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Clinical testing of CSF circulation in hydrocephalus

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Summary

Introduction. Recent 'NPH Dutch trial' has re-emphasised the importance of the resistance to cerebrospinal fluid (CSF) outflow (Rcsf) in the diagnosis of hydrocephalus. We re-evaluated the clinical utility of the physiological measurements revealing CSF dynamics. The results were summarized from our previous publications.

The Computerised Infusion Test was designed to perform quick and low-invasive assessment of CSF dynamics described by parameters as Rcsf, brain compliance, elasticity coefficient, estimated sagittal sinus pressure, CSF formation rate and other variables. Overnight ICP monitoring with quantitative analysis of CSF dynamics was used in those cases where infusion study was unreliable or producing results close to the borderline. We found that the threshold of normal and increased Rcsf should be age-matched because in patients older than 55 Rcsf increases 0.2 mm Hg/(ml/min) per year ($p < 0.04$; $N = 56$). Rcsf was positively correlated with cerebral autoregulation ($R = 0.41$; $p < 0.03$; $N = 36$) indicating that in patients with symptoms of NPH but normal Rcsf underlying cerebrovascular disease is more frequent.

Computerized infusion tests and overnight ICP monitoring are useful diagnostic technique alone or in conjunction with other forms of physiological measurement.

Keywords: Hydrocephalus; cerebrospinal fluid; intracranial pressure; shunt.

Introduction

Hydrocephalus manifests with excessive accumulation of fluid within the brain. Implantation of hydrocephalus shunt is a standard way of management in communicating hydrocephalus. As shunting is almost purely mechanistic treatment, which radically affects pressure-volume compensation, the hydrodynamics of patient's own compensation should be ideally examined before a shunt is implanted.

Testing of CSF dynamics, although invasive, may help with the decision about surgery. It also provides basic information for further management of shunted patient when complications, such as shunt blockage, under-, and over-drainage, arise. In such cases, physiological measurement may aid the decision regarding shunt revision.

This paper reviews our 10 years of experience with physiological measurements in patients suffering from hydrocephalus [3–5, 11, 13, 15].

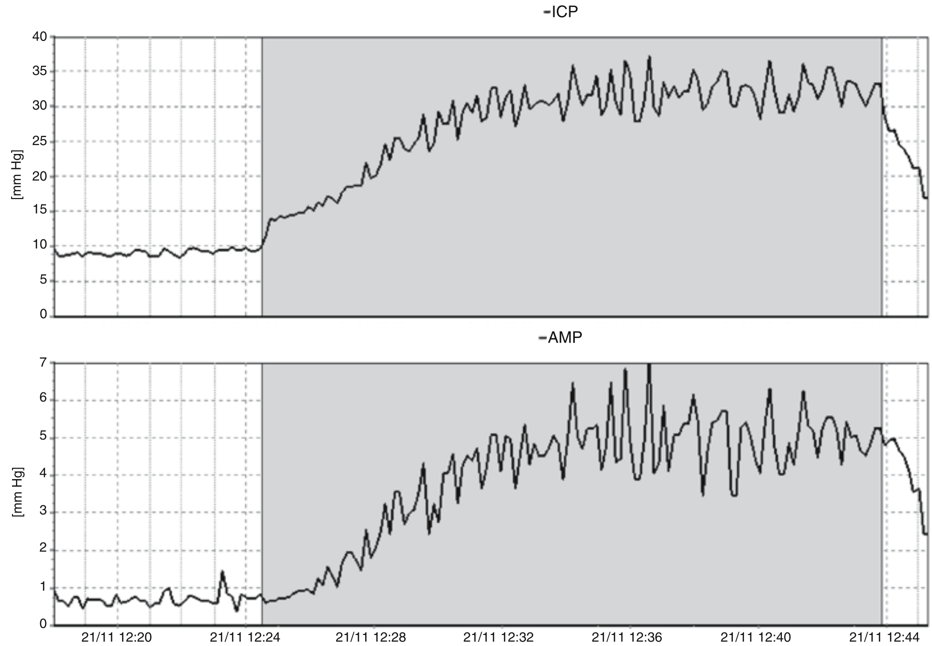
Material and methods

1250 infusion studies and 256 overnight ICP monitoring were performed in 653 patients over a 10 year period. All patients presented with clinical symptoms of hydrocephalus (solely or overlapping other CNS diseases) and various degree of ventricular enlargement on brain CT/MRI scans. 63% of tests were performed to assess CSF dynamics before shunting and 37% to assess shunt function. In total, 64% of tests were performed to pre-implanted Ommaya Reservoirs connected with the ventricular space, 11% to shunt pre-chamber and 25% into lumbar space. There were only two serious complications related to the infusion study (one brain abscess-treated successfully and one internal CSF leak related to a rapid mobilization of a patient after lumbar puncture – also managed with good results. Minor adverse effects such as headaches or nausea reported during the study resolve quickly after infusion and affect less than 10% of patients.

The aim of CSF infusion study was

1. To measure the Rcsf along with other compensatory parameters and consider whether the cerebrospinal circulation is disturbed and can be improved by shunting
2. In patients with shunts, to assess quality of shunt functioning in-vivo.

Almost all authors agree that in hydrocephalus the drainage of CSF is disturbed. This may be expressed quantitatively by an elevated resistance to CSF outflow. The limit of resistance is reported



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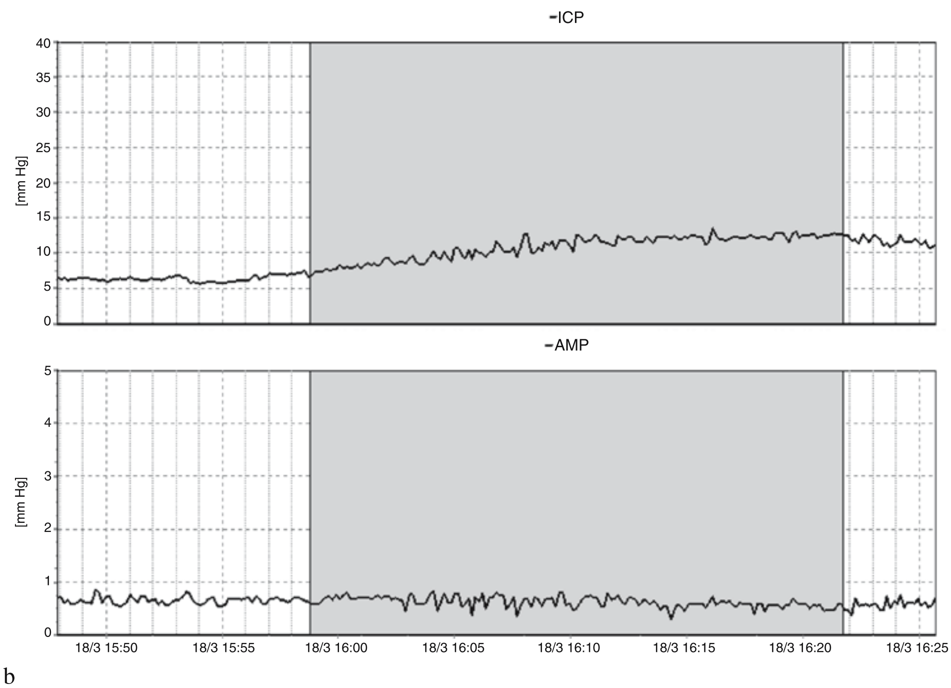

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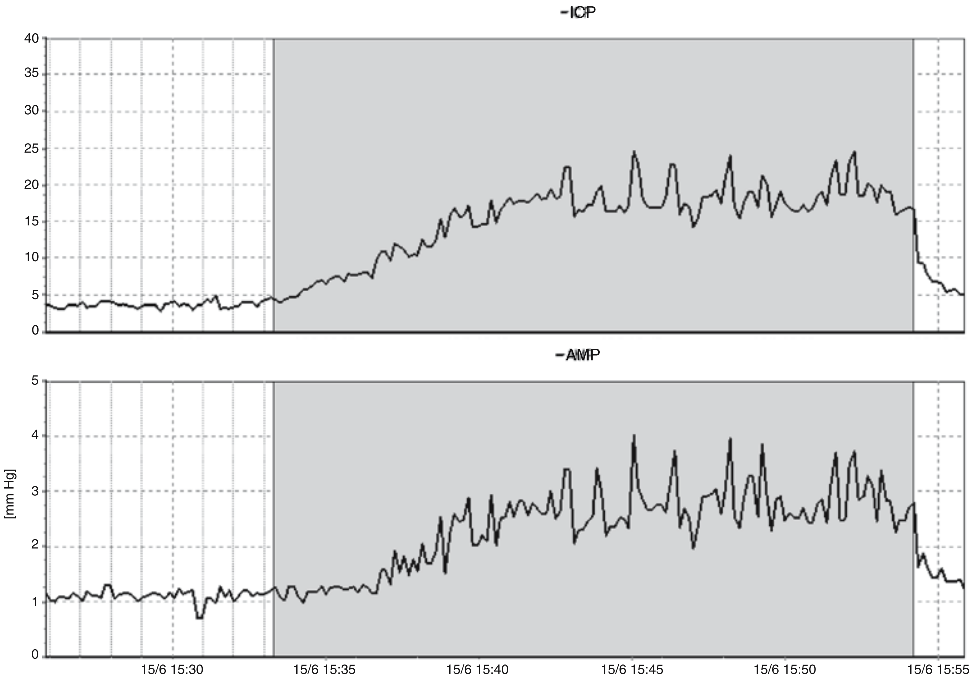
Fig. 1. Examples of constant rate infusion test. ICP – mean ICP (10 second averages) and AMP – pulse amplitude of ICP. Vertical lines mark beginning and the end of infusion of Hartman solution at a rate of 1.5 ml/min. (a) In patient suffering from normal pressure hydrocephalus (*NPH*). Baseline pressure is normal, resistance to CSF outflow increased, there are plenty of strong vasogenic waves, and changes in pulse amplitude are very well correlated with changes in mean ICP. (b) Cerebral atrophy. Baseline pressure is also low, resistance to CSF outflow is in norm, there are no vasogenic waves and pulse amplitude responds to changes in mean ICP very sluggish or (like in this particular case) there is no response

to range from 13 mm Hg/ml/min (in younger patients) [2] to 18 mm Hg/ml/min [1]. The computerized infusion test [3] is a modification of the traditional constant rate infusion as described by Katzman [10]. The method requires a fluid infusion to be made into any accessible CSF compartment. A lumbar infusion, even if it has understandable limitations, is less invasive than ventricular infusion. However, the most frequent approach in our centre is an intraventricular infusion into a subcutaneously positioned reservoir, con-



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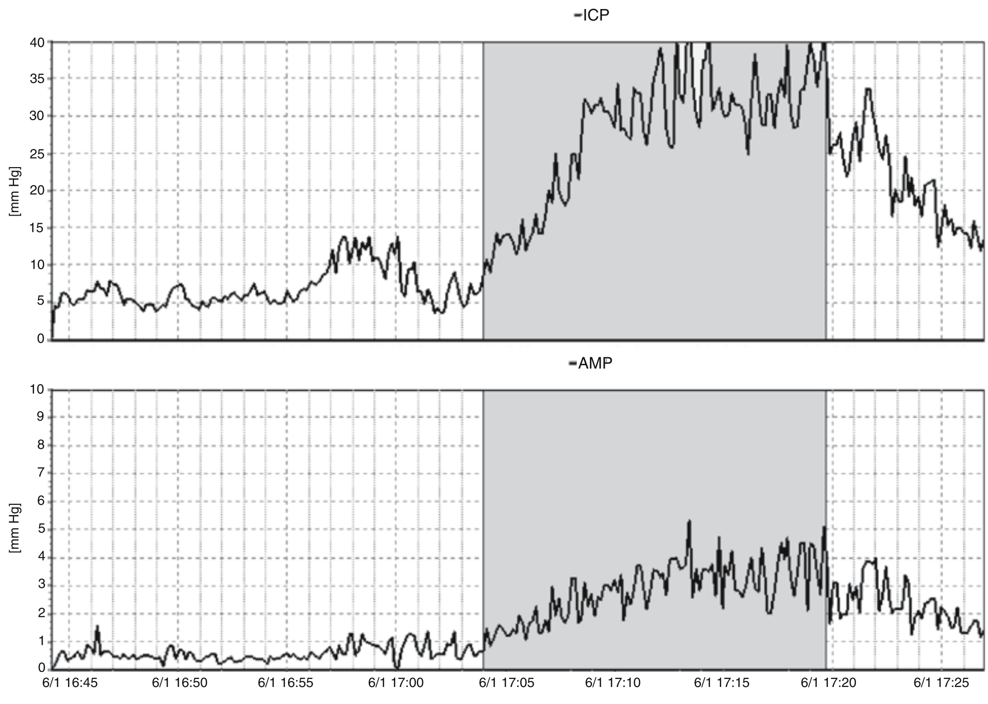

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Fig. 2. Examples of two infusion tests performed to assess shunt functioning in vivo. In both cases ICP increased in the response to infusion. (a) Response was lower than the threshold level for the used valve (Strata, level 1.5). (b) Baseline pressure was low but the response of ICP during the test exceeded the critical threshold level. Valve is blocked. (Strata, level 1.5)

nected to an intraventircular catheter or shunt antechamber. In such cases two needles (gauge 25) are used: one for the pressure measurement and the second for the infusion.

During the infusion, the computer calculates and presents mean pressure and pulse amplitude (with time along the x axis – see Fig. 1). The resistance to CSF outflow can be estimated using simple arithmetic as the difference between the value of the plateau pressure during infusion and the resting pressure divided by the infusion rate.

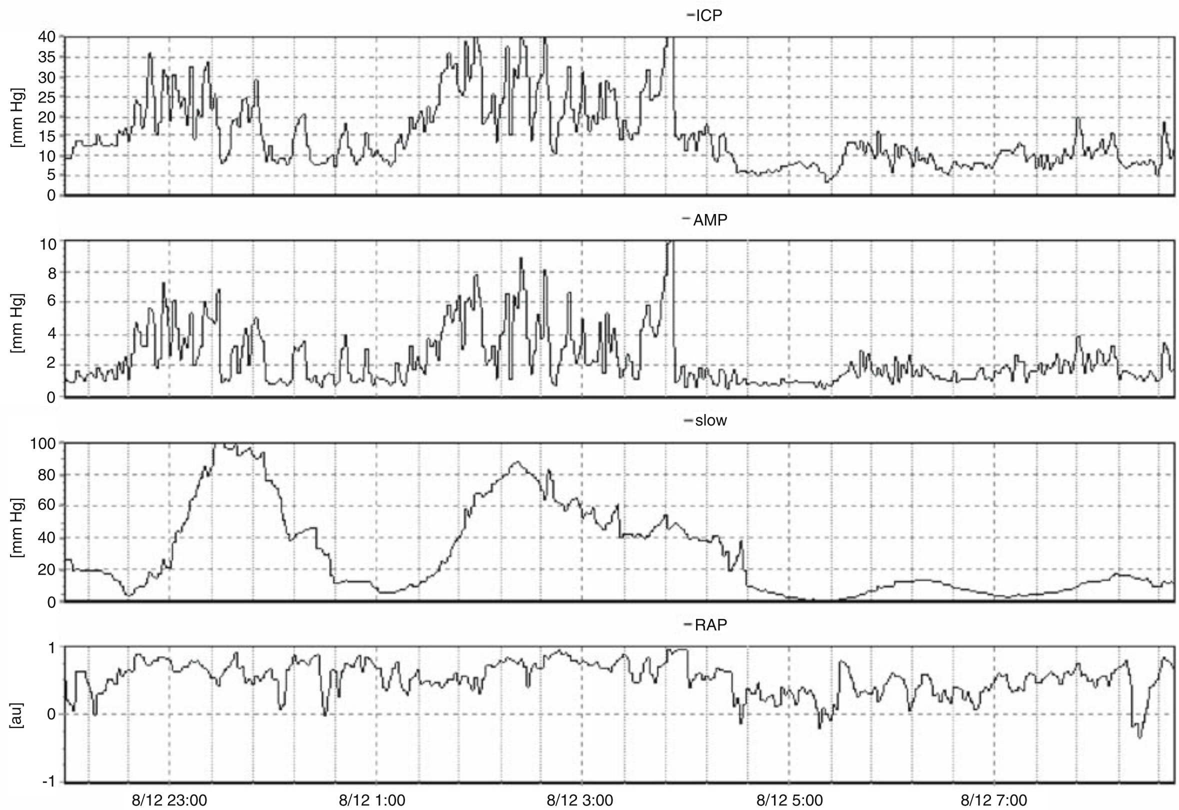

Fig. 3. Example of overnight monitoring of ICP (using Camino bolt) revealing increased CSF dynamics. Slow – magnitude of slow waves (B waves) is elevated. RAP – correlation coefficient between mean ICP and pulse amplitude (*AMP*) indicates poor compensatory reserve (RAP > 0.6 overnight)

However, in many cases strong vasogenic waves or an excessive elevation of the pressure above the safe limit of 40 mm Hg do not allow the precise measurement of the final pressure plateau. Computerized analysis, produces results even in difficult cases when the infusion is terminated prematurely (i.e., without reaching the end-plateau). The algorithm utilizes a time series analysis for volume-pressure curve retrieval, the least-mean-square model fitting and an examination of the relationship between the pulse amplitude and the mean CSF pressure. Apart from resting CSF pressure and the resistance to CSF outflow, the elastance coefficient or pressure-volume index, cerebrospinal compliance, CSF formation rate and the pulse wave amplitude of CSF pressure are estimated.

However, not all patients presenting with abnormal CSF circulation may improve after shunting [1, 11]. As positive predictive power of infusion study is usually reported as satisfactory, some patients with apparently normal profile of CSF circulation may still get better after surgery [1]. Therefore, the infusion test does not offer a definite indication for the management of hydrocephalus. It should be always interpreted in conjunction with other forms of investigations (neuropsychological, brain imaging, gait analysis, CSF tap test or diagnostic drainage [17], vascular reactivity [4], biochemical composition of CSF, etc.).

In hydrocephalus a shunt is used to drain excess CSF to elsewhere in the body according to a pressure difference between inlet (ventricles) and outlet (peritoneal or atrial) compartments. Ideally, the resistance of an open shunt taken together with the natural CSF outflow resistance (usually increased in hydrocephalus) should be close to the normal resistance to CSF outflow, i.e. 6 to 10 mm Hg/ml/min [7]. The flow through the shunt should not depend on the body posture or be affected by body temperature, external pressure (within the physiological range for subcutaneous pressure) or the pulsatile component of CSF pressure.

After shunting, the model of CSF space [12] should be supplemented by the branch representing the property of the shunt. The most sensitive indicator of the shunt partial blockage is the steady state level achieved during the test [5]. With known value of the shunt pressure-flow curve (opening pressure and its hydrodynamic resistance where the curve is quasi-linear) the critical threshold may be evaluated for each individual type of the shunt:

$$\textit{5 mm Hg} + \textit{shunt opening pressure}$$
$$+ \textit{infusion rate* hydrodynamic resistance of shunt}$$

Examples of the tests revealing properly functioning shunt and the blocked shunt are presented in Fig. 2.

Parameters describing vascular effects and pressure-volume compensation can also be evaluated during the infusion study, using for example non-invasive transcranial Doppler ultrasonography. As the study usually starts with 10–15 minutes of period of baseline assessment, which can be easily extended. Vasogenic waves of ICP, analogical to these monitored during ICP overnight (see Fig. 3) recording, can be calculated.

Results

In patients with clinical symptoms of NPH ($N = 133$) resistance to CSF outflow is associated with severity of symptoms (modified Stein-Langfitt score: $R = 0.18$; $p < 0.05$).

In different subgroup [6] ($N = 56$) the resistance to CSF increased with age ($R = 0.57$; $p < 0.0001$) and estimated CSF formation rate decreased ($R = 0.49$; $p < 0.002$).

Vasogenic waves (pulse amplitude, slow waves and respiratory waves) of intracranial pressure are positively correlated with the resistance to CSF outflow [13], with the strongest association between respiratory waves and Rcsf ($R = 0.52$; $p < 0.003$; $N = 35$).

Baseline ICP measured after the test is usually greater than the value measured before the test. This phenomenon can be described as hysteresis of the pressure-volume curve [11]. The width of hysteresis is positively associated with width of ventricles ($R = 0.63$; $P < 0.03$; $N = 35$) and negatively with modified Stein-Langfitt score ($R = -0.61$; $p < 0.02$).

Cerebral autoregulation assessed using transcranial Doppler ultrasonography during the test proved to correlate with Rcsf [4] in a manner suggesting worse autoregulation in those having lower resistance to CSF outflow ($R = -0.41$; $p < 0.03$; $N = 36$).

Conclusion

Physiological monitoring can be useful in the management of hydrocephalus. It helps to exclude patients from unnecessary shunting, to evaluate shunt functioning in-vivo, and to detect vascular components of hydrocephalus.

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