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Does the Shunt Opening Pressure Influence the Effect of Shunt Surgery in Normal Pressure Hydrocephalus?

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Summary

Thirteen patients with normal pressure hydrocephalus were operated upon with an externally manoeuvrable shunt system (Sophy SU8) in order to investigate its influence on clinical outcome, intracranial pressure and cranial CT parameters. The opening pressure was set at high at surgery and lowered stepwise at intervals of three months to medium and low. The clinical condition, intracranial pressure and cranial CT parameters were examined at the end of the 3 months interval on each pressure level.

The patients improved within the first 3 months inspite of an unchanged mean intracranial pressure and remained in a stable clinical condition during the rest of the study period. The intracranial pressure was significantly reduced at 9 months. The ventricular index, Evans index, temporal horn and third ventricle width were reduced 3 months post-operatively and did not change significantly during the rest of the study. The pre-operative third ventricle width was correlated to high psychometric test results after shunt surgery. Reduction in ventricular index, Evans index and third ventricle width after surgery correlated to improvement in psychometric scoring.

The clinical improvement after shunt surgery for normal pressure hydrocephalus is seen within 3 months and is independent of the adjusted valve pressure.

Keywords: Normal pressure hydrocephalus; intracranial pressure; CT parameters; psychometric scoring.

Introduction

Normal pressure hydrocephalus (NPH) is clinically characterised by gait disturbance, mental deterioration and urgency incontinence, in combination with an enlarged ventricular system and a normal cerebrospinal fluid (CSF) pressure[19]. The usual mode of treatment is shunting of CSF by means of a ventriculo-peritoneal or ventriculo-atrial shunt device.

The influence of the opening pressure of the shunt device on the clinical symptoms is, however, only partly known and medium pressure valves have been used in most of the earlier studies regarding the effect of shunt surgery[2, 5, 17, 24, 37, 40]. McQuarrie compared medium and low pressure valves and found the latter to be slightly more beneficial[36], and Schmitt and Spring[42] found Sophy shunts superior to Holter-Hausner and Sigma-orbis valves.

When an externally manoeuvrable shunt system (Sophy SU8) became available, we decided to further study that problem and the main aim of this study was to investigate the effect on clinical outcome of a gradually lowered shunt opening pressure. Furthermore we wanted to study; 1) the effect on intracranial pressure (ICP) and cranial computerized tomography (CT) parameters of the lowered shunt opening pressure and 2) the relationship between clinical, cranial CT and ICP parameters.

Materials and Methods

Thirteen consecutive patients diagnosed as NPH in the Department of Neurology and operated upon in the Department of Neurosurgery were included for the study. Three patients were excluded after shunt surgery due to shunt complications which could not be settled in one case, diminished visual acuity making psychometric testing impossible in another and unwillingness to participate. The remaining ten patients (six males and 4 females) are reported in this study.

The mean age was 62 ± 13 years (± SD) and the range 42–80 years. Three patients had mental symptoms and gait disturbances but all the other patients presented with the full triad of symptoms. In all patients cranial CT revealed enlarged ventricles with an Evans Index (EI) $\geqslant 0.30$ and radionuclide cisternography (RC) showed ventricular reflux and block of convexity flow[28]. The lumbar cerebrospinal fluid pressure (LSP) was $\leqslant 27$ cm H_2O in all patients. The aetiology of the NPH state was subarachnoid haemorrhage in 2, CNS trauma in 2 and cerebrovascular disease in 2. Four patients were considered as idiopathic NPH.

All patients were operated upon by one neuro-surgeon (H.S) and all had a Sophy SU8 ventriculo-peritoneal shunt inserted into the right lateral ventricle. According to the manufacturer high, medium, and low valve position corresponds to 17, 11, and 5 cm H_2O respectively. At surgery the shunts were set at position high. Three months later, and after evaluation, the valve was set at medium position. After another 3 months and an identical investigation the valve position was changed to low. Nine months after insertion of the shunt the final evaluation was done and the shunt was left at the low pressure level.

The shunts were considered patent if the patients improved or the width of the ventricular system diminished. In three patients shunt malfunction (distal catheter block) was detected by "shuntography"[51] during the study period and immediately operatively corrected. The subsequent control examination was accordingly postponed until the shunt had been patent for 3 months.

The patients were investigated in a standardized way pre-operatively as well as 3, 6, and 9 months post-operatively by clinical examination, ICP measurement and cranial CT.

The following clinical and neuro-psychological parameters were registered (with scale and function tested within brackets); degree of incontinence (0–4; nocturnal, nocturnal and intermittently daytime, constantly daytime, constantly both urinary and faecal), number of steps needed to advance 18 meters (absolute number), Reaction-Time Test (seconds, perceptual speed and accuracy), Raven matrices (0–36, cognitive ability), Identical Forms Test (0–60, perceptual speed and accuracy), Cronholm-Molander Memory Test (1–30, learning and memory)[10, 13, 25].

The ICP was measured pre-operatively as lumbar spinal pressure (LSP) by a lumbar puncture with the patients resting for 5 minutes in the lateral recumbent position using an ordinary level indicator attached to a 0.7 mm needle and the puncture site set as the zero level. Post-operatively the ICP was measured by a puncture of the Rickham reservoir under the same circumstances, connecting the needle to an identical level indicator and with the patients supine. Zero level was set at the level of the external auditory meatus. No continuous pressure recordings were done.

The cranial CT examinations were performed with routine axial scans. Ventricular index (VI), Evans index (EI), the maximal width of the temporal horns (TH) as well as the third ventricle (TV) were judged according to Fig. 1. We used a modified VI described by Hughs and Gado[24] (Fig. 1). Since the CT examinations were performed with different CT-scanners at various hospitals in our region we found it difficult to correctly judge and compare some parameters such as the cortical sulcal width and periventricular oedema and this is the reason why these parameters were not included.

One patient with extremely large ventricles was suspected of having a congenital occult hydrocephalus. Since the CT parameters were extraordinary they were not included in the calculations of descriptive statistics and correlations. The clinical and pressure results were however used.

One patient was lost to follow-up at the 9 months examination. It was an 80 year-old patient who died of pneumonia in the interval between the 6 and 9 months investigations.

Statistics

The psychometric test results were standardized to allow summation to one common psychometric parameter. The pre-operative values were standardized to a mean of 0 and a standard deviation of 1. The post-operative values were standardized by using the pre-operative values for mean and standard deviation. Simple descriptive statistics were done using univariate analysis. Further, non-parametric comparison (Wilcoxon rank-sum and ranked sign test) and correlations (Spearman rank correlation) were used (SAS Institute Inc.).

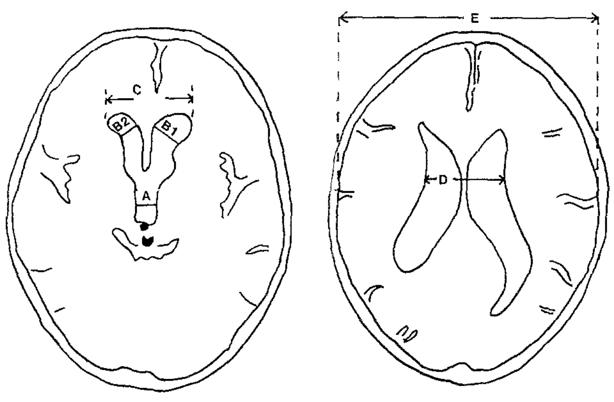

Fig. 1. The linear measurements of the VI consists of; *A*: The maximal width of the third ventricle, *B1* and *B2*: The caudate span between the caudate nucleus and septum pellucidum on each side. *C*: The bifrontal span between the farthest point of the frontal horns. *D*: The shortest width of the lateral ventricles in their midplane and *E*: The distance between the internal tabulae at the same scan as level as *D*. The index was calculated with the equation: A + (B1 + B2)/2 + C + D/E × 100 = VI. The Evans Index was calculated as the maximal width of the frontal horns/maximal width of the inner skull. The measurements of the temporal horns as well as the third ventricle were exact (mm) measurements

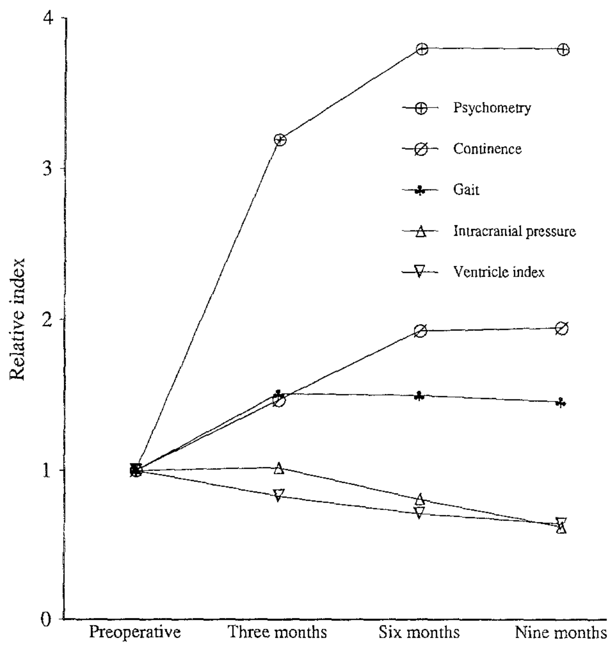

Fig. 2. Relative values of psychometric score, gait (inversed number of steps needed to advance 18 m), continence (inversed value of incontinence), intracranial pressure and ventricular index pre-operatively and at 3, 6, and 9 months (see Statistics)

The relative changes in some parameters were calculated by setting the pre-operative mean of each parameter to 1 to be able to compare them in a common figure (Fig. 2).

Results

All patients improved in at least 2 of the 3 main symptoms after shunt surgery. One patient did not improve psychometrically and one not in gait ability. The three patients without urgency incontinence pre-operatively remained continent. The improvement was seen within the first 3 months ($p < 0.05$). The clinical condition remained stable and no further improvement was seen during the rest of the study period (Figs. 2 and 4).

The LSP was 17 ± 7 cm H_2O (mean ± SD) and the ICP 16 ± 5, 13 ± 5 and 10 ± 5 cm H_2O at the 3, 6, and 9 months examinations respectively (Figs. 2 and 3). The ICP at 9 months was significantly ($p < 0.05$) lower than the LSP (Fig. 3).

The VI, EI, TH, and TV width were significantly

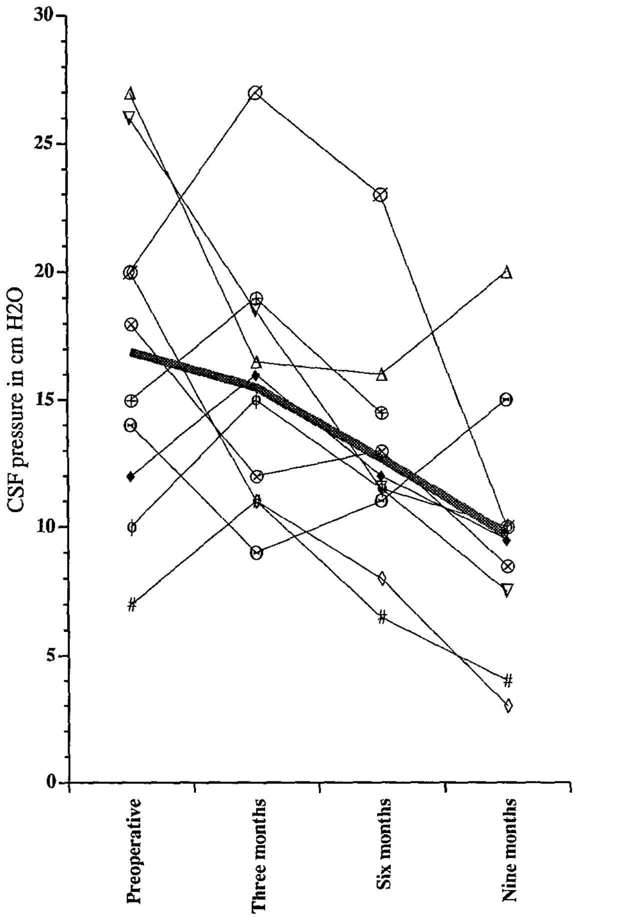

Fig. 3. Absolute values of CSF pressure pre-operatively, at 3, 6, and 9 months for each patient. Marked line represents mean value

reduced at the 3 months examination compared to the pre-operative measurements ($p < 0.01$, < 0.01, < 0.05, and < 0.05 respectively) (Fig. 5). The patient with initially extremely large ventricles showed no reduction in any CT parameter after surgery despite an obvious clinical improvement (Figs. 4 and 5).

The LSP did not correlate to the magnitude of any pre-operative clinical or CT parameter. Nor did it correlate with the clinical improvement or with the reduction in any CT parameter. Likewise, there were no correlations between the changes in ICP and in clinical or CT parameters at the 3, 6, and 9 months examinations.

The pre-operative CT changes did not correlate with the degree of clinical impairment or the clinical improvement during any part of the study period. However, the pre-operative TV width correlated to a high psychometric scoring after surgery (3, 6, and 9 months) ($p \leqslant 0.05$, 0.01, 0.01 respectively). The reduction in VI, EI, and TV width correlated with the improvement in psychometric test score but only when calculated for the entire study period ($p \leqslant 0.02$, 0.05, and 0.005 respectively). Likewise, the reduction in TV width correlated with the improvement in gait ability ($p \leqslant 0.05$) for the entire study period.

Discussion

All patients available for follow-up in this study improved after shunt surgery. This is a better result than expected since the success rate in most other studies varies between 30 and 75%[3, 18, 23, 38, 41, 54]. This was not due to a selection bias since the patients were consecutively included independent of aetiology. The patient lost to follow-up at the 9 months examination died of a disease unrelated to shunt surgery and had shown a clear response to shunting at the completed examinations.

We decided not to use a mixed up sequence of pressure changes in the study, since we did not want any patient to be at risk of developing a subdural haematoma when primarily shunted with a low pressure valve, as we had earlier experienced.

Improvement was seen in all clinical parameters but a specifically marked and uniquely stable response was seen in gait performance (Fig. 4). This may imply that this simple test should be preferable to more complex arrangements in NPH investigations.

The improvement achieved by the shunt operation was seen within 3 months, in accordance with the results reported by Maegnes[34]. During the same interval the

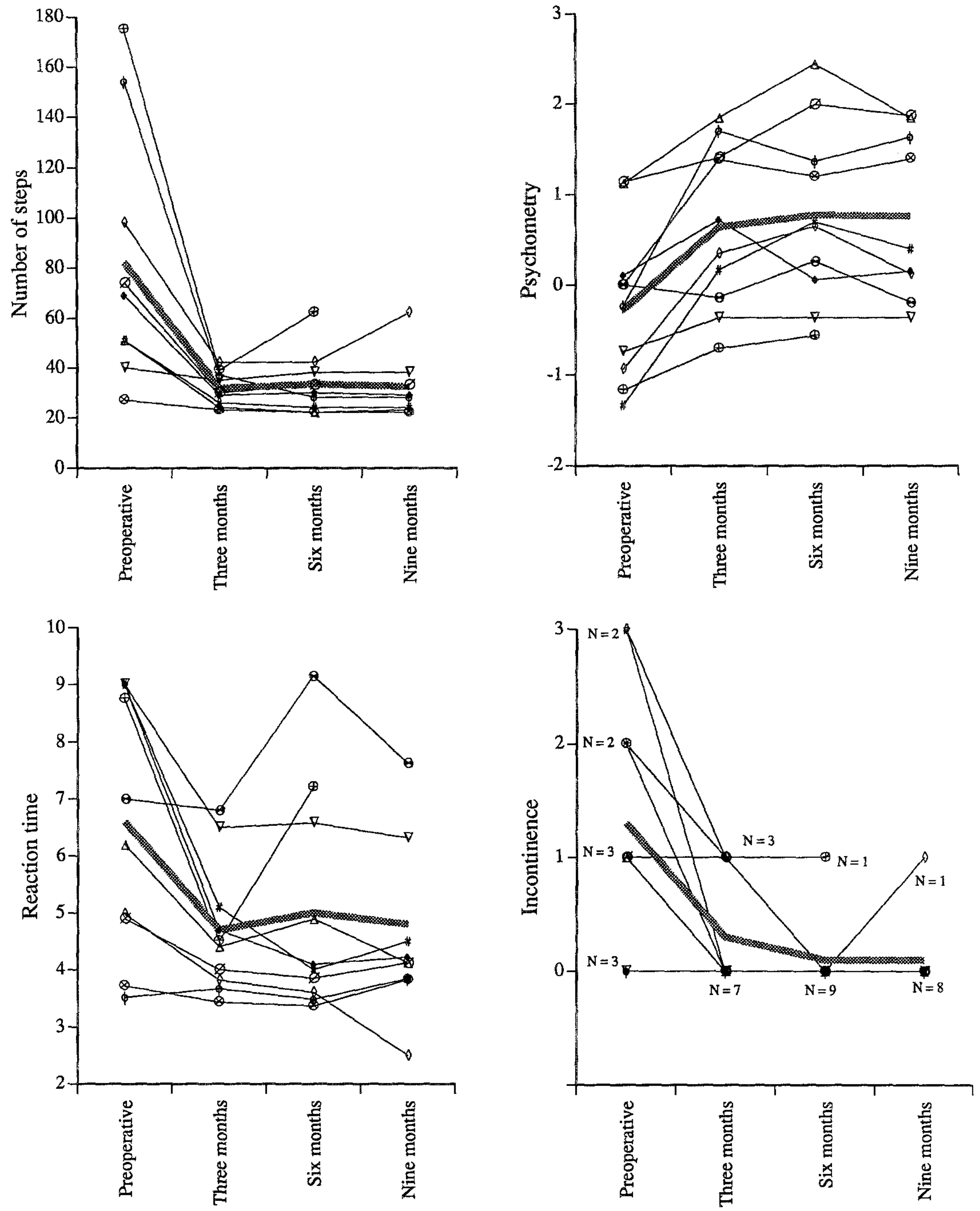

Fig. 4. Individual values (exact number) and mean values (marked line) of the clinical parameters; number of steps, psychometric test results (see Statistics), reaction time test and incontinence pre-operatively and at 3, 6, and 9 months after surgery

ICP was not significantly reduced compared to the LSP. No further improvement was seen despite down-regulation of the opening pressure and a significantly reduced ICP at 9 months compared to the LSP. As no negative effects were seen the shunts were left in position "low". Furthermore, there were no correlations between LSP or the reduction in ICP and the clinical improvement which is in accordance with the results of Delwel *et al.*[9]. Thus, we could not confirm the results of McQuarrie *et al.*[36] and Schmitt and Spring[42] that low is more beneficial than medium pressure valves. Although our results are quite uniform in this respect,

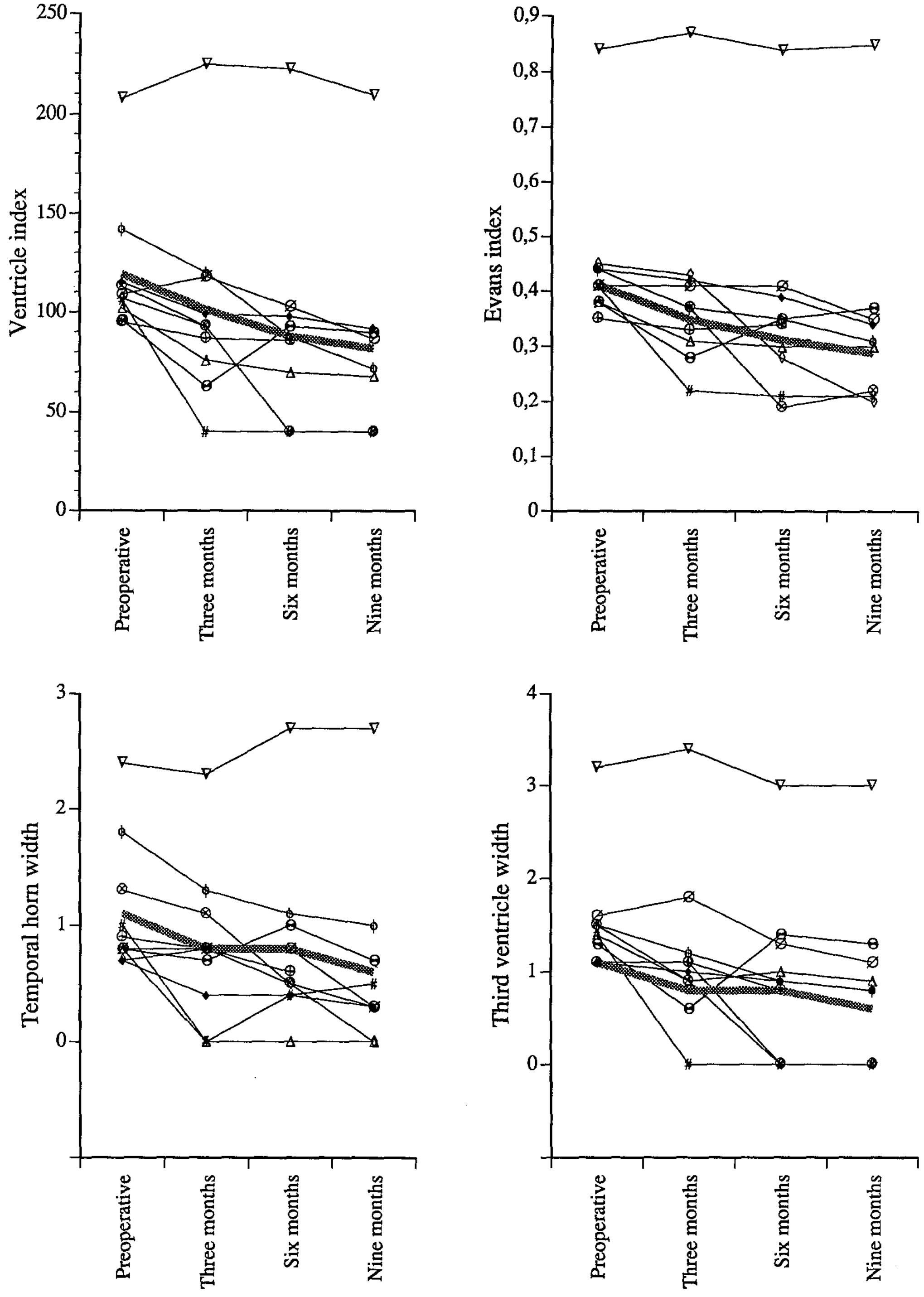

Fig. 5. Individual values of the CT parameters; ventricle index (see Fig. 1), Evans index (see Fig. 1), temporal horn width (cm) and third ventricle width (cm) pre-operatively and at 3, 6, and 9 months after surgery. Marked line represents the mean values

our material is small and we have seen occasional patients with shunt opening pressures at the level of 25 cm H_2O who have benefited from a lowered opening pressure.

The absolute uniformity in improvement at 3 months reasonably excludes shunt malfunction in any patient at that time. Furthermore, the lack of deterioration at 6 and 9 months respectively, strongly speaks against this supervening later.

As the ICP was unrelated to the clinical improvement, other aspects of the changed CSF dynamics induced by the shunt insertion must be considered.

Presence of A- and B-pressure-waves[32] and a high time-percentage of B-waves has been shown in patients with NPH and to be predictive for shunt surgery[5, 8, 17, 21, 27, 39, 46]. Measurements of resistance to outflow (R_{out}) or conductance have been shown to be of prognostic value in many series[1, 5, 51], but not in all publications in NPH investigations. Further, a correlation between clinical response and intracranial elastance and pulse pressure have been shown[1, 40]. A reduction in B-wave time percentage after shunt surgery has also been shown[8, 47, 48] and Tanaka[47] found a reduction in R_{out} after shunt surgery. Thus, the important effect of a shunt insertion could be a reduction of R_{out} leading to elimination of pressure-waves. The lack of effect of a variable shunt opening pressures well below peak pressure levels claimed to be at approximately 25 cm H_2O[22] further supports this view. Furthermore, the immediate reduction of R_{out} induced by a shunt insertion is compatible with the prompt clinical response to shunt surgery. With increasing duration of the disease, R_{out} decreases[6] and this may make measurements of this parameter less predictive, reducing the possible effect of shunt insertion. This is well in line with the known fact[5, 15, 17, 29] of a negative correlation between duration of symptoms and response to surgery. Irreversible symptoms could be explained by permanent damage to the periventricular brain tissue.

Twenty-four hour trend analysis of ICP is of course superior if one mainly wants to study that parameter. This was not our prime aim but we included estimations of ICP due to the simple accessibility of the single time measurements well aware of the method's limitations. That LSP closely parallels the intracranial pressure seems well documented[20, 22, 33, 35] and thus the comparison of results from LSP and ICP recordings seems justified since they were done under the same circumstances. Pre-operatively there was a considerable pressure range. Three patients had a pressure over 20 cm H_2O. We do not consider this as strictly contradictive to the diagnosis of NPH since a large range in CSF pressure has been shown in NPH[2, 8, 11, 17, 21, 37, 39, 40, 41, 46] and all our patients had a characteristic clinical picture. Further, LSP exceeding 20 cm H_2O has been found in healthy subjects[7, 14]. Fluctuations induced by patient stress could also have influenced these measurements.

The post-operative recordings are likely to be more accurate since previous investigations have shown a reduction in pressure waves after shunt surgery[8, 46, 47] and since all the shunts were patent. Further, the lack of significant reduction in ICP after shunt insertion indicates that the LSP measurements were fairly reliable.

All the CT parameters were exclusively reduced at the 3 months examination and thus paralleled the clinical response. The degree of ventricular enlargement pre-operatively was not correlated with the gravity of the clinical picture or the degree of improvement after shunt surgery. However, a large TV width pre-operatively correlated with a high post-operative psychometric score in accordance with earlier reports[37, 53]. The reduction in VI, EI, and TV width correlated with the psychometric improvement, and TV width to gait improvement as well. The lack of correlation at the 3 months interval is probably due to a combined effect of variability in ventricular reduction after shunt surgery[49, 50] and the small patient material. The significant reduction of all CT parameters within 3 months in spite of an unchanged ICP indicates that the ventricular dilation is induced by pressure-wave activity eliminated by shunt insertion.

Our results show that estimations of general ventricular dilation as VI and EI seem to be of questionable prognostic value, whereas the TV width is important in this context. Estimations of general ventricular dilation owes its value in differential diagnosis and as an indicator of shunt patency.

The TH width could have been biased and underestimated since different gantry angels will markedly affect their appearance making a correct measurement difficult. This could be the explanation of the lack of correlation between TH width and the clinical parameters.

The patient with extremely large ventricles showed no reduction in ventricular size and almost certainly represents a case of congenital occult hydrocephalus with clinical deterioration in adult life as described by Graff-Radford *et al.*[16]. Interestingly, she showed a clear clinical response underscoring the necessity to consider shunt surgery in patients presenting with what is often called "arrested hydrocephalus".

Conclusions

The main conclusion is that the clinical effect and the reduction of ventricular size are independent of the adjusted shunt opening pressure within the 5–17 cm H_2O range.

The clinical effect of shunting appears within 3 months despite an unchanged ICP and no further improvement is achieved through a diminished ICP.

The reduction in ventricular size on cranial CT is also seen within 3 months.

There is no correlation between the clinical effect or CT parameters and ICP as appreciated by simple static measurements.

In this study, only the third ventricle width was predictive of the result of shunt surgery.

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