Posttraumatic ventriculomegaly: hydrocephalus or atrophy? A new approach for diagnosis using CSF dynamics

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Cerebrospinal fluid (CSF) dynamics were correlated to the changes in ventricular size during the first 3 months post-trauma in patients with severe head injury (Glasgow Coma Scale score ≤ 8, 75 patients) to distinguish between atrophy and hydrocephalus as the two possible causes of posttraumatic ventriculomegaly. Using the bolus injection technique, the baseline intracranial pressure (ICP), pressure volume index, and resistance for CSF absorption (R0) provided a three-dimensional profile of CSF dynamics that was correlated with ventricular size and Glasgow Outcome Scale (GOS) score at 3, 6, and 12 months post-trauma.

Patients were separated into five different groups based on changes in ventricular size, presence of atrophy, and CSF dynamics. Group 1 (normal group, 41.3%) demonstrated normal ventricular size and normal ICP. Group 2 (benign intracranial hypertension group, 14.7%) showed normal ventricular size and elevated ICP. Group 3 (atrophy group, 24%) displayed ventriculomegaly, normal ICP, and normal R0. Group 4 (normal-pressure hydrocephalus group, 9.3%) had ventriculomegaly, normal ICP, and high R0. Group 5 (high-pressure hydrocephalus group, 10.7%) showed ventriculomegaly and elevated ICP with or without high R0. The GOS score in the nonhydrocephalic groups (Groups 1, 2, and 3) was better than in the hydrocephalic groups (Groups 4 and 5). It is concluded from these results that 44% of head injury survivors may develop posttraumatic ventriculomegaly. Posttraumatic hydrocephalus, as identified by abnormal CSF dynamics, was diagnosed in 20% of survivors and their outcome was significantly worse. This study demonstrates the importance of using CSF dynamics as an aid in diagnosis of posttraumatic hydrocephalus and identifying those patients who may benefit from shunt placement.

KEY WORDS • severe head injury • posttraumatic ventriculomegaly • posttraumatic hydrocephalus • frontal horn index • cerebrospinal fluid dynamics • benign intracranial hypertension • normal-pressure hydrocephalus • high-pressure hydrocephalus

The management of ventricular dilation following severe head injury has been controversial because it has been difficult to determine whether posttraumatic ventriculomegaly is related to an atrophic process or to a true hydrocephalus with a cerebrospinal fluid (CSF) absorptive deficit. A wide variety of clinical and radiologic diagnostic criteria have been suggested for posttraumatic hydrocephalus. Consequently, the incidence of posttraumatic hydrocephalus has been reported to be as low as 0.7% or 1.5% and as high as 29%. Furthermore, the accuracy of computerized tomography (CT) scanning in determining the underlying cause(s) of posttraumatic ventriculomegaly, namely atrophy and/or hydrocephalus, has been uncertain. As a result, the response of patients with posttraumatic hydrocephalus to CSF shunting procedures has been difficult to predict, and, generally, the results of CSF diversion in these patients have not been encouraging.

Over the past two decades, CSF dynamics studies have proven to be beneficial in establishing the diagnosis of normal-pressure hydrocephalus. Some authors have indicated the importance of obtaining a measurement of the CSF pressure in making the decision to perform CSF shunting in patients with posttraumatic hydrocephalus. In the present work, CSF dynamics studies were conducted in the early and late phases of severe head injury to describe the course of recovery of CSF dynamics and to outline the profile of CSF biomechanical characteristics in patients with posttraumatic ventriculomegaly. A third objective was to determine the usefulness of CSF dynamics studies as an adjunctive tool to CT for the diagnosis of posttraumatic hydrocephalus.

Clinical Material and Methods

Patient Population

Two hundred thirty-seven patients with severe head injury (Glasgow Coma Scale (GCS) score ≤ 8 on admission) were eligible for this study, which was conducted...
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according to procedures approved by the internal review board. One hundred eighty patients were male and 57 were female. All patients included in the study underwent an early CT scan on admission and early CSF dynamics studies. The CSF studies were performed via the ventricular catheter used for intracranial pressure (ICP) measurement on a daily basis during the first 5 days posttrauma and chronic studies were performed via lumbar puncture.

The study was designed so that CT scans and CSF dynamics studies would be performed on a monthly basis for 3 consecutive months posttrauma for all survivors. However, of 157 survivors at 1 month, late CT and CSF dynamics studies could only be performed in 75 patients (studied group). The majority of patients who could not be studied (nonstudied group) were discharged prior to 1 month or transferred to other rehabilitation centers, and another small group refused the CSF dynamics studies.

Computerized Tomography Evaluation

The admission CT scan was examined for the presence of one or more of the following findings: 1) brain contusion and/or subdural hemorrhage; 2) subarachnoid and/or intraventricular hemorrhage (IVH); and 3) diffuse brain swelling.

Kosteljantzet and Ingstrup demonstrated that ventricular size and the frontal horn index, or Evans’ ratio, were highly correlated. In the current study, we used the frontal horn index, which is the ratio between the widest span of the frontal horns to the maximum width of the brain in the same axial CT section, as a representative of the ventricular size. Ventricular size was considered to be dilated if the frontal horn index equaled or exceeded 0.3. The frontal horn index was calculated using the admission CT and the follow-up CT scans were obtained 1, 2, and 3 months after trauma. In addition, follow-up scans were studied for the presence of periventricular translucency and/or abnormally dilated cisterns and sulci.

Cerebrospinal Fluid Dynamics Studies

Follow-up CSF dynamics studies (conducted 1–3 months after trauma) were performed via a lumbar puncture with the patient placed in the lateral decubitus position. Mild sedation was used for the more severely injured patients. The spinal needle was connected via a pressure tube and a three-way stopcock to a syringe and a transducer. The latter was connected to a pressure monitor. A four-channel MacLab hard drive (Analog Digital Instruments Pty Ltd., Castle Hill, Australia) was used to transfer the pressure waves from the monitor to a Macintosh computer (model SE/30; Apple Computer, Inc., Cupertino, CA) to monitor, record, and accurately analyze the CSF pressure changes. Pressure was calibrated in the pressure monitor and in the Macintosh computer and zeroed at the level of the needle site before starting the pressure recording.

First, the baseline ICP was recorded. The ICP was considered to be elevated if it was equal to or greater than 15 mm Hg. Then, using the bolus injection technique, the pressure volume index (PVI) and the resistance for CSF absorption (R0) were calculated. A 2- to 5-ml injection of saline was administered at a rate of 1 ml/second. After each injection, three CSF pressures were measured: the baseline pressure just before injection (P0), the maximum pressure immediately after injection (Pp), and the pressure after a time (t) from the injection (Pt). Then PVI was calculated using the following equation:

\[ PVI = \frac{dv}{log(P0/Pp)} \]

The R0 was calculated from the following equation:

\[ R0 = \frac{P0}{PVI \times \log \left( \frac{Pp}{P0} \times \frac{(Pp - P0)}{(Pt - P0)} \right)} \]

The R0 was considered to be elevated if it was higher than 6 mm Hg/ml/minute. The average values of the PVI and R0 were calculated for each patient. Using these methods, the temporal courses of frontal horn index, baseline ICP, PVI, and R0 were investigated for the first 3 months posttrauma.

Clinical Follow Up

The outcome of patients was determined at 3, 6, and 12 months and graded according to the Glasgow Outcome Scale (GOS) in the following categories: good recovery, moderate disability, severe disability, persistent vegetative state, and death. For statistical purposes, the outcomes were assigned a score from 0 to 4 ranging from good recovery to death, respectively.

Statistical Analysis

The Student t-test was used for comparisons of age, severity of injury (calculated using the GCS), clinical outcome (calculated using the GOS), ventricular size (frontal horn index), and CSF dynamics parameters (baseline ICP, PVI, and R0) in different groups. A probability value of less than 0.05 was considered statistically significant. Also, correlation coefficients were calculated and examined to determine the dependence of clinical outcome on ventricular size, age of patients, and severity of injury.

Results

Patient Population

Of 237 patients included in this study, 80 (33.8%) died within 1 month posttrauma and the mortality rate increased to 39.7% by 1 year posttrauma. Patient age and severity of injury (admission GCS score) were poorly correlated with 3-, 6-, or 12-month GOS scores. The incidence of favorable outcome in survivors (good recovery and moderate disability) increased from 41% at 3 months to 71.5% at 12-month follow-up review, whereas the incidence of unfavorable outcome (severe disability and persistent vegetative state) decreased from 54% to 22.2% during the same period. Furthermore, the age and severity of injury in the studied group were not significantly different from those in the nonstudied group. However, the GOS scores at 3, 6, and 12 months in the studied group were significantly worse than those of the nonstudied patients (p = 0.046, 0.014, and 0.017, respectively; Table 1).

Classification According to CT Findings

The findings on admission CT scans in the studied group of patients are shown in Table 2. The studied group of 75 patients was separated into hydrocephalic and non-hydrocephalic groups according to the measured frontal horn index of the 1-month follow-up CT scan: Set 1
included those patients with normal ventricles (frontal horn index < 0.3, 42 patients (56%)), and Set II included those patients with ventricular dilation (frontal horn index ≥ 0.3, 33 patients (44%)). The gender distribution of Set I was 32 males and 10 females, and in Set II, 27 males and six females. The patient age in the group of patients who developed ventriculomegaly (Set II) was 33.7 ± 16.9 years (mean ± standard deviation) and severity of injury (GCS score) was 5.4 ± 1.4. Age and GCS scores were not significantly different from those in patients with normal ventricular size (Set I, 30.2 ± 13.4 years and GCS, 5.5 ± 1.3, respectively).

The average ventricular size (frontal horn index) in Set II (ventriculomegaly group) continued to be significantly larger than that in Set I in the first 3 months of follow-up review posttrauma. However, the degree of ventricular dilation in Set II progressed in 18 patients (54.5%), was stationary in 12 (36.4%), and slightly decreased, but did not return to normal in three (9.1%).

Analysis of the admission CT scan showed that brain edema was a frequent finding in Set I (61.6%), followed by brain contusion (33.3%), whereas subarachnoid hemorrhage (SAH) was uncommon (9.5%). In Set II, brain edema, brain contusion, and SAH were equally observed in 48.5% of the patients.

The outcome at 3, 6, or 12 months in Set I was generally more favorable than that in Set II; however, the difference in outcome in both groups was statistically significant at 6 months (p = 0.016) but not at 3 or 12 months.

Classification According to CT and CSF Dynamic Characterization

The studied group of 75 patients was separated into five groups according to the ventricular size (frontal horn index), baseline ICP, and R0 measured 1 month posttrauma: Group 1 (normal, 31 patients (41.3%)) included patients with normal ventricular size and normal ICP. Group 2 (benign intracranial hypertension, 11 patients (14.7%)) included patients with normal ventricular size and high ICP. Group 3 (atrophy, 18 patients (24%)) included patients with ventriculomegaly, normal ICP, and normal R0. Group 4 (normal-pressure hydrocephalus, seven patients (9.3%)) included patients with ventriculomegaly, normal ICP, and normal R0. Group 5 (high-pressure hydrocephalus, eight patients (10.7%)) included patients with ventriculomegaly and high ICP with or without high R0 (Fig. 1).

Characteristics of Different Groups

Age. The mean age in Group 1 was significantly lower than that in Groups 2, 3, or 4 (p = 0.007, 0.028, and 0.0001, respectively), but not significantly different from the age in Group 5.

| TABLE 1
| Changes in outcome during the 1st year posttrauma in 157 survivors of severe head injury |
| --- | --- | --- | --- | --- | --- |
| | 3 Mos | 6 Mos | 12 Mos |
| Favorable | Unfavorable | Favorable | Unfavorable | Favorable | Unfavorable |
| total survivors after 1 mo | 40.9 | 59.1 | 59.2 | 40.8 | 70.0 | 30.0 |
| nonstudied group (82 patients) | 51.4 † | 48.6 | 74.0 † † | 26.0 | 80.0 † † † | 20.0 |
| studied group (75 patients) | 30.7 | 69.1 | 44.0 | 56.0 | 60.0 | 40.0 |
| nonhydrocephalic (60 patients) | 36.7 † † | 63.3 | 50.8 † † | 49.2 | 66.7 † † † | 33.3 |
| hydrocephalic (15 patients) | 6.7 | 93.3 | 20.0 | 80.0 | 33.3 | 66.7 |

* Significant at p = 0.0006; † † p = 0.036, as compared to the studied group.

| TABLE 2
| Incidence of early admission CT findings in 75 patients undergoing CSF dynamics studies* |
| --- | --- |
| Finding | No. of Patients (%) |
| brain edema | 41 (54.7) |
| contusion and/or subdural hemorrhage | 29 (38.7) |
| subarachnoid and/or intraventricular hemorrhage | 20 (26.7) |

* More than one finding was observed in the same patients. Abbreviations: CSF = cerebrospinal fluid; CT = computerized tomography.

| TABLE 3
| Findings on CT scans in the five groups of patients classified according to diagnosis* |
| --- | --- | --- | --- | --- |
| Finding on CT Scan | Normal (31 patients) | BIH (11 patients) | Atrophy (18 patients) | NPH (7 patients) | HPH (8 patients) |
| enlarged ventricle | no | no | yes | yes | yes |
| brain edema | 71.0 | 45.5 | 38.9 | 53.0 | 53.0 |
| contusion | 30.5 | 45.5 | 55.6 | 33.3 | 33.3 |
| SAH | 6.5 | 18.2 | 33.3 | 66.7 † | 66.7 † † |

* BIH = benign intracranial hypertension; CT = computerized tomography; HPH = high-pressure hydrocephalus; NPH = normal-pressure hydrocephalus; SAH = subarachnoid hemorrhage.
† Significant at p = 0.0009 and † † p = 0.002, as compared to normal group.

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Severity of Injury. The severity of injury according to GCS score was not statistically different in the five groups. However, the findings on admission CT scans differed between groups (Table 3). In Group 1, brain edema was observed in 71%, brain contusion in 30.5%, and SAH in only 6.5% of patients. The presence of SAH on CT scans of both hydrocephalic groups (Groups 4 and 5) compared to the normal group was statistically significant (p = 0.0009 and 0.0002, respectively). In Group 2, brain edema and contusions were observed in 45.5% and SAH in only 18.2% of patients. In Group 3, brain contusion was the most common finding (55.6%), followed by brain edema (38.9%) and SAH in 33.3% of patients. Moreover, SAH was the most common finding in the two hydrocephalic groups (Groups 4 and 5) (66.7%) whereas brain edema was observed in 53% and brain contusion in only 33.3% of patients.

Progression of Ventricular Dilation. At 1 month posttrauma, the degree of ventricular dilation in Group 3 was not significantly different from that in Groups 4 and 5 (Fig. 2). By 2 months posttrauma, a progressive increase in the degree of ventricular dilation was observed in Groups 4 and 5, which was highly significant (p = 0.0004), but was not observed in Group 3. As time progressed, the ventricular size in Groups 4 and 5 became significantly larger than that in Group 3 (p = 0.046). By 3 months, no further increase in ventricular size was noted in any of these groups (Fig. 3). In all groups, age and severity of injury (admission GCS score) were poorly correlated with ventricular size (frontal horn index).

The observed incidence of dilated sulci and cisterns in the follow-up CT scans increased over time in all groups. The observed incidence of dilated cisterns in Group 3 was similar to that in Groups 4 and 5. On the other hand, periventricular translucency was observed more frequently in Groups 4 and 5 (40%) than in Group 3 (20%).

Characterization of CSF Dynamics

The baseline ICP was above normal in all groups, with the highest ICP levels observed in Group 5 during the first 5 days postinjury. The baseline ICP was not statistically different in the five groups. However, the ICP remained elevated during the 3 months of follow-up review in Group 5 patients (Fig. 5A). The ICP in Group 2 was found to be elevated in the first 2 months posttrauma but returned to normal at 3 months posttrauma. In contrast, patients in Group 5 maintained an elevated baseline ICP during the 3 months of follow-up review (Fig. 5A).

Pressure Volume Index

No significant difference was observed between PVI values of the five groups during the first 2 months posttrauma. However, at 3 months posttrauma, PVI was found to increase in Group 3 and to a lesser degree in Group 5. These changes were not found to be significantly different from PVI levels in other groups. Interestingly, PVI in Group 4 showed a trend of gradual decrease over the 3-month study period (Fig. 5B).

Cerebrospinal Fluid Absorption Resistance

With the exception of Group 5, R0 was elevated (> 6 mm Hg/ml/minute) in all groups during the first 5 days posttrauma. The R0 of Group 5 did not show a consistent trend and was found to be normal by the 1st month, elevated by the 2nd month, and normal by the 3rd month posttrauma. The R0 of Groups 1 and 3 was initially elevated but returned to normal values as early as 1 month posttrauma.

In the first 2 months posttrauma, R0 was found to be significantly elevated (compared to that in the normal group) in Group 2 (p = 0.016 and 0.012, respectively) and in Group 4 (p = 0.005 and 0.001, respectively). By the 3rd month posttrauma, R0 returned to normal values in Group 2 but continued to be elevated in Group 4 (Fig. 5C).

In two patients (25%) in Group 5, the baseline ICP returned to normal values by the 3rd month posttrauma, whereas the R0 remained elevated, and both were associated with progressive ventricular dilation, signifying a change in classification from high-pressure to normal-pressure hydrocephalus.

Clinical Outcome (GOS Score)

At follow-up review, no significant difference could be observed between the clinical outcomes (GOS scores at 3, 6, or 12 months) in the three nonhydrocephalic groups (Groups 1–3). In comparison, the outcome at 3, 6, and 12 months of the nonhydrocephalic groups was significantly better than that of the hydrocephalic groups (Groups 4 and 5) (p = 0.006, 0.002, and 0.0036 respectively). The outcome of the two hydrocephalic groups was not significantly different.

Posttraumatic Hydrocephalus and Ventriculomegaly in Patients With SAH

Subarachnoid hemorrhage was observed in 20 patients (26.7%) on initial CT scans. Of those patients who had SAH, 80% developed posttraumatic ventriculomegaly, but...
only 50% of this group exhibited changes in CSF dynamics characteristic of hydrocephalus (Groups 4 and 5). On the other hand, of those patients who did not have SAH, 30.8% developed posttraumatic ventriculomegaly and only 9.1% had the CSF dynamics changes suggestive of posttraumatic hydrocephalus.

Subarachnoid Hemorrhage and Outcome

The outcome at 3, 6, and 12 months in patients with SAH was significantly worse than that in patients without SAH \((p = 0.01, 0.006, \text{ and } 0.003 \text{ respectively})\). In nonhydrocephalic groups, the 1-year outcome in patients with SAH was significantly worse than that in patients without SAH \((p = 0.03)\). On the other hand, no significant difference was observed between outcome in patients in the hydrocephalic groups with or without SAH.

Discussion

Although CT scanning has greatly facilitated the detection of posttraumatic ventriculomegaly, its limited ability to reveal the underlying cause(s) of ventricular dilation has created a medical and ethical controversy. On one hand, the correction of the hydrocephalic process should improve morbidity and offer the maximum opportunity of recovery for those patients. On the other hand, the usefulness of CSF shunting has been doubtful because it has been difficult to relate the ensuing ventricular dilation to a true hydrocephalic process or to determine the degree to which hydrocephalus contributes to the neurological deficits seen in survivors of head injury. This study demonstrates that approximately 45% of patients with posttraumatic ventriculomegaly have CSF dynamic changes characteristic of hydrocephalus, and these patients have the worst outcome among survivors of head injury. We found that the diagnosis of posttraumatic hydrocephalus in survivors of head injury can be determined by a combination of CT and CSF dynamics criteria, preferably at 1 month postinjury, thereby providing an opportunity for shunt diversion and the potential for improving outcome.

Patient Population: Outcome

The mortality and morbidity incidence in this series was
similar to that previously reported by the Traumatic Coma Data Bank investigators. Our data also support the notion that clinical improvement, based on the percentage of patients with good to moderate outcome, is greatest during the first 6 months posttrauma and recovery is much slower thereafter. Although the age and severity of injury (admission GCS score) in the nonstudied and studied groups were not significantly different, it is not clear why the outcome in the nonstudied group was significantly more favorable than that in the studied cohort. We surmised that patients with better outcome would tend to be discharged from our facility and therefore would account for the difference in the study group. However, our findings still represent a failure of GCS score and age to predict outcome in this group.

Computerized Tomography and Posttraumatic Ventriculomegaly

The incidence of posttraumatic ventriculomegaly in our study was similar to that reported by other investigators. Ventricular dilation was observed as early as 7 to 8 hours after severe head injury and it was evident within 2 weeks posttrauma in more than 93% of patients who developed posttraumatic ventriculomegaly. In all patients with posttraumatic ventriculomegaly (atrophic or hydrocephalic) in our series, ventricular dilation was evident by 1 month postinjury. The highest incidence of posttraumatic hydrocephalus was evident at 2 months and reached a plateau thereafter, an observation similar to that reported by others. These observations indicate that ventricular dilation will most probably develop during the 1st month after severe head trauma and the diagnosis of posttraumatic hydrocephalus by serial CT measurements of ventricular size alone would be unreliable because progressive ventricular dilation was observed not only in patients with posttraumatic hydrocephalus but also in patients with posttraumatic brain atrophy.

Specificity of CT Criteria in the Diagnosis of Posttraumatic Hydrocephalus

The diagnosis of posttraumatic hydrocephalus by CT criteria was introduced by Gudeman and associates. These criteria included the distended appearance of the anterior horns of the lateral ventricles and the enlargement of the temporal horns and third ventricle in the presence of normal or absent sulci. Periventricular translucency was considered as confirming evidence. In our series, dilated
temporal horns were observed in only seven of 15 patients with posttraumatic hydrocephalus and in one-third of patients with brain atrophy. In addition, third and fourth ventricular dilation was observed not only in patients with posttraumatic hydrocephalus, but also in the majority of patients with brain atrophy. These findings are similar to those reported by others. Furthermore, our results and those of others indicated that the presence of periventricular translucency was not limited to patients with posttraumatic hydrocephalus, but was also found in patients with brain atrophy. Thus, it is not clear if periventricular hypodensity represents a hydrocephalic transventricular edema or an atriotic process secondary to diffuse axonal injury as observed in other reports and the question requires further investigation. Moreover, these observations question the specificity of the criteria suggested by Gudeman and colleagues as diagnostic features of posttraumatic hydrocephalus.

Late CSF Biomechanical Characterization of Severe Head Injury

Early CSF dynamics studies of patients with severe head injury are characterized by significantly elevated baseline ICP and R0. The temporal course of CSF dynamics studies in our study, coupled with the changes in ventricular size, showed that five groups with different CSF dynamics characterizations could be identified.

Normal (Group 1). In this group, representing 41.3% of the study population, the baseline ICP, PVI, and R0 returned to normal values by 1 month posttrauma and ventricles were of normal size. We suggest that the normalization of CSF dynamics and ventricular size in this group could be explained by the lower incidence of SAH and brain contusion evident on initial CT scans. Also, the lack of a significant difference in severity of injury or outcome between this and the remainder of the nonhydrocephalic groups attests to the low sensitivity of CT parameters in detecting the severity of the pathological changes of diffuse axonal injury.

Benign Increased ICP (Group 2). An elevated baseline ICP, high R0, and normal PVI was associated with Group 2, which comprised 14.7% of the study population, and these findings were identical to those reported by others in patients with benign increased ICP. The development of late papilledema at 2 weeks posttrauma in patients with severe head injury and normal ventricular size was also reported by Selhorst, et al., but unfortunately, ICP was not recorded. However, papilledema resolution, which occurred approximately 3 months posttrauma in the Selhorst study, matched the time at which the elevated ICP and R0 of our group with benign intracranial hypertension returned to normal.

Cause of Benign Intracranial Hypertension. We speculate along with Portnoy, et al., that the benign elevation of ICP is caused by an increase in the dural sinus pressure (downstream of the so-called Starling resistor at the level of lateral lacunae), thereby affecting the venous outflow impedance. In an earlier report, we documented the presence of an elevated venous outflow pressure in a group of patients with severe head injury. The vascular contribution to ICP elevation in this group of patients (86.5%) was significantly higher than that observed in others with severe head injury. The reason for the elevation of venous outflow pressure in patients with severe head injury is still speculative. Also, whether this late elevation in ICP and R0 is simply a continuation of the early disturbance of CSF dynamics in severe head injury, or a representation of the syndrome of pseudotumor cerebri, deserves further investigation because we posit that this state of prolonged
ICP elevation would have detrimental effects on a brain that is already compromised by severe mechanical injury.

**Brain Atrophy (Group 3).** Ventricular dilation in patients with an associated progressive enhancement of PVI, together with normal ICP and R0, represented 24% of the study group. We suggest that the changes in CSF dynamics and ventricular size in this group could be explained on the basis of the relatively higher incidence of brain contusion together with the low incidence of SAH observed in the early CT scans. The GCS score on admission and the GOS score in the atrophic group were not significantly different from those in the other nonhydrocephalic groups. This is consistent with our observations in an earlier experimental study that there were no differences between the severity of histopathological changes in animals that developed posttraumatic ventriculomegaly and changes in animals with normal ventricles after severe head trauma.15 In addition, the animals with posttraumatic ventriculomegaly exhibited normal CSF dynamics.

**Normal-Pressure Hydrocephalus (Group 4).** Posttraumatic ventriculomegaly in this group of patients (9.3% of the study group) was associated with a normal baseline ICP and high R0 together with a progressively decreasing PVI. The CSF dynamics characteristics in this group were identical to those reported by others in patients with normal-pressure hydrocephalus.7,53,54 Thus, the presence of normal baseline ICP cannot preclude the possibility of an active hydrocephalic process. Several reports demonstrated clinical improvement after shunt placement in patients with posttraumatic hydrocephalus and normal ICP.26,34,35,43,45

The important factor in the diagnosis of normal-pressure hydrocephalus in this study has been the presence of an elevated R0. Several authors considered the presence of elevated R0 as the most important finding in the diagnosis of normal-pressure hydrocephalus and also as a good predictor of improvement after CSF shunting.4,5,7,18,19,26,30,31 In contrast to CSF absorption in patients with high-pressure hydrocephalus, CSF absorption in patients with normal-pressure hydrocephalus occurs at normal levels of ICP, but opposed by an abnormally elevated R0.

The causes underlying the decreased PVI in this group of patients are not clear. We suggest that it may be related to the exhaustion of compensatory mechanisms for CSF absorption at normal ICP levels, which renders these patients more liable to periodic pressure fluctuations (B waves), as was observed by other investigators during continuous IPC monitoring of patients with normal-pressure hydrocephalus.5,21,51

**High-Pressure Hydrocephalus (Group 5).** Ventricular dilation in this group, representing 10.7% of studied patients, was accompanied by an elevated baseline ICP, but with variable R0 and normal PVI. The importance of detecting an elevated baseline ICP in the management of posttraumatic hydrocephalus has been repeatedly emphasized by several authors.3,6,26,33-35,48,57 However, the presence of normal R0 in this group of patients could be misinterpreted. The major pathophysiological finding of the CSF dynamics in this group would be the presence of an absorption pressure that is significantly higher than normal. Above this elevated absorption pressure, the R0 is within the normal range and the rate of CSF absorption is also normal. Thus, CSF absorption does occur at normal rates in this group of patients but at higher levels of ICP than that in normal individuals.

**Posttraumatic Ventriculomegaly and Outcome**

Our results support the notion that the outcome of patients with posttraumatic ventriculomegaly, found in 44% of the study population, is less favorable than in patients with normal ventricles.5,25,30,35,50 Interestingly, the outcome of patients with ventriculomegaly and normal CSF dynamics, classified as the atrophic group, was not significantly different from the outcome of patients with normal ventricles or, for that matter, the entire survivor group. However, patients classified as hydrocephalic, presenting with elevated ICP and/or high R0, had the poorest outcome among all survivors. Thus, on the basis of our findings, the presence of ventriculomegaly is not an indication of poor prognosis unless it is associated with abnormal CSF dynamics. At our institution, four of the 15 patients diagnosed as hydrocephalic underwent shunt placement during the course of this study, and each patient improved one GOS grade. Three patients were diagnosed with high-pressure hydrocephalus and one with normal-pressure hydrocephalus. These data are few, and a well-controlled multicenter study with an appropriate control group would be necessary to test the prognostic accuracy of these methods, specifically with regard to outcome following shunt placement.

**Subarachnoid Hemorrhage, Posttraumatic Hydrocephalus, and Outcome**

The results of this study and others6 emphasize the importance of SAH detected on the admission CT scan as a warning sign for the development of posttraumatic hydrocephalus. In our study, more than 70% of those patients who developed posttraumatic hydrocephalus demonstrated SAH and/or IVH on their admission CT scan, in contrast to 16% in other groups. Our results also support the notion that patients with head injury will have a worse outcome should they develop posttraumatic SAH12,49 or IVH.17,32 The association of poor outcome with SAH was related by other investigators to the development of posttraumatic arterial vasospasm similar to that observed in spontaneous SAH,13,41 whereas the association of poor outcome with IVH was related to the higher incidence of associated space-occupying lesions.17,32

The outcome of nonhydrocephalic patients with SAH was more favorable than that of hydrocephalic patients whether or not SAH was present. However, among hydrocephalic patients, outcomes were similar among those with and without SAH. We infer from these observations that an active hydrocephalic process plays a major role in worsening the outcome in patients with severe head injury.

**A New Approach for the Diagnosis of Posttraumatic Hydrocephalus**

Data from the current study suggest a simple scheme for the diagnosis of posttraumatic hydrocephalus using the CT scan and CSF dynamics testing. Ideally, these studies should be performed at 1 month posttrauma, or earlier if
the patient’s neurological condition deteriorates. The suggested procedure is as follows: 1) measure the frontal horn index from the CT scan and if the index is greater than 0.3, CSF dynamics studies should be performed via a lumbar puncture. 2) A lumbar pressure equal to or greater than 15 mm Hg, independent of absorption resistance, indicates a high-pressure hydrocephalus and shunt placement is recommended. 3) A pressure less than 15 mm Hg with R0 equal to or greater than 6.0 mm Hg/ml/minute indicates a normal-pressure hydrocephalus and shunt placement is recommended. 4) A normal pressure and outflow resistance indicates a postransmural ventriculomegaly secondary to an atrophic process and patients are unlikely to benefit from shunt placement.

Conclusions

A new approach using CT and CSF dynamics studies has been developed for the diagnosis of postransmural hydrocephalus in patients with head injury. Serial CSF dynamics studies conducted at 1, 2, and 3 months post-trauma have shown that benign intracranial hypertension, high-pressure hydrocephalus, and normal-pressure hydrocephalus could develop in survivors of severe head injury. With correct diagnosis, CSF diversion in patients with postransmural hydrocephalus would provide the maximum opportunity for an improved recovery.

References

Posttraumatic ventriculomegaly: diagnosis by CSF dynamics


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