated with worsening of survival when used in brain-injured patients who meet current published indications. A prospective randomized controlled trial is needed before ICP monitoring can be established as a clinical standard. Until then, the use of ICP monitoring in accordance with current guidelines should not be used as a quality assurance indicator or quality benchmark.

REFERENCES


