Quantitative analysis of continuous intracranial pressure recordings in symptomatic patients with extracranial shunts

P K Eide


during the four year period from 1997 to 2001. Possible shunt related symptoms were defined as persistent symptoms indicating an abnormal ICP (intracranial hypertension or hypotension) in hydrocephalic cases with an extracranial shunt. Patient data and data about decision making at the time of ICP monitoring were derived from the patients' records.

During the four year period from 1997 to 2001, the total number of shunt revisions was 716 in this department (189 in 1997, 234 in 1998, 157 in 1999, and 136 in 2000). Thus the present sample of 69 cases represents a small proportion of the total number of extracranial shunt failures. In the present cases, the median number of shunt revisions undertaken before ICP monitoring was three, with a range from 0 to 16.

Study design
The study was in two parts. First, the outcome of management of shunt related symptoms by ICP monitoring was examined, using conventional methods of ICP assessment. Second, all ICP curves were analysed quantitatively to explore the ICP profile more accurately in the different management groups.

In the first part of the study, the 69 patients were divided into three management groups. Management was heavily based on results of continuous ICP monitoring. The three groups were as follows:

- Patients
- The study involved 69 consecutive cases undergoing continuous ICP monitoring because of suspected extracranial shunt failure during the four year period from February 1997 to March 2001.
- Possible shunt related symptoms were defined as persistent symptoms indicating an abnormal ICP (intracranial hypertension or hypotension) in hydrocephalic cases with an extracranial shunt. Patient data and data about decision making at the time of ICP monitoring were derived from the patients' records.
- During the four year period from 1997 to 2001, the total number of shunt revisions was 716 in this department (189 in 1997, 234 in 1998, 157 in 1999, and 136 in 2000). Thus the present sample of 69 cases represents a small proportion of the total number of extracranial shunt failures. In the present cases, the median number of shunt revisions undertaken before ICP monitoring was three, with a range from 0 to 16.

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In the first part of the study, the 69 patients were divided into three management groups. Management was heavily based on results of continuous ICP monitoring. The three groups were as follows:
• Group 1 included the 46 patients in whom the ICP recordings were considered normal, and no treatment was given.
• Group 2 included the 14 patients in whom the ICP recordings were considered abnormally reduced. In these cases action was taken to prevent overdrainage and to increase ICP (that is, by implantation of an antisiphon device and valve replacement in seven cases, and by valve replacement only in the other seven).
• Group 3 included the nine patients in whom the ICP recordings were considered abnormally increased. In these cases action was taken to reduce the ICP (that is, by calvarial expansion surgery in three cases, by ventricular catheter replacement in four cases, and by valve replacement in two cases).

At the time of ICP monitoring, the assessment of ICP was according to the following criteria. A mean ICP below 10 mm Hg was considered normal, between 10 and 15 mm Hg borderline, and above 15 mm Hg abnormal, as previously described.\(^{1,2}\) In addition, a visual inspection of the ICP curve for the detection of plateau waves\(^{3}\) was done. In this department, rises above 50 mm Hg lasting for several minutes have been considered as plateau (A) waves. The significance of rises in ICP between 20 and 50 mm Hg of short durations (0.5 to 1 minute, corresponding to B waves) have been unclear, with no strict criteria about what might be considered abnormal.

In the second part of the study, all continuous ICP recordings were analysed quantitatively. This was done to explore the ICP profile in the various management groups. The quantitative analysis was performed after the end of patient management, as the software was not available at the time of the ICP monitoring.

**Sampling and storage of intracranial pressure and software description**

The methods and equipment used for digital sampling and storage of continuous ICP recordings have been described previously.\(^{3,5,6}\) A minimal opening was made in the dura and a Codman\(^\text{®}\) pressure sensor (MicroSensor\(^\text{™}\) Johnson & Johnson, Raynham, Massachusetts, USA) was introduced into the brain parenchyma. The pressure sensor was coupled to a Codman pressure analyser apparatus (Codman ICP Express\(^\text{™}\) Johnson & Johnson), which in turn was coupled to a Siemens 9000 XL series vital signs monitor (Siemens Medical Systems Inc, Danvers, Massachusetts, USA). The ICP signals were digitised in the Siemens 9000 XL monitor and sampled at five second intervals (EWICUM streamer reader tool, Evicum AS, Oslo, Norway). The software was developed using LabVIEW version 5.0 (National Instruments Co, Texas, USA).

The software used for quantitative analysis of the ICP data (Sensometrics\(^\text{™}\) pressure analyser, version 1.2; Sensometrics AS, Oslo, Norway) has been described previously in detail.\(^{5,7}\) This software was also developed using LabVIEW (version 5.1). The calculation of numbers of ICP elevations of different levels and durations was done using the peak detection function. The data required for analysis include the ICP recordings as well as the width (time expressed in seconds) and threshold levels (ICP expressed in mm Hg). After the ICP curve was visualised in the user interface, a suitable width/threshold matrix was selected, specifying the width/threshold combinations. In this study, the software recorded the numbers of samples that fitted a given combination of width (0.5, 1, or 5 minutes) and thresholds (–10, –5, 20, 25, 30, or 35 mm Hg). The output from the analysis was a matrix containing the numbers of the different width and threshold combinations. As the actual ICP recording period during sleep or in the awake state varied between cases, calculation of width/threshold combinations during a standardised recording time of 10 hours was undertaken. During the awake state the patient was allowed to sit or stand up.

**Statistics**

The data calculated by the software were saved as ASCII (American standard code for information interchange) files, and transferred to Microsoft Excel version 97 for statistical analysis. The computer program PC-SPSS, version 9.0 (SPSS Inc, Chicago, Illinois, USA) performed the statistical analysis. Non-parametric tests were used. Comparisons between two independent samples were done by the Mann–Whitney test. Comparisons were only done when there were eight or more patients in each group. Two tailed probability (p) values were calculated.

**RESULTS**

Management and outcome of shunt failure at the time of ICP monitoring

As indicated in table 1, in the 69 patients with persistent putative shunt related symptoms, ICP was considered normal in 46 cases (group 1), abnormally low in 14 cases (group 2), and abnormally increased in nine cases (group 3). In groups 1 and 2, mean ICP during sleep was either normal (< 10.0 mm Hg) or borderline (10.0 to 15.0 mm Hg). In group 3, mean ICP during sleep was either considered borderline or abnormally increased (> 15.0 mm Hg). Visual inspection of the ICP curves showed no plateau (A) waves of 50 mm Hg lasting several minutes. The frequency of B waves also contributed to the diagnosis; however, B wave assessment is observer dependent and was not systematically evaluated.

The continuous ICP recordings had a low predictive value for patient management. Elevated ICP was suspected in 45 of the 69 cases (65%), but was considered as confirmed in only 73%. Too low ICP was suspected in 24 cases (35%), but was considered as confirmed in only 10. After a median observation time of 12 months (range 1 to 37 months), persistent symptoms were observed in as many as 40 of the 69 cases (58%)—in 65% of the cases in group 1 and in 57% in group 2.

Complications of ICP monitoring were observed in three of the 69 cases (4.4%). In a 12 month old boy, ICP monitoring caused meningitis which was treated with systemic antibiotics and external ventricular drainage. The treatment was ended after two weeks and a new ventriculo-peritoneal shunt inserted. The boy has not required any further shunt revisions over the observation period of 12 months. In a 13 year old boy, a local wound infection developed that required a local treatment for some days. In a 10 year old girl, a signal change was observed on computed tomography (CT) at the site of the ICP sensor. There was no evidence of haemorrhage and this finding was not associated with symptoms.

Linear measures of ventricular size by cranial CT revealed no differences in ventricular size between the different management groups.

**Retrospective quantitative analysis of the continuous ICP recordings**

The quantitative analysis of the ICP recordings was done retrospectively. Examples are given in figs 1 to 3. Figure 1 shows the ICP curves of two cases in group 1, both with a mean ICP below 12.0 mm Hg. Quantitative analysis revealed a rather high frequency of ICP elevations. Symptoms remained unchanged in both cases.

Figure 2 shows the ICP curves during the awake state of two cases with a low mean ICP. Though mean ICP was comparable in these two cases (2.2 ± 1.7 mm Hg), the qualitative analysis showed a large number of ICP depressions in case B (24 episodes of ICP > 5 mm Hg lasting five minutes or more during a standardised recording time of 10 hours). In this case, the ICP was considered normal, no action was taken, and symptoms remained unchanged.

Figure 3 shows the ICP recordings during the awake state of two cases of group 1, in whom mean ICP was 2.1 and 9.4 mm
The matrix shows both a large number of ICP elevations above 20 mm Hg and a large number of ICP depressions below −5 mm Hg.

Comparisons of numbers of ICP elevations between the different management groups are presented in table 2. The most important observation was that a rather high frequency of ICP elevations of 20 to 35 mm Hg lasting 0.5 to 1 minute was found in the cases in group 1. This trend was more obvious during sleep than during the awake state. For example, in group 1 during sleep, ICP elevations of 25 mm Hg lasting one minute occurred in 22 of the 46 cases (48%).

Comparisons of ICP depressions between the different management groups are presented in table 3. The major observation is that reductions in ICP of −10 to −5 mm Hg lasting 0.5, 1, or 5 minutes were quite frequent in group 1. For example, during the awake state, depressions in ICP of −5 mm Hg lasting one minute occurred in 15 of the 46 cases (33%) in group 1. Depressions of ICP occurred more commonly during the awake state than during sleep, owing to the fact that the patients were sitting or standing up during the awake state.

The frequency of ICP depressions was explored in comparable patient material, including 135 cases undergoing ICP monitoring for suspected craniosynostosis or hydrocephalus (unpublished data). None of the cases had an extracranial shunt. The numbers of ICP depressions during a standardised recording period of 10 hours during the awake state were as follows:

- n (−5 mm Hg/0.5 min) = 16 (11.9%); median number of depressions, 2 (range 1 to 7);
- n (−5 mm Hg/1.0 min) = 9 (6.7%); median number of depressions, 1 (range 1 to 5);
- n (−5 mm Hg/5 min) = 1 (0.7%); median number of depressions, 1 (range 1 to 1).

Comparisons of ICP depressions of −5 mm Hg between this group of 135 cases and the cases in group 1 showed significant differences in the numbers of depressions lasting 0.5 minutes (p = 0.002) or 1 minute (p = 0.001) (Mann–Whitney test).

DISCUSSION

Continuous ICP monitoring in cases with shunt related symptoms

In hydrocephalic cases treated with extracranial shunts, persistent symptoms of abnormal intracranial pressure may sometimes indicate shunt failure. Several investigators have shown previously that symptoms indicating extracranial

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### Table 1 Demographic and clinical data at the time of intracranial pressure monitoring

<table>
<thead>
<tr>
<th></th>
<th>Total</th>
<th>Group 1</th>
<th>Group 2</th>
<th>Group 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total number of patients</td>
<td>69</td>
<td>46</td>
<td>14</td>
<td>9</td>
</tr>
<tr>
<td>Male/female</td>
<td>40/29</td>
<td>29/17</td>
<td>7/7</td>
<td>4/5</td>
</tr>
<tr>
<td>Age (months) at ICP monitoring</td>
<td>66 (12 to 358)</td>
<td>65 (12 to 358)</td>
<td>93 (20 to 255)</td>
<td>46 (21 to 234)</td>
</tr>
<tr>
<td>Clinical symptoms before ICP monitoring</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Headache</td>
<td>41 (59)</td>
<td>26 (57)</td>
<td>9 (64)</td>
<td>6 (67)</td>
</tr>
<tr>
<td>Irritability</td>
<td>29 (42)</td>
<td>21 (46)</td>
<td>4 (29)</td>
<td>4 (44)</td>
</tr>
<tr>
<td>Nausea</td>
<td>19 (28)</td>
<td>10 (22)</td>
<td>3 (21)</td>
<td>6 (67)</td>
</tr>
<tr>
<td>Lethargy</td>
<td>24 (35)</td>
<td>18 (39)</td>
<td>3 (21)</td>
<td>3 (33)</td>
</tr>
<tr>
<td>Epileptic seizures</td>
<td>9 (13)</td>
<td>5 (11)</td>
<td>3 (21)</td>
<td>1 (11)</td>
</tr>
<tr>
<td>Positional symptoms</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Relief by lying down</td>
<td>15 (22)</td>
<td>7 (15)</td>
<td>7 (50)</td>
<td>1 (11)</td>
</tr>
<tr>
<td>Relief by sitting up</td>
<td>7 (10)</td>
<td>5 (11)</td>
<td>2 (14)</td>
<td></td>
</tr>
<tr>
<td>Worsening by lying down</td>
<td>5 (7)</td>
<td>3 (7)</td>
<td>2 (14)</td>
<td></td>
</tr>
<tr>
<td>Worsening by sitting up</td>
<td>5 (7)</td>
<td>1 (2)</td>
<td>4 (29)</td>
<td></td>
</tr>
<tr>
<td>Day and night variation in symptoms</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Worst in the morning</td>
<td>5 (7)</td>
<td>3 (7)</td>
<td>2 (22)</td>
<td></td>
</tr>
<tr>
<td>Worst in the evening</td>
<td>5 (7)</td>
<td>2 (4)</td>
<td>2 (14)</td>
<td>1 (11)</td>
</tr>
<tr>
<td>Worst in the night</td>
<td>6 (9)</td>
<td>5 (11)</td>
<td>1 (11)</td>
<td></td>
</tr>
<tr>
<td>Clinical indications for ICP monitoring</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Clinically suspected increased ICP</td>
<td>45 (65)</td>
<td>33 (72)</td>
<td>4 (29)</td>
<td>8 (89)</td>
</tr>
<tr>
<td>Clinically suspected reduced ICP</td>
<td>24 (35)</td>
<td>13 (28)</td>
<td>10 (71)</td>
<td>1 (11)</td>
</tr>
<tr>
<td>Mean ICP during sleep</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt;10.0 mm Hg</td>
<td>37 (54)</td>
<td>24 (52)</td>
<td>13 (93)</td>
<td></td>
</tr>
<tr>
<td>10.0 to 15.0 mm Hg</td>
<td>28 (41)</td>
<td>22 (48)</td>
<td>1 (7)</td>
<td>5 (56)</td>
</tr>
<tr>
<td>&gt;15.0 mm Hg</td>
<td>4 (6)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean ICP during the awake state</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt;10.0 mm Hg</td>
<td>56 (81)</td>
<td>41 (89)</td>
<td>13 (93)</td>
<td>2 (22)</td>
</tr>
<tr>
<td>10.0 to 15.0 mm Hg</td>
<td>8 (12)</td>
<td>5 (11)</td>
<td>1 (7)</td>
<td>2 (22)</td>
</tr>
<tr>
<td>&gt;15.0 mm Hg</td>
<td>5 (7)</td>
<td></td>
<td></td>
<td>5 (56)</td>
</tr>
<tr>
<td>Outcome after management</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Relief of symptoms</td>
<td>29 (42)</td>
<td>16 (35)</td>
<td>6 (43)</td>
<td>7 (78)</td>
</tr>
<tr>
<td>Lasting and unchanged symptoms</td>
<td>40 (58)</td>
<td>30 (65)</td>
<td>8 (57)</td>
<td>2 (22)</td>
</tr>
</tbody>
</table>

Data presented as absolute numbers. The percentages are given in parenthesis and represent the proportions of numbers within each group.

ICP, intracranial pressure.

Group 1, “normal” mean ICP; group 2, “low” mean ICP; group 3, “high” mean ICP.
Shunt failure (headache, irritability, nausea, vomiting, and lethargy) may result from different underlying causes. The authors suggested a role for ICP monitoring in patients with shunt failure, though the numbers of patients in their studies were quite small. The first part of the present study, however, did not suggest a particularly useful role for ICP monitoring in extracranial shunt failure. Among the 69 patients, symptoms remained unchanged in 58% despite using ICP monitoring. In the 46 patients whose ICP was considered normal (group 1), symptoms remained unchanged in 65%; the percentages were 57% and 22% in groups 2 and 3, respectively.

The patients in this study with putative shunt related symptoms represent a small subgroup of shunt failure patients. In most cases shunt failure is straightforward to diagnose on the basis of symptoms and radiological findings. During the period when the present cases were tested, 716 shunt revisions were done in the same department. There could be several reasons for the high frequency of persistent symptoms despite the use of ICP monitoring. First, symptoms might not be related to shunt malfunction in some cases. In general, invasive and in vivo testing of the hydrodynamic properties of the shunt may be required to test whether symptoms suggestive of shunt malfunction are in fact due to...
However, as this approach is not available in most departments, the clinical diagnosis of shunt malfunction commonly relies on symptoms with or without radiological findings. In the patients reported here, the symptoms were persistent and considered to be related to shunt malfunction by both the doctor and the patients or the patients’ parents.

Second, the patient population was heterogeneous. Different types of shunt dysfunction were probably involved. It seems difficult to relate symptoms to a particular type of shunt failure. However, in group 3 the assumed intracranial hypertension was treated with calvarial expansion surgery in three cases, ventricular catheter replacement in four, and valve replacement in two. Symptoms remained unchanged in fewer than one quarter of these cases. In group 2, on the other hand, the assumed intracranial hypotension was treated with implantation of an antisiphon device and valve replacement in seven cases and valve replacement only in the other seven, and the symptoms remained unchanged in two thirds of those cases.

The observation of a high frequency of persistent symptoms raises the question of whether ICP monitoring is ethically justified in these cases. Continuous ICP monitoring is accompanied by a small but definite risk. In this study, complications were observed in three of the 69 cases (4.4%), though no long

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### Table 2

Comparison of intracranial pressure elevations of different levels and durations in the different groups of patients

<table>
<thead>
<tr>
<th>Duration of ICP elevations</th>
<th>Level of ICP elevations</th>
<th>Management groups</th>
<th>Group 1</th>
<th>Group 2</th>
<th>Group 3</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>20 mm Hg</td>
<td>25 mm Hg</td>
<td>30 mm Hg</td>
<td>35 mm Hg</td>
<td></td>
</tr>
<tr>
<td>0.5 min</td>
<td>N (%)</td>
<td>Median (range)</td>
<td>N (%)</td>
<td>Median (range)</td>
<td>N (%)</td>
</tr>
<tr>
<td>Sleep state</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Group 1</td>
<td>33 (72)</td>
<td>22 (1 to 121)</td>
<td>27 (59)</td>
<td>7 (1 to 64)</td>
<td>20 (43)</td>
</tr>
<tr>
<td>Group 2</td>
<td>5 (36)</td>
<td>2 (1 to 25)</td>
<td>2 (14)</td>
<td>4 (2 to 5)</td>
<td>2 (14)</td>
</tr>
<tr>
<td>Group 3</td>
<td>9 (100)</td>
<td>186 (15 to 765)</td>
<td>8 (89)</td>
<td>107 (1 to 233)</td>
<td>8 (89)</td>
</tr>
<tr>
<td>1 min</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Group 1</td>
<td>30 (65)</td>
<td>15 (1 to 79)</td>
<td>22 (48)</td>
<td>6 (1 to 36)</td>
<td>17 (37)</td>
</tr>
<tr>
<td>Group 2</td>
<td>3 (21)</td>
<td>4 (1 to 15)</td>
<td>1 (3)</td>
<td>3 (3 to 3)</td>
<td>1 (1)</td>
</tr>
<tr>
<td>Group 3</td>
<td>9 (100)</td>
<td>86 (2 to 560)</td>
<td>8 (89)</td>
<td>55 (1 to 148)</td>
<td>7 (78)</td>
</tr>
<tr>
<td>Awoke state</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.5 min</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Group 1</td>
<td>30 (65)</td>
<td>10 (1 to 166)</td>
<td>21 (46)</td>
<td>8 (1 to 92)</td>
<td>12 (26)</td>
</tr>
<tr>
<td>Group 2</td>
<td>5 (36)</td>
<td>5 (2 to 58)</td>
<td>3 (21)</td>
<td>3 (3 to 40)</td>
<td>3 (21)</td>
</tr>
<tr>
<td>Group 3</td>
<td>9 (100)</td>
<td>232 (20 to 684)</td>
<td>9 (100)</td>
<td>57 (5 to 296)</td>
<td>6 (67)</td>
</tr>
<tr>
<td>1 min</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Group 1</td>
<td>22 (48)</td>
<td>10 (1 to 107)</td>
<td>13 (28)</td>
<td>7 (1 to 55)</td>
<td>10 (22)</td>
</tr>
<tr>
<td>Group 2</td>
<td>3 (21)</td>
<td>10 (1 to 33)</td>
<td>2 (14)</td>
<td>10 (1 to 19)</td>
<td>1 (10)</td>
</tr>
<tr>
<td>Group 3</td>
<td>9 (100)</td>
<td>140 (12 to 422)</td>
<td>9 (100)</td>
<td>27 (2 to 174)</td>
<td>5 (56)</td>
</tr>
</tbody>
</table>

Percentages of cases within each group presented in parentheses. Numbers of ICP elevations during a standardised recording time of 10 hours presented as median numbers with ranges in parentheses.

*p < 0.05; †p < 0.01; ‡p < 0.005; §p < 0.001 (Mann–Whitney test).

ICP, intracranial pressure.

Group 1, “normal” mean ICP; group 2, “low” mean ICP; group 3, “high” mean ICP.

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This Figure 3 Intracranial pressure (ICP) curves during the awake state for two cases in group 1. To the left is the ICP curve of a 3 year, 5 month old boy with irritability, transient abducens paresis, and nausea (case A). To the right is the ICP curve of a 4 year, 1 month old boy with headache and lethargy (case B). Mean ICP was 2.1 mm Hg in case A and 9.4 mm Hg in case B. The corresponding matrix presents the numbers of ICP elevations (20 to 35 mm Hg) and depressions (−10 to −5 mm Hg) lasting 0.5, 1.0, or 5.0 minutes during a standardised recording time of 10 hours.
that a high frequency of the short lasting ICP elevations may
compute of short lasting ICP elevations (20 to 35 mm Hg,
normal differ markedly in published reports.
quantify, as reflected by the fact that frequencies considered
described recently.
limitations with current strategies of ICP assessment.
In the second part of the study, all ICP curves were analysed
cases (group 1). However, symptoms remained unchanged in
dependent. Thus continuous ICP monitoring using conven-
waves by visual inspection of the curves is observer
frequency was undertaken, as the observers found it difficult
approaches. As many as 94% of the cases in this study had
mean ICP combined with a visual inspection of the curves to
plateau waves. Similar criteria to those used by
others... were employed to assess the mean ICP. The crite-
reria for the various plateau waves remain problematic.
Contrasting with the original description by Lundberg,... type A
plateau waves are described by most investigators as pressure
elevations of 50 mm Hg lasting for more than five minutes. Type B waves are increases in ICP of up to 50 mm Hg lasting for
0.5 to 2 minutes. However, these waves have been difficult to
quantify, as reflected by the fact that frequencies considered
normal differ markedly in published reports.
The present results highlight some problems with these
approaches. As many as 94% of the cases in this study had
either a normal ICP (≤10 mm Hg) or a borderline (10–15 mm Hg)
mean ICP, and no classical A waves were observed. At the time
of ICP monitoring, no systematic determination of B wave
frequency was undertaken, as the observers found it difficult
to define the frequency of these waves. The determination of B
waves by visual inspection of the curves is observer
dependent. Thus continuous ICP monitoring using conven-
tional criteria often turned out to be inconclusive. At the time
of monitoring, the ICP was considered normal in 46 of 69
cases (group 1). However, symptoms remained unchanged in
40 of the 69 cases.

Retrospective quantitative assessment of continuous ICP
recordings
In the second part of the study, all ICP curves were analysed
quantitatively in order to reveal potential methodological
limitations with current strategies of ICP assessment.
The quantitative analysis of ICP presented here has been
described recently. In this study, calculation of the numbers of ICP
elevations of 20 to 35 mm Hg lasting 0.5 to 1 minute during a standardised recording time of 10 hours allowed objective and accurate comparisons between patients. The most important observation was a high frequency of ICP
elevations of 20 to 35 mm Hg lasting 0.5 or 1 minute in the
cases in group 1. Patients in this group were considered to
have a normal ICP at the time of ICP monitoring. The frequency of ICP elevations in group 1 was comparable with the frequencies found in cases with hydrocephalus. The computation of short lasting ICP elevations (20 to 35 mm Hg,
lasting 0.5 to 1 minute) may be comparable to the
computation of B wave frequency. A tentative hypothesis is
that a high frequency of the short lasting ICP elevations may
indicate intracranial hypertension, even though baseline or
mean ICP remains within normal limits. However, the normal
frequency and distribution of ICP elevations is not known. Thus it is not possible to conclude whether the frequency of ICP elevations in the different treatment groups was more
than or less than normal. The present numbers should be
compared with the numbers of ICP elevations in asympto-
nic patients with shunts, but such material does not exist.
This paper also focuses on another aspect of variation in ICP,
namely the so called ICP depressions. The term ICP depressions refers to potentially abnormal reductions in ICP. Reduced ICP because of overdrainage is a well known problem
in patients with extracranial shunts. Abnormal ICP reductions
in such patients have been described previously. These reductions depend on body position and are most evident in
the standing position. Accordingly, the frequency of ICP
depressions was greatest during the awake state, when the
patients were allowed to sit or stand, resulting in lowered ICP
because of increased drainage of cerebrospinal fluid.
At present, the normal frequency of ICP depressions of –10
and –5 mm Hg lasting for 0.5, 1, or 5 minutes is not
established. In an unpublished sample of 135 cases, the
percentage of ICP depressions of –5 mm Hg lasting 0.5, 1, or 5
minutes during 10 hours of recording were 11.9%, 6.7%, and
0.7%, respectively. These figures show that ICP depressions are
more common in shunted than in non-shunted patients. For
example, ICP depressions of –5 mm Hg lasting five minutes
occurred in 29% of the shunted patients in the present study,
as compared with 0.7% of the 135 non-shunted patients.
Furthermore, in the patients with an ICP considered acceptable at
the time of monitoring (group 1), the percentage of
ICP depressions of –5 mm Hg lasting five minutes was 24%. In
fact, the frequency of ICP depressions of –5 or –10 mm Hg
lasting one to five minutes was not significantly different
between cases in groups 1 and 2. It seems reasonable to
speculate that the high frequency of ICP depressions in group
1 results from non-recognised overdrainage in some cases.
Based on the present data, it may be hypothesised that
computation of numbers of ICP elevations and depressions
may provide a more accurate description of the ICP curve than
the more conventional assessment strategies. However, this
hypothesis must be tested in a prospective study. Based on the
present data it is not possible to conclude whether patient
management would have been more successful if ICP had
been analysed using the quantitative method compared with
the conventional method.

Conclusions
In patients with possible shunt related symptoms, symptoms
were persistent in a significant proportion of cases despite the
use of ICP monitoring. The inadequacy of ICP monitoring in

Table 3
Comparison of intracranial pressure depressions of different levels and durations in the different groups of
patients

<table>
<thead>
<tr>
<th>Duration of ICP elevations</th>
<th>Management criteria</th>
<th>Awake state</th>
<th>Asleep state</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N (%)</td>
<td>Median (range)</td>
<td>N (%)</td>
</tr>
<tr>
<td>0.5 min Group 1</td>
<td>10 (22)</td>
<td>11 (1 to 25)*</td>
<td>21 (44)</td>
</tr>
<tr>
<td>Group 2</td>
<td>6 (43)</td>
<td>63 (10 to 803)</td>
<td>10 (71)</td>
</tr>
<tr>
<td>1 min Group 1</td>
<td>7 (15)</td>
<td>8 (1 to 149)</td>
<td>15 (33)</td>
</tr>
<tr>
<td>Group 2</td>
<td>6 (43)</td>
<td>32 (4 to 509)</td>
<td>9 (64)</td>
</tr>
<tr>
<td>5 min Group 1</td>
<td>3 (14)</td>
<td>13 (1 to 50)</td>
<td>11 (24)</td>
</tr>
<tr>
<td>Group 2</td>
<td>9 (64)</td>
<td>30 (3 to 137)</td>
<td>9 (64)</td>
</tr>
</tbody>
</table>

Numbers of ICP reductions during a standardised recording time of 10 hours presented as median numbers with ranges in parentheses.
*p < 0.05 (Mann-Whitney test). No ICP reductions in group 3.
ICP, intracranial pressure.
Group 1, “normal” mean ICP; group 2, “low” mean ICP; group 3, “high” mean ICP.
the management of extracranial shunt failure may be related to the current strategies of assessing ICP. In cases where ICP is considered normal at the time of monitoring, a rather high frequency of short lasting ICP elevations and depressions was found. However, the role of quantitative ICP analysis in the management of shunt failure needs to be explored in a prospective study.

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Quantitative analysis of continuous intracranial pressure recordings in symptomatic patients with extracranial shunts

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J Neurol Neurosurg Psychiatry 2003 74: 231-237
doi: 10.1136/jnnp.74.2.231

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