Servo-controlled lumbar infusions in children

A quantitative approach to the problem of arrested hydrocephalus

FREDERICK H. SKLAR, M.D., CHESTER W. BEYER, JR., M.D., MURUGAPPAN RAMANATHAN, PH.D., AND W. KEMP CLARK, M.D.

Division of Neurological Surgery and Department of Anesthesiology, The University of Texas Health Science Center at Dallas, Dallas, Texas

Servo-controlled variable-rate lumbar infusions were performed in 11 children with presumed cerebrospinal fluid (CSF) absorptive defects. The CSF dynamics were determined as a function of intracranial pressure in terms of CSF absorptive capacity and resting pressure. These physiological measurements showed poor correlation with traditional clinical signs. On the basis of the CSF measurements there were four children with arrested hydrocephalus, one with compensated hydrocephalus, three with active hydrocephalus, and three with brain atrophy. Retrospective management decisions based on the clinical presentations, physical findings, and traditional diagnostic tests disagreed with management as indicated by the CSF measurements in eight of 11 cases. It is suggested that this technique may be a useful diagnostic tool for difficult clinical problems.

KEY WORDS • cerebrospinal fluid • arrested hydrocephalus • shunt • intracranial pressure

In children with presumed non-obstructive disorders of the cerebrospinal fluid (CSF) system, traditional neuroradiological studies are occasionally inconclusive as to whether the hydrocephalic process is active or arrested. Clinical signs and symptoms may be subtle or absent entirely. Poor school performance in a child with “arrested” hydrocephalus may be attributed to the residua of past disease or to an ongoing, slowly progressive, active process.

Foltz and Shurtleff have made a distinction between arrested and compensated hydrocephalus. According to their definitions, “arrested hydrocephalus” implies resolution of the underlying pathological process responsible for the ventricular dilatation. On the other hand, the term “compensated hydrocephalus” indicates that other mechanisms function to prevent further ventricular enlargement, such as a shunt or transependymal absorption.

However, it is frequently difficult in a particular patient to determine if the child might benefit by a more aggressive surgical approach. In instances of clinical uncertainty, it should be helpful to evaluate the CSF dynamics in these children, parameters of basic etiological importance. The present study reports measurements of CSF dynamics as a function of intracranial pressure (ICP) in children with likely CSF absorptive defects. The results are examined as to if and how they might alter patient management.

Measurement Technique

Eleven children with presumed non-obstructive disorders of the cerebrospinal system were included in the study. Measurements of CSF dynamics as a function of ICP were done as part of each child’s diagnostic evaluation. The patients’ ages ranged from 6 months to 9 years.

Each child was sedated with diazepam (Valium), and several children also required supplementation with fentanyl (Sublimaze). Two infants were studied under endotracheal anesthesia with nitrous oxide, oxygen, curare (Tubocurarine chloride), and diazepam supplement. In all patients, indwelling arterial catheters were placed to monitor continuously the systemic arterial pressure.
The servo-controlled variable-rate lumbar infusion technique to measure CSF dynamics as a function of ICP has been described in detail previously. In brief, the technique required a single lumbar puncture with a large-gauge Touhy needle through which a No. 20 epidural catheter was advanced 4 to 6 cm within the lumbar subarachnoid space to monitor CSF pressure. A Y adapter permitted the infusion or withdrawal of fluid around the pressure recording catheter. Blood and CSF pressures were monitored with Statham pressure transducers and a Sanborn polygraph. A servo-controlled infusion pump with reciprocally arranged 12-cc syringes was used to control CSF pressure; one syringe filled while the other emptied. A solenoid valve system interfaced the syringe pump with the patient's subarachnoid space and a fluid reservoir. This valve system made it unnecessary to interrupt the test to refill a syringe. A calibrated position detector indicated syringe plunger movement as a measure of fluid volume infused or withdrawn from the patient. The arrangement of the procedure is summarized in Fig. 1.

Mean CSF pressure, mean arterial blood pressure, and infusion volume data were sampled at 1-second intervals by an on-line PDP 11/34 computer. The computer activated the solenoid switching device when the syringes were at their limits. The CSF pressure and volume data were displayed on a Tektronix 4010 graphics terminal.

The older children were positioned on their side with the head supported by a pillow. The infants were positioned prone with their heads turned to one side. The pressure transducers were zeroed at the intracranial midline.

Lactated Ringer's solution was infused into the lumbar subarachnoid space to bring ICP to a desired level. In general, ICP did not exceed 40 mm Hg in the older children and 20 mm Hg in the infants. Arterial blood pressure was monitored continuously to insure that cerebral perfusion pressure was maintained in safe ranges. At a desired pressure, the servo system automatically adjusted the pump rate to maintain ICP constant. Each constant pressure plateau was held for 3 to 6 minutes. At constant ICP, the infusion pump rate at a given ICP then approximated the difference between the rate of CSF absorption (A) and formation (F), as well as the rate at which cerebral blood volume (CBV) changed with time:

\[ R = (A - F) - \Delta CBV/\Delta t. \]  

It was assumed that the cerebrovascular changes reached steady state rapidly, and the blood volume term in Equation 1 was negligible. The pump rate at a given ICP then approximated the arithmetic difference between absorption and formation:

\[ R = A - F. \]  

The effective pump rate at each pressure plateau was determined by the computer from the infusion volume versus time data with linear regression techniques. Numerous constant pressure plateaus were examined in a random fashion, and the pump rate (A - F) was considered as a linear function of pressure. The study was stopped when the data fit a linear model relating (A - F) and ICP with statistical significance. The resulting slope relating (A - F) to ICP was calculated to indicate net CSF absorptive capacity. The x-axis in-
Table 1

Cerebrospinal fluid (CSF) dynamics in 11 children with presumed disorders of the CSF system

<table>
<thead>
<tr>
<th>Case No.</th>
<th>Age, Sex</th>
<th>Clinical Presentation</th>
<th>CSF Absorptive Capacity (cc/min/mm Hg)</th>
<th>P&lt;sub&gt;o&lt;/sub&gt; (mm Hg)</th>
<th>Probability</th>
<th>Measured Resting Pressure (mm Hg)</th>
<th>Diagnosis Based on CSF Dynamics</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>5 yrs, M</td>
<td>marked ventricular enlargement from posterior fossa arachnoid cyst; 14 months postop</td>
<td>0.208</td>
<td>6.8</td>
<td>&lt;0.001</td>
<td>8</td>
<td>compensated hydrocephalus</td>
</tr>
<tr>
<td>2</td>
<td>9 yrs, M</td>
<td>porencephaly &amp; enlarged ventricles; seizures; behavior disorder</td>
<td>0.178</td>
<td>5.6</td>
<td>&lt;0.002</td>
<td>5</td>
<td>arrested hydrocephalus</td>
</tr>
<tr>
<td>3</td>
<td>15 mos, M</td>
<td>communicating hydrocephalus</td>
<td>0.060</td>
<td>2.6</td>
<td>&lt;0.001</td>
<td>8</td>
<td>active hydrocephalus atrophy</td>
</tr>
<tr>
<td>4</td>
<td>12 mos, F</td>
<td>atrophy vs. hydrocephalus after meningitis</td>
<td>0.204</td>
<td>5.3</td>
<td>&lt;0.002</td>
<td>6</td>
<td>atrophy vs. arrested hydrocephalus*</td>
</tr>
<tr>
<td>5</td>
<td>9 mos, M</td>
<td>atrophy vs. hydrocephalus after meningitis</td>
<td>0.150</td>
<td>6.8</td>
<td>&lt;0.001</td>
<td>9</td>
<td>atrophy (vs. arrested hydrocephalus)*</td>
</tr>
<tr>
<td>6</td>
<td>9 mos, M</td>
<td>moderate ventricular enlargement; developmental delay</td>
<td>0.249</td>
<td>13.9</td>
<td>0.001</td>
<td>8</td>
<td>arrested hydrocephalus</td>
</tr>
<tr>
<td>7</td>
<td>7 mos, M</td>
<td>achondroplasia; slightly enlarged ventricles; generous subarachnoid spaces</td>
<td>0.058</td>
<td>17.9</td>
<td>&lt;0.001</td>
<td>20</td>
<td>active hydrocephalus</td>
</tr>
<tr>
<td>8</td>
<td>9 mos, M</td>
<td>slightly enlarged ventricles; large subarachnoid spaces</td>
<td>0.208</td>
<td>7.8</td>
<td>&lt;0.05</td>
<td>10</td>
<td>arrested hydrocephalus</td>
</tr>
<tr>
<td>9</td>
<td>2 yrs, M</td>
<td>von Recklinghausen’s disease; enlarged ventricles; delayed development</td>
<td>0.149</td>
<td>4.0</td>
<td>&lt;0.005</td>
<td>not measured</td>
<td>arrested hydrocephalus</td>
</tr>
<tr>
<td>10</td>
<td>6 mos, M</td>
<td>achondroplasia; slightly enlarged ventricles; generous subarachnoid spaces</td>
<td>0.061</td>
<td>16.6</td>
<td>&lt;0.04</td>
<td>16</td>
<td>active hydrocephalus</td>
</tr>
<tr>
<td>11</td>
<td>9 mos, M</td>
<td>moderate ventricular enlargement; marked developmental delay; history of anoxic brain injury</td>
<td>0.139</td>
<td>9.6</td>
<td>&lt;0.001</td>
<td>11</td>
<td>atrophy (vs. arrested hydrocephalus)</td>
</tr>
</tbody>
</table>

*Ventricular reflux and stasis on isotope cisternal scan and 98th percentile head circumference raise question whether child had had active hydrocephalus previously.

Results

Variable-rate constant-pressure lumbar infusions were performed in 11 children with presumed disorders of the CSF system. Their clinical presentations are summarized in Table 1 with corresponding measurements of CSF dynamics. In each child, the relationship between (A-F) and ICP could be expressed as a linear function with statistical significance (p < 0.002 in eight cases; p < 0.05 in the worst case). Calculated values of P<sub>o</sub> agreed closely with actual measured resting pressure in each study. The relationship between the calculated values of P<sub>o</sub> and actual measured resting pressure was determined with the least squares technique: calculated P<sub>o</sub> = (0.924) (measured P<sub>o</sub>) - 0.0381, with a coefficient of correlation of 0.827 (p < 0.003). These results are interpreted to indicate a near-identity relationship.

The original computer display of the pressure versus time and volume versus time data for 30 minutes of a 72-minute infusion is shown in Fig. 2A for Case 1. These data points, with the results from the remaining 42 minutes of the infusion, are summarized graphically in Fig. 2B. The figure shows a linear relationship between (A-F) and ICP.

On the basis of the manometric determinations of CSF dynamics, three children had CSF absorptive capacity of less than 0.1 cc/min/mm Hg. Two of these patients had intracranial hypertension. On the other hand, four children had absorptive capacities greater than 0.2 cc/min/mm Hg, a range considered normal in this laboratory. Four children had intermediate absorptive capacities ranging from 0.139 to 0.178 cc/min/mm Hg, values thought to be at the lower limits of normal.

Four of the 11 children had normal CSF dynamics, ventricular enlargement, and a static neurological picture without clinical settings suggesting an atrophic process. It is suggested that these children meet the criteria of Foltz and Shurtleff* of having arrested hydrocephalus. In an additional two patients (Cases 5 and 11), the diagnostic differential could not be settled.
between brain atrophy and arrested hydrocephalus, although the latter seemed likely.

Eight of the 11 children had head circumference measurements greater than the 98th percentile. Patient selection accounted for this high incidence, since a clinical suspicion of a CSF absorptive defect was a prerequisite to be included in this study. Three patients with head circumference measurements greater than the 98th percentile had low CSF absorptive capacities (< 0.1 cc/min/mm Hg); three had values well within normal ranges (> 0.2 cc/min/mm Hg); and two had intermediate values in the low normal range (> 0.13, < 0.2 cc/min/mm Hg). On the other hand, none of the three children with head circumference measurements of less than the 98th percentile had net CSF absorptive capacities of less than 0.1 cc/min/mm Hg.

Computerized tomography (CT) scans were reviewed for the presence or absence of periventricular lucencies. In no case were lucencies definitely present at the time of the diagnostic evaluation. In two patients, CT scans were very suggestive of hypodense areas adjacent to the ventricles, but not striking. In a third, periventricular lucencies were possibly present.
Lumbar infusions and arrested hydrocephalus

Each of these three patients had disturbances of CSF absorptive capacities (< 0.1 cc/min/mm Hg) and two of the three had resting pressures greater than 16 mm Hg.

The status of the anterior fontanel and its relationship to CSF absorptive capacity and measured resting pressure were also examined. These results are summarized in Table 2. Two of the patients with CSF absorptive capacities less than 0.1 cc/min/mm Hg had unquestionably full fontanels. On the other hand, one child with a soft fontanel also had an absorptive capacity less than 0.1 cc/min/mm Hg. The two children with fontanels described as “possibly full” had measurements greater than 0.13 cc/min/mm Hg. Similarly, only two of the four children with full or questionably full anterior fontanels had measured resting pressures greater than 10 mm Hg. In summary, physiological measurements of CSF absorptive capacity and resting pressure (P₀) did not appear to correlate well with the clinical impression as to status of the fontanel.

For each patient, retrospective management decisions were made based on objective clinical criteria on the one hand, and CSF dynamics on the other (Table 3). This analysis showed agreement in only three of the 11 cases. Management decisions based on CSF dynamics contradicted clinically based therapy in the remaining group of eight patients, of which six children were believed not to need a shunt procedure. These results suggest that in this small series of patients, physiological measurements did not parallel traditional clinical clues.

Representative case histories will be presented.

**Illustrative Cases**

**Case 1**

This 5-year-old boy was admitted with a long history of headaches and several weeks of incoordination and slurring of speech. On examination, he had papilledema with hemorrhages, in addition to ataxia of the trunk and limbs. A CT scan demonstrated a large arachnoid cyst communicating with the fourth ventricle with preservation of the cerebellar vermis (Fig. 2C). There was marked hydrocephalus and a small porencephalic cyst communicating with the left temporal horn.

The child underwent a suboccipital craniectomy and posterior fossa exploration, and a large arachnoid cyst was encountered. The walls of the cyst were excised to allow free communication with the subarachnoid space. The procedure was complicated by a right parietal epidural hematoma, which was evacuated on the day of the initial surgery. The child made a gradual recovery after both operative procedures. He became essentially asymptomatic, but the ataxia required several months to resolve. A postoperative CT scan done 6 months after his surgery showed slight reduction of ventricular size (Fig. 2D).

At 14 months after surgery, the patient was readmitted to the hospital for evaluation of lethargy, headache, and questionable change in his coordination lasting several days. Physical examination was essentially unchanged; funduscopic examination was normal. A repeat CT scan (Fig. 2E) showed no change in ventricular size. The child was thought to be symptomatic from slowly progressive active hydrocephalus. An infusion test was done, and a normal CSF absorptive capacity was documented (Fig. 2B). No surgery was performed, and the patient’s symptomatology resolved completely. He has remained entirely asymptomatic for 2 years after his original surgery.

**Comment**

This case is an example of compensated hydrocephalus. The hydrocephalic process was brought under control by correcting the anatomical obstruction. When the child was readmitted with signs consistent with slowly progressive active hydrocephalus of the communicating variety, measurements of CSF dynamics as a function of ICP were invaluable in determining disease activity. On the basis of normal measurements of CSF absorptive capacity, he has been followed and has done well without surgical intervention.
Case 2

This 8-year-old boy had a known right frontal porencephalic cyst, originally demonstrated on pneumoencephalography (PEG) at 1 year of age. Hydrocephalus was not present on this original study. The patient was readmitted for worsening seizures and behavior difficulties. He was hyperactive and showed offensive aggressive behavior. The patient was having occasional generalized seizures and frequent absence spells. Headaches were frequent and usually associated temporally with the seizures. The patient was mentally dull but could carry on a conversation. He had a left spastic hemiparesis with left-sided dystonic posturing.

Skull x-ray films were normal. An electroencephalogram (EEG) showed right frontal slow and right posterior temporal spike activity. A CT scan demonstrated a large right frontal porencephalic cyst (Fig. 3A). In addition, the left lateral and third ventricles were moderately enlarged. This panventricular enlargement was not present on the original air study performed in infancy.

The CSF dynamics were defined with the servo-controlled lumbar infusion technique. The study indicated a normal CSF absorptive capacity and a normal resting pressure. These results are summarized graphically in Fig. 3B.

The child was followed after adjustment of his anticonvulsant regimen. Follow-up examination at 1½ years indicated that his seizures were under control, and his behavior was less of a problem. There were no new symptoms of pressure.

Comment

It is suggested that this patient represents an example of arrested hydrocephalus. The documented ventricular enlargement was not shown on a study done 7 years previously. The child's symptomatology was thought consistent with his having slowly progressive active hydrocephalus. Without the normal measurements of CSF dynamics, the child would have probably been shunted. Extended follow-up review has revealed no evidence of disease progression.

Case 3

This 9-month-old baby boy was brought for neurological evaluation of abnormal head growth (Fig. 4B) and moderately severe hydrocephalus on CT scan (Fig. 4A upper). The child was born prematurely.
Lumbar infusions and arrested hydrocephalus

FIG. 4. Case 3. A: Serial computerized tomography scans showing no progression of the moderately severe hydrocephalus over a 6-month period. B: Head circumference measurements. C: Cerebrospinal fluid (CSF) absorption minus formation (A-F) vs pressure. Low-slope value indicates severe CSF absorptive defect consistent with diagnosis of active hydrocephalus.

at 32 weeks gestational age. He required mechanical ventilation, prolonged intubation, and oxygenation for hyaline membrane disease. He had chest tubes placed for pneuemothoraces.

The child's development was appropriate. He sat up at 6 months; at 9 months, he was pulling himself up to stand and was saying simple words, such as “dada” and “hi.” He had a large open fontanel described by many observers as soft. A shunting procedure was postponed because of otitis media, and subsequent readmission to the hospital was delayed for recurrent upper respiratory infections. However, during this time of observation, his head growth appeared to stabilize (Fig. 4B). Follow-up CT scan showed no progression of the hydrocephalus (Fig. 4A lower). The question was raised whether the child's hydrocephalus had arrested. Pneumoencephalography confirmed that there was no obstruction to the CSF pathways. Accordingly, the patient’s CSF dynamics were studied at age 15 months, and a severe absorptive defect was demonstrated (Fig. 4C). The resting pressure as determined by the CSF dynamics was 2.6 mm Hg. The child underwent a ventriculoperitoneal shunt at 16 months of age.

Comment

This patient represents an example of active communicating hydrocephalus. Disease activity was not apparent on the basis of clinical information alone. Head growth measurements had reached a plateau, and the fontanel was soft. The patient's developmental progress was considered to be appropriate.

Case 4

This 1-year-old girl had been treated for presumed bacterial meningitis with parenteral ampicillin and chloramphenicol 1 month before admission. No organism could be isolated. The patient remained febrile for the first 5 days of treatment with a marked CSF pleocytosis, and it became apparent that there was swelling and tenderness behind the left ear over the mastoid area. Mastoid x-ray films showed clouding. A mastoidectomy was done on the sixth hospital day, and the patient's fever defervesced thereafter. The child was given a full 14-day course of antibiotics.

Three days after the child was discharged from the hospital, readmission was necessary for fever and ap-
F. H. Sklar, C. W. Beyer, Jr., M. Ramanathan and W. K. Clark

Figs. 5. Case 4. A: Computerized tomography scan showing ventricular enlargement with asymmetrical periventricular lucencies thought to represent infarction. B: Cerebrospinal fluid (CSF) absorption minus formation (A-F) vs pressure. Normal CSF absorptive capacity and clinical history suggest diagnosis of brain atrophy.

parent exacerbation of the CSF pleocytosis associated with an abnormally low CSF glucose. The child was treated with methicillin and chloramphenicol and seemed to respond clinically. Negative cultures required an exhaustive but non-contributory mycotic and immune evaluation. After 2 weeks in the hospital, a left-sided hemiparesis evolved. A CT scan revealed panventricular enlargement with low-density areas surrounding the frontal horns, especially on the left (Fig. 5A). The radiological findings were thought to represent infarction.

Although the patient became afebrile and the CSF laboratory findings returned to normal, the child showed only minimal clinical improvement in her hemiparesis and irritability. The question of whether her failure to improve could be related to a CSF absorptive defect and hydrocephalus was entertained. Measurements of CSF dynamics showed a normal absorptive capacity (Fig. 5B).

Comment

This patient represents an example of brain atrophy with normal CSF absorptive mechanisms.

Case 5

This baby boy was followed as a pediatric outpatient for presumed “arrested” hydrocephalus with head circumference measurements just above the 98th percentile. The child was born 4 weeks prematurely. He had a low Apgar count and required resuscitation. In the nursery, his head circumference measurements were noted to increase rapidly, but seemed to level off, paralleling the 98th percentile on follow-up review in the clinic. The child had significant developmental delay. He first rolled over at 8½ months; he was not sitting, pulling himself up, or crawling. There were occasional problems with vomiting.

At 9 months of age, the child was admitted to the hospital with wheezing and fever. Asthma was diagnosed and responded well to appropriate medications.

The child’s fontanel was very small and nearly closed. Skull films showed calvarial asymmetry; the sutures were normal. A CT scan demonstrated enlargement of the entire ventricular system with prominence of the sulci and enlarged subarachnoid spaces (Fig. 6A). The radiographic findings were thought consistent with cortical atrophy or hydrocephalus, and it was suggested that the latter diagnosis seemed more likely because of the enlarged head size. Isotope cisternography showed marked reflux of the radionuclide into the lateral ventricles.

A servo-controlled lumbar infusion showed that the patient’s CSF absorptive capacity was at the lower limits of normal with a normal resting pressure (Fig. 6B).
Lumbar infusions and arrested hydrocephalus

![Computerized tomography scan showing moderately enlarged ventricles with prominent sulci and subarachnoid spaces.](image)

**Fig. 6. Case 5.** A: Computerized tomography scan showing moderately enlarged ventricles with prominent sulci and subarachnoid spaces. B: Cerebrospinal fluid (CSF) absorption minus formation. A-F vs pressure. The normal CSF absorptive capacity, enlarged head measurements, and ventricular reflux on isotope cisternography are most consistent with the diagnosis of arrested hydrocephalus.

**Comment**

This child is thought to be an example of arrested hydrocephalus. The clinical history of the anoxic birth injury, as well as the radiological features, raised the question of brain atrophy. The results of the infusion study showed a CSF absorptive capacity in the lower limits of normal. It seems likely that both atrophy and hydrocephalus played a role early in this patient's development.

**Case 6**

This 8½-month-old boy was brought for neurosurgical evaluation of his 98th percentile head circumference measurements and mild developmental delay. The child was slow to hold his head up. He rolled over at 7 months. His parents volunteered that they thought his soft spot was prominent at times.

Skull x-ray films were normal. A CT scan demonstrated moderately enlarged ventricles (Fig. 7A). The patient's anterior fontanel was considered flat and pulsatile. The child underwent a servo-controlled lumbar infusion and was shown to have a normal CSF absorptive capacity.

**Comment**

This patient represents an example of arrested hydrocephalus with a normal CSF absorptive capacity.

**Discussion**

The 11 children in the present study were presumed likely to have CSF absorptive defects based on clinical interpretation of history, symptomatology, head circumference measurements, fontanel, and CT scan. Only three of the 11 showed impaired CSF absorptive capacities with the variable-rate lumbar infusion technique. Moreover, the status of the fontanel was not a sensitive indication of what the measurements of CSF dynamics would show. As to the accuracy of the technique, resting pressures calculated from linear regression analysis of the (A-F) versus ICP data agreed closely with actual measured resting pressures. The physiological data fit a linear model with statistical significance. Furthermore, in another report, serial measurements of CSF dynamics as a function of ICP were found to be reproducible in patients with pseudotumor cerebri. These factors collectively attest to the credibility of the results of the present study.

The variable-rate lumbar infusion method is a manometric technique that assumes rapid equilibration of the cerebrovascular compartment for each constant pressure plateau. However, numerous reports in the literature imply that cerebral blood volume (CBV) may indeed increase as ICP is increased. The \( \Delta \text{CBV}/\Delta t \) term in Equation 1 may then become significant, and would result in artificially low CSF absorptive capacities. In pseudotumor patients, this...

The phenomenon apparently alters measurements of CSF dynamics by the servo-controlled variable-rate infusion technique very little.\textsuperscript{20} Moreover, the fact that the majority of patients in the present series had normal absorptive capacities suggests that this potential artifact did not have a major effect on the observed results.

It is difficult to define with certainty the lower limits of normal with the variable-rate infusion technique. In this laboratory, CSF absorptive capacities of less than 0.13 cc/min/mm Hg are considered abnormal, based on a cumulative experience in adults and children with communicating hydrocephalus, brain atrophy, and pseudotumor cerebri. Similarly, Ekstedt\textsuperscript{9} has considered values of less than 0.1 cc/min/mm Hg to be abnormal with a similar infusion technique in which pressures were increased in a stepwise fashion. We selected ICP plateaus at random in the present protocol. Obviously, extensive data in normal volunteers is not available.

The concept of “arrested” hydrocephalus is confusing in the literature. On the basis of large clinical studies of untreated hydrocephalic patients, it has been said that spontaneous arrest of hydrocephalus is common.\textsuperscript{9,11,12} Although numerous criteria to define this entity have been suggested,\textsuperscript{11,12,19} these are based primarily on serial measurements of head circumference. However, the clinical usefulness of serial head circumference measurements must be seriously challenged as a sensitive indicator of disease activity. In this clinic, there have been occasional examples of progressive ventricular enlargement in children without inappropriate head growth. Bird, \textit{et al.}\textsuperscript{1} have described a 8-year-old child with presumed arrested hydrocephalus and a nonfunctioning shunt. Although the child was entirely asymptomatic and the head circumference growth pattern was subnormal, diagnostic tests indicated active disease. Air study showed marked ventricular enlargement; isotope cisternography showed ventricular stasis; and constant-rate lumbar infusion manometry suggested a CSF absorptive defect. These authors concluded that head circumference measurements and clinical signs may not indicate the need for a shunt revision.

Some consider the condition of arrested hydrocephalus to be pathological, and recommend shunting in many of these patients.\textsuperscript{2,17,22} On the other hand, Epstein, \textit{et al.}\textsuperscript{9} have reported success in weaning patients from their shunts with an externally controlled valve system to bring about “arrest” or “compensation” without apparent ill effects to the patient. Head wrapping has been reported as an effective alternative to a shunt in some children.\textsuperscript{4} But the dilemma of recognizing poor performance as a symp-
Lumbar infusions and arrested hydrocephalus

tom of active hydrocephalus, rather than as an expression of static brain damage, can be difficult. Schick and Matson have summarized this problem well: "Perhaps of even greater importance is the false security that is drawn from the fact that these children [with slowly progressive hydrocephalus] continued to acquire motor skills during the periods of observation although in several cases, at a retarded rate. . . . So often a child with mild hydrocephalus masquerading as 'arrested' hydrocephalus may appear to be normal up to four or five years of age, only to show retardation as school problems are encountered."

The findings of Hammock, et al., are worrisome in this regard. These researchers did pre- and postshunt psychological testing in eight meningomyelocoele children with macrocephaly and nonfunctioning shunts. Although the children were without signs and symptoms of intracranial hypertension, most showed dramatic improvement in intellectual performance after the shunt revision. They concluded that large ventricles and normal pressure in children with stable head measurements and nonprogressive neurological condition may not necessarily indicate arrested hydrocephalus.

On the other hand, the results of the present study support the concept that active communicating hydrocephalus can go on to an arrested state. According to the criteria of Foltz and Shurtleff, it is necessary to show that a patient with arrested communicating hydrocephalus has a normal CSF absorptive capacity, despite radiological evidence of non-atrophic ventricular dilatation. Four (possibly six) of the 11 children in the present series met these requirements.

Computerized tomography can provide accurate anatomical information about ventricular size. Certainly, progressive enlargement of the ventricles on serial scans is strong evidence for disease activity, and the CT scan remains a primary diagnostic tool in following children with presumed arrested hydrocephalus. But the ventricles frequently remain large after a shunt. It may therefore be difficult to evaluate shunt function on the basis of ventricular size alone, especially when a patient is encountered for the first time without a radiological baseline. Periventricular hypodensity is a common CT feature of hypertensive hydrocephalus, and CT numbers have been shown to correlate with ICP measurements in these patients. But periventricular lucencies are less frequently present in normotensive hydrocephalus, and may therefore be of little use in distinguishing compensated from slowly progressive active hydrocephalus. In the present study, the three patients with reduced CSF absorptive capacities (< 0.1 cc/min/mm Hg) all had suggestions of periventricular lucencies on CT scan. The use of the CT scan as an indicator of disease activity may be somewhat limited.

Finally, in this small series of children with difficult clinical presentations, there was a striking discrepancy between therapeutic decisions based on clinical intuition and those based on measurements of CSF dynamics. Retrospective management decisions were made on the basis of the clinical history, examination, and diagnostic tests without consideration of the results of the CSF measurements. Such disagreement occurred in eight of the 11 cases. Moreover, clinical intuition suggested the need for surgery in six children, in whom the CSF measurements indicated no need for a shunt. Several of the latter patients have been followed for over 1 year without surgery, and have shown no progression of signs or symptoms. One child (Case 7) with mild ventricular enlargement and a severe absorptive defect was followed without surgery and had shown evidence on CT scan of progressive dilatation of the ventricles over a 7-month period. However, it remains to be proven with certainty that physiological measurements of CSF dynamics as a function of ICP can be safely used to define quantitatively the state of the disease activity in children with possible arrested hydrocephalus. Although the results of this pilot study are encouraging, experience in larger numbers of patients with extended follow-up review will be necessary to corroborate these findings.

Acknowledgment

The authors wish to thank Ms. Jena Simmons for her assistance in preparing the manuscript.

References


17. Raimondi AJ: Personal communication, 1978

Address reprint requests to: Frederick H. Sklar, M.D., Division of Neurological Surgery, The University of Texas Health Science Center at Dallas, 5323 Harry Hines Boulevard, Dallas, Texas 75235.