Intracranial pressure and cerebral perfusion pressure as risk factors in children with traumatic brain injuries

ALBERT CATALÀ-TEMPRANO, M.D., GEMMA CLARET TERUEL, M.D., FRANCISCO JOSÉ CAMBRA LASAOSA, M.D., PH.D., MARTÍ PONS ÓDEXA, M.D., ANTONI NOGUERA JULIÁN, M.D., PH.D., AND ANTONIO PALOMEQUE RICO, M.D., PH.D.

Pediatric Intensive Care Unit, Pediatrics Department, Integrated Unit Sant Joan de Déu-Clínic, Hospital Universitari Sant Joan de Déu, Universitat de Barcelona, Esplugues, Barcelona, Spain

Object. The authors evaluated the initial intracranial pressure (ICP) and cerebral perfusion pressure (CPP) as prognostic factors in severe head injury in children and tried to determine the optimal CPP range.

Methods. The authors performed a 9-year retrospective review of all patients with severe traumatic brain injuries (TBIs) who required invasive ICP monitoring and were admitted to the pediatric intensive care unit at their institution between January 1995 and December 2003. These patients had Glasgow Coma Scale scores lower than 8 and/or required ICP monitoring due to worsening neurological status or neuroimaging results suggestive of cerebral hypertension. Clinical summaries and imaging studies were reviewed. Data for 156 pediatric patients who ranged in age from 1 to 18 years were obtained. Half of these patients presented with normal initial ICPs (< 20 mm Hg), and a good outcome was achieved in 80% of these children. An unfavorable outcome was observed in more than 60% of patients with an initial CPP lower than 40 mm Hg. The proportion of patients with an unfavorable outcome decreased to 10% with initial CPPs higher than 60 mm Hg, but patients with initial CPPs higher than 70 mm Hg did not improve.

Conclusions. Initial ICP and CPP measurements were useful as prognostic factors in pediatric patients with severe TBIs: patients with initial CPPs between 40 and 70 mm Hg were found to have a better neurological prognosis than those with CPPs either higher or lower than that range.

Key Words • traumatic brain injury • intracranial pressure • cerebral perfusion pressure • pediatric neurosurgery

Head trauma is the most common cause of death and long-term disability among children, therefore an investigation into the earliest prognostic markers in pediatric patients with TBIs is warranted. Initial ICP and CPP measurements (CPP = MAP – ICP), have been identified as prognostic markers in adults. Some optimal values of CPP have been proposed as endpoints in the management of brain injuries. An acute brain injury can damage autoregulation of cerebral blood pressure and leave the brain unprotected from the hemodynamic oscillations that these patients suffer. This means that when CPP is below the lower limit of autoregulation, cerebral blood flow is dependent on MAP, causing a detrimental effect. Additionally, the increase in CPP beyond the highest autoregulation limit produces damage to the blood–brain barrier and causes a dangerous hyperemic situation. We know that arterial hypotension has an independent adverse effect on children with brain injuries. In this report, initial ICP and CPP are analyzed as prognostic markers in children with brain injuries, and optimal CPP thresholds in children are proposed.

Clinical Material and Methods

We performed a retrospective review of all patients with severe head injury admitted to the PICU at our institution between January 1995 and December 2003. Our institution is a pediatric university hospital with a neurotrauma unit. Clinical summaries and neuroimaging studies obtained in each child were reviewed. We included all patients with severe brain injuries; that is, those with a GCS score less than 8 and/or those who required ICP monitoring due to neurological worsening or the presence of a lesion on neuroimaging suggestive of cerebral hypertension. Data recorded included age, sex, mechanism of injury, initial GCS score, injury progression on cerebral computed tomography scans using the Marshall score, pharmacological management, initial ICP and CPP measurements obtained within the first hour after ICP sensor collocation, ICP progression, and the
neurological status of the child during the 12 months after discharge from the PICU according to GOS score. These data were periodically evaluated by pediatric neurologists, psychologists, and neurosurgeons, and no evident clinical variations were seen after 12 months. Based on the findings of Rodriguez et al., we created an instrument for classifying children with TBI into six stages of ICP progression (Table 1). In the first three stages the patient has a normal ICP (<20 mm Hg) or a one-time spike in intracranial hypertension that improves without pharmacological measures. Patients in Stages 4 and 5 require pharmacological treatment for intracranial hypertension, and in children in Stage 6 the intracranial hypertension is refractory.

Data were entered into a computerized database (Access, Microsoft Corp.) and analyzed with commercially available software (SPSS 11.0). Statistical significance was reached at a probability value of 0.05.

### Results

Data for 156 patients ranging in age from 1 to 18 years (median 13 years, SD 15 months) were collected; 72% were boys. The mechanism of injury in 99 patients (63.4%) was a traffic accident. The initial GCS score was 8 or less in 70% of those injured in a traffic accident. After 12 months, 17% of patients had died (GOS Score 1), 7% were in a persistent vegetative state (GOS Score 2), and 64% had some or no disabilities (GOS Score 3), and 6% had more significant disabilities or only minimal ones. In contrast, more than 50% of children with initial GCS scores between 9 and 13 died or remained in a vegetative state, and only 50% had no disabilities or only minimal ones (Fig. 1). Only 14% of children with normal initial ICP had a good outcome either with or without minimal disabilities, and only 12% died or remained in a vegetative state. Furthermore, 36% of patients with initial ICPs greater than 20 mm Hg died or remained in a vegetative state, and only 50% had no disabilities or only minimal ones (Fig. 1). Only 14% of children with normal initial ICP had a good outcome either with or without minimal disabilities.

We also found a relationship (p < 0.05) between ICP progression and neurological outcome. We observed that 90% of patients in ICP Stages 1 through 3—that is, those who did not require treatment for intracranial hypertension—had no disabilities or only minimal ones. In contrast, more than 50% of patients with ICP in Stages 4 through 6 had significant disabilities (Fig. 2).

There was a relationship (p < 0.05) between initial CPP and neurological outcome. A better neurological outcome in terms of GOS score was observed in proportion to higher

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**TABLE 1**

Intracranial pressure progression after TBI in children

<table>
<thead>
<tr>
<th>Stage</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>normal &amp; maintained (&lt;15 mm Hg)</td>
</tr>
<tr>
<td>2</td>
<td>15–25 mm Hg &amp; maintained</td>
</tr>
<tr>
<td>3</td>
<td>15–25 mm Hg w/ occasional increases that do not require treatment</td>
</tr>
<tr>
<td>4</td>
<td>15–25 mm Hg w/ maintained increases (&gt;10 min) which require treatment</td>
</tr>
<tr>
<td>5</td>
<td>&gt;25 mm Hg w/ good response to treatment</td>
</tr>
<tr>
<td>6</td>
<td>&gt;25 mm Hg w/o response to treatment</td>
</tr>
</tbody>
</table>

* Data adapted from Rodriguez JO et al., 2001.

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**TABLE 2**

Data obtained in 156 children with TBIs

<table>
<thead>
<tr>
<th>Age (yrs), No. of Patients (%)</th>
<th>w/ Initial GCS Score &lt;8</th>
<th>w/ Initial ICP &lt;20 mm Hg</th>
<th>w/ GOS Score 4 or 5</th>
<th>Initial CPP in mm Hg (% of patients)</th>
<th>Most Frequent MOI (% of patients)</th>
<th>% Male</th>
</tr>
</thead>
<tbody>
<tr>
<td>0–2, 24</td>
<td>1 (50)</td>
<td>0</td>
<td>0</td>
<td>&lt;40 (100)</td>
<td>fall (100)</td>
<td>100</td>
</tr>
<tr>
<td>3–7, 36</td>
<td>29 (80)</td>
<td>19 (52)</td>
<td>22 (62)</td>
<td>&lt;40 (22); &gt;60 (56)</td>
<td>run over (41)</td>
<td>67</td>
</tr>
<tr>
<td>8–13, 34</td>
<td>27 (79)</td>
<td>13 (38)</td>
<td>20 (59)</td>
<td>&lt;40 (10); &gt;60 (48)</td>
<td>MVC (31)</td>
<td>69</td>
</tr>
<tr>
<td>≥14, 34</td>
<td>56 (67)</td>
<td>46 (54)</td>
<td>55 (66)</td>
<td>&lt;40 (20); &gt;60 (51)</td>
<td>motorcycle accident (48)</td>
<td>72</td>
</tr>
</tbody>
</table>

* MOI = mechanism of injury; MVC = motor vehicle crash.
Risk factors in children with TBI

Fig. 2. Graph of the correlation between ICP progression and GOS score. Numbers on the y axis represent the number of patients. There were a total of 65 patients in ICP Stages 1 through 3, and 91 in Stages 4 through 6.

Fig. 3. Graph of the correlation between initial CPP and GOS score. CPP i = initial CPP.

The outcomes are distributed homogeneously among all ages. However it is important to obtain more results in infants younger than 2 years of age. The only two infants in our series both had initial CPPs below 45 mm Hg; one died and the other remains in a vegetative state. The correlations among initial assessments of GCS score, CPP, and ICP and with the pattern of disease progression in children with TBI is very interesting and could offer valuable information as to the expected outcome in such patients. Most children with initial GCS scores of 9 or higher will not require treatment for intracranial hypertension as they will typically have a normal ICP and follow a favorable clinical course (Stages 1–3).

Since Pigula and colleagues demonstrated that arterial hypotension was an independent risk factor in pediatric patients after TBI, some authors have claimed that all we can do to help patients with high CPP is to maintain their MAP at optimal levels, and that there would be no advantage to elevating CPP beyond the threshold value of approximately 40 mm Hg. We did not analyze MAP independently as a risk factor in the present study, but it seems clear that the outcome is much better in patients with initial CPPs between 40 and 70 mm Hg.

Conclusions

In this study we tried to address the controversial issues surrounding the optimal CPP threshold in the pediatric population and whether a higher CPP confers additional benefit to the pediatric patient after TBI. Although further studies are required, particularly in young infants, we have demonstrated that there is a correlation between neurological improvement and initial CPP higher than 40 mm Hg; however, values greater than 70 mm Hg do not offer any advantage. The treatment of children with TBI must include ICP control measures and the attainment of an optimal CPP level.

References


3. Chesnut RM: Avoidance of hypotension: condition sine qua non

initial CPPs between 40 and 70 mm Hg. No significant difference was found in GOS scores in patients with initial CPPs greater than 70 mm Hg. If we divide the initial CPP into deciles, 30% of the children with an initial CPP greater than 40 mm Hg, 50% with an initial CPP greater than 50 mm Hg, and 65% with an initial CPP greater than 60 mm Hg had good outcomes (Fig. 3).

Discussion

One of the most controversial areas of pediatric neurotrauma is CPP control, and for these age groups the studies are limited and include a variety of values of optimal CPP thresholds. The old style of managing brain injury only considered ICP control, and CPP was not seen as an important parameter. In recent years, two opposing theories have been advanced to justify CPP control in treating cases of TBI. The theory posited by Rosner et al. is based on the vasodilator cascade: a reduction in CPP via a decrease in MAP or an elevation in ICP will stimulate the cerebral vessels to dilate in an attempt to maintain cerebral blood flow. An increase in MAP under these circumstances would break this cycle and lower ICP. Another approach, the Lund theory, has been postulated which emphasizes reducing microvascular pressure to prevent edema.

In contrast to the findings of other authors, we did not observe a 100% mortality rate in patients with initial CPPs below 40 mm Hg. However, the rate of morbidity and mortality in these patients was not trivial; 70% had an unfavorable outcome (GOS Score 1 or 2). This difference can perhaps be explained by the limited number of patients in the other series, or by the fact that the other authors were discussing CPP progression, rather than initial CPP. We found significant improvement on follow-up imaging and a decrease in the rate of morbidity in proportion to the increase in initial CPP between 40 and 70 mm Hg. However we did not find significant differences in GOS scores at 12 months after discharge from the PICU in children who had had initial CPPs higher than 70 mm Hg compared with those who had CPPs between 60 and 70 mm Hg. Robertson found an elevated risk of acute respiratory distress, renal failure, and brain injuries with loss of autoregulation in patients with CPPs higher than 70 mm Hg. Although only eight of our patients had initial CPPs higher than 70 mm Hg, we saw none of these complications.

Address reprint requests to: Albert Català-Temprano, M.D., Passeig Sant Joan de Déu, 208950 Esplugues de Llobregat, Barcelona, Spain. email: acatala@hsjdbcn.org.