Clinical study

Intraoperative applications of intracranial pressure monitoring in patients with severe head injury

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Abstract

From December 2002 to January 2004, 30 patients (20 men and 10 women; mean age 36.8 years [±14.9 years]) with preoperative Glasgow Coma Scale scores of 8 or less underwent emergency haematoma evacuation surgery and continuous intracranial pressure (ICP), cerebral perfusion pressure (CPP) and mean arterial blood pressure monitoring to determine ICP and CPP thresholds to predict patient outcomes. Receiver-operating characteristic (ROC) curves were plotted. Using the ROC curve, the diagnostic accuracy is given by the area under the curve and at the point on the curve farthest from the diagonal, which indicates the threshold value. The results showed that the initial ICP for unfavourable outcomes was 47.4 ± 21.4 mmHg, resulting in a CPP of 22.8 ± 12.83 mmHg. The initial ICP for favourable outcomes was 26.4 ± 10.1 mmHg, resulting in a CPP of 48.8 ± 13.4 mmHg. The CPP had the largest area under the ROC curve in all stages of the operation, corresponding to intraoperative CPP thresholds of 37 mmHg (initial), 51.8 mmHg (intraoperative) and 52 mmHg (after scalp closure). The ROC curve analysis showed that CPP was a better predictor of outcome than ICP.

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1. Introduction

The optimal cerebral perfusion pressure (CPP) in severe head injury is still controversial. In 2000, Juul et al. indicated that a CPP of greater than 60 mmHg appeared to have little influence on the outcome of patients with severe head injury.1 In 2000, recommendations from the Brain Trauma Foundation advocated raising CPP to at least 70 mmHg.2 In 2003, Nordstrom et al. suggested that CPP may be reduced to 50 mmHg in patients with severe traumatic brain lesions.3 However, in most of this literature, data were recorded postoperatively.1–9 Continuous recordings of intracranial pressure (ICP) and CPP values during surgery were not included.10

The receiver-operating characteristic (ROC) curve is a tool to evaluate the benefits of a procedure or to compare one procedure with another. Using the ROC curve, the diagnostic accuracy of a test is given by the area under the ROC curve and at the point on the curve farthest from the diagonal, which indicates the threshold value.11,12 The purposes of this study were to establish the early values of ICP and CPP which may be better predictors of outcome and to determine the thresholds of ICP and CPP during surgery that were predictive of outcome, using ROC curves.

2. Materials and methods

Patients with isolated brain injury with acute subdural haemorrhage (SDH) and/or epidural haemorrhage (EDH) or intracerebral haemorrhage (ICH) and preoperative Glasgow Coma Scale (GCS) scores of ≤8 were admitted to the Neurosurgical Intensive Care Unit of Chi-Mei
Medical Center, Taiwan. All patients underwent emergency craniectomy for haematoma removal. They received anaesthesia induction with fentanyl, propofol, xylazine and atracurium and general anaesthesia with desflurane. Desflurane (9–10%) mixed with 1 L/min oxygen by inhalation was given during the entire operation. An ICP microsensor (Codman and Shurtlef, Inc., Rayman, MA, USA) was placed in the parenchyma of the ipsilateral frontal lobe of each patient. The mean arterial blood pressure (MAP) was monitored using standard pressure transducers. During surgery, ICP was monitored continuously and ICP, MAP and CPP values recorded at different time points depending on the type of haemorrhage. Postoperatively, patients underwent CPP-guided management, with the aim of a CPP of 60 mmHg or more.

Data were expressed as mean ± standard deviation. The data were analysed using the Mann–Whitney U-test for continuous data between two groups and Fisher’s exact test for categorical data using commercial statistical software (SPSS for Windows, V. 10.0.7, SPSS, Inc., Chicago, IL, USA). A p-value of less than 0.05 was considered statistically significant. In each case, the ROC graph is a plot of all sensitivity (y-axis)/(1–specificity) (x-axis) pairs resulting from continuously varying the decision threshold over the entire range of ICP and CPP observed. Using ROC curves, the diagnostic accuracy of a test is given by the area under the ROC curve and at the point that the curve is farthest from the diagonal, indicating that this is a threshold value. Outcomes were determined 3 months after head injury, with a favourable outcome defined as a Glasgow Outcome Score (GOS) of 4–5 (moderate disability or better) and an unfavourable outcome defined as a GOS of 1–3 (death, vegetative state or severe disability).

3. Results

The mean age of the 30 patients (20 male and 10 female) was 36.8 ± 14.9 years (range, 20–61 years). There was a significant predominance of male patients (66.7%). The primary lesions included acute SDH in 22, ICH in six and EDH in two patients. The mean preoperative GCS score was 6.5 ± 1.1. The admission and preoperative GCS scores were significantly lower in patients with a GOS of 1–3. Patients with preoperatively reactive pupils had favourable outcomes. Midline shift on brain CT scan was not a significant variable between the favourable and unfavourable outcome groups. At 3 months postoperatively, 63.3% (19/30) of patients had favourable outcomes, with a GOS of 4–5; 30.7% (11/30) of patients had unfavourable outcomes, with a GOS of 1–3. Patient demographic data are summarized in Table 1.

Figs. 1–3 show that the initial ICP is significantly higher and the CPP is significantly lower in patients with unfavourable outcomes. The ICP decreased immediately after removal of the bone flap (large craniotomy) and decreased further after opening of the dura and removal of the blood clot. Simultaneously, the values of CPP increased stepwise in patients with both favourable and unfavourable outcomes. After scalp closure, the ICP dramatically increased to 35.5 ± 15.5 mmHg, resulting in a decrease of the CPP to a very low level in patients with unfavourable outcomes. The ICP slightly increased to a mean of 12.4 ± 8.5 mmHg in patients with favourable outcomes. Simultaneously, the CPP values remained at greater than 60 mmHg after scalp closure. Although MAPs were not significantly different between patients with and without favourable outcomes, patients with favourable outcomes tended to have higher MAP.

Figs. 4–6 show the ROC curves for ICP and CPP at different stages of the operation (initial, during surgery and after scalp closure). Table 2 summarizes the area under the ROC curve and thresholds of ICP and CPP. In the majority of cases, CPP had the greatest area under the curve during the different stages of surgery. The largest area under the CPP ROC curve was 0.943 after the scalp closure. At a value of 46.5 mmHg, the sensitivity for CPP after scalp closure was 1; patients with an average CPP after scalp closure of less than or equal to 46.5 mmHg had unfavourable outcomes. The ROC curve for CPP after scalp closure rose in specificity from 0.727 at 46.5 mmHg to

<table>
<thead>
<tr>
<th>Variable</th>
<th>Favourable outcome (n = 19)</th>
<th>Unfavourable outcome (n = 11)</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Male (%)</td>
<td>14 (70)</td>
<td>6 (30)</td>
<td></td>
</tr>
<tr>
<td>Female (%)</td>
<td>5 (50)</td>
<td>5 (50)</td>
<td></td>
</tr>
<tr>
<td>Age</td>
<td>38.3 ± 15.8 years</td>
<td>34.3 ± 13.8 years</td>
<td>0.582*</td>
</tr>
<tr>
<td>Admission GCS score</td>
<td>8.8 ± 3.2</td>
<td>6.1 ± 1.9</td>
<td>0.016†</td>
</tr>
<tr>
<td>Preoperative GCS score</td>
<td>6.9 ± 0.8</td>
<td>5.7 ± 1.4</td>
<td>0.014†</td>
</tr>
<tr>
<td>Pupil reaction (both fixed; one fixed; both reactive)</td>
<td>4; 4; 11</td>
<td>7; 4; 0</td>
<td>0.003‡</td>
</tr>
<tr>
<td>Time elapsed to operation</td>
<td>622.4 ± 518.5 min</td>
<td>365.0 ± 366.6 min</td>
<td>0.084†</td>
</tr>
<tr>
<td>Brain CT midline shift</td>
<td>8.7 ± 5.8 mm</td>
<td>10.1 ± 4.4 mm</td>
<td>0.497†</td>
</tr>
<tr>
<td>Operation duration</td>
<td>139.6 ± 56.9 min</td>
<td>95.6 ± 44.3 min</td>
<td>0.033‡</td>
</tr>
</tbody>
</table>

CT = computed tomography, GCS = Glasgow Coma Scale, SD = standard deviation.
* Significant at p < 0.05.
† Fisher’s exact test.
‡ Mann–Whitney U-test.
a value of 1.0 at 60.5 mmHg, indicating that patients with CPP of greater than or equal to 60.5 mmHg had a favourable outcome. At a value of 52.0 mmHg, the sensitivity was 0.947 and the specificity was 0.818. At this point, the curve was farthest from the diagonal, indicating that this was a threshold value.

4. Discussion

The early values of ICP and CPP during neurosurgery for severe head injury are not well studied. This is primarily because the surgical team is concerned with the rapid removal of the haematoma, rather than placement of monitoring devices before clot evacuation. Of the ICP monitors placed intraoperatively, most are placed at the end of the surgery, and the first ICP measurement is not taken until after scalp closure or on arrival in the intensive care unit. However, the presence of an ICP monitor intraoperatively allows calculation of CPP (MAP–ICP), which may be important. Rosner and Daughton demonstrated the importance of maintaining adequate CPP in patients with head injuries in the intensive care unit, and it seems prudent to do so in the operating room as well.

In our study, the ICP monitor was inserted in the frontal lobe on the side of the lesion. The ICP, CPP and MAP were continuously measured during the procedure. We emphasize that surgical decompression in our patients was not delayed by our investigations: it takes less than 5 minutes to insert an ICP monitor.

The effects of decompressive craniectomy in patients with intracranial hypertension have been reported. However, most of these reports do not show the relationship between ICP, CPP and MAP during the entire operation. In our study, the results of these analyses demonstrated significant differences in the relationships between ICP, CPP and outcome at different stages of the operation. The ICP values in most patients decreased gradually from skull removal to dural opening, and reached the lowest level after evacuation of the haematoma in patients with both favourable and unfavourable outcomes. Simultaneously, the CPP progressively increased. These results show that decompressive craniectomy with clot removal is highly effective to treat intracranial hypertension, increasing CPP while decreasing ICP. Improvement in outcome by clot removal is intuitively related to timely correction of low CPP and high ICP, and our data confirm this supposition: 19 of 30 patients were discharged from the hospital with favourable outcomes.

In our study, although MAP did not statistically differ during surgery between patients with favourable and unfavourable outcomes, patients with favourable outcomes tended to have higher MAP. A possible mechanism for the low MAP might be the Cushing response after decompression, as initially high ICP occurred or there was inadequate fluid resuscitation during surgery. In 2003, Mahoney et al. demonstrated that isolated brain injury alone was sufficient to cause hypotension. Thus in our patients, another important explanation for low MAP might be brain injury itself. Hypotension is deleterious as it reduces oxygen and glucose delivery to the brain. When intraoperative hypotension does occur, it should be vigorously managed with fluids initially and pharmacologic support, if necessary, to effect expeditious reversal of low CPP.

**Fig. 1.** Intracranial pressure changes during surgery. *Significant at p < 0.05, Mann–Whitney U test.

**Fig. 2.** Mean arterial pressure changes during surgery.

**Fig. 3.** Cerebral perfusion pressure changes during surgery. *Significant at p < 0.05, Mann–Whitney U test.
We suggest that both surgeons and anaesthesiologists pay close attention to monitoring blood pressure throughout the early phase of care.

The ROC curve is a tool to evaluate the benefits of a procedure or to compare one procedure with another. Using the ROC curve, the diagnostic accuracy of a test is given by the area under the ROC curve and at the point on the curve farthest from the diagonal, which indicates the threshold value. In our study, the ROC curves showed that in the majority of cases, CPP was a better pre-
dictor of outcome because the curves lie above and to the left of the ICP, and the areas under the curves are greater in the different stages of surgery. This means that the CPP is more predictive of outcome than ICP at every stage of surgery and, therefore, must be closely monitored. The largest area under the CPP ROC curve was 0.943, found after scalp closure, suggesting that the CPP after scalp closure has the greatest accuracy for predicting outcome compared to other phases of the operative procedure. Based on these analyses, we emphasize that CPP plays a more important role in determining patient outcome than ICP does. However, the ICP is still a significant factor, because high ICP may lead to an unfavourable outcome.

Using the ROC curve, we found that if the CPP after scalp closure remained equal to or higher than 52.0 mmHg, this predicted a good outcome with a sensitivity of 0.947 and specificity of 0.818. At this point, the ROC curve was farthest from the diagonal, indicating that this is a threshold value. We found the intraoperative CPP threshold value to be 51.8 mmHg.

The aims of this study were to establish the early value of optimal CPP and ICP during surgery for severe traumatic brain injury. Prior this study, the optimal blood pressure and CPP to be maintained during general anaesthesia were unknown. Our results show that patients with CPP thresholds of 51.8 mmHg (intraoperative) and 52 mmHg (after scalp closure) have better outcomes. We want to emphasize again that both surgeons and anaesthesiologists must closely monitor blood pressure throughout this early phase of care in order to maintain optimal CPP. Although a value of 70 mmHg is suggested in the American Association of Neurological Surgeons Guidelines for the Management of Severe Head Injury as a minimum target level for CPP, it may be that favourable outcomes can be achieved at lower levels of CPP, as in our patients. One possible explanation for this might be the effects of inhalational general anaesthesia during surgery, which may have a protective effect on the brain through mechanisms such as metabolic depression, decreased cerebral oxygen consumption and inhibition neurotransmitter (glutamate) release. Additional evaluations, including intracerebral microdialysis, jugular venous oxygen saturation and brain tissue oxygen pressure are needed to clarify the metabolic requirements of the injured brain during surgery. A larger study will be necessary to confirm the accuracy of our estimates, and further experience is needed to determine the optimal CPP during operation for different types of haemorrhage in severe head injury.

5. Conclusions

We conclude that the initial ICP may be higher than suspected and CPP very low in patients with severe head injury, particularly those with unfavourable outcomes. Removal of the skull flap at surgery results in a significant reduction in ICP, which is further decreased by opening the dura and evacuating the haematoma. Simultaneously, the CPP increased stepwise. Based on ROC curve analyses, CPP is a better predictor of outcome than ICP. Our measured intraoperative CPP thresholds (initial of 37 mmHg, during surgery of 51.8 mmHg and at scalp closure of 52 mmHg) are lower than recommended postoperative CPP values in previously published articles.

References

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