Cerebrospinal Fluid Drainage and Dynamics in the Diagnosis of Normal Pressure Hydrocephalus

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INTRODUCTION: Because of the difficulty in distinguishing idiopathic normal pressure hydrocephalus (INPH) from other neurodegenerative conditions unrelated to cerebrospinal fluid (CSF) dynamics, response to CSF shunting remains highly variable. We examined the utility of CSF drainage and CSF pressure (Pcsf) dynamics in predicting response to CSF shunting for patients with INPH.

METHODS: Fifty-one consecutive INPH patients underwent continuous lumbar Pcsf monitoring for 48 hours followed by 72 hours of slow CSF drainage before ventriculoperitoneal shunting. Response to CSF drainage and B-wave characteristics were assessed via multivariate proportional-hazards regression analysis.

RESULTS: Improvement in 1, 2, or all 3 INPH symptoms was observed in 35 (69%), 28 (55%), and 11 (22%) patients, respectively, after CSF shunt implantation by 12 months after surgery. A positive response to CSF drainage was found to be an independent predictor of shunt responsiveness (relative risk, 0.30; 95% confidence interval, 0.09–0.98; $P = 0.05$). There was no difference in Pcsf wave characteristics between the shunt-responsive and -nonresponsive groups, regardless of whether 1-, 2-, or 3-symptom improvement was used to define response to CSF shunting.

CONCLUSION: In this study of 51 INPH patients who underwent Pcsf monitoring with waveform analysis and CSF drainage followed by shunt surgery, there was no correlation between specific Pcsf wave characteristics and objective symptomatic improvement after shunt placement. Pcsf monitoring with B-wave analysis contributes little to the diagnostic dilemma with INPH patients. Clinical response to continuous CSF drainage over a 72-hour period suggests a high likelihood of shunt responsiveness.

KEY WORDS: B-wave, Cerebrospinal fluid drainage, Cerebrospinal fluid shunt, Idiopathic normal pressure hydrocephalus, Pressure monitoring

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Despite nearly 4 decades of investigation, the pathoetiology of idiopathic normal pressure hydrocephalus (INPH) remains unclear. The term *normal pressure hydrocephalus* (NPH) was coined in 1965 to describe the syndrome of progressive cognitive deterioration with psychomotor retardation, gait apraxia and imbalance, and urinary incontinence associated with hydrocephalus and normal cerebrospinal fluid (CSF) pressure on lumbar puncture (1). Although NPH can be secondary to disease processes that cause inflammation of the arachnoid, such as subarachnoid hemorrhage, traumatic brain injury, or meningitis, as much as half of NPH has no identifiable risk factor and is called INPH (34).

ABBREVIATIONS: CSF, cerebrospinal fluid; **INPH**, idiopathic normal pressure hydrocephalus; **NPH**, normal pressure hydrocephalus; **Pcsf**, cerebrospinal fluid pressure

The decision to treat individual patients with INPH with a CSF shunt is difficult because of the challenge in distinguishing INPH from other neurological conditions of the elderly with a similar clinical picture (e.g., vascular dementia, Parkinsonism, Lewy body dementia, cervical spondylotic myelopathy, peripheral neuropathy) but which do not respond to CSF shunting (7, 9, 11, 13, 33). Because INPH is potentially reversible, its correct identification, often in the setting of coexisting diseases, is critical to successful treatment. The criteria for selecting patients for shunt surgery remain unclear.

Multiple diagnostic techniques have been proposed, including radiographic findings (18, 35), measurement of CSF outflow resistance (3, 5, 6, 10), CSF removal via lumbar puncture or continuous drainage (8, 19), analysis of soluble CSF markers (25, 29, 31), and CSF pressure (Pcsf) monitoring (20–22, 36). Current evidence suggests that continuous CSF drainage via spinal catheter and measurement of CSF outflow resistance are the most sensitive and specific tests (23); however, the complexity of these techniques can limit their use.

Patients with NPH have abnormal Pcsf waveforms, including B-waves, which can be consistent with impaired intracranial compliance and CSF resorption (20, 36). The ability of B-waves to predict improvement after CSF shunting varies among studies (36). Few studies have compared the Pcsf waveform characteristics in those patients who do or do not respond to CSF shunting. CSF drainage has also been shown to predict which INPH patients will respond to CSF shunting with varying degrees of success (8, 15, 36). One of the criticisms of CSF drainage has been that, because of its relatively low negative predictive value, diagnosis in many patients with potentially reversible symptoms is missed.

The Johns Hopkins Adult Hydrocephalus Program has long used a protocol of spinal catheter insertion for lumbar Pcsf monitoring and controlled CSF drainage to diagnose INPH. The goal of this study was to compare the predictive power of Pcsf monitoring and CSF drainage to identify INPH patients who will respond to shunt surgery. A secondary aim was to identify specific B-wave characteristics associated with response to shunt surgery.

PATIENTS AND METHODS

Diagnostic Criteria and Treatment Algorithm

Over a 3-year period, from 2000 to 2003, more than 200 patients were referred for evaluation of INPH at the Johns Hopkins Adult Hydrocephalus Program. Fifty-one were found to be candidates for CSF shunt insertion, based on rigorous screening and preadmission testing. Possible INPH was defined as ventriculomegaly (cerebroventricular/bifrontal index greater than 40) (16, 17), at least 2 clinical features of INPH (gait impairment, urinary incontinence, or dementia), and the absence of risk factors for secondary NPH. In cases where fourth ventricle outflow obstruction could not be ruled out, magnetic resonance imaging was also performed with cine flow sequences. Patients were admitted to the hospital for elective spinal catheter insertion for 2 days of continuous lumbar Pcsf monitoring and 3 days of controlled continuous CSF drainage at 10 mL/hour (240 mL/day). Patient inclusion and study variables were approved in accordance with the Johns Hopkins Hospital institutional review board. Response to CSF drainage was defined as objective improvement in gait, cognition, or bladder control. Patients were classified as having probable INPH if B-waves were present on continuous Pcsf monitoring, and/or there was clinical improvement in response to CSF drainage.

If set pressure valves were used (most shunts before 2000), a "medium pressure" valve was initially implanted. If minimal or no symptomatic improvement was observed by 6 months and there was no evidence of shunt malfunction, a lower-pressure valve was surgically implanted. If adjustable valves were used (all shunts after 2000, Strata; Medtronic, Inc., Minneapolis, MN), they were initially set in the medium pressure range. Patients were assessed at regular intervals, and the valve setting was changed as clinically indicated until maximum symptomatic improvement was noted without low-pressure side effects. Antisiphon devices were used in almost all cases (95%).

Because of our concern for overdrainage in this patient population, we are conservative with the shunts implanted. Our current protocol features adjustable valves with antisiphon devices initially set at the medium setting. The valve is then adjusted slowly in the outpatient setting to maximize the effect and minimize likelihood of overdrainage symptoms or subdural hematoma. With the valve at the lowest setting, we think that most patients will be able to achieve a similar amount of CSF diversion compared with the lumbar drainage trial. However, it is possible this is not the case; that is, an effect may have been seen during the lumbar drainage trial in the setting of a greater amount of CSF diversion than could be achieved with this shunt system. If this situation was suspected, the patient was offered a new shunt without an antisiphon device and counseled on the risks of overdrainage.

In cases in which shunt malfunction was suspected, the shunt reservoirs were tapped to assess proximal flow and intracranial pressure. If concern for distal malfunction was still present, a radionucleotide shunt patency evaluation was performed to assess flow through the distal catheter. In cases in which either test showed malfunction, the shunt was revised promptly.

Continuous Lumbar Pcsf Monitoring

A spinal catheter (Codman/Johnson & Johnson, Raynham, MA, or Medtronic PS Medical, Goleta, CA) was inserted percutaneously into the lumbar subarachnoid space using a 14-gauge Tuohy needle under local anesthesia at the bedside using sterile technique. The puncture site and spinal catheter were covered by a transparent occlusive dressing (OPSITE; Smith & Nephew, London, UK) to prevent dislodgement or contamination. Physiological parameters, including Pcsf, O_2 saturation, pulse rate, and respiratory excursion, were recorded continuously for 2 days on a computer using a commercially available analog-to-digital signal converter and software (MacLab and PowerLab; AD Instruments, Colorado Springs, CO). An external strain gauge transducer was leveled to the external acoustic meatus as an external anatomic zero reference point.

Although Pcsf was recorded continuously, portions of the recordings were unsuitable for analysis because of movement artifact. Therefore, Pcsf from 1:00 to 5:00 AM was analyzed, using artifact-free epochs when the annotated record indicated the transducer was properly leveled. This was also combined with an analysis of the 30-minute period of greatest variability in the pressure waveforms within this 4-hour period in all patients. Abnormal Pcsf waveforms were identified according to criteria adapted from the original description by Lundberg (20). We defined B-waves as rhythmic or semirhythmic waves occurring at a frequency of 0.5 to 2 cycles per minute with peak Pcsf more than 5 mm Hg. Percent B-wave time, maximum B-wave frequency, and mean and maximum B-wave amplitude were recorded or calculated for each period.

Outcome Assessment

Follow-up consisted of clinical evaluation postoperatively at 1, 3, 6, and 12 months, and yearly thereafter. Patient records were retrospectively reviewed. At each clinical visit, the Folstein Mini-Mental State Examination (12) was administered and patients and their families were asked about symptoms. Improvement in cognitive function was defined as at least a 3-point improvement in Mini-Mental State Examination and improvement in the patient's cognitive function from the perspective of either the patient or family. Improvement in urinary incontinence was defined as a decrease in incidence of urinary frequency, urgency, or incontinence, as well as improvement subjectively reported by the patient or family (often characterized by less dependence on an incontinence undergarment or pad). Improvement in gait was documented by change in detailed clinical evaluation (e.g., stride length, pace, base, stability on turning, presence of shuffling, or side-stepping), and was also assessed on the basis of the patient's and family's perspective, and included documentation of dependence on assistive devices (e.g., cane, walker, wheelchair). Assessments were performed in the hospital during the drainage period and at each clinic follow-up visit. Patients were offered CSF shunt placement if there was clear improvement in at least 1 INPH symptom during the lumbar drainage trial.

Statistical Analysis

Summary statistics were calculated for the entire study population. Parametric data are given as mean ± standard deviation. Nonparametric data are given as median (interquartile range). For intercohort comparison, continuous data were compared via 2-way analysis of variance for parametric data and Mann-Whitney *U* test for nonparametric data. Percentages were compared via χ^2 and Fisher exact tests where appropriate.

The association among specific Pcsf waveform characteristics, response to CSF drainage, and treatment response was assessed via log-rank analysis for stratified covariates and proportional hazards analysis for continuous covariates. Pcsf waveform and drainage variables achieving a statistical significance of $P < 0.10$ in the univariate analysis were included in a multivariate proportionate hazards regression analysis, because of the large number of variables in the intercohort comparison. A *P* value of 0.05 or less was considered significant in the multivariate analysis. Data were also graphically represented using Kaplan-Meier curves with percentage of patients experiencing 1 or more symptom improvements as a function of time after shunt surgery, and grouped by Pcsf waveform characteristic or response to CSF drainage.

RESULTS

Patient Population

There were 27 women (53%) and 24 men (47%) in this patient population. Mean age at presentation was 75 ± 5 years. Eleven patients (22%) had clinical depression, 5 (10%) were cigarette smokers, 20 (39%) had hypertension, 1 (2%) had peripheral vascular disease, and 12 (24%) had diabetes mellitus. Gait impairment was a feature for 50 (98%), urinary incontinence or urgency was present for 40 (78%), and cognitive decline was reported for 41 (80%). Headaches were a complaint for 8 patients (15%). The complete INPH triad was present for 32 patients (63%). The primary (most debilitating) symptom was gait impairment for 37 patients (73%), cognitive impairment for 11 (22%), and urinary incontinence or urgency for 3 (6%). On preoperative computed tomography or magnetic resonance imaging, corpus callosum distension was observed in 8 patients (16%), and diffuse cerebral atrophy in 16 patients (32%). There were no significant differences in the characteristics between the shunt-responsive and -nonresponsive groups (Table 1). Periventricular white matter changes consistent with microvascular disease on magnetic resonance imaging were observed in 12 patients (34%) who experienced at least 1 symptom improvement compared with 11 patients (69%) in the group that had no improvement after shunt placement ($P = 0.04$) (Figs. 1 and 2; Table 1).

Clinical improvement after continuous lumbar drainage was noted in 41 patients (80%). The sensitivity (91%) and specificity (70%) were calculated for the continuous CSF drainage test. These calculations assume the definition of INPH is "shunt-responsive

TABLE 1. Demographic, clinical, radiographic, and summary cerebrospinal fluid pressure monitoring characteristics of shunt-responder and nonresponder groups[a]

	Treatment response (n = 35)	No treatment response (n = 16)	*P* value
Demographic/clinical characteristics			
Age (y)	73 ± 12	73 ± 7	0.45
Female	17 (49%)	10 (63%)	0.36
Depression	6 (17%)	5 (31%)	0.26
Smoker	2 (6%)	3 (19%)	0.15
Hypertension	10 (29%)	10 (63%)	0.39
Peripheral vascular disease	1 (3%)	0 (0%)	0.49
Diabetes mellitus	7 (20%)	5 (31%)	0.38
Dementia	28 (80%)	13 (81%)	0.91
Duration (mo)	12 (7–24)	15 (11–51)	0.15
Apraxia	34 (97%)	16 (100%)	0.49
Duration (mo)	24 (12–57)	33 (12–60)	0.46
Urinary incontinence	25 (71%)	15 (94%)	0.07[b]
Duration (mo)	12 (0–24)	24 (11–51)	0.08[b]
Headache	7 (20%)	1 (6%)	0.21
CT/MRI findings			
Cerebral atrophy	11 (31%)	5 (31%)	0.99
Corpus callosum distension	6 (17%)	2 (13%)	0.67
Periventricular change	12 (34%)	11 (69%)	0.04[b]
CSF Pressure studies			
Pcsf (30 min)			
% B-wave time	62 ± 38	82 ± 31	0.07[b]
Maximum B-wave frequency	0.73 ± 0.45	0.83 ± 0.40	0.21
Mean B-wave amplitude (mm ± Hg)	10 ± 5	12 ± 4	0.26
Maximum B-wave amplitude (mm Hg)	13 ± 7	16 ± 7	0.10[b]
Pcsf (4 h)			
Percent B-wave time	9 (4–31)	17 (6–33)	0.48
Maximum B-wave frequency	0.83 ± 0.49	0.93 ± 0.41	0.46
CSF drainage			
≥1 symptom improved	32 (91%)	9 (56%)	<0.01[b]

[a] CT, computed tomography; MRI, magnetic resonance imaging; CSF, cerebrospinal fluid; Pcsf, cerebrospinal fluid pressure. Values are given as number (%), mean ± standard deviation, or median (interquartile range). A significantly larger number of patients in the nonresponder group had hypertension and periventricular changes on MRI. This group also showed a significantly smaller percentage who responded to continuous CSF drainage.
[b] $P \leq 0.05$.

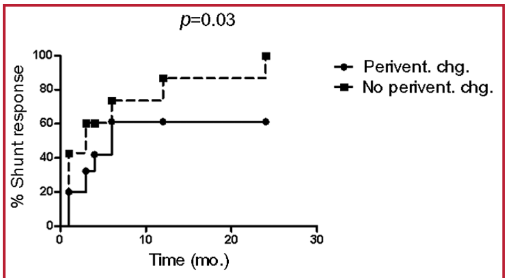

FIGURE 1. *Graph showing comparison of patients with and without periventricular white matter changes (perivent. chg.) on preoperative imaging and shunt outcome. Significantly more patients without these periventricular changes improved after cerebrospinal fluid (CSF) shunting over time (P = 0.03).*

FIGURE 2. *Axial FLAIR magnetic resonance image depicting the typical periventricular white matter changes seen in patients less likely to respond to long-term CSF shunting.*

INPH," given our study group of shunted patients. B-waves suggestive of INPH physiology were present more than 25% of the time in 15 patients (29%) and during the majority (more than 50%) of the recording time in 9 patients (18%). Ventriculoperitoneal shunts were used in 49 cases (96%), and ventriculoatrial shunts in 2 cases (4%). Programmable valves were used in 44 cases (86%), and set pressure valves in 7 cases (14%).

Outcome

After shunt surgery, 20 patients (39%) complained of low-pressure headaches, all of which improved after change of the valve setting. Small, asymptomatic subdural hematomas or hygromas developed in 3 patients (6%) during the follow-up period, but each of these resolved by increasing the setting of the shunt valve. There was no perioperative morbidity or mortality during the study period.

Median follow-up was 10 months (range, 6–16 months). Sixteen patients (31%) showed no improvement in any symptom, and thus no response to treatment. Improvement in at least 1 symptom occurred in 35 patients (69%), 2 symptoms in 28 patients (55%), and all 3 presenting INPH symptoms in 11 patients (22%). In those patients who showed improvement in at least 1 symptom, 31 (89%) experienced better gait performance. Median time to symptom improvement after shunt surgery was 1 month. Time to treatment response is detailed in Figure 3.

Shunt failure occurred in 16 patients (32%). The cause of shunt failure was distal obstruction in 9 (18%), proximal obstruction (ventricular catheter or valve mechanism) in 2 (4%), and infection in 5 (10%). There was no significant difference in shunt failure between the shunt-responder and shunt-nonresponder groups. Median time to shunt failure was 8 months (interquartile range, 4–12 months).

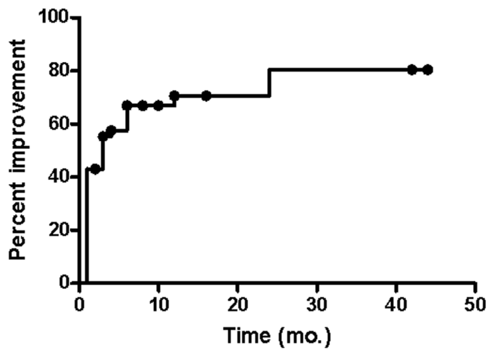

FIGURE 3. *Graph showing time to symptomatic improvement after shunt surgery. Median time to improvement was 1 month; however, many patients continued to show improvements through 2 years.*

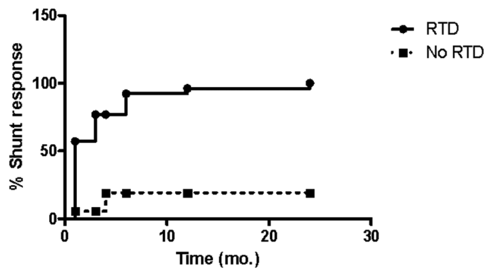

FIGURE 4. *Graph showing comparison of patients who did and did not respond to controlled CSF drainage and eventual shunt outcome. Responders were significantly more likely to improve over time (P < 0.01). RTD, response to drainage.*

Correlation of Pcsf Dynamics and Outcome

Patients demonstrating a positive response to trial CSF drainage were 3.2-fold more likely to improve after CSF shunting (relative risk, 3.2; 95% confidence interval, 0.09–1.00; $P < 0.05$) (Fig. 4; Table 2).

There was no difference in lumbar Pcsf waveform characteristics, including percent B-wave time, maximum B-wave frequency, and mean and maximum B-wave amplitude between patients responding versus not responding to CSF shunting (Table 2). During the 30-minute period of greatest waveform variability, B-wave characteristics were also similar between shunt responders and nonresponders: mean B-wave amplitude (10 ± 5 versus 12 ± 4 mm Hg), maximum B-wave amplitude (13 ± 7 versus 16 ± 7mm Hg), percent B-wave time (9% [4%–31%] versus 17% [6%–33%]), and maximum B-wave frequency (0.73 ±

TABLE 2. Univariate and multivariate associations with improvement in 1 or more idiopathic normal pressure hydrocephalus symptoms after shunt surgery[a]

	Univariate analysis RR (95% CI)	*P* value	Multivariate analysis RR (95% CI)	*P* value
Preoperative symptoms				
Dementia	0.84 (0.37–1.96)	0.71		
Duration (mo)	0.99 (0.98–1.01)	0.35		
Apraxia	0.42 (0.06–3.12)	0.40		
Duration (mo)	1.00 (0.99–1.01)	0.85		
Urinary incontinence	1.81 (0.86–3.81)	0.12		
Duration (mo)	0.99 (0.98–1.01)	0.22		
CT/MRI findings				
Cerebral atrophy	0.99 (0.48–2.02)	0.98		
Corpus callosum distension	0.84 (0.35–2.03)	0.70		
Periventricular change	1.93 (0.95–3.90)	0.07[b]	1.82 (0.89–3.67)	0.10
Pcsf (30 min)				
% B-wave time	1.76 (0.81–3.83)	0.15		
Maximum B-wave frequency	0.68 (0.29–1.56)	0.36		
Mean B-wave amplitude (mm Hg)	0.96 (0.90–1.03)	0.25		
Maximum B-wave amplitude (mm Hg)	0.97 (0.92–1.01)	0.16		
Pcsf (4 h)				
% B-wave time	0.99 (0.98–1.01)	0.56		
Maximum B-wave frequency	0.69 (0.33–1.45)	0.33		
Mean B-wave amplitude (mmHg)	0.99 (0.93–1.06)	0.81		
Maximum B-wave amplitude (mm Hg)	1.00 (0.96–1.04)	0.96		
CSF drainage				
≥1 symptom improved	0.29 (0.09–0.96)	0.04[c]	0.31 (0.09–1.01)	0.05[bs]

[a] RR, relative risk (likelihood of shunt response); CI, confidence interval; CT, computed tomography; MRI, magnetic resonance imaging; Pcsf, cerebrospinal fluid pressure; CSF, cerebrospinal fluid. Patients with periventricular white matter changes on preoperative MRI scan were less likely to respond to CSF shunting (trend, not statistically significant). Patients who showed a positive response to CSF drainage were more than 3 times more likely to respond to permanent CSF shunting.
[b] $P \leq 0.05$.

0.45 versus 0.83 ± 0.40 cycles/minute). During the 1:00–5:00 AM period, B-wave characteristics remained similar between shunt responders and nonresponders: mean B-wave amplitude (8 ± 5 versus 12 ± 4 mm Hg), maximum B-wave amplitude (13 ± 9 versus 13 ± 8 mm Hg), percent B-wave time (9% [4%–31%] versus 17% [6%–33%]), and maximum B-wave frequency (0.83 ± 0.49 versus 0.93 ± 0.41 cycles/minute). All Pcsf wave characteristics remained unassociated with subsequent response to CSF shunting regardless of whether 1, 2, or 3 symptom improvements were used to define treatment response.

DISCUSSION

In this study, when we compared Pcsf waveform analysis to controlled CSF drainage in a cohort of patients who had both, only response to controlled CSF drainage discriminated between patients with treatment response and those without. Treatment response showed no correlation with lumbar Pcsf waveform characteristics. Percentage of patients responding to CSF drainage differed significantly between the 2 groups, and response to CSF drainage was independently associated with treatment response.

These results confirm that response to controlled CSF drainage helps to predict response to shunt surgery for patients with INPH, as detailed in the studies by Marmarou et al. (24) and Pfisterer et al. (28). However, this diagnostic method has been criticized for failing to include many patients who would otherwise benefit from shunt therapy. Interestingly, the range of times (10 minutes to 3 days) and volumes of CSF drained (50 to 720 mL) varied between each of these reports (2, 8, 15, 24), hence some differentiate this test by the terms, "CSF tap test," versus "continuous CSF drainage." The more recent study by Pfisterer et al. (28) used continuous intraventricular pressure monitoring, and found excellent shunt response rates (96%). This and other studies have shown that the benefits of CSF diversion for patients with NPH extend years after the initial shunt placement (26, 27). Whereas some patients will respond immediately to CSF drainage, others can take months to years to respond. Therefore, to increase the likelihood of identifying all potential shunt responders, the location and duration of CSF drainage should be increased to more closely mimic the effects of long-term CSF shunting. For this reason, we use a continuous 3-day CSF drainage period at a rate of 10 mL/hour in our diagnostic protocol. It is also plausible that repeated clinical examinations over 3 days are more likely to detect clinical change than a single examination after the tap test. Although the sensitivity and specificity of ventricular monitoring may be greater than the lumbar method, we have not determined whether this benefit outweighs the additional risks associated with intraventricular catheter placement. Yet, based on our experience with a 1% to 2% risk of CNS infection with prolonged lumbar catheter implantation, the importance of limiting this risk with a shorter diagnostic period must be highlighted. By showing the limited benefit of CSF pressure monitoring in this patient population, this study has enabled a shorter diagnostic protocol in our center.

Although this study showed that a positive response to CSF drainage is independently associated with shunt responsiveness, some of our patients did not have a positive response and were offered surgery based more on significant B-wave amplitudes, frequencies, and times, and less on response to CSF drainage. These patients generally did not experience improvement after shunt placement. In a separate analysis of the Pcsf wave characteristics of this subset of patients, no variables were found to be predictive of outcome after CSF shunting.

The contribution of Pcsf monitoring and B-waves to the diagnosis of INPH has been unclear since the original description by Lundberg (20). Some have found that specific waveforms, frequency, or amplitude of B-waves correlate with response to CSF shunt treatment. Specifically, Graff-Radford et al. (14) found that percent-time B-waves present over a 24-hour period correlated with surgical outcome in 30 prospectively studied elderly patients with hydrocephalus. Similarly, Raftopoulos et al. (30) prospectively studied 23 patients who underwent shunt surgery on the basis of the presence of "high" Pcsf waves with an amplitude greater than 9 mm Hg. A significant correlation was seen between "high wave relative frequency" and the grade of improvement. Conversely, Williams et al. (36) found that B-waves poorly predict which patients will respond to shunt surgery in INPH. Our results suggest a limited role for Pcsf monitoring in distinguishing shunt-responsive INPH from other disease processes that have the same symptoms. Importantly, this can serve to limit the diagnostic equipment and technical expertise needed to conduct these studies and make it more reasonable to evaluate these patients in less specialized centers.

Some have suggested that the rhythmic cycling pattern of B-waves is the result of changes in brain tissue compliance, changes similar to those seen with increased pulse pressure in patients with less-compliant large arteries caused by the stiffening effects of atherosclerotic disease (4, 7, 9). The lack of specificity of B-waves for shunt-responsive NPH could be the result of other neurodegenerative, microvascular, and age-related effects that cause similar compliance changes, all resulting in this characteristic Pcsf pattern. In fact, our observation of periventricular changes correlating with worse shunt outcomes may reinforce this concept (Fig. 1).

This study used Pcsf monitoring and CSF drainage response data to explore specific differences in pressure wave patterns between shunt-responsive and shunt-nonresponsive patients. The diagnostic criteria used to include patients in this study were used consistently throughout the study period. It should be noted that this study was initiated using the Mini-Mental State Examination; we have since moved on to define more closely the baseline neuropsychological profile and cognitive response to CSF shunting in INPH patients (32). The outcome data were retrospectively compiled and analyzed with the monitoring data in a blinded setting with no knowledge of surgical outcome, thereby limiting any interpretation or outcomes-driven biases. Selection bias is a significant factor because only patients who went on to surgery were included. Therefore, we cannot comment of the relative differences in Pcsf monitoring or continuous CSF drainage between those deemed shunt-worthy or not based on our protocol.

CONCLUSION

In this study of 51 INPH patients who underwent Pcsf monitoring with wave-form analysis and CSF drainage followed by shunt surgery, response to continuous CSF drainage was found to be an independent predictor of improvement after long-term CSF shunting. There was no correlation found between specific Pcsf wave characteristics and improvement in 1 or more INPH symptoms after shunt placement. A diagnostic protocol using continuous CSF drainage rather than Pcsf monitoring might more successfully identify shunt-responsive INPH patients.

Disclosure

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COMMENTS

This is a well-conducted study that highlights some of the challenges of investigating normal pressure hydrocephalus (NPH). The extended lumbar cerebrospinal fluid (CSF) drainage trial is the current "gold standard" (2), achieving accuracy of prediction greater than 90% in a prior large prospective study (3). Using a nearly identical CSF drainage trial methodology, however, Woodworth et al. report a response rate of only 78%. Although this might be attributed to differing assessment tools between the 2 studies, there is a more likely explanation: functional underdrainage by the shunt. Particularly in patients in whom an antisiphon device was used (here, in all patients), documenting shunt patency, or even low intracranial pressure (ICP), is insufficient to rule out functional underdrainage (1). It suggests that at least 12% of the patients might have experienced improvement with removal of the antisiphon device.

The authors found no correlation found between specific CSF pressure wave characteristics and improvement in 1 or more idiopathic NPH (INPH) symptoms after shunt placement. It is premature to conclude, however, that ICP waveform analysis is of no value in the diagnostic evaluation of NPH. It is possible, and likely, that CSF leakage occurred at the dural puncture site (around the catheter) into the paravertebral musculature during the first night after insertion. As a result, all aspects of CSF waveform analysis could have been altered in the direction of lowering sensitivity.

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Woodworth et al. report a study of 51 possible INPH patients preoperatively investigated by lumbar CSF pressure monitoring (48 hours) followed by CSF drainage (72 hours, 240 mL/d). B-wave characteristics and clinical response to lumbar CSF drainage were compared with clinical response at 12 months to ventriculoperitoneal or ventriculoatrial shunting. There was no difference in lumbar B-wave characteristics between ventriculoperitoneal shunting-responsive and -nonresponsive groups. Only the positive clinical response to the lumbar CSF drainage was an independent predictor of VPS responsiveness.

Considering CSF pressure monitoring, the quality of the lumbar location is very limited. Analyzing ICP waves by lumbar monitoring remains controversial, especially if there is a suspicion of increased resistance to CSF circulation, as in INPH. This increased resistance could explain the inversion of B-wave amplitude in favor of the shunt-nonresponsive group. In this context, it seems reasonable that lumbar CSF B-wave analysis did not contribute to the diagnostic of INPH. Regarding the percentage of referred patients with possible INPH submitted to a lumbar CSF catheter insertion, 25% seems rather low, even if the authors applied a very rigorous preadmission test. Furthermore, with such a rigorous selection, I expected a higher rate of improvement in at least 1 symptom after VPS.

The work of Woodworth et al. is important because it confirms that lumbar CSF pressure monitoring with wave analysis has little clinical interest. Regarding lumbar CSF drainage, if it is a possible investigation for those who do have not access to ventricular ICP monitoring, this examination has relative effectiveness: indeed, 22% of those who improved after lumbar drainage rather surprisingly did not respond to VPS, and in contrast, a significant number of lumbar drainage–nonresponsive patients will respond to VPS. Therefore, I continue to recommend ventricular ICP monitoring, which should be performed in specialized centers for possible INPH.

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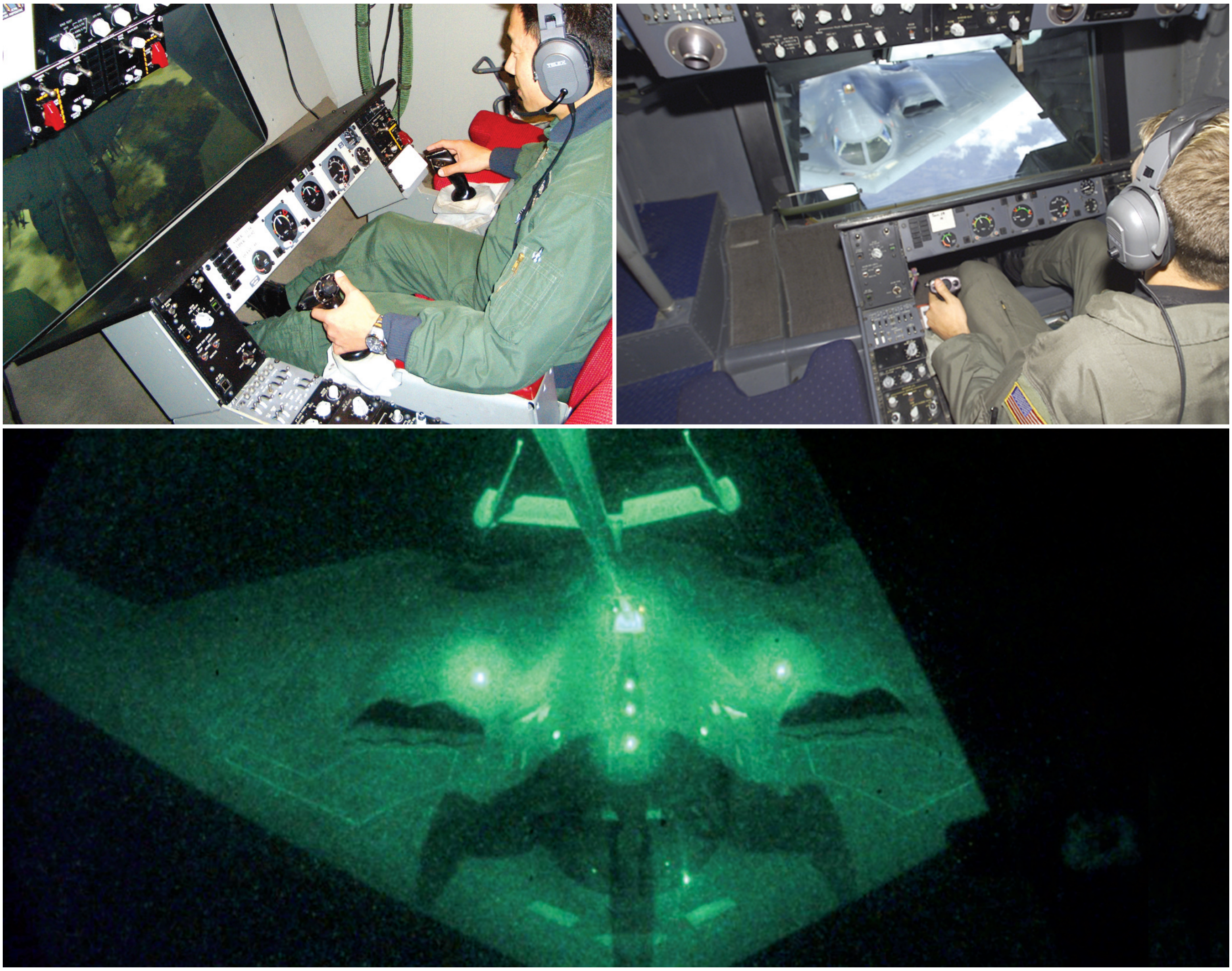

USAF Air refueling simulator and B-2 Spirit refueling. Operational Trainer simulates refueling an aircraft (*top left*) Travis Air Force Base, Fairfield, California, a B-2 Spirit moves into position for refueling (*top right*), and B-2 Spirit refueling at night (*bottom*). Credit: U.S. Air Force photo. See Apuzzo p 785, and Apuzzo et al. pp 788–795.