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ORIGINAL ARTICLE

Cerebrospinal fluid dynamics study in communicating hydrocephalus

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ABSTRACT

Context: Communicating hydrocephalus often poses a challenge in diagnosis and management decisions.

Aims: The objective of this study is to measure the opening pressure (P_o), pressure volume index (PVI), and cerebrospinal fluid outflow resistance (R_{out}), in patients with communicating hydrocephalus using bolus lumbar injection method and to evaluate its diagnostic and prognostic value.

Materials and Methods: The study was conducted in 50 patients with communicating hydrocephalus, including normal pressure hydrocephalus (NPH) (19), post-meningitic hydrocephalus (23) and post-traumatic hydrocephalus (8). An improvised bolus lumbar injection method [the Madras Institute of Neurology (MIN) method] was used.

Results: In the NPH Group, the CSF dynamics studies correlated well with the clinico-radiological classification. The prediction of shunt responsiveness by CSF dynamics studies correlated with good outcome in 87.5%. In the post-meningitic hydrocephalus group, the value of CSF dynamics studies in predicting patients needing shunt was 89.5%. The CSF dynamics studies detected patients who needed shunt earlier than clinical or radiological indications. In the post-traumatic hydrocephalus group, 62.5% of patients improved with the treatment based on CSF dynamics studies.

Conclusions: The improvised bolus lumbar injection method (MIN method) is a very simple test with fairly reliable and reproducible results. Study of CSF dynamics is a valuable tool in communicating hydrocephalus for confirmation of diagnosis and predicting shunt responsiveness. This is the first time that the value of CSF dynamics has been studied in patients with post-meningitic hydrocephalus. It was also useful for early selection of cases for shunting and for identifying patients with atrophic ventriculomegaly, thereby avoiding unnecessary shunt.

Key words: Bolus lumbar injection test, cerebrospinal fluid dynamics study, cerebrospinal fluid outflow resistance, communicating hydrocephalus, normal pressure hydrocephalus, post-meningitic hydrocephalus

Introduction

The study of disorders of cerebrospinal fluid (CSF) physiology is an interesting and under-explored field. Disorders of CSF circulation like communicating hydrocephalus often pose a challenge in diagnosis and management decisions. In communicating hydrocephalus, there is defective absorption of CSF. Hence, CSF dynamics studies, like measurement of opening pressure, pressure volume index (PVI) and CSF outflow resistance would be of help in establishing the diagnosis and assessing the prognosis. In this study, an attempt has been made to evaluate the usefulness of an improvised bolus lumbar injection method of CSF dynamics study in the management of communicating hydrocephalus.

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Materials and Methods

The study was conducted at our institute over a 4 year period from June 2006 to January 2010 on 50 patients with communicating hydrocephalus. The patients included three groups, namely normal pressure hydrocephalus (NPH), post-meningitic hydrocephalus and post-traumatic hydrocephalus.

Methodology

The Madras Institute of Neurology (MIN) method devised at our institute is an improvised Marmarou's bolus lumbar injection method, using saline manometer made with easily available bed-side material.[1-3]A saline manometer (if not readily available) was made using an intravenous set mounted on a meter scale and was filled with saline up to 11 cm of water with zero level corresponding to the level of the spine. Lumbar puncture was performed with 20-G spinal needle and connected to the saline manometer through a three-way adapter. After the saline column stabilizes the opening pressure (P_o) was noted. A known volume of saline (rV), usually 5 or 10 ml was injected into the subarachnoid space through the three-way port at the rate of 1 ml/second. The peak pressure (P_p) reached after the bolus injection was noted. Once the saline column in the manometer started falling gradually, after a fixed time ('t' in minutes), the pressure recording in the manometer (P_t) was noted. The CSF outflow resistance (R_{out}) was calculated using a two-step formula described by Marmarou.[1,2]

I step: Pressure Volume Index (PVI) $= rV/\log (P_p/P_o)$

II step: $R_{out} = t.P_o/PVI\ [\log P_t(P_p-P_o)/P_p(P_t-P_o)]$ cm of water/ml/min.

This was converted into mmHg/ml/min (cm of water/ml/min divided by 1.36).

The period of follow up was from 6 months to 1 year. The shunt responsiveness was assessed using the Black shunt outcome scale (*vide infra*).[4]

Black scale for assessment of shunt outcome

Excellent	Resumed pre-illness activity without deficit
Good	Resumed pre-illness activity with deficit, improved in two or more categories
Fair	Improved but did not return to previous work, improved in one category
Transient	Temporary major improvement
Poor	No change or worsening
Dead	Died within 6 wk of surgery or as a result of surgery

Statistical method

The one-sample Kolmogorov-Smirnov test was used for the analysis of the data in the three groups and a *P* value less than 0.05 was considered statistically significant.

Results

Normal pressure hydrocephalus group

This group included 19 patients with one or more of the triad of symptoms of NPH with ventriculomegaly in computerized tomography (CT) or magnetic resonance imaging (MRI) scan brain. This included 13 males and 6 females. Based on the NPH guidelines 2005, the patients were sub-classified as probable NPH (ten patients) and possible NPH (nine patients).[5] In all the patients, the bifrontal index was calculated from CT scan or MRI scan. CSF opening pressure (P_o), PVI and CSF outflow resistance (R_{out}) were measured in these patients. In all the 19 patients the opening pressure was between 11 and 20 cm of water [Figures 1 and 2].

In the present study, 11 out of 19 had R_{out} more than 18 mmHg/ml/min and as per the conclusions from the study of Boon *et al.* (1997) were expected to be shunt responsive and were advised shunt.[6] Eight patients out of the 11 underwent ventriculo-peritoneal shunt. Seven patients had excellent/good outcome and one patient died 25 days after the shunt due to co-morbid factors. Three patients who had R_{out} more than 18 mm Hg/ml/min refused surgery and they remained static. The prediction of shunt responsiveness by CSF dynamics studies correlated with good outcome in 7/8 cases (87.5%). Three patients predicted to be shunt responsive NPH by CSF dynamics refused shunt and remained static. The prediction of shunt responsiveness by CSF dynamics study and its correlation with outcome was found to be statistically significant ($P = 0.037$).

Eight patients who had normal R_{out} and P_o were not advised shunt, since they were not expected to do well with shunt.

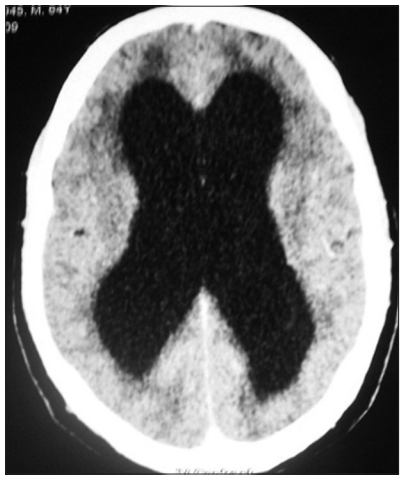

Figure 1: CT scan image of a 60-year-old man who presented with gait disturbance, memory disturbance and unconcerned micturition since 9 months. Clinical examination showed mild dementia with gait ataxia and normal fundus. CSF dynamics showed opening pressure of 25 cm H_2O and outflow resistance of 55.8 mmHg/ml/min. Showed good clinical improvement after shunt surgery over 2 months

Among them seven were managed conservatively. One patient who had shunt because of clinical and radiological considerations remained static after the surgery.

Post-meningitic hydrocephalus group

This included 23 patients with communicating hydrocephalus secondary to tuberculous meningitis including 14 females and 9 males. P_o and R_{out} were measured on the day of admission. The patients were managed as per the clinical and radiological features and the relevance of the CSF dynamics study was analyzed retrospectively. The first group of 13 patients, who had clinical and radiological indications of raised intracranial pressure (progressive fall in sensorium and communicating hydrocephalus with peri-ventricular lucency in CT scan), underwent early shunt surgery. In the second group of seven patients who were initially managed conservatively developed clinical and radiological features of progressive hydrocephalus 7 to 10 days later and underwent late shunt surgery. Three patients in the third group did not require shunt and were managed conservatively.

The CSF dynamics studies in the three groups were compared. The mean P_o and R_{out} in the first two groups were grossly higher than the normal range and those in the third group were within the normal range [Table 1].

The highest values of P_o and R_{out} in the third group were kept as the threshold. $P_o > 15$ cm of water and $R_{out} > 8$ mmHg/ml/min were considered as raised. In the first and second groups there were no patients with normal P_o and normal R_{out}. Twelve out of 13 patients in the first group had raised P_o. Ten of them had raised R_{out} also. Six out of seven patients in the second group had raised P_o and R_{out}, suggestive of high pressure hydrocephalus. One patient each in first and second groups had normal P_o with raised R_{out}, suggestive of NPH. If $P_o > 15$ cm of water and $R_{out} > 8$ mmHg/ml/min were kept as threshold and as indication for surgery at admission, all patients in the second group would have been shunted earlier. Seventeen out of 19 patients (89.5%) who underwent shunt surgery improved. Two patients died due to progressive meningitis. One patient died on the day of admission before surgery because of the severe meningitis. Hence, the CSF dynamics study would have been useful in determining the indication for shunt surgery in 17 out of 19 patients (89.5%), which was found to be statistically significant. Only 12 out of the 19 patients had clinical and radiological indications for shunt, whereas all of them had either elevated P_o and R_{out} or elevated R_{out} alone [Figures 3-6].

Table 1: The CSF dynamics in the three groups of Post-meningitic hydrocephalus

	P_o range cm of H_2O	Mean P_o	R_{out} range mmHg/ml/min	Mean R_{out}
Group 1	11-72	30.76	4.5-122	32.4
Group 2	12.5-46	29.64	11.35-61	25.36
Group 3	11-14.5	12.17	6.4-7.95	6.95

CSF: Cerebrospinal fluid

Figure 2: Postoperative CT of the same patient after 2 months showing mild reduction in ventricular size

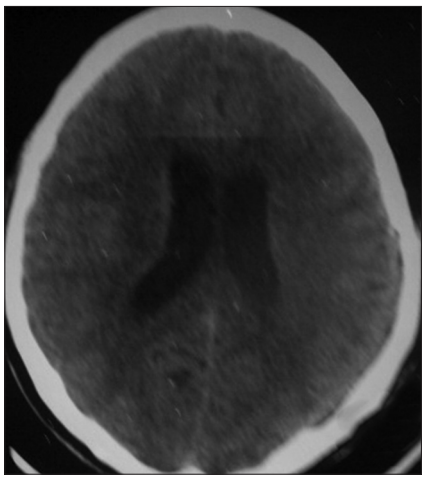

Figure 3: CT scan image of a 33-year-old man presenting with headache, confused speech which followed fever with altered sensorium 4 months earlier. Clinical examination showed memory disturbance with early papilledema. CSF dynamics showed opening pressure of 45 cm H_2O and outflow resistance of 25.3 mmHg/ml/min. The patient showed good improvement after shunt surgery and anti-tuberculous drugs

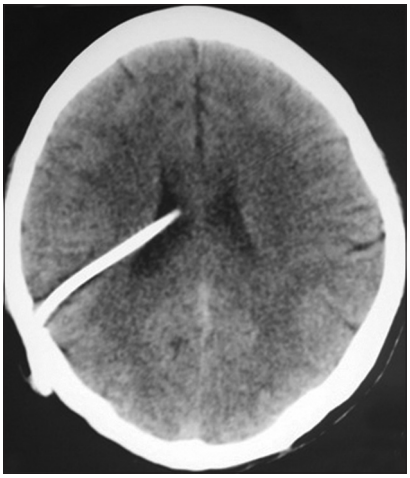

Figure 4: Postoperative CT of the same patient after 3 months shows good reduction in ventricular size

Figure 5: CT scan image of a 16-year-old girl admitted with intermittent fever with headache since 45 days. Neurological examination showed a conscious patient with papilledema. She had elevated erythrocyte sedimentation rate and elevated protein in CSF. CSF dynamics showed opening pressure of 13 cm H_2O and outflow resistance of 25 mmHg. Showed good improvement with shunt surgery and anti-tuberculous drugs

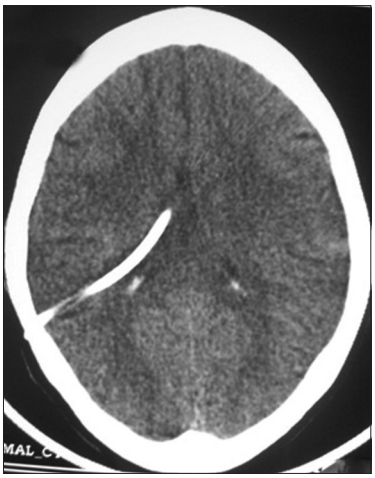

Figure 6: Postoperative CT shows normal ventricles 3 months later

Post-traumatic hydrocephalus group

There were eight patients in this group including seven males and a female. The time interval between trauma and presentation ranged from 15 days to 8 months. The CSF dynamic study was performed on all these patients after CT scan showed evidence of ventriculomegaly. The patients who had elevated P_o and/or elevated R_{out} underwent shunt. The threshold values were kept at P_o 15 mmHg and R_{out} 6 mmHg/ml/min, as per the guidelines of Marmarou *et al*.[7] Two patients had elevated P_o and R_{out}, suggestive of high pressure hydrocephalus and one had normal P_o and elevated R_{out} suggestive of NPH. All the three patients who underwent shunt surgery improved. The remaining five patients had normal P_o and R_{out} suggestive of atrophic ventriculomegaly and did not undergo shunt. Five out of eight (62.5%) patients improved with the management based on CSF dynamics studies. The mean bifrontal index in the hydrocephalic group was 0.397, as against 0.37 in the atrophic ventriculomegaly group.

Discussion

Communicating hydrocephalus is a fairly common clinical problem. This is due to a defect in the CSF absorption, which is mainly in the arachnoidal villi. The causes of communicating hydrocephalus are varied. The most common of them are NPH, post-meningitic hydrocephalus and post-traumatic hydrocephalus. All these situations may be mimicked by atrophic ventriculomegaly, either due to age related, post-traumatic or post-meningitic causes. This might confuse the neurosurgeon in the decision making regarding shunt. Hence, in addition to the clinical and radiological parameters which may be dubious, there is a need for a fool proof investigative tool to determine the indications for shunt in these patients. A defect in the CSF absorption results in early increase in CSF outflow resistance. The increase in CSF outflow resistance (R_{out}) precedes the clinical and radiological manifestations in patients with communicating hydrocephalus. The increase in R_{out} also often precedes the increase in intracranial pressure or subarachnoid CSF pressure as determined by measuring the opening pressure (P_o) by lumbar puncture. Hence, the measurement of R_{out} is likely to help in the early diagnosis of patients suitable for shunt in communicating hydrocephalus.

There are various methods for measuring R_{out}. They include constant pressure servo-controlled infusion method, constant infusion method (Kartzman), bolus lumbar injection method (Marmarou), radio-isotope dilution method.[1,2,8-10] The constant infusion, constant pressure and radio-isotope dilution methods are accurate methods. But they are time consuming and require sophisticated equipment. Hence, they are less useful for routine clinical application. The bolus lumbar injection method is a relatively simple method and less time consuming and suitable for routine clinical application. The MIN method is an improvised bolus lumbar injection test (Marmarou), which involves readily available bedside equipment and can be performed quickly with good accuracy.[3]

Normal pressure hydrocephalus

The diagnosis of NPH is traditionally by clinical and radiological methods. Often the diagnosis of NPH is made difficult because of the presence of age-related cortical atrophy and this may pose a diagnostic dilemma. The outcome of shunt surgery also depends as to whether the ventriculomegaly is because of hydrocephalus or cortical atrophy. One of the more objective methods for establishing the diagnosis of NPH and for determining shunt responsiveness is the study of CSF dynamics and

R_{out} measurement. There are other methods like lumbar tap test, trial lumbar drainage etc., which though may be useful, are not objective. R_{out} measurement is a more objective and accurate method. The normal value of R_{out} in various studies ranged from 5.98 to 9.1 mmHg/ml/min. The normal value of R_{out} in Indian population ranges from 3.82 to 9.7 mmHg/ml/min, with a mean of 6.09 mmHg/ml/min.[3] The threshold value for raised R_{out} quoted in various studies, ranges from 8 to 18 mmHg/ml/min.[5,6,11-14] The usefulness of R_{out} measurement in NPH has been studied by various authors and the threshold R_{out} value has been established [Table 2].

In the present study, of the 10 patients with probable NPH, 9 had a R_{out} more than 18 mmHg/ml/min. Among nine patients with possible NPH, seven had R_{out} of 7.1 mmHg/ml/min or less and two had R_{out} more than 18 mmHg/ml/min. This indicates a good correlation between clinical and R_{out} measurement in the diagnosis of NPH.

In NPH, the determination of shunt responsiveness is as challenging as establishing the diagnosis. In the Dutch NPH study, Boon *et al.* (1997) concluded that measurement of R_{out} reliably predicts good outcome if the threshold limit of R_{out} is kept at 18 mmHg/ml/min.[6] At lower R_{out} values, the decision to shunt or not depends on the clinical and radiological parameters.

Evidence-based guidelines for supplementary tests in NPH report that a positive response to a 40 to 50 ml tap test has a higher degree of certainty for a favorable response to shunt placement but low sensitivity (26 to 61%). Prolonged external lumbar drainage in excess of 300 ml is associated with high sensitivity (50-100%) and high positive predictive value (80-100%). Determination of the R_{out} carries a higher sensitivity (57% to 100%) and a similar positive predictive value of 75% to 92%.[15]

In the present study, R_{out} measurement by the MIN method of bolus lumbar injection is shown to be correlating well with the clinico-radiological classification as probable and possible NPH and the prediction of shunt responsiveness was 87.5% of cases.

Post-meningitic hydrocephalus

Post-meningitic hydrocephalus is due to the formation of thick gelatinous basal exudates around the interpeduncular and pontine cisterns in the acute stages and adhesive leptomeningitis in the chronic stages. In some cases arteritis, ischemia, and encephalopathy are the cause of the altered sensorium and adverse neurological condition. All these factors pose problems in the management and selection of patients for shunt and prediction of prognosis after shunt. Marked increase in R_{out} has been seen in animals with experimental bacterial meningitis.[16,17] Kemaloglu *et al.* (2002) found that outcome was better with early shunting in mild and moderate post-meningitic hydrocephalus.[18]

In the present study, the value of CSF dynamics in 23 patients with post-meningitic hydrocephalus has been analyzed. This is the first time that CSF dynamics study has been done on post-meningitic hydrocephalus in clinical practice. The mean P_o and R_{out} values of patients who underwent shunt were found to be higher than the group who did not require a shunt. Patients having P_o above 15 cm of water and R_{out} above 8 mmHg/ml/min would need a shunt. In the present study, CSF dynamics would have been useful in determining the indication for shunt surgery in 17 out of 19 patients (89.5%). In seven patients the altered CSF dynamics were present 7 to 10 days before the development of clinical indications for shunting. Hence, CSF dynamics studies would help in choosing patients for shunt, before the clinical and radiological indications and help in reducing the morbidity and mortality to a great extent.

Table 2: Rout measurement in NPH

	R_{out} threshold (mmHg)	PPV (%)
Boon *et al.*, 1997[6]	>18	92
Børgesen *et al.*,1979[11]	>8	96
Kahlon *et al.*, 2002[12]	>14	80
Meier and Bartels 2001[13]	>13	56
Borgesen et al.,1982[14]	>12.5	

PPV: Positive predictive value

Post-traumatic hydrocephalus

The accuracy of CT in differentiating post-traumatic hydrocephalus from atrophic ventriculomegaly is uncertain.[7,19] Marmarou *et al.* have suggested classification of these patients based on CSF dynamics studies and management accordingly.[7] In the present study, five out of eight (62.5%) patients improved with the management based on CSF dynamics studies.

Conclusion

CSF dynamics studies are an important tool in the physician's armamentarium in the management of communicating hydrocephalus. The MIN method of bolus lumbar injection is a very simple bedside test with easily available equipment and has a good accuracy. CSF dynamics studies were useful in the diagnosis and prediction of shunt responsiveness in 87.5% of patients with NPH, 89.5% of patients with post-meningitic hydrocephalus and 62.5% of patients with post-traumatic hydrocephalus. This is the first time that a clinical study with CSF dynamics has been done in post-meningitic hydrocephalus. This study firmly establishes the role of CSF dynamics measurements in the management of various types of communicating hydrocephalus.

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Nil.

Conflicts of interest

There are no conflicts of interest.

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