Pre- and Postoperative Evaluation of Cerebral Blood Flow in Low-Pressure Hydrocephalus

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Several theories have been launched to explain the often dramatic improvement that follows the shunting procedure in patients with hydrocephalus. In cases with intracranial hypertension an increase in blood flow seems a likely consequence of the reestablishment of normal pressure conditions. In low pressure hydrocephalus the favorable results seem more difficult to explain. One theory, first set forth by Yakovenko, states that the neurological disturbances, particularly those affecting the gait, are due to stretching of the long paracentral fibers located close to the walls of the lateral ventricles, and that release of this stretching could explain the postoperative improvements. Periventricular demyelination was found by Penfield and others, and a vascular cause of the changes was considered most plausible. A decrease in cerebral blood flow has been found in occult hydrocephalus, in the high-pressure as well as in the low-pressure type, and improvement of flow following the shunting procedure has been described in a few cases with an ectatic basilar artery. It therefore seems justified to present data allowing more definite and generalized conclusions to be reached about the pre- and postoperative cerebral circulation in hydrocephalic patients.

Material and Methods

Seven consecutive patients with low-pressure hydrocephalus were examined. The hydrocephalus was due to trauma in two cases and to subarachnoid hemorrhage in one. Three patients had an elongated basilar artery deforming the third ventricle (Fig. 1), and one of these patients had been operated on for a subdural hematoma (Table I).

Angiography of the internal carotid artery was performed 1 to 2 weeks before and 3 to 4 weeks (in one case, 2 months) after operation. In conjunction with this procedure cerebral blood flow was determined by the $^{133}$Xenon clearance method of Lassen and Ingvar. By extracranial recording of the radioactive from the freely diffusible inert gas $^{133}$Xenon which, dissolved in saline, is injected into the internal carotid artery, a clearance curve is obtained from the cerebral hemisphere. This curve can be resolved into two monoeponential clearance functions that correspond to the flow in the gray and the white matter. Graphical analysis of the original curve allows the estimation of the relative weight of these two tissue components as well as of the mean cerebral blood flow. The relative weights are calculated from the intercepts of the two clearance functions at time zero, each of the two compartments having at the start of the clearance obtained a degree of saturation proportional to its blood flow.

The arterial carbon dioxide tension ($pCO_2$) of arterial blood was determined with the micro Astrup method. The flow values are given without $pCO_2$ correction, because the $pCO_2$ values were essentially within normal variations and, furthermore, cerebral blood flow is not only dependent upon $pCO_2$ of the arterial blood, but also upon the regional tissue $pCO_2$, a parameter which is unknown. As a check, however, the mean flow values were corrected to the standard CBF ($pCO_2 = 40$ mm Hg) and this did not significantly change the results and conclusions presented here.

Cerebral circulation time (CCT) was determined by angiography of the carotid artery and taken according to Greitz as an interval between maximum contrast filling of the carotid siphon and maximum filling of parietal veins.

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Encephalography was carried out mainly in accordance with the technique described by Lindgren in 1949. Repeated attempts were made to ensure filling of the basal cisterns as well as the subarachnoid space over the cerebral hemispheres. The hydrocephalic index was determined according to Lindgren as the quotient between the greatest width of the anterior horn and the greatest internal width of the skull. A similar quotient was determined at carotid angiography using the central veins to determine the size of the lateral ventricles.\(^2\)

Gammaristernography was carried out by the method described by Di Chiro.\(^5\) Biplane scans were taken after 3, 6, 24, and 48 hours, and if needed also after 3, 4, and 5 days. In all patients intraventricular pressure was measured during operation with electromagnetic methods. In some patients the lumbar CSF pressure was measured simultaneously.

The clinical history and the results of operation are given in the following case reports. Reference is made in Table 2 to the radiologic findings and CBF measurements.

### Table 1

<table>
<thead>
<tr>
<th>Case No.</th>
<th>Age, Sex</th>
<th>Cause of Hydrocephalus</th>
<th>Duration</th>
<th>Encephalography Type of Hydrocephalus</th>
<th>Hydrocephalic Index</th>
<th>RHISACisternography</th>
<th>CSF pressure cm H(_2)O</th>
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<td>trauma</td>
<td>7 mos</td>
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TABLE 2

Angiography and cerebral blood flow in seven hydrocephalic patients

<table>
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<tr>
<th>Case No.</th>
<th>Exam. No.</th>
<th>Hydrocephalic Index</th>
<th>Interposition of Subdural Fluid (mm)</th>
<th>Width of Intracranial Arteries</th>
<th>Cerebral Circulation Time (sec)</th>
<th>Mean Flow (ml/100 gm/min)</th>
<th>Flow in Gray Matter (fast comp.)</th>
<th>Flow in White Matter (slow comp.)</th>
<th>Rel. Gray Matter Weight (%)</th>
<th>pCO₂ (mm Hg)</th>
<th>Postop. Improvement</th>
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<td>11</td>
<td>29</td>
<td>35</td>
<td>35</td>
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</table>

Mean
preop. | 0.36 | 0.1 | — | 5.2
postop. | 0.29 | 2.7 | — | 4.6
difference | −0.07 | 2.6 | — | −0.6

Case Reports

(Cases 4 and 5 have been published in another paper.7)

Case 1. A 64-year-old man 7 months earlier had suffered a fracture of the occiput, followed by periods of great confusion and agitation, progressive disorientation in time and place, poor memory for recent events, incontinence of urine and feces, and progressive disturbance of gait. On admission the patient was unable to stand. The EEG showed abnormal episodes of symmetrical rhythmic activity of low frequency occurring maximally in the frontal leads. Encephalography and bilateral carotid angiography showed a high grade communicating hydrocephalus. A ventriculoatrial shunt procedure was carried out. Postoperatively there was a marked clinical improvement. The patient was more alert and less disoriented, but still had periods of agitation. He nursed himself, attained better control of his sphincters, and walked without support.

Case 2. This 54-year-old man had had a head injury 1 year previously after which he was unconscious for 1 week and had a transient right hemiparesis. After a second head injury 5 months later his condition deteriorated with progressive dementia, total disorientation, incontinence of urine and feces, and inability to stand. Encephalography showed a communicating hydrocephalus, and RIHSA-cisternography revealed a block at the level of the tentorium cerebelli. A ventriculoatrial shunt procedure was carried out. Postoperatively he improved progressively, became less disoriented, more responsive, and more emotionally stable. He could walk again.

Case 3. This 45-year-old woman had had a subarachnoid hemorrhage associated with temporary loss of consciousness 1 ½ years before admission. Three months later her condition deteriorated after a series of epileptic fits; she developed difficulty in concentration, dizziness, and disturbance of balance and walking. Bilateral carotid and vertebral angiography showed no aneurysm. The EEG showed an abnormal pattern with a slight episodic frontotemporal abnormality, maximal on the left side. Encephalography
showed that the lateral ventricles were dilated while only a minute amount of air was seen over the cerebral hemispheres. A ventriculoatrial shunt procedure was carried out. Postoperatively the patient improved progressively, and the only residual complaint was a slight headache.

**Case 4.** This 61-year-old woman had had essential hypertension for 9 years and progressive dementia and disturbance of gait for 2 years. Angiography showed that the third ventricle was deformed by an ectatic basilar artery. A ventriculoatrial shunt procedure was carried out. Postoperative improvement was marked, especially in regard to the dementia.

**Case 5.** This 62-year-old man with essential hypertension had had headache and apathy for 2 years, and left-sided epileptic fits with aphasia for three months. A communicating hydrocephalus and an ectasia of the basilar artery was found by neuroradiology. A ventriculoatrial shunt procedure was carried out. Postoperatively there was a transient left-sided hemiparesis (cause unknown, and at angiography no visible lesion). Two months later further angiography showed that the hydrocephalus was diminished, and that the cerebral blood flow had increased. There was a continuous improvement in the confusion and aphasia while the headache disappeared completely.

**Case 6.** This 55-year-old man, a chronic alcoholic, had previously been operated on for a cerebral contusion with rupture of the left sigmoid sinus. Postoperatively a slight paresis of the left arm and the right leg and an expressive aphasia had been noticed. Because of psychic disturbances the patient was admitted to a mental ward. Nine months after the trauma a broad-based disturbance of gait was observed. Encephalography and angiography showed dilatation of the ventricles with ectasia and elongation of the basilar artery. A ventriculoatrial shunt procedure was carried out, but postoperatively there was no obvious improvement.

**Case 7.** This 65-year-old woman, a chronic alcoholic, had a 1-year history of daily episodes of “unawareness,” progressive dementia, poor memory for recent events, and incontinence of urine. Neuroradiological investigation showed a severe communicating hydrocephalus. A ventriculoatrial shunt was inserted and postoperatively there was a striking clinical improvement. The patient became more alert, less forgetful, ceased to be incontinent of urine, and the episodes of unawareness disappeared completely.

**Results**

The changes in mean cerebral blood flow, the slow flow component, and ventricular size were of the same sort in all patients (Table 2). This is significant at the 1% level as judged by a one-tailed sign test. The weight component of gray matter increased in six cases. This is not quite significant when judged by the same sign test. This change as well as the increase in blood flow varied considerably in different individuals and seemed to correlate well with the clinical improvement observed. It remained essentially unchanged in one patient, in whom improvement was questionable. Postoperatively the fast component was considerably greater in the three patients in whom the improvement was most striking and was virtually unchanged in the remainder.

The hydrocephalic index, as determined by angiography, decreased in all patients.

![Graph](image)

**Fig. 2.** Correlation between post-operative percentile decrease of hydrocephalic index (abscissa) and increase in mean cerebral blood flow (ordinate). Rings indicate cases with ectasia of basilar artery; crosses, cases without ectasia.
FIG. 3. Case 3. Angiography before operation, showing lateral displacement of thalamostriate vein due to ventricular enlargement (*arrows*), narrow arteries, and no interposition of fluid over the convexity.
Fig. 4. Case 3. Angiography after operation, showing an increase in arterial size, decrease in ventricular size (heavy arrows) and an interposition of fluid over the convexity (thin arrows).
In six a very close correlation seemed to exist between the percentage decrease in ventricular size and the percentage increase in mean flow (Fig. 2). The seventh patient differed from the other six in that she had a shorter history, was 45 years old, had the highest preoperative mean flow, and had an almost normal RHISA cisternogram before operation. The decrease in the size of the lateral ventricle in three patients was accompanied by an increased distance between the brain surface and the inner table of the skull (Figs. 3 and 4). In one patient previously operated for a subdural hematoma, a gap of 1 mm was present before operation and remained unchanged.

In five of the seven patients the circulation time as determined by angiography was shorter after operation than before, and in four of these the emptying of the cerebral veins was markedly faster postoperatively. In three patients the internal cerebral vein increased in size after operation, in three it remained unchanged, and in one it decreased. No definite change in the diameter of the convexity veins was noted. In four patients without ecstasia, the arteries were narrow and returned to normal size after shunting (Fig. 2).

Discussion

The decrease in ventricular size after atrioventricular shunting as seen in our series is in agreement with earlier observations and with the theory of Yakovlev, who considered the neurological symptoms to be due to the stretching of nerve fibers. However, the concomitant increase in CBF seems to be related to the clinical improvement. As a matter of fact, our results show not only an inverse relationship between decrease in ventricular size and increase in cerebral blood flow, but also a correlation between these two parameters and the patients' improvement. This was especially true with the mean cerebral blood flow and its slow component, which increased in all patients, particularly in those who showed clinical improvement.

With regard to other circulatory variables, a trend toward improved circulation time was present although the difference between the pre- and postoperative results was less significant. This is in agreement with the statement of Greitz that the mean cerebral blood flow, as determined by the isotope clearance method, is a better indicator of circulatory disturbances in hydrocephalic patients than is cerebral circulation time evaluated by carotid angiography. This observation is contrary to the findings in acute cerebrovascular lesions.

The enlargement of the subdural space, seen after operation in three of our most improved patients, might indicate that the relief of the compression of the cerebral cortex against the calvarium is a contributory factor for the reestablishment of brain circulation. This reaction of the cortex does not, however, seem to be mandatory for clinical improvement as seen in Case 1. The gap between the calvarium and the brain surface is probably due to an external hydrocephalus with subdural collection of cerebrospinal fluid and is of radiological importance as it could be mistaken for a subdural hematoma, which is a well-known complication of intracranial shunting procedures. Furthermore, it may give a false impression of the width of the "cerebral mantle" at postoperative pneumoencephalography. External hydrocephalus is probably more likely to occur in brain atrophy which might have been caused by hypoxia in long-lasting internal hydrocephalus.

From the angiographic findings, a significant change in the transit time could be noted only in one patient (Table 1). However, an increase of flow was suggested by the return of the narrowed cerebral arteries to normal size that occurred in four patients who improved. The changes in the caliber of the internal cerebral veins seen after operation could not be correlated with increase in flow or clinical improvement and might be explained by individual variations in the response to the pharmacological action of the contrast medium.

The increase in gray matter component seen in the postoperative CBF determinations suggests that estimated weight of the gray matter should not be interpreted on a strictly morphological basis for it does not reflect the actual percentage weight of gray matter.

Summary

In patients with low-pressure hydrocephalus, cerebral blood flow is reduced. It is in-
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increased following installation of an atrio-ventricular shunt. The increase in flow seems to be correlated both to clinical improvement and to decrease in ventricular size. In hydrocephalic patients the reduced cerebral circulation is less accurately determined with angiography than with the 133Xenon clearance method. Postoperative cerebral angiography in improved patients may reveal, in addition to decrease in ventricular size and shortening of circulation time, dilatation of cerebral arteries, improved emptying of central and cortical veins, and occasionally an interposition of subdural fluid between the convexity and the skull.

Acknowledgment

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References