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Idiopathic Normal Pressure Hydrocephalus: Analysis of Factors Related to Cerebrospinal Fluid Dynamics Determining Functional Prognosis

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Summary

This investigation has been undertaken to analyze the findings with both the cerebrospinal fluid (CSF) pressure (Pcsf) and CSF pulse pressure (PP) in order to predict the outcome of patients with the syndrome of idiopathic normal pressure hydrocephalus (NPH). Accordingly, a prospective clinical study was planned in which two groups of patients with NPH, having analogous prevalence of several matched clinical and radiological parameters, were separated on the basis of their positive or negative response to shunting. Both the resting Pcsf and CSF PP profiles were compared in these two groups, and between them and normal controls. CSF PP amplitude and CSF PP latency correlated directly in conditions associated with either normal or high compliance (controls and patients with Alzheimer-like disorders), whereas this correlation was inverse in states of low compliance (NPH). On the other hand, shunt-responders showed a resting Pcsf significantly higher than both non-responders and controls.

The following conclusions were obtained: 1) CSF PP is a high-amplitude and relative low-latency wave in NPH when compared with controls; 2) CSF PP amplitude and latency correlate directly in normal subjects and in those with primary cerebral atrophy; 3) a non-reversible stage of NPH could be conceived in contradistinction to the reversible one, in both of which an inverse correlation between the amplitude and the latency takes place, the main difference between them being the resting Pcsf, which is significantly lower in the former than in the latter, depending on the degree of atrophic changes developed.

Keywords: Cerebrospinal pulse pressure; intracranial pressure; normal pressure hydrocephalus.

Introduction

A reduced cerebrospinal fluid (CSF) outflow conductance is often an important pathogenetic factor in normal pressure hydrocephalus (NPH) [1, 9, 12, 29]. This low-conductance value may determine a hyperdynamic CSF state, defined by high-amplitude and low-latency CSF pulse pressure (PP) waves when compared with normal subjects [2–5, 17]. This undamped waveform reflects the reduction in intracranial compliance due both to a diminished cerebral venous venting capability and to a maximal CSF space distention [4]. Such a hyperdynamic state could result in CSF spreading into the peri-ependymal regions [15, 16] and in abnormally high interstitial periventricular pressure [2, 8, 10]. The analysis of CSF PP alone, however, failed to identify the patients with the syndrome of NPH prone to improve with CSF shunting [5, 13].

One possible explanation for this CSF PP-based prediction failure includes the fact that a non-reversible stage for this condition would have been reached. In this regard, the increased peri-ependymal pressure, applied on the wall of Sylvian perforator arteries, would be the factor responsible for the periventricular watershed zone to undergo ischaemia and infarction [2]. Hence, if the early stages of NPH of long standing are left untreated, the subsequent decrease in total cerebral blood flow may cause demyelinization, fibrogliotic scarring around the infarcted areas and marked brain atrophy resulting in stiffness of deep brain structures [4, 18, 19, 21, 22], thus precluding any possibility of clinical improvement [2]. Accordingly, we hypothesize that CSF pressure (Pcsf) should be lower in this stage than before brain atrophy develops, but high-amplitude and low-latency CSF PP waves are present both in reversible and non-reversible stages of NPH because of the brain stiffness. On this basis, we have performed a prospective clinical study to assess whether the lumbar CSF PP in association with the resting Pcsf consitute reliable parameters for identifying the clinically reversible stages of NPH, and if so, to improve the selection of candidates for CSF diversion.

Methods and Patients

Patient Population and Inclusion Criteria

The present study includes 30 cases selected from a series of 41 patients with the syndrome of NPH who were studied in our department from October 1988 to March 1994.

The diagnosis of NPH syndrome was based on the following progressive clinical symptoms and signs:

1) Mental impairment; 2) Gait apraxia and/or ataxia; and 3) Urinary dyscontrol without other recognized spinal or urological potential causes. Additional criteria consisted of absence of previous subarachnoid haemorrhage, a measured Evans index of 0.3 or greater on the computerized tomographic (CT) scan, and a resting Pcsf of 15 mmHg or lower.

All patients eventually underwent CSF shunting by means of a ventriculoperitoneal valve system with opening pressure in the range of 51–110 mm H_2O (*Pudenz ventriculoperitoneal shunt system, supplied by Baxter Healthcare Co., V. Mueller, Illinois, U.S.A.*).

Fourteen individuals without symptoms of dementia (group B) were randomly selected from a pool of 45 patients with symptomatic protruded lumbar discs in order to make a control group composed of past history antecedents similarly distributed in relation with NPH patients. CSF dynamics in group B were studied by lumbar route immediately before a myelographic examination was performed.

Written permission was obtained from the patients or their relatives for the study and treatment to be done.

Study Protocol

Patients presenting with the syndrome of NPH were separated into two groups depending on whether or not they improved following CSF shunting (group AR and group AnR, respectively). These groups were paired for several matched variables, obtained from the clinical and radiological data, and the study of CSF dynamics.

Clinical data. Clincial variables included: 1) Patient's age and sex; 2) past history such as either minor or mild head injury, cerebrovascular accidents, and vascular risk indicators (arterial hypertension and Diabetes mellitus); 3) duration of symptoms before diagnosis; and 4) the overall clinical picture, scored by applying the following neurological dysfunction scale (DS):

Gait score: (1) Normal; (2) discrete imbalance when turning, with short steps, widened base and occasional falling; (3) aid needed for ambulation and frequent falls; (4) impossible gait.

Mental status score: (1) Normal; (2) impaired anterograde memory; (3) low judgement capability; (4) stuporous and delusive patients.

Urinary control score: (1) Normal; (2) precipitate micturition; (3) incontinence two or more times per day; (4) absolute incontinence.

DS total score was obtained by adding the individual scores, thus ranging from 3 to 12 points. Fluctuating symptoms and signs were scored by using the mean value obtained between the best and the worst score reached within the last month before the admission.

Radiological data. Radiological variables obtained from CT scans were: 1) The Evans index; 2) The maximum horizontal diameter (width) of the third ventricle; 3) The mean width of cortical sulci; and 4) Periventricular hypodensities (present vs. absent).

Cerebrospinal fluid dynamic study. CSF dynamic variables compared in groups AR, AnR and B were CSF PP-amplitude (APP), CSF PP-latency (LPP) and resting Pcsf. APP was defined as the differential pressure from the valley to the wave spike, and LPP as the time elapsed between these two points [4, 5]. APP and LPP values were averaged for 10 pulses or more. Resting Pcsf was assumed to be the mean Pcsf recorded by an automatic analogical analyzer during the monitoring period.

In order to evaluate possible changes of these variables through the craniospinal space, the study of CSF dynamics was performed by both lumbar and ventricular route in almost every case by employing a No. 18 gauge Tuohy needle and a No. 20 gauge catheter, respectively. When conspicuous differences between CSF PP amplitudes at lumbar (APPl) and at ventricular (APPv) levels were found in any patient, a 99mTc-diethylene triamine pentacetic acid-cisternographic scan was performed to rule out the existence of a craniospinal block. For instance, the lumbar CSF PP-wave should be extremely buffered to become almost flat even if APPv is 4 or 5 mmHg in the presence of a partial spinal CSF block.

Needles and catheters were connected to a pressure transducer (Pressure transducer, Gould Model P50, manufactured by Gould Electronics BV, Bilthoven, The Netherlands), their signals being continuously recorded on a patient monitor (Monitoring unit, Hellige Servomed, Model Trantec, manufactured by Hellige GmbH, Freiburg, Germany). Monitoring duration of CSF dynamics was 45 minutes, and longer than 8-hours-sleep period for lumbar and ventricular recordings, respectively, the interval between them being 48 to 72 hours. Paper speed was 5 mm $\cdot$ min^{-1} and 10 mm $\cdot$ s^{-1} for the Pcsf measurement and CSF PP waveform analysis, respectively.

Postoperative evaluation. Postoperative workup consisted of a quantitative analysis of DS score and a CT scan, performed at seven days from discharge, and monthly thereafter, until a 24-months follow-up period was concluded. Postshunting improvement was defined as a decrease in DS total score of at least 60% in relation to the preoperative one, lasting over 6 months postoperatively. Non-improvement was assumed when postoperative DS total score remained unchanged. Patients with a postoperative DS total score reduction lesser than 60% were excluded from the study. A new follow-up was always re-started after solving each shunt-related complication.

Statistical analysis. To assess the degree of association between different qualitative variables, quality scores were used by applying a contingency matrix and percent comparisons (X^2-test). In cases meeting the parametric requirements, the relationship between quantitative variables was assessed by the Pearson's correlation test (r-test), mathematically defined by simple linear regression analysis. Quantitative-variable comparison was achieved by the two-tailed Student's T test and one-way ANOVA (F-test).

When non-parametric statistics had to be employed, rank tests were applied in order to compare two-group medians, and the Spearman's one-sided rank correlation coefficient (r_s-test) was used instead of the Pearson's one. A p value of less than 0.05 was considered statistically significant.

Table 1. *Past History Antecedents in Two Groups of Patients Presenting with the Syndrome of Normal Pressure Hydrocephalus and a Control Group*[a]

Group	Head injury Cases No/N (%)	CVA Cases No/N (%)	VRF Cases No/N (%)	None Cases No/N (%)
AR	12/18 (66.6)	7/18 (38.8)	8/18 (44.4)	6/18 (33.3)
AnR	6/12 (50)	6/12 (50)	5/12 (41.6)	6/12 (50)
B	4/14 (28.5)	6/14 (42.8)	6/14 (42.8)	8/14 (57.1)
P (X^2)	0.1 (4.57)	0.8 (0.36)	0.9 (0.02)	0.38 (1.93)

[a] *AR* responder patients to CSF shunting; *AnR* non-responders to CSF shunting; *B* control group; *CVA* cerebrovascular accident; *VRF* vascular risk factors.

Results

Shunt-Related Complications

The incidence of subdural haematomas was 11% and 16% in AR and AnR groups, respectively. Two patients from group AnR who showed shunt malfunction were treated by replacement of the shunt. One patient from group AR with CSF infection (*Staphylococcus epidermidis*) was managed with antibiotic therapy and shunt replacement.

Clinical Data

There were 18 patients and 12 patients in the groups AR and AnR, respectively. The prevalance of males was 66% (12 of 18 cases) in group AR and 33% (4 of 12 cases) in group AnR, the difference being not statistically significant ($X^2 = 2.01$; $p = 0.15$). Mean ages were 65.8 ± 14.9 years, 68 ± 15.3 years and 58.2 ± 14 years in AR, AnR and B groups, respectively, the difference between them being not significant ($F = 1.63$; $p = 0.2$). The incidence of clinical antecedents was not significantly different in the three study groups (4 × 3 contingency matrix) (Table 1). DS total score was similar in both AR and AnR groups, as was the score corresponding to each symptom of the syndrome of NPH (Table 2). The duration of symptoms was also similar in both groups of patients (11.8 ± 2.5 months vs. 11.4 ± 4.5 months for the group AR and the group AnR, respectively) ($T = 0.05$; $p = 0.81$).

Radiological Data

The Evans index and third ventricle width were not significantly different in AR and AnR groups. However, the widening of cortical sulci was significantly greater in patients from the group AnR than in those from the group AR (Table 3). The prevalence of periventricular hypodensities was 44% (8 of 18 cases) in group AR and 50% (6 of 12 cases) in group AnR ($X^2 = 0.003$; $p = 0.95$).

Cerebrospinal Fluid Dynamics

Correlations between lumbar and ventricular CSF dynamics. Data obtained from the study of CSF dynamics in AR and AnR groups are shown in Tables 4 and 5, respectively, whereas data related to group B are given in Table 6.

Non-statistically significant differences between

Table 2. *Neurological Dysfunction Scale Scores in Two Groups of Patients Presenting with the Syndrome of Normal Pressure Hydrocephalus*

	DS total score[a]		Gait score		Mental sscore		Urinary control score	
	AR	AnR	AR	AnR	AR	AnR	AR	AnR
Mean	8.2	7.6	2.6	2.3	2.6	2.4	2.9	2.8
± SD	1.8	1.7	0.8	0.7	0.8	0.6	0.9	1.1
Median	8.0	7.2	2.5	2.0	2.5	2.0	3.0	2.7
P	0.4 (T = 0.85)		0.2 (T = 1.29)		0.6 (T = 0.55)		0.8 (T = 0.18)	

AR responders to CSF shunting; *AnR* non-responders to CSF shunting. [a] DS total score: Sum of gait, mental and urinary control scores.

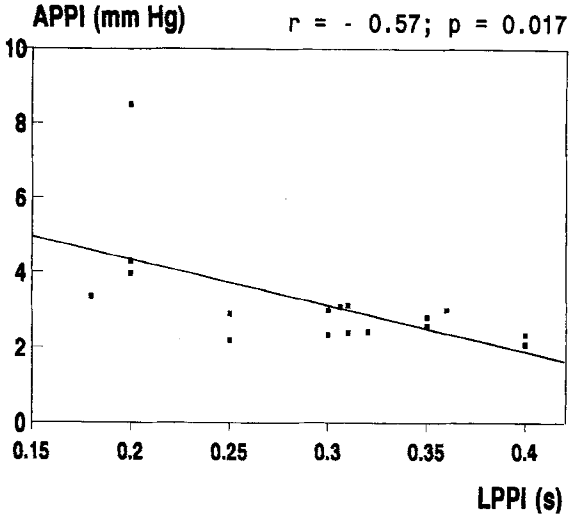

Fig. 1. Correlation between lumbar cerebrospinal fluid pulse pressure latencies (*LPPl*1 and amplitudes (*APPl*1 found in a series of patients suffering from the syndrome of normal pressure hydrocephalus improved by CSF shunting

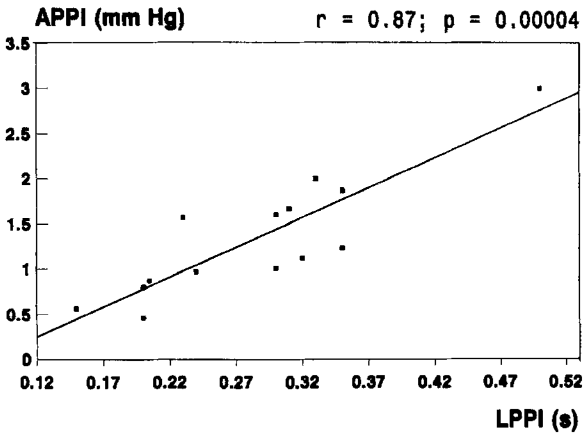

Fig. 2. Correlation between lumbar cerebrospinal fluid pulse pressure latencies (*LPPl*) and amplitudes (*APPl*1 found in a control group

the resting Pcsf recorded at ventricular and at lumbar levels were found in both AR and AnR groups.

APPl and APPv in NPH patients (group AR plus group AnR) were linked by a dependant correlation (r = 0.51; p = 0.02), as did their lumbar (LPPl) and ventricular (LPPv) CSF PP latencies ($r_s = 0.59$; $p < 0.005$). APPl and LPP1 were significantly lower than APPv and LPPv (T = 5.8; p = 0.00001, and p = 0.0002 calculated by two-tailed signed rank test, respectively).

Cerebrospinal fluid pressure. The prevalence of B-activity longer than 30% of the total ventricular recording time was 70% (9 of 13 cases) in group AR and 33% (3 of 9 cases) in group AnR, the difference being not significant ($X^2 = 1.5$; p = 0.2).

Resting Pcsf was higher in group AR (11.2 ± 1.3 mmHg) than both in group AnR (5.03 ± 2.7 mmHg) and in group B (9.6 ± 2.2 mmHg), the difference calculated by two-tailed Wilcoxon rank sum test being statistically significant (p = 0.000001 and p = 0.037, respectively). The prevalence of resting Pcsf over 9 mmHg was 100% (18 of 18 cases) in group AR and 8% (1 of 12 cases) in group AnR.

Amplitude and latency of the CSF PP wave and correlations between them. Mean APPl in group AR (3.19 ± 1.47 mmHg) was significantly higher than in group B (1.33 ± 0.67 mmHg) (T = 4.35; p = 0.00015) but not than in group AnR (2.26 ± 0.96 mmHg) (T = 1.77; p = 0.08). No differences in LPPl between the three-study groups were found (F = 2.21; p = 0.12). On the other hand, APPl was significantly higher in the patients from group AR than in those from group B with Pcsf over 9 mmHg (1.75 ± 0.58 mmHg; cases No. 1, 2, 4, 6, 11, 12, 13, and 14) (p = 0.0002, calculated by the two-tailed Wilcoxon rank sum test). Non-statistically significant difference in resting Pcsf was found between both subsets of patients (11.26 ± 1.3 mmHg and 11.17 ± 1.4 mmHg, respectively) (T = 0.16; p = 0.87).

APPl and LPPl values correlated inversely in the group of patients improved by CSF shunting (r = –0.57; p = 0.017), the regression function being

$$Y = 6.5 - 11.8X \qquad (1)$$

where X is LPPl and Y is APPl (Fig. 1).

When the group B was analyzed (Fig. 2), these variables appeared closely linked by the following direct correlation (r = 0.87; p = 0.00004):

$$Y = -0.55 + 6.6\,X \qquad (2)$$

Correlation coefficients from equations No. 1 and No. 2 were significantly different for $p < 0.001$ (Z = –4.92, calculated by Fisher's Z-transformation).

Though no correlation was found between APP and LPP in non-responders, they could be distributed into two separated subgroups. The first was composed of patients showing a mean APPl of 2.98 ± 0.8 mmHg and a mean LPPl of 0.22 ± 0.06 s (cases No. 6, 19, 20, 22, and 30), and the second subgroup included those with a mean APPl of 1.55 ± 0.23 mmHg and a mean LPPl of 0.24 ± 0.05 s (cases No. 1, 5, 7, 10 and 21), the difference in APPl between these both subgroups being significant

Table 3. *Comparative Radiological Parameters in Two Groups of Patients Presenting with the Syndrome of Normal Pressure Hydrocephalus*[a]

	Evans index		Third ventricle diameter (mm)		Sulci width (mm)	
	AR	AnR	AR	AnR	AR	AnR
Mean	0.39	0.35	5.33	5.38	3.10	3.8
± SD	0.08	0.05	1.5	2.4	0.7	0.9
Median	0.37	0.35	5.00	4.65	3.00	3.70
P	0.14 (T = 1.51)		0.95 (T = 0.062)		0.02 (T = 2.42)	

[a] *AR* responders to cerebrospinal fluid shunting; *AnR* non-responders to cerebrospinal fluid shunting.

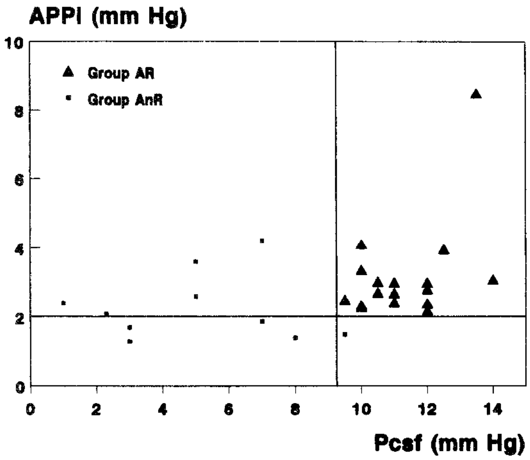

Fig. 3. Plotting of cerebrospinal fluid pressure (*Pcsf*) against lumbar cerebrospinal pulse pressure amplitude (*APPl*) in a series of patients with normal pressure hydrocephalus. *Group AR* shunt-responders. *Group AnR* non-responders to shunting. All responders cluster inside the upper right quadrant of the chart, these being separated from the non-responders by the coordinates *Pcsf > 9 mmHg* and *APPl1 > 2.1 mmHg*. Results were similar when recordings were performed at ventricular level, the restrictive APPv being 2.4 mmHg in this case

($p = 0.008$, calculated by the two-tailed Wilcoxon rank sum test). APPl and LPPl in the first subgroup correlated inversely ($r = -0.88$), its correlation coefficient being not significantly different from that of the equation No. 1 ($Z = -0.48$; $p = 0.5$), though being different from the r associated to equation No. 2 ($Z = 3$; $p < 0.01$). APPl and LPPl correlated better according to equation No. 2 in the second subgroup, but non-statistical significants was found in this regard.

Resting CSF pressure associated to CSF pulse pressure. The prevalence of the association of resting Pcsf over 9 mmHg plus APPl over 2.1 mmHg was 100% (17 of 17 cases) in group AR, and 0% (0 of 11 cases) in group AnR (Fig. 3).

Discussion

Postoperative Evaluation System

Since the validity of the clinical system grading used in this study to determine the response to treatment is unknown, the breakdown of responders vs. non-responders has just been established for the more extreme scored values. It means that an unsound range was deliberately left interposed between those limits, so that the patients with a postoperative score in such a range were excluded for further investigation in order to avoid doubtful responses.

Homogeneity of Patients' Groups

No significant differences in clinical parameters were found in the three study groups. Although the analyzed sample sizes are relatively small, the objective incidence of the compared clinical data were so similar in almost every instance that the possibility of having committed a stochastical type 2 error is remote. Likewise, the prevalence of most radiological variables compared in the present study was analogous in the patients presenting the syndrome of NPH who either improved or not following CSF shunting. However, since the percent of cortical atrophy was significantly higher in patients who did not improve than in those who did, possible bias may be included. In any case, the relatively high prevalence of widened cortical sulci in the group of patients who did not improve following CSF shunting is in accordance with the expected anatomical changes for either a non-reversible stage of NPH or primary cerebral atrophy.

Cerebrospinal Fluid Dynamics in Improved Patients

All patients who improved following CSF shunting in the present study showed a resting Pcsf higher than

Table 4. *Cerebrospinal Fluid Dynamics in Patients Presenting with the Syndrome of Normal Pressure Hydrocephalus who Improved Following CSF Shunting*[a]

Case no.	APPv (mmHg)	APPl (mmHg)	LPPv (sec.)	LPPl (sec.)	Pcsf (mmHg)
2	5.54	2.35	0.29	0.30	10.00
3	5.20	2.80	0.17	0.25	12.00
4	4.87	3.00	0.24	0.30	12.00
8	2.80	2.10	0.30	0.40	12.00
9	5.20	2.43	0.24	0.32	11.00
11	3.90	3.09	0.19	0.30	14.00
12	–	4.10	–	0.20	10.00
13	3.70	3.02	0.25	0.36	10.50
14	4.00	2.30	0.30	0.40	10.00
15	6.40	3.36	0.15	0.17	10.00
16	8.56	3.97	0.15	0.20	12.50
17	5.70	2.50	0.32	0.25	9.50
18	4.68	2.71	0.22	0.35	10.50
23	5.23	3.00	0.28	0.30	11.00
25	–	–	–	–	9.00
26	–	2.40	–	0.31	12.00
28	–	2.69	–	0.35	11.00
29	–	8.5	–	0.20	13.5
Mean	5.04	3.19	0.23	0.29	11.26
± SD	1.42	1.47	0.05	0.07	1.30
Median	5.00	2.80	0.24	0.30	11.00

[a] *APPv* ventricular CSF pulse pressure amplitude; *APPl* lumbar CSF pulse pressure amplitude; *LPPv* ventricular CSF pulse pressure latency; *LPPl* lumbar CSF pulse pressure latency; *Pcsf* CSF pressure.

9 mmHg, APPl values higher than 2.1 mmHg, and LPP values inversely correlated with APP magnitudes. That APPl is significantly higher in responder patients suffering from NPH (mean value of 3.19 mmHg) than in controls (mean value of 1.33 mmHg) is in accordance with the widespread observation that peak pressure normally rises with mean pressure, but also supports the hypothesis that undamped CSF PP waves occur when venous venting capability is almost exhausted [2–5]. In fact, the cerebral blood volume shift following arterial systolic output may be considered as an endogenous net volume-bolus generating the CSF PP. Applying the Marmarou's notation to CSF PP, a ratio of systolic to diastolic CSF pressure is obtained, which correlates inversely with the compliance of the craniospinal system [4, 5, 7, 11].

On the other hand, while the craniospinal compliance is normal, the time available for the systolic blood output to be buffered is long, and so must be the value of LPP. By contrast, conditions such as cerebral atheromatosis or poor cerebral venous capacitance NPH-related, in which the buffer time is almost wasted, could be factors capable of shortening the physiological span of CSF PP rise [4, 8]. These factors make that systolic cerebral intake of blood volume be followed by a CSF PP wave in which the less the LPP, the higher the APP rise.

Our results also support the hypothesis that NPH represents a state of hyperdynamic CSF flow since a post hoc observation showed that APPl was significantly higher in group AR than in controls with the same Pcsf. This hyperdynamic CSF flow state is in accordance with the presence in magnetic resonance imaging from NPH patients of a flow void resulting from a marked to-and-fro motion of CSF through the aqueduct and contiguous third and fourth ventricles [2].

Cerebrospinal Fluid Dynamics in Non-Improved Patients

Patients who did not improve by CSF shunting in this series had a mean resting Pcsf lower (5 mmHg)

Table 5. *Cerebrospinal Fluid Dynamics in Patients Presenting the Normal Pressure Hydrocephalus Syndrome Who Did Not Improve Following CSF Shunting*

Case no.	APPv (mmHg)	APPl (mmHg)	LPPv (sec.)	LPPl (sec.)	Pcsf (mmHg)
1	2.40	1.40	0.20	0.20	8.00
5	2.51	1.29	0.16	0.21	3.00
6	5.32	2.40	0.17	0.26	1.00
7	2.30	1.50	0.15	0.30	9.50
10	3.88	1.70	0.15	0.20	3.00
19	2.30	2.10	0.15	0.30	2.30
20	10.00	3.60	0.15	0.20	5.00
21	4.30	1.87	0.25	0.30	7.00
22	–	4.20	–	0.15	7.00
24[a]	4.10	0.95[a]	0.15	–	4.0[b]
27	–	–	–	–	6.00
30	–	2.60	–	0.20	5.00
Mean	4.12	2.26	0.17	0.23	5.03
± SD	2.45	0.96	0.03	0.05	2.76
Median	3.88	1.98	0.15	0.20	4.75

APPv ventricular CSF pulse pressure amplitude; *APPl* lumbar CSF pulse pressure amplitude; *LPPv* ventricular CSF pulse pressure latency; *LPPl* lumbar CSF pulse pressure latency.

[a] Cervical block proven by 99mTc-DTPA-cisternography.

[b] Pcsf was 4 ± 0.5 mm Hg and 4 ± 0.1 mm Hg at ventricular and lumbar levels, respectively.

than responders to CSF shunting (11 mmHg). These patients may be separated into two subgroups based on the findings with APPl and LPPl magnitudes. The first showed high-APPl values (over 2.1 mmHg) and low-LPPl magnitudes, so that such parameters correlated inversely as should be expected to occur in patients suffering from NPH, in accordance with the equation No. 1. That these patients had Pcsf values less than 9 mmHg may be attributed to the occurrence of postinfarction brain atrophy. Consequently it may be assumed that they most probably suffered from either an irretrievable stage of NPH of arteriosclerotic dementia. In both of these conditions the stiffness around the infarcted areas allows that arterial pulsations are transmitted in an undamped manner. Thus, the main difference in CSF dynamics between the reversible NPH and the non-reversible stage of this condition must be that resting Pcsf is higher in the former than in the latter.

In the second subgroup, again cell depopulation could be the factor responsible for the low Pcsf observed in the majority of these patients. Moreover, they had a relatively low APPl (under 2.1 mmHg) and the LPPl in the range expected for controls showing the above APP values, so that these parameters correlated directly according to equation No. 2. Since the relationship between APPl and LPPl must be similar in both normal individuals and patients with primary brain atrophy, we conclude that this subgroup is most probably composed of patients with Alzheimer-like disorders.

Possible influences on CSF PP waveform by additional factors, either cerebral (i. e., head injury, cerebrovascular accidents) or non-cerebral effects (i. e., age, arterial hypertension, Diabetes) may be reasonably ruled out because past history antecedents were similarly distributed through the groups in this study.

In practice, a patient with the clinical picture of NPH in whom the resting Pcsf is 9 mmHg or higher, the APPl is over 2 mmHg and the LPPl is inversely correlated with the APPl, according to equation No. 1, should be considered the best candidate for CSF shunting. On the other hand, postshunting functional prognosis is uncertain in patients with Pcsf ranging from 8.2 mmHg to 8.9 mmHg in spite of the fact that an inverse correlation between APPl and LPP1 might have been proven [13]. Thus, the reversibility of this borderline stage of NPH remains to be determined. In the end, if one of the previous criteria is not met, the likelihood of improvement is very low.

Table 6. *Cerebrospinal Fluid Dynamics in a Control Group*

Case no.	Pcsf (mm Hg)	APPl (mm Hg)	LPPl (sec.)
1	10.00	1.12	0.32
2	11.00	3.00	0.50
3	9.00	0.80	0.20
4	9.67	2.00	0.33
5	7.00	0.56	0.15
6	14.00	1.67	0.31
7	8.00	1.01	0.30
8	7.00	0.97	0.24
9	6.00	0.46	0.20
10	8.00	0.80	0.20
11	11.00	1.57	0.23
12	10.00	1.23	0.35
13	12.00	1.60	0.30
14	11.70	1.87	0.35
Mean	9.59	1.33	0.28
± SD	2.24	0.67	0.09
Median	9.83	1.17	0.30

Pcsf CSF pressure; *APPl* lumbar CSF pulse pressure amplitude; *LPPl* lumbar CSF pulse pressure latency.

On the other hand, it should be noted that in some cases there could exist a craniospinal block, this possibility restricting the prognostic value of the lumbar CSF PP wave. In order to evaluate the patency of the craniospinal subarachnoid space, those patients with the syndrome of NPH in whom the resting Pcsf is higher than the lowest value found in our group of responders to CSF diversion (9 mmHg) and the APPl value is under 2 mmHg, must undergo a 99mTc-cisternographic scan. In our opinion, the fact that most of the non-symptomatic spinal blocks are incomplete, make the Pcsf quantitatively similar when measured either by ventricular or lumbar route, whilst the CSF PP rise should be higher at ventricular than at lumbar level, where APPl may be greatly damped in the presence of a proximal subarachnoid block according to Bernouilli's law (case No. 24, Table 5).

Influence of CSF Diversion Modalities

An important concern arising is the relative influence of the CSF diversion systems on the response obtained in borderline patients in whom the brain shows little amount of either demyelinizated or infarcted areas, so that no significant atrophy is yet present. In this respect, it has been reported that clinical improvement was independent of the adjusted valve pressure with externally manageable shunt systems [14].

Conclusions

The following conclusions were obtained: 1) CSF PP is a high-amplitude and relative low-latency wave in patients with NPH when compared with normal individuals. 2) Through the pathogenetic process of NPH a non-reversible stage may be reached in which the brain stiffness and ischaemia are so extremely marked that they preclude any possibility of clinical improvement. 3) APPl and LPPl correlate inversely in CSF systems of low compliance. 4) APPl and LPPl correlate directly in both normally and highly CSF compliant systems. 5) A major difference between the reversible and non-reversible stages of NPH is the Pcsf value, which is higher in the former than in the latter.

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References

1. Albeck MJ, Børgesen SE, Gjerris F, Schmidt JF, Sørensen PS (1991) Intracranial pressure and cerebrospinal fluid outflow conductance in healthy subjects. J Neurosurg 74: 597–600
2. Bradley WG Jr, Whittermore AR, Watanabe AS, Davis SJ, Teresi LM, Homyak M (1991) Association of deep white matter infarction with chronic communicating hydrocephalus: implications regarding the possible origin of normal-pressure hydrocephalus. AJNR 12: 31–39
3. Bret P, Chazal J, Janny P, Rénaud B, Tomassi M, Lemaire JJ, Bret M, Jouvet A (1990) Hydrocéphalie chronique chez l'adulte. Neurochirurgie [Suppl] 36: 1–159
4. Foltz EL (1984) Hydrocephalus and CSF pulsatility: Clinical and laboratory studies. In: Shapiro K *et al* (eds) Hydrocephalus. Raven, New York, pp 337–361
5. Foltz EL, Aine C (1981) Diagnosis of hydrocephalus by CSF pulse-wave analysis: a clinical study. Surg Neurol 15: 283–293
6. Foltz EL, Blanks HP (1988) Symptomatic low intracranial pressure in shunted hydrocephalus. J Neurosurg 68: 401–408
7. Foltz EL, Lederhaus S (1979) Ventricular CSF pulse pressure amplitude: an index of intracranial compliance. In: Marguth F *et al* (eds) Advances in neurosurgery. Springer, Berlin Heidelberg New York, pp 295–304
8. Gjerris F, Børgesen SE (1992) Current concepts of measurement of cerebrospinal fluid absorption and biomechanics of hydrocephalus. Adv Tech Stand Neurosurg 19: 145–177

8a. Hakim CA (1985) The physics and physicopathology of the hydraulic complex of the central nervous system. (The mechanics of hydrocephalus and normal pressure hydrocephalus). Thesis. MIT, Massachusetts

9. Janny P, Colnet G, Veyre A, Chazal J, Barreto LC (1981)

Hydrocéphalie a pression normale. Etude pré- et postoperatoire de 56 cas. Neurochirurgie 27: 89–96
10. Kimura M, Tanaka A, Yoshinaga S (1992) Significance of periventricular hemodynamics in normal pressure hydrocephalus. Neurosurgery 30: 701–705
11. Kosteljanetz M (1987) Intracranial pressure. Cerebrospinal fluid dynamics and pressure-volume relations. Acta Neurologica Scand [Suppl] 75: 1–23
12. Kosteljanetz M, Ingstrup HM (1985) Normal pressure hydrocephalus: correlation between CT and measurements of cerebrospinal fluid dynamics. Acta Neurochir (Wien) 77: 8–13
13. Lamas E, Lobato RD (1979) Intraventricular pressure and CSF dynamics in chronic adult hydrocephalus. Surg Neurol 12: 287–295
14. Larsson A, Jensen C, Bilting M, Ekholm S, Stephensen H, Wikkelso C (1992) Does the shunt opening pressure influence the effect of shunt surgery in normal pressure hydrocephalus? Acta Neurochir (Wien) 117: 15–22
15. Meyer JS, Kitagawa Y, Tanahashi N, Tachibana H, Kandula P, Cech DA, Rose JE, Grossman RG (1985) Pathogenesis of normal-pressure hydrocephalus. Preliminary observations. Surg Neurol 23: 121–133
16. Meyer JS, Tachibana H, Herdenberg JP, Dowell RE, Kitagawa Y, Mortell KF (1984) Normal pressure hydrocephalus. Influence on cerebral hemodynamic and cerebrospinal fluid pressure – chemical autoregulation. Surg Neurol 21: 195–203
17. Pappadá G, Poletti C, Guazzoni A, Sani R, Colli M (1986) Normal pressure hydrocephalus: relationships among clinical picture, CT scan and intracranial pressure monitoring. J Neurosurg Sci 30: 115–121
18. Rubin RC, Hochwald GM, Tiel M, Mizatani H, Ghatak N (1976) Hydrocephalus: I. Histological and ultrastructural changes in the pre-shunted cortical mantle. Surg Neurol 5: 109–114
19. Rubin RC, Hochwald GM, Tiel M, Liwiez BH (1976) Hydrocephalus: II. Cell number and size, and myelin content of preshunted cortical mantle. Surg Neurol 5: 115–118
20. Turner DA, McGeachie RE (1988) Normal pressure hydrocephalus and dementia – evaluation and treatment. Clin Geriatr Med 4: 815–830
21. Weller RO, Mitchel J (1980) Cerebrospinal fluid edema and its sequelae in hydrocephaly. Adv Neurol 28: 111–123
22. Weller RO, Shulman K (1972) Infantile hydrocephalus; Clinical, histological and ultrastructural study of brain damage. J Neurosurg 36: 255–256

Comment

The aim of the study was to improve the patient selection for shunting. Although normal pressure hydrocephalus (NPH) has been described many years ago (Salomon Hakim, 1964) the pathomechanisms remain mysterious. Therefore still many symposia and papers are devoted to the diagnosis differentation between patients with NPH and brain atrophy.

In this paper the authors investigate the connection between cerebrospinal pulse pressure and cerebrospinal pressure level and the clinical outcome in patients with NPH. The paper is interesting, the methods applied and the analysis are adequate and the results obtained are important.

Z. Czernicki

The authors have described 30 patients selected from a group of 41 patients with NPH and separated them into two groups depending on improvement after CSF shunting. They also measured the CSF pulse pressure amplitude and latency and, of course, the resting CSF pressure. The authors also compared ventricular CSF pressure and pressure at the lumbar levels and found no significant differences.

The main message is that they found differences in the CSF pulse pressure in patients improving compared with patients not improving after shunting and that the CSF pressure was higher in improved patients than in non-improved patients.

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