Measurement of Intracranial Pressure via the Anterior Fontanelle in Infants with Hydrocephalus

—Special observations on the operative indications and pathophysiology of Infantile hydrocephalus—

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Summary: A miniaturized paper strain gauge transducer was developed which atraumatically and continuously monitored intracranial pressure via the anterior fontanelle of newborn infants. Using this equipment, six infants with hydrocephalus were prospectively studied to relate the change in ICP during sleep with clinical symptoms, head circumference, ventricular size by CT-scan, CSF dynamics and development. In the first group, the pulse wave amplitude increased with age and no B-type waves were observed during non-REM sleep. These patients were observed prospectively without surgical intervention, because they seemed to have an arrested hydrocephalus. In the second group, the pulse wave amplitude was extremery low and there was little increase in amplitude with age during non-REM sleep. The frequent appearance of B-type waves was demonstrated. These patients were considered to have a compensated hydrocephalus and a V-P shunting operation was performed in both of them. In the third group, the pulse wave amplitude increased with age, and a B-type wave was frequently identified during non-REM sleep. A plateau type wave was identified with a pressure more than 250 mmH2O, approximately equal to 310 mmH2O, from the serial measurement of ICP during REM sleep. There was a progression of the ventriculomegaly and a disproportionate increase in head circumference developed. Continuous atraumatic measurement of ICP during sleep may be quite useful for assessing the reserve capacity of the intracranial space in hydrocephalic infants and for determining whether a shunt should be implanted.

Key words: Intracranial pressure—pressure wave—pulse wave—Hydrocephalus fontanelle—prematures

Introduction

In hydrocephalic infants whose symptoms appear arrested, it is often difficult to decide whether to implant a shunt. A miniaturized paper strain gauge transducer has been developed recently which can atraumatically and continuously monitor intracranial pressure (ICP) of newborns and infants via the anterior fontanelle (Hayashi et al 1975, Honda, 1982).

The purpose of the present prospective study was to investigate the changes in ICP during rapid eye movement (REM) sleep and non-rapid eye movement (non-REM) sleep, and to describe the clinical
symptoms, head circumference, ventricular size by CT-scan, CSF dynamics and developmental milestones of the hydrocephalic infants.

**Materials and Methods**

The ICP during sleep was observed in six infants with hydrocephalus. Four of the infants had congenital hydrocephalus and two had postmeningitic hydrocephalus (Table 1). A paper strain gauge transducer was connected to the anterior fontanelle and fixed by a guide ring with three foot points which were attached to the scalp around the anterior fontanelle. A detailed description of the method has been published elsewhere (Hond, 1982). The ICP was continuously monitored for 3 to 4 hours, and oscillographic records were obtained from all patients. To determine the stage of sleep, that is, REM sleep or non-REM sleep, electroencephalograms (EEG), electromyograms (EMG) and electro-oculograms (EOG) were intermittently recorded, simultaneous with the ICP recording.

All the patients were reviewed with respect to clinical symptoms, head circumference and ventricular size by CT-scan. Studies of CSF dynamics by RI-cisternography were performed five times on four of the cases. The length of follow up ranged from 10 to 34 months and their development was evaluated by Tsumori’s method (1978, 1980). They were divided into three developmental groups i.e., normal with a score greater than 80, borderline with a score of 70 to 79, impaired with a score less than 69. The ICPs of a control group of five normal infants from 2 to 6 months of age were monitored using the same method.

**Results**

The ICPs of the five normal infants from 2 to 6 months of age are shown in Fig. 1. During non-REM sleep the ICP of all infants was less than 150 mmHgO. The ICP remained at 110 mmHgO, but the cerebral pulse wave amplitude ranged from 30 to 40 mmHgO at the age of 2 months and from 50 to 70 mmHgO at 6 months of age, demonstrating an increase in cerebral pulse wave amplitude with age (Fig. 1).

All the normal infants had an ICP during REM sleep with both plateau waves and spiky sharp waves (B waves) as described by Lundberg (1960). In a 6 month old infant, the peak value of the plateau wave was as high as 180 mmHgO, and the pulse wave amplitude increased to almost 100 mmHgO. This suggested that in normal infants the ICP remained less than 200 mmHgO during sleep, and the pulse wave amplitude increased with age.

The ICP measurements via the anterior fontanelle were performed a total of 43 times on six hydrocephalic infants, 36 preoperatively and 7 postoperatively.

These patients were classified into three groups according to the presence of a B wave, the pulse wave amplitude during non-REM sleep, and the eight of the plateau wave during REM sleep (Table 1). There was a good correlation between the ICP results and the clinical manifestations.

The first group consisted of two patients, one with postmeningitic hydrocephalus and the other with congenital hydrocephalus. Both were clinically arrested as indicated by normal increases in head circumference (Fig. 4). A mild ventriculomegaly was demonstrated on the CT-scan in each patient. The CSF flow was abnormal in the patient with postmeningitic hydrocephalus (Fig. 5). This infant appeared to partially resolve the ventricular size on the CT scan (Fig. 3) and normalize the CSF circulation by the age of 13 months (Fig. 5). There was no abnormality of CSF flow in the infant with congenital hydrocephalus. Neither infant demonstrated psychomotor retardation.
TABLE 1
Clinical summary of 6 cases of hydrocephalic infants

<table>
<thead>
<tr>
<th>Group</th>
<th>No.</th>
<th>Name</th>
<th>Age</th>
<th>Sex</th>
<th>Nature</th>
<th>Operation</th>
<th>Follow up</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>M. F.</td>
<td>3M</td>
<td>F</td>
<td>Postmeningitic H.</td>
<td>(−)</td>
<td>29M</td>
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<tr>
<td></td>
<td>2</td>
<td>T. K.</td>
<td>1 day</td>
<td>M</td>
<td>Congenital H.</td>
<td>(−)</td>
<td>10M</td>
</tr>
<tr>
<td>2</td>
<td>3</td>
<td>Y. I.</td>
<td>4M</td>
<td>M</td>
<td>Postmeningitic H.</td>
<td>V-P shunt</td>
<td>28M</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>K. K.</td>
<td>5M</td>
<td>M</td>
<td>Congenital H.</td>
<td>V-P shunt</td>
<td>28M</td>
</tr>
<tr>
<td>3</td>
<td>5</td>
<td>K. A.</td>
<td>1M</td>
<td>F</td>
<td>Congenital H.</td>
<td>V-P shunt</td>
<td>34M</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>Y. I.</td>
<td>1M</td>
<td>F</td>
<td>Congenital H.</td>
<td>(−)</td>
<td>30M</td>
</tr>
</tbody>
</table>

ICP Via Fontanelle
Normal Infants

AGE                NON-REM PERIOD            REM PERIOD

2M

25M

25M

3M

6M

Fig. 1.
<table>
<thead>
<tr>
<th>AGE</th>
<th>Non-REM Period</th>
<th>REM Period</th>
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</thead>
<tbody>
<tr>
<td>7 Days</td>
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</tr>
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</tr>
<tr>
<td>1 M</td>
<td></td>
<td></td>
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<tr>
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<td></td>
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<tr>
<td>2 M</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7 M</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Fig. 2.

ICP Via Fontanelle

<table>
<thead>
<tr>
<th>AGE</th>
<th>Non-REM Period</th>
<th>REM Period</th>
</tr>
</thead>
<tbody>
<tr>
<td>35 M</td>
<td></td>
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</tr>
<tr>
<td>4 M</td>
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</tr>
<tr>
<td>5 M</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6 M</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7 M</td>
<td></td>
<td></td>
</tr>
<tr>
<td>11 M</td>
<td></td>
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</tr>
</tbody>
</table>

Fig. 3.
GROUP 1

Head circumference

Fig. 4.

Fig. 5.
Preoperative ICP Via Fontanelle

Fig. 6.

Fig. 7.
In the infant with congenital hydrocephalus, as shown in Fig. 2, the ICP was periodically monitored from seven days of age to seven months of age. The ICP during non-REM sleep in this patient ranged from 120 to 150 mmH2O; and at the same time, the pulse wave amplitude was 20 mmH2O at the age of 6 days, 30 mmH2O at 1.5 months of age, and 60 mmH2O at the age of 7 months. It was clear that the pulse wave amplitude increased with age. Rarely there was a rapid change in ICP, like a B wave, during non-REM sleep (Fig. 2, 3). But during REM sleep, plateau type pressure waves were identified, intermittently mixed with B waves. The ICP was less than 220-230 mmH2O and did not increase to more than 250 mmH2O (Fig. 2, 3).

The two patients in the first group have been followed, without surgical intervention, because their hydrocephalus was considered to be arrested.

The second group also consisted of two infants, one with congenital hydrocephalus. Both were severely impaired as indicated by the scores of 25 and 32 in development and head circumferences (Fig. 7). The other infant with postmeningitic hydrocephalus had no change in moderate ventriculomegaly by a serial CT-scan, as shown in Fig. 6. A CSF flow study in this infant demonstrated a ventricular reflex and a delayed clearance (Fig. 8) without any sign or symptom of intracranial hypertension.

Characteristic ICPs are shown in Fig. 6. The ICP was as high as 180 mmH2O during non-REM sleep, but the pulse wave amplitude remained as low as 5 mmH2O at the age of 4 to 6.5 months. The pulse wave amplitude did not appear to increase with age.

During REM sleep, the plateau wave was less than 250 mmH2O during subsequent measurements of the ICP (Fig. 6). This data suggested that the brain of these two infants had already been impaired and relevant surgical intervention was necessary. Both underwent a V-P shunting operation and the infant with congenital hydrocephalus improved somewhat when evaluated 24 months after the operation.
Fig. 9-1.

ICP Via Fontanelle

AGE

NON-REM PERIOD

REM PERIOD

1 M

2 M

5 M

7 M

Fig. 9-2.

ICP Via Fontanelle

AGE

NON-REM PERIOD

REM PERIOD

7 M

8 M

9 M

10 M

11 M

13 M

CT scan
The third group consisted of two infants with congenital hydrocephalus (Table 1). In one of the two infants, the ICP during non-REM sleep was almost always at 150 mmH₂O, and the pulse wave amplitude was near 40 mmH₂O when the patient was five months old. Subsequently, the pulse wave amplitude increased to 100 mmH₂O at the age of eight months. The same data from ICPs was obtained in the other infant during non-REM sleep.

During REM sleep, the value of the plateau pressure wave remained approximately 240-250 mmH₂O until the patients were 5 and 7 months old. Then it increased to more than 250 mmH₂O at the age of eight months and was almost 310 mmH₂O at the age of ten months (Fig. 9).

No sign or symptom of increased intracranial pressure was noticed in either infant and it was obvious that both of the infants in the third group had progressive hydrocephalus. A ventriculo-peritoneal shunt was inserted into one infant with the consent of the family.

**Discussion**

It is generally accepted that cerebral pulse wave amplitude in adults increases in relation to the ICP, as Cushing reported (Lundbere, 1960).

The cerebral pulse wave amplitude in infants is affected by age, thickness of cerebral mantle, as well as the ICP (Granholm et al. 1974). This implication is very important when the pulse wave amplitudes in infants with hydrocephalus are evaluated.

In the study presented here, the patients in the first and second groups, had slight increases in ICP during non-REM sleep without any sign or symptom of intracranial hypertension, but there were large differences in pulse wave amplitudes and clinical manifestations between the first and second groups.

In the second group, the pulse wave amplitude was extremely low and increased...
very little with age. Frequently, a B-wave fluctuation of the ICP was identified during non-REM sleep. Clinically, the patients in the second group had compensated hydrocephalus with severely impaired psychomotor development.

In infants with hydrocephalus, a low pulse wave amplitude and frequent B-type pressure waves in the ICP during non-REM sleep indicated that severe brain damage had already occurred. Surgical intervention should be scheduled urgently to prevent further progression of brain damage.

In the first group, the pulse wave amplitude of the ICP during non-REM sleep was similar to that of normal infants. That is, the pulse wave amplitude increased with age without the frequent appearance of B-type pressure waves. Patients in this group had normal psychomotor development.

It should be stated that the pulse wave amplitude and the appearance of B-type pressure waves in the ICP during non-REM sleep were very important for evaluating infants with hydrocephalus to determine whether the hydrocephalus was progressive, and whether surgical intervention should be scheduled.

There are some studies on the relationship between ICP and sleep. Symon (1972, 1975), Granholm (1974) and Allain-Pierre-Kahn (1976) observed an increase in ICP during sleep. Allain-Pierre-Kahn (1976) observed that plateau waves occurred during REM sleep, and they suggested that the factor responsible for the transient elevation in ICP during REM sleep was an increase of cerebral blood volume.

As shown in table 1, infants with progressive hydrocephalus from the third group had a plateau-type wave of more than 250 mmHgO, approximately equal to 310 mmHgO, during serial measurements of the ICP during sleep. Clinically, patients from the third group had progressive ventriculomegaly and a disproportionate increase in head circumference.

Considering the pressure-volume relationship described by Granholm (1974) for the hydrocephalic infants of the third group, it seemed that the ICP might be near the break point of the pressure-volume curve. A slight increase in cerebral blood volume during REM sleep may produce a large increase in ICP i.e., a plateau wave more than 250 mmHgO.

In normal infants the ICP must be at the horizontal portion of pressure-volume curve. A transient elevation of ICP i.e., plateau wave, occurred in relation to the period of REM sleep, and the value of ICP was always less than 250 mmHgO, as described above. If, in infants with hydrocephalus, a plateau wave of the ICP during REM sleep is observed that is more than 250 mmHgO, the compensatory reserve capacity of intracranial space should be considered to be reduced. This may result in brain damage. Thus atraumatic, continuous measurement of the ICP during sleep via the anterior fontanelle may be quite useful for assessing the reserve capacity in hydrocephalic infants and for considering the neurosurgical intervention to compensate for the low reserve capacity in the intracranial space.

Furthermore, by evaluating the pulse wave amplitude and the frequency of B-type waves during non-REM sleep, the pathophysiology in infants with hydrocephalus could be analysed more precisely.

References


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