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Yoshiki Nosaka*

*Okayama University,

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Yoshiki Nosaka

Abstract

Thirteen patients exhibited a communicating hydrocephalus following subarachnoid hemorrhage secondary to ruptured intracranial aneurysms and were treated with shunt procedures. The interval between subarachnoid hemorrhage and surgery averaged 9 weeks. Seven of the patients showed improvement. The prognostic value for surgical management was evaluated on the basis of three different diagnostic examinations (computed tomography(CT), cisternography and constant infusion test). A correct diagnosis was obtained in 78 per cent in cisternography, and 63 per cent in infusion test and CT. All patients responding to surgery showed a typical pattern in cisternography, consisting of ventricular retention of radiopharmaceutical tracer for 48 h or longer in association with no radioactivity over the cerebral hemispheres. The constant infusion test correlated well with typical cisternographic patterns. CT is useful in demonstrating pathophysiological changes in hydrocephalus. Periventricular hypodensity was visible in patients with normal or slightly elevated intracranial pressure, accompanied by fairly rapid deterioration. All of them responded well to shunting. In most cases which benefited from the shunt, the postoperative CT showed not only normal-sized ventricles but also marked regression of the hypodensity over a short period.

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HYDROCEPHALUS ASSOCIATED WITH SUBARACHNOID HEMORRHAGE: CLINICAL STUDY BY COMPUTED TOMOGRAPHY, RADIOISOTOPE CISTERNOGRAPHY AND CONSTANT INFUSION TEST

Yoshiki NOSAKA

*Department of Neurological Surgery, Okayama University Medical School,
Okayama 700, Japan (Director: Prof. A. Nishimoto)*

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Abstract. Thirteen patients exhibited a communicating hydrocephalus following subarachnoid hemorrhage secondary to ruptured intracranial aneurysms and were treated with shunt procedures. The interval between subarachnoid hemorrhage and surgery averaged 9 weeks. Seven of the patients showed improvement. The prognostic value for surgical management was evaluated on the basis of three different diagnostic examinations (computed tomography(CT), cisternography and constant infusion test). A correct diagnosis was obtained in 78 per cent in cisternography, and 63 per cent in infusion test and CT. All patients responding to surgery showed a typical pattern in cisternography, consisting of ventricular retention of radiopharmaceutical tracer for 48 h or longer in association with no radioactivity over the cerebral hemispheres. The constant infusion test correlated well with typical cisternographic patterns. CT is useful in demonstrating pathophysiological changes in hydrocephalus. Periventricular hypodensity was visible in patients with normal or slightly elevated intracranial pressure, accompanied by fairly rapid deterioration. All of them responded well to shunting. In most cases which benefited from the shunt, the postoperative CT showed not only normal-sized ventricles but also marked regression of the hypodensity over a short period.

Key Words : hydrocephalus, subarachnoid hemorrhage, aneurysm, CT, cisternography

Extraventricular obstructive hydrocephalus following spontaneous subarachnoid hemorrhage (SAH) in adults has been well documented. The ventricular dilatation is postulated to occur secondary to arachnoiditis and fibrosis caused by the bleeding, leading to obstruction of the cerebrospinal fluid (CSF) pathway. The appearance of the hydrocephalus is often delayed. Bagley (1, 2) in 1928 demonstrated in clinical and experimental studies of subarachnoid bleeding, a marked leptomeningeal reaction which, over a period of weeks, could result in a progressive fibrotic reaction in the basal leptomeninges. His experimental studies in dogs showed that the ventricular dilatation occurred in 30 per cent of puppies after blood was injected into the cisterna magna. He did not actually demonstrate a communicating hydrocephalus, though he showed that intermittent spinal fluid drainage produced clinical improvement.

In a series of 53 patients coming to postmortem examination at varying time-intervals after hemorrhage from ruptured aneurysms, Hammes (3) in 1944 found obliteration of subarachnoid spaces secondary to the fibrotic response of meninges to blood in over half the patients who survived ten days or longer. Foltz and Ward (4) in 1956 reported ten cases of hydrocephalus following SAH, the etiologies of which included operative hemorrhage, ruptured intracranial aneurysms and head trauma. Treatment by ventriculomastoid shunt was reported to have resulted in marked clinical improvement in six cases, with impending fatality being averted in three of these. Pneumoencephalography performed in each case demonstrated ventricular dilatation with air trapped in the basal cisterns. Recognition of the hydrocephalus varied between 2 to 12 weeks. It is noteworthy that they observed two symptomatic patients with ventricular enlargement, CSF pressure less than 180 mm water and clinical improvement after ventriculoatrial shunting.

In 1965, Hakims and Adams (5), and Adams (6) *et al.* described similar cases in which clinical improvement followed CSF diversion. The syndrome they reported is now known as "low pressure", "normotensive" or "adult onset" communicating hydrocephalus. The syndrome is characterized by the association of progressive dementia, gait disturbance and sphincteric incontinence. Several etiological factors are recognized: head trauma (4 - 9), subarachnoid hemorrhage (4, 7, 9 - 13), meningitis (11, 14), and intracranial surgery (11, 15). It is also found in patients without medical history.

In most cases, diagnosis of the hydrocephalus is based on the combination of clinical status, pneumoencephalography (PEG), and radioisotope cisternography (7, 11, 16 - 19). Isotope cisternography has been widely employed since it is a reliable means of demonstrating CSF patterns. The advent of computed tomography (CT) brought a new method to study the size and configuration of the cerebral ventricles without the instillation of air by lumbar puncture and without discomfort or risk to the patients. Furthermore, CT is particularly useful in investigating the intraparenchymal pathology. Additional diagnostic investigations include the constant infusion manometric test, the aim of which is to study the capacity for absorption of CSF, and intracranial pressure recording which is, in practice, difficult. Recently, CT cisternography with water-soluble contrast material (metrizamide) has been reported to be used in assessment of both the ventricular size and CSF circulation (20, 21). Nevertheless, correct diagnoses and good therapeutic results are not always obtained (9, 16, 22 - 25).

In this study, thirteen patients with the diagnosis of adult onset communicating hydrocephalus following SAH were examined with CT scan. The results were compared with radioisotope cisternographic findings and the clinical responses to ventricular shunting. A similar comparison was made with findings of the constant manometric saline infusion test.

This communication is intended as an analysis of the importance of in-

dividual findings and their interrelationships from a clinical standpoint since there have been no reports on the relationships between these three examinations.

MATERIALS AND METHODS

Initially, twenty patients were suspected to have hydrocephalus on the basis of mental impairment and each of them had a CT scan. Seven of them were excluded from this study because they improved clinically over a few weeks' period of observation. The remaining thirteen patients were entered into the investigative study and finally had ventricular shunting.

Age and Sex. The ages of the patients varied from 22 to 66 years with an average of 54. There were 9 males and 4 females.

Sites of aneurysms. The aneurysm was located on the internal carotid artery in six cases, the anterior communicating artery in three, the middle cerebral artery in one, and the basilar artery in two. Multiple aneurysms were present in one case.

Clinical features. It is difficult to assess the symptoms specifically related to the presence of a communicating hydrocephalus because of complex factors of recent SAH and craniotomy. Nevertheless, symptoms common to all the patients were mental deterioration, gait disturbance and incontinence. The presence of all three symptoms were not required for the diagnosis. Occult hydrocephalus was diagnosed in a patient with only mental changes and incontinence if he met the radiographic criteria for the diagnosis. Mental signs included disorientation, impaired memory, and a decrease in mental and physical activity. Akinetic mutism developed in one patient with an aneurysm of the middle cerebral artery.

It is also impossible to assess the exact time of onset of the hydrocephalus because the onset of these symptoms is insidious. The time interval between the latest SAH and the establishment of the diagnosis is a rough measure of the period of time required for the development of the hydrocephalus. In this study, the interval ranged from 27 to 103 days with an average of 61 days.

Diagnostic procedures. Three tests were used as aids in diagnosing hydrocephalus and evaluating the results of treatment: a CT scan, radionuclide cisternography and a manometric saline infusion test.

CT is accepted as a valuable procedure for the evaluation of the ventricular size. A CT scan using an ACTA scanner (0100) with a 160×160 matrix and a slice 8.5 mm thick was performed in each case in a standard fashion with an approximate 15 degree tilt from the canthomeatal line. In all cases, images 2 and 4 cm above the canthomeatal line were used because they provided the best images of the frontal horn. The ventricular size was measured with the frontal ventricular dimension. The measurements were made from the original Polaroid images using a ruler. In each case, the following dimensions were measured (Fig. 1): A. The maximal bifrontal diameter: the transverse distance defined by a line connecting the two anterior corners of the frontal horn. B. The transverse dimension of the brain (brain width): the distance measured along in the line of the bifrontal diameter from the right to the left cortical surfaces. All measurements were made in millimeters. The ratio (A/B) obtained is dimensionless and may be called the cerebroventricular index (CV index) of the frontal horns.

To obtain data for normal-sized ventricles, normal CT scans were derived from 50 patients with normal neurological findings whose main complaints were headaches. These 50 normal individuals consisted of 30 males and 20 females, between the ages of 40 and 70 years. The ratio (A/B) varied from 0.23 to 0.4 (mean 0.29 ± 0.04).

The ventricular size of each patient who was subjected to ventricular shunting was defined in the same manner. On the basis of this measurement, the sizes of the ventricles were graded as follows: Grade 1 (normal-sized ventricle) : CV index less than 0.39. Grade 2 (slight ventricular dilatation) : CV index between 0.40 and 0.49. Grade 3 (moderate ventricular dilatation) : CV index between 0.50 and 0.59. Grade 4 (marked ventricular dilatation) : CV index more than 0.6. In two patients, CT cisternography was performed at 6, 12 and 24 h following injection of 9 ml water-soluble contrast material (metrizamide) into the lumbar subarachnoid space.

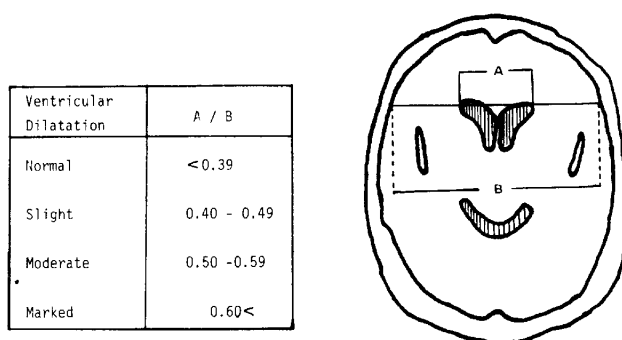


Fig. 1. Schematic drawing for measurements of distance A and B.

Radioisotope cisternography was performed in conjunction with a constant manometric saline infusion test in these 13 patients. Radiopharmaceutical agent, $^{169}\text{Yb-DTPA}$ 1.0 mCi was injected into the subarachnoid space following the lumbar spinal puncture. Serial images were obtained at 4, 24 and 48 h in the lateral and anterior positions with a Toshiba Gamma scintillation camera. The images were evaluated for ventricular entry and stasis of radioisotope.

The infusion test was carried out, as described by Hussey and Katzman (26), by the infusion of normal saline into the lumbar subarachnoid space at the conclusion of the injection of radioisotope. The patient was placed in the lateral recumbent position. The lumbar puncture needle was connected by a flexible plastic catheter to a three-way stopcock. An open-ended manometer stabilized with a clamp or a pressure transducer (Statham p37-A) was attached to this stopcock. The zero level of the manometer was set equal to the horizontal plane through the site of the lumbar puncture. A second flexible catheter connected the stopcock to a 50 ml syringe in a Harvard infusion pump. This syringe and its catheter were filled with sterile saline prior to the lumbar puncture. Then normal saline was infused at 0.76 ml per minute for 40 to 60 min. Pressures were recorded from the manometer in millimeters of CSF. The infusion was stopped when the pressure rose above 500 mm CSF.

Operation. All 13 patients received a ventriculoperitoneal shunting with a low

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pressure Spitz-Holter valve and then were reevaluated at regular intervals. Seven of these 13 cases improved. They were considered improved one month after operation only when the patient was better oriented and regained continence. As to improvement, the mental and sphincteric disturbance was slower and less marked.

RESULTS

A comparative study between each result of the three diagnostic procedures and surgical response was made (Table 1).

TABLE 1. RESULTS OF THE THREE STUDIES AND CEREBROSPINAL FLUID SHUNT

No.	Patient		Isotope convexity block	Infusion test	Dilatation of frontal horn on CT	Surgical outcome
	Age	Sex				
1	50	M	Complete	Abnormal	Slight	Good
2	62	F	"	"	"	"
3	67	F	"	"	"	"
4	43	M	"	"	Moderate	"
5	56	M	"	"	"	"
6	69	M	"	"	"	"
7	22	M	"	"	Marked	"
8	54	M	Incomplete	Normal	Normal	Poor
9	55	F	"	Abnormal	"	"
10	56	M	"	Normal	Slight	"
11	61	M	Complete	Abnormal	"	"
12	49	M	"	"	Moderate	"
13	62	F	Incomplete	"	"	"

Isotope cisternography. All 13 patients who underwent shunting demonstrated ventricular stasis at 48 h. They were further divided into two groups according to the presence or absence of the radioactivity over the cerebral hemispheres. Group I consisted of 9 cases showing a "characteristic" pattern in cisternography which demonstrated no radioactivity over the convexity. Seven (77.8%) of these nine cases made clinical improvement following a shunting procedure. Group II was composed of four cases which had a "mixed" pattern in cisternography demonstrating the radioactivity in the sylvian fissures and/ or over the convexity as well as ventricular stasis. None of these cases had beneficial results from the shunt.

Infusion test. The infusion test was interpreted as abnormal only when the pressure arose above 300mm CSF. Eleven of the 13 shunted patients were abnormal and the remainder normal. Seven (63%) of these 11 cases benefited from shunting, but the remaining 4 with abnormal and 2 with normal test had disappointing results. Nine of the 11 patients with abnormal tests had a "characteristic" pattern in cisternography, and the remaining two cases showed

a "mixed" pattern. Shunting was satisfactory in seven of nine who had both an abnormal infusion test and a "characteristic" pattern.

Computed tomography. Eleven of the 13 shunted cases showed varying degrees of ventricular dilatation. The other two had normal-sized ventricles. These two patients had a "mixed" pattern in cisternography. In addition, this cisternographic finding was also seen in one of five patients with slightly enlarged ventricles and in one of five with moderately dilated ventricles. Nine of the 11 cases with ventricular dilatation showed a "characteristic" pattern, regardless of the degree of ventricular enlargement. Abnormalities in the infusion test were observed in ten of those with ventricular enlargement. A normal infusion test was seen in one patient with slightly enlarged ventricles. One of the two with normal-sized ventricle showed an abnormal infusion test. The other one was normal. The relationship between the degree of ventricular size and surgical results is shown in Table 2. Shunting was satisfactory in seven (63%) of the 11 cases whose ven-

TABLE 2. VENTRICULAR SIZE VS. OPERATIVE RESULTS

Ventricle	Results		
	Good	Poor	Total
Normal	0	2	2
Slight Dilatation	3	2	5
Moderate	3	2	5
Marked	1	0	1
Total	7	6	13

tricles were enlarged to various degrees, but was disappointing in the three with ventricular dilatation and in the two cases with normal-sized ventricles. Surgical results did not correlate well with the degree of ventricular dilatation since shunting was beneficial in three of five cases with slightly enlarged, in three out of five with moderately enlarged and in one with markedly enlarged ventricles.

The correlation between each of the three procedures and the surgical results is summarized here (Table 3). All of the seven patients who had good results from shunting had abnormalities in all three diagnostic studies, namely a "characteristic" pattern (7/9, 77.8%), an abnormal curve in the infusion test (7/11, 63%), and ventricular dilatation (7/11, 63%). Conversely, those who did not benefit from surgery despite abnormalities in all of the three studies consisted of two out of 9 cases with the "characteristic" pattern, four of 11 with abnormal infusion tests and four of eleven with ventricular enlargement on CT.

Alteration of ventricular size in serial CT before and after shunting. In six patients, repeat CT scanning was carried out 10 to 14 days after the initial one to observe the change in ventricular size. In four of them, the ventricular dilatation advanc-

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TABLE 3. SURGICAL RESULTS VS. COMBINATIONS OF FINDINGS IN THE THREE STUDIES

Combination of findings of three studies	Surgical results	
	Good	Poor
Complete convexity block abnormal IT ventricular dilatation	7	2
Incomplete convex. block abnormal IT ventricular dilatation	0	1
Incomplete convex. block normal IT ventricular dilatation	0	1
Normal ventricle	0	2

IT: Saline infusion test

ed by one degree of the grading system of the ventricular size over this periods of time. Each of these four cases were between 42 and 72 days postbleed and had benefited from surgery. The remaining two cases, whose ventricles were unchanged in size, had disappointing surgical outcomes.

In three cases, CT demonstrated a low density area (periventricular hypodensity) in the white matter anterolateral to the frontal horns (Figs. 2, 3). This finding was recognized in cases with slightly, moderately, or markedly enlarged ventricles, respectively (Patients 3, 4 and 7), and was seen 5 to 12 weeks after the latest SAH. All of them had further ventricular dilatation in a repeat CT scan and improved following shunting. In one of them, CT cisternography

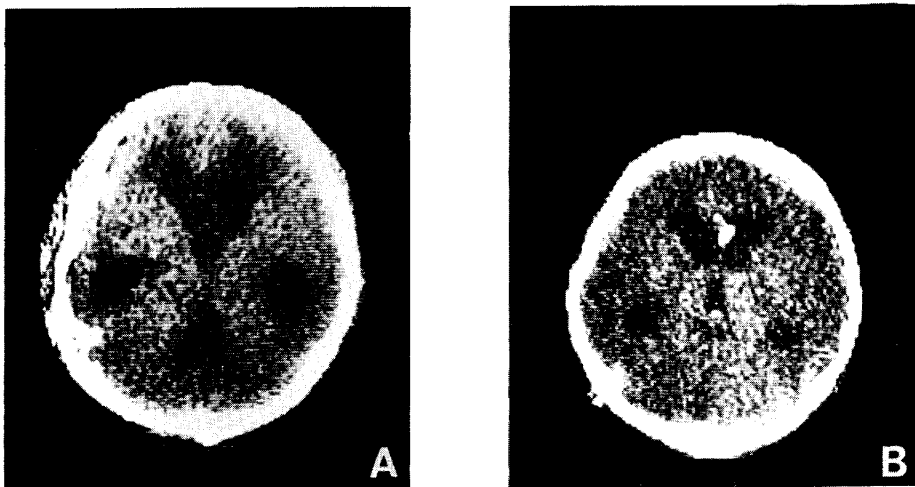


Fig. 2. A 22-year-old male (Patient 7) with an aneurysm of the lt. internal carotid artery. A. 12 weeks after subarachnoid hemorrhage. There is periventricular lucent zone in the anterolateral aspect of the frontal horn. B. 3 weeks after shunting. No lucent zone is noted with regression of the ventricular dilatation.

following metrizamide injection disclosed periventricular hypodensity with retention of the dye within the ventricles (Fig. 3). The hypodense zone had disappeared or decreased markedly in size 3 weeks after shunting. This was associated with improvement of mental status.

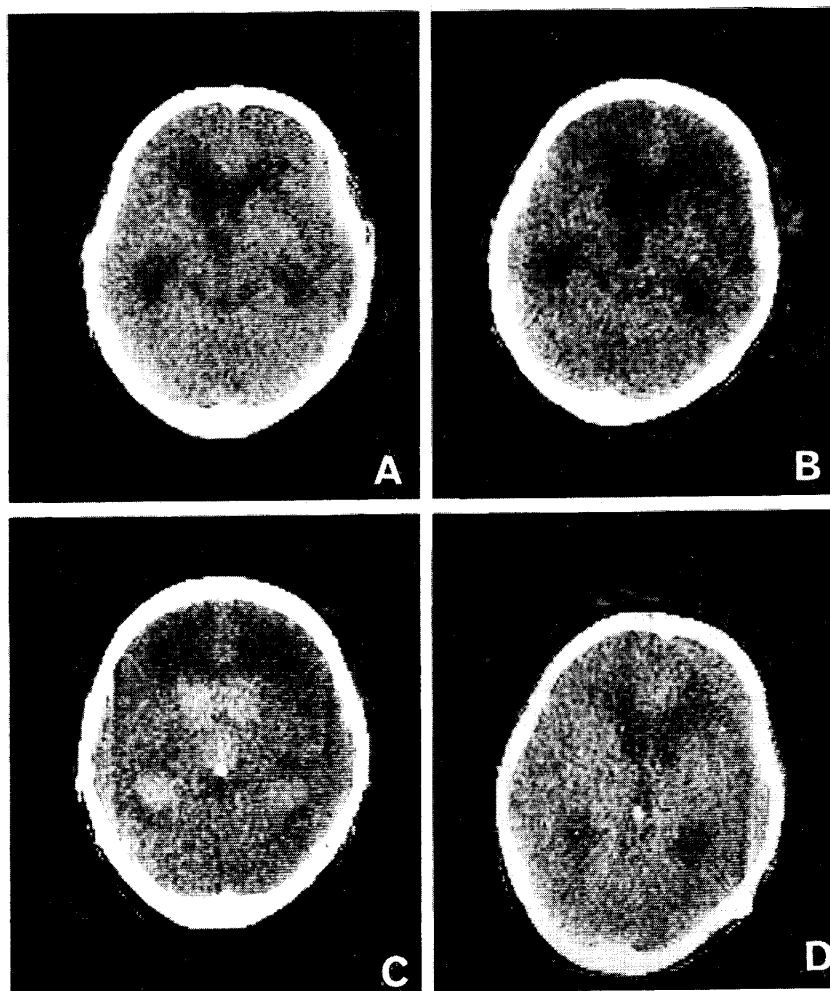


Fig. 3. A 67-year-old female (Patient 3) with an aneurysm of the rt. middle cerebral artery. A. 4 weeks after SAH. B. 5 weeks after SAH. There is marked periventricular hypodensity. C. 6 h. after metrizamide injection. Periventricular hypodensity is well delineated. D. 4 weeks following shunting. The ventricular enlargement and periventricular lucency have regressed.

Postoperative alteration of the ventricular size was evaluated at intervals of one to two weeks in the ten shunted patients (Figs. 4, 5). In seven patients, the postoperative CT scan showed either normal-sized ventricles or a decrease in size when compared with the preoperative scan. In all of them, clinical improvement

was obtained, but tended to lag several days behind the ventricular change. In one of the three cases which did not respond to shunting, the ventricular size returned to normal over the nearly same period as seen in the improved patients. In the remaining two, the ventricles remained enlarged one month thereafter without

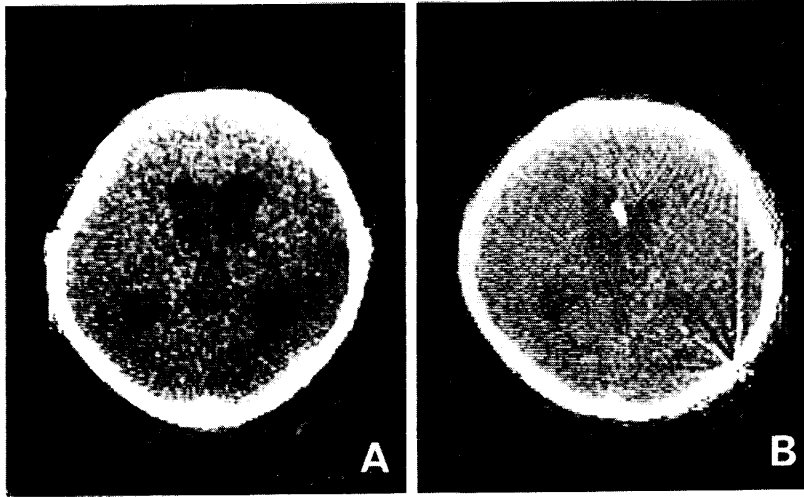


Fig. 4. A 50-year-old male (Patient 1) with an aneurysm of the anterior communicating artery. A. 7 weeks after SAH. The lateral and third ventricles are dilated. B. 8 days after shunting. The ventricular size is decreased.

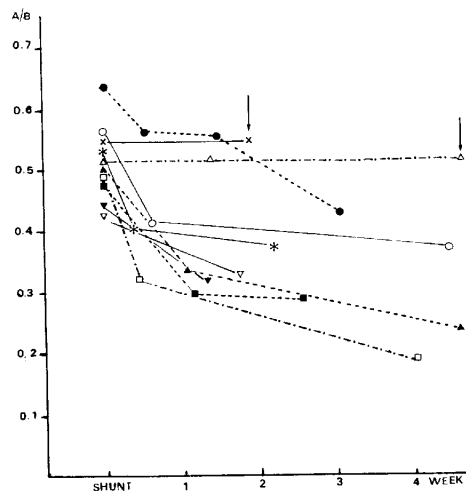


Fig. 5. Postoperative alterations of the ventricular size. Downward arrows indicate a case whose ventricles remained enlarged after surgery.

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evidence of cortical atrophy. During the course of observation, the flushing device of a Holter valve appeared to function well. No subdural collections were detected postoperatively. No shunt revision was required in any patient.

DISCUSSION

It is well known that alterations of CSF circulation follow SAH. Galera and Greitz (10) studied 100 subarachnoid hemorrhage patients in which they used the ventriculocranial index on angiogram to determine ventricular enlargement. A value greater than an index of 0.33 was considered to represent hydrocephalic index. Of the 100 patients, 34 per cent were found to develop enlarged ventricles and 17 of these were found to have a hydrocephalic index. This corresponds with various other series which report an incidence of 10 to 43 per cent (8, 27, 28).

Postsubarachnoid hemorrhage hydrocephalus should be divided into acute and chronic progressive types. Clinical recognition of the acute type of hydrocephalus usually relies on the presence of rapid deterioration of a patient or failure of a patient to improve. This type of hydrocephalus is probably secondary to the collection of blood within the basal cisterns, or occasionally at the outlet foramina of the fourth ventricle (29). The clinical presentation in chronic, progressive communicating hydrocephalus is a very subtle, sometimes nonspecific syndrome, which is frequently attributed to other causes. Yasargil (27) refers to this as the psychoorganic syndrome consisting of disorientation, impaired memory, depressed mental or physical activity, gait disturbance, and fecal and urinary incontinence. Some series (4, 27, 28, 32) have reported akinetic mutism as a part of this syndrome. Many of these symptoms are also present in patients without hydrocephalus following SAH or successful surgical treatment of aneurysm. These may be attributable to brain injury at the time of SAH, at operation or postoperatively to arterial spasm. But in the clinical setting, the physician caring for the patient should proceed to rule out communicating hydrocephalus.

As for the mechanism of producing chronic progressive hydrocephalus, the evidence provided by radioisotope studies, PEG and postmortem studies all seems to point to leptomeningeal fibrosis producing an obstruction of the CSF pathway.

In many cases, the radioisotope cisternographic findings are not clear-cut and some investigators (30, 31) have established less stringent criteria for the diagnosis of the hydrocephalus. These include poor concentration of activity in the parasagittal areas at 24 h and/or delay in the isotope reaching the convexities of the hemispheres. In this series, these criteria did not prove reliable since none of the shunted patients who showed a "mixed" cisternographic finding had satisfactory surgical results. Messert *et al.* (32) and Harris (33) advocated that greater success with shunting is achieved when specific diagnostic criteria are maintained than when less rigid criteria are utilized. Their criterion by cister-

nography includes penetration of the tracer isotope into the lateral ventricles for longer than 48 h associated with little or no activity over the convexity. Their emphasis was confirmed in this study in which only the patients who had a "characteristic" pattern had satisfactory therapeutic results (78%). On the contrary, some authors (14, 15, 27, 34) cast doubt on the usefulness of this radionuclide criterion, pointing out that in their series it did not reliably predict improvement after shunting.

Katzman and associate (26,35) devised a constant infusion manometric test to evaluate CSF absorptive capacity. Normal subjects demonstrated equilibrium pressure of less than 300 mm H₂O, while abnormal pressure responses were indicated by a sharp continuous rise. Their results correlated well with communicating hydrocephalus in infants, but only one adult with occult or normal pressure hydrocephalus was included in their study. Wolinsky *et al.* (25) reported that the infusion test was not useful as a diagnostic aid in evaluation of 22 cases with possible communicating hydrocephalus. In the series of Stein *et al.* (15), of 20 infusion tests in idiopathic normal pressure hydrocephalus, abnormal results were obtained in 16 patients, none of whom responded to shunt. However, Trotter *et al.* (36) found an excellent correlation between abnormal infusion data and ventricular reflux of longer than 48 h on cisternography. They stressed that the previously published poor correlation between the infusion test and other criteria for absorptive defects was caused by failure to recognize artifacts. In the study by DiRocco *et al.* (24), there was a good correlation between abnormal infusion tests and satisfactory surgical results in seven of eleven operated patients, though etiological factors of the hydrocephalus were not clearly stated. In the 20 infusion tests in the series of Symon (14), abnormal infusion tests occurred in only five cases with a definite etiological factor for communicating hydrocephalus; two following meningitis, one following posterior fossa surgery, and one post-traumatic. Of these five abnormal infusion tests, only two showed improvement following shunting. It seems that an abnormal infusion test is likely to occur much more frequently in secondary communicating hydrocephalus than in idiopathic ones. This study indicates that the infusion test has fairly high validity (63%) in diagnosis of this type of hydrocephalus.

CT scan is a noninvasive technique for visualizing the brain, the ventricular system, and the sulci over the cerebral hemispheres. The advantage of CT over PEG is that visualization of the sulci on CT does not depend on filling the sulci with air. Air studies occasionally failed to demonstrate any peripheral cerebral sulci in patients with normal-sized ventricles and even in patients with cerebral atrophy (37). The reason the atrophy is not shown by PEG is obscure. In addition, unlike patients with cerebral atrophy from degenerative disease, patients with normal pressure hydrocephalus occasionally show considerable deterioration following PEG. This may precipitate such patients into coma (38, 39). Serial CT scanings can be carried out with no risk to assess the progress of ventricular

size. Further increase of ventricular dilatation seen by repeated CT scan seems to be a good indicator for ventricular shunting, though only four patients fell into this category in this study.

Ventricular dilatation on CT, regardless of its degree, can be described as 'treatable' communicating hydrocephalus with the same confidence as with an abnormal infusion test. This implies that ventricular dilatation itself is not a precise parameter essential for the expectation of beneficial results from surgical intervention.

Two patients with normal-sized ventricles did not respond to surgery, though two other diagnostic examinations showed varying degrees of abnormalities. This suggests that SAH brings about alterations of CSF circulation and absorptive capacity, and that a negative result of CT scan can simply rule out the diagnosis of hydrocephalus. This means that CT, cisternography and infusion tests are complementary to each other. A correct diagnosis of normal pressure hydrocephalus and a reliable surgical prognosis were obtained in 78 per cent in this series from the combined results of the three examinations. This figure corresponds with the surgical success rate of other investigators (11, 14, 15). This is in agreement with the belief that cases which show a known etiological factor for their hydrocephalus have a much more favorable prognosis than patients in which no such factor can be determined (11, 14, 15). While the presence of an etiological factor is important, equally important is the length of time for which the symptoms have been present. Symon (30) and Ojemann (27) found that the most favorable results were those studied promptly following the development of suggestive clinical features in cases with known etiological factors. They recommend shunt procedures within six months after the onset of symptoms.

Certain pathophysiological changes within the brain substance in hydrocephalus are well demonstrated by CT. Based on a variety of data in humans and experimental animals (40, 41), it is believed that periventricular hypodensity seen on CT represents extension of CSF across an altered or disrupted ependyma into the white matter. It was shown by Milhorat *et al.* (42) that transependymal imigration of tracers is greatly increased in experimental obstructive hydrocephalus. Microscopically under such conditions, the ependymal lining of the ventricles first become thin and then the ependymal cells become separated from one another (40, 41). In these animals, water content in the subependymal white matter increases particularly at the superolateral angle of the ventricles (40, 43) and decreases progressively from the ventricles to the pial surface (44). It is postulated that these morphological changes promote transependymal penetration of fluid into the subependymal white matter (18, 28).

Periventricular lucency on CT was first described by Naidich *et al.* (47) in hydrocephalus of children with an obstructing mass and signs of acutely elevated intracranial pressure. This finding is visible on CT as blurring of the ventricular

margin at the supralateral angle of the frontal horns. This blurring is associated with a contiguous lucent zone which is particularly lucent immediately adjacent to the ventricles and progressively less so peripherally. This lucent zone appears to be confined to the white matter. In three cases of this series, the reduction of periventricular tissue density was indistinguishable from that seen in other types of localized or generalized edema. However, progressively decreased density peripherally on CT is compatible with the fashion of the subependymal edema in experimental hydrocephalus. Mori (48) and Hopkins (49) reported that this hypodensity was observed both in adults and children, regardless of types and causes of hydrocephalus. As seen in this series, this hypodensity is of varying degrees in extent and unrelated to the degree of ventricular dilatation. Although excessive intraventricular pressure is a likely cause, the edema can also occur in patients with normal or slightly increased pressure as seen in this study. In three cases, this finding occurred between five and twelve weeks following SAH, in association with no isotope activity over the convexities by cisternography and abnormal infusion test. The periventricular hypodensity is likely to represent progressively a decompensated absorptive capacity for CSF, probably accompanied by increased intraventricular pressure. These patients deteriorated rapidly over a period of two or three weeks and one of them progressed to akinetic mutism. All patients with this CT appearance responded dramatically to shunting. The lucent zone disappeared or markedly decreased in size several weeks following CSF diversion. These observations indicate that the presence of hypodensity is of great assistance in predicting the outcome of surgery. As described by other authors (47, 49), the periventricular lucency was minimal in long-standing hydrocephalus.

There has been very few reports on the relationship between postoperative ventricular size and clinical response to operation in normal pressure hydrocephalus. Jacob *et al.* (50) found that 40 per cent of improved patients following shunting had ventricles that remained enlarged during the follow-up periods of 2 to 48 months. Their finding is contrary to the present study in which all patients who benefited from surgery had normal or nearly normal ventricles in a few weeks postoperatively, and in which a patient with ventricles still enlarged postoperatively, had a poor prognosis. It is impossible to come to a conclusion in this small experience, but it is felt that patients with postoperative decrease of the ventricles in size might have favorable results in cases of communicating hydrocephalus with known etiologies. Thus, the postoperative CT scan is helpful in determining the anatomical and functional response to shunting and in detecting complications particularly subdural collections, though none of this series had such complication.

A combination of abnormal cisternographic pattern and infusion test associated with ventricular dilatation was seen in two patients who did not respond to ventricular shunting. The presence of these abnormal findings may well

have represented abnormal CSF dynamics, but the failure of surgical shunting in these cases might indicate that hydrocephalus or basic disease process had already created irreversible cerebral damage rather than a wrong diagnosis (25). This suggests that there is still much need for careful prospective study for assessment of brain damage. Careful clinical observation and perhaps serial CT scans are recommended before surgery is considered.

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