Scand J Rehab Med 27: 205–209, 1995

GAIT ABNORMALITY IS NOT THE ONLY MOTOR DISTURBANCE IN NORMAL PRESSURE HYDROCEPHALUS

Elisabeth Blomsterwall, RPT,[1] Marianne Bilting, PhD,[2] Hannes Stephensen, MD[2] and Carsten Wikkelsö, MD, PhD[3]

From the Departments of [1]Physiotherapy, [2]Neurosurgery and [3]Neurology, University of Gothenburg, Sahlgren's Hospital, Gothenburg, Sweden

ABSTRACT. Thirteen different motor and balance functions were examined in 76 patients aged 65 ± 13 (mean ± SD) years with normal pressure hydrocephalus (NPH) before and 3 months after a ventriculoperitoneal shunt operation. Preoperatively, the tests were performed before and after lumbar tap of 50 cc cerebrospinal fluid. The patients showed significant improvement in all thirteen functions at the 3-month examination. The improvement was approximately 25% in all the motor functions, except for balance, in which the improvement was even more striking. Different etiological subgroups of NPH patients, including the idiopathic form, exhibited the same degree of improvement. The improvement after the lumbar tap was significant in all functions except one-legged stance, and amounted to approximately 30% of the improvement seen after the shunt operation. Our results clearly show that the impairment in motor functions in NHP patients is general, involving many motor activities performed in daily life, and is not restricted solely to the gait.

Key words: normal pressure hydrocephalus, motor functions, gait, cerebrospinal fluid tap test.

Traditionally, patients with normal pressure hydrocephalus (NPH) present with the clinical triad of gait disturbance, mental deterioration and urinary incontinence (6, 8, 14). The gait problem is usually the first sign to appear and is generally considered the single most important sign in NPH (2). The gait is characteristically unsteady and broad-based, with markedly diminished foot-clearance and trunk torsion, low speed and short stride-length (9, 10). Electrophysiologically, continuous activity in both agonistic and antagonistic muscles acting over hip and knee joints has been found in NPH patients, together with an almost non-existent activity in the tricepts surae and little activity in pretibial muscles (4). Very few clinical studies in NPH have focused on motor functions other than gait. Soelberg Sörensen et al. (9) noted diminished postural stability and slow speed when writing. They also found that the fine movements of the hands were impaired and the intensity of hand tremor was significantly greater than in controls. Tromp et al. (11) showed that the motor speed of the index finger, as measured in the 'tapping-test', improved after shunt surgery.

Since 1978 we have closely studied NPH patients attending our clinic. Our studies have included, among other things, repeated observations on several aspects of the motor disturbance and postoperative improvement in an array of ADL functions. The purpose of this particular investigation was to analyse the type and degree of motor function impairment seen in NPH and to assess the preoperative predictive value of the cerebrospinal fluid tap test (CSF-TT) (13) of 50 cc CSF. We report on an examination of thirteen different motor functions in 76 NPH patients before and after a ventriculoperitoneal shunt operation.

PATIENTS AND METHODS

Between November 1988 and June 1993, 81 patients received the diagnosis 'communicating NPH' at the Department of Neurology and subsequently underwent ventriculoperitoneal shunt surgery at the Department of Neurosurgery.

The local work-up for the basic investigation of patients with suspected NPH includes the following: a neurological examination, psychometric testing by means of a memory test, a reaction time test, and an identical form test, appropriate blood and CSF analyses to exclude metabolic or inflammatory disorders, cranial computerized tomography (CT) or magnetic resonance tomography (MRT), radionuclide-cisternography (RC) (5) and regional cerebral blood flow (rCBF) examination (7). Additionally, the CSF-TT (13) is performed in cases where the decision on whether or not to operate is still uncertain

Table I. *Etiology and duration of signs prior to operation of 76 patients with NPH*

SAH: subarachnoid haemorrhage; CVD: other cerebrovascular diseases; Miscellaneous: cerebral tumour (4) [1 pituitary adenoma (operated), 1 small meningeoma (not operated), 1 tumour of unknown type operated and treated with radiation therapy 50 years prior to study and 1 benign tumour posterior to the third ventricle] meningitis (2), cerebral anoxia (1), multiple sclerosis (1), rheumatoid arthritis (1), congenital (1) and probably radiation induced (1). Age is given in years + standard deviation (SD) and duration of NPH symptoms prior to diagnosis in months + SD.

Etiology	SAH	CVD	Traumatic	Idiopathic	Miscellaneous	All
Number of patients (%)	14(18%)	22(29%)	14(18%)	15(20%)	11(15%)	76(100%)
Age (years)	65 ± 8	70 ± 11	58 ± 14	68 ± 13	58 ± 15	65 ± 13
Duration (months)	7 ± 8	31 ± 20	51 ± 120	44 ± 41	79 ± 138	39 ± 76

after the complete protocol. In this study it was used in 37 patients.

The diagnostic criteria for NPH were signs consistent with the diagnosis (gait disturbances, mental deterioration and/or urinary incontinence), enlarged ventricles on CT (Evans' index > 0.30), a lumbar CSF pressure below 20 cmH_2O, ventricular filling and block of convexity flow at RC. Improvement in the CSF-TT and a characteristic pattern on rCBF examination supported the case for surgical intervention. Five patients, not examined physiotherapeutically before surgery, were excluded. Thus, 76 patients aged 65 ± 13 (mean ± SD) years were included. Forty-four were men and 32 women. Table I shows demographic data.

All patients underwent ventriculoperitoneal shunting. Three months after the operation, the patients were re-examined. The examination included clinical, psychometric and physiotherapeutic evaluation, CT or MR and rCBF. In those cases where no improvement was seen and where CT showed unchanged ventricular enlargement, the shunt system was checked (12) and in cases of dysfunction surgically corrected. Seven patients were reoperated once and 5 patients twice due to shunt dysfunction. The re-examination of these patients was postponed to 3 and 12 months after the reconstructive surgery. Thus, all shunts were patent at the time of assessment.

Seventy-six patients were examined preoperatively and 63 at the 3-month re-examination. Thirty-seven patients were also examined in connection with a CSF-TT.

Thirteen patients could not be re-evaluated 3 months after shunt surgery: one died of a shunt complication, 3 had heart attacks, 1 had a cerebral infarction and 8 patients could not be retested, 2 due to unwillingness to participate and 6 due to problems with coordination of time for evaluation.

The physiotherapeutic examinations of the motor functions were identical, irrespective of the point in time during the study at which they were carried out: preoperatively, 3 and 12 months postoperatively, and in the relevant cases before and after a lumbar tap of 50 cc CSF. The following motor functions were examined: *Walking 25 m* [tests 1 and 2] and *Walking 5 m backwards and forwards* including turning around [3, 4]. The mean time (tests 1 and 3) and the mean number of steps (tests 2 and 4) used during two attempts were calculated. *Climbing 6 steps*, up and down [5], *Turning around in bed* supine-right side-supine-left side-supine position [6], *Rising from supine to sitting on the edge of the bed* [7]. The mean time of two attempts was calculated for each of the tests 5–7. *Knee extension and flexion 90-0-90* degrees, 10 times whilst sitting on a chair [8], *Moving hand from knee to chin and back* 10 times whilst sitting on a chair [9], *Finger to nose and back* 10 times with index finger from knee with eyes closed sitting on a chair [10]. The mean time of six attempts, 3 with the right and 3 with the left side, was calculated for each of the tests 8–10. *Romberg's test* [11], *One-legged stance* with eyes open [12]. The mean time of two attempts was calculated for tests 11 and 12. *Standing with feet apart* and eyes open [13]. The mean time of two trials in seconds/distance between the feet in cm was calculated.

The patients were instructed to carry out all parts of the test as quickly as possible, in tests of balance as long as possible. A mechanical stopwatch was started at 'go' ('ready, steady, go') and stopped when both feet had passed the finishing line or the body or extremity was returned to the starting position. In tests of balance, the clock was stopped when the patient made compensatory movements or opened his or her eyes. For practical reasons, maximum or minimum limits were applied in certain tests. The 25 m walking tests were maximized to 300 s and 200 steps, turning around in bed to 150 s, moving to the sitting position and leg and arm movements to 60 s each. The time for Romberg's test was maximized to 60 s.

Statistics

Apart from simple descriptive statistics, correlations were calculated using non-parametric tests (Wilcoxon's signed rank and/or rank sum tests and Spearman's rank correlation).

RESULTS

The patients showed significant improvement in all thirteen motor functions 3 months after the shunt operation (Table II). The different etiological groups, including the idiopathic group, showed equal improvement. In all motor functions except for balance, the degree of improvement was around 25% (8–43%). In Romberg's test the improvement was more than 1000% (Table II). Velocity (m/sec) and cadence (steps/min) in the NPH patients walking as fast as possible are shown in Table III. After the shunt operation, velocity and cadence improved. The need for walking aids decreased after surgery. At the

Table II. *Results of 13 motor and balance tests preoperatively, post CSF-TT and 3 months postoperatively*

The tests are described in detail in the text. n = number of patients performing each test. The results are given as 1st, 2nd and 3rd quartiles preoperatively and as improvement in % at the CSF-TT and at the 3-month postoperative examination. ($^{*} = p < 0.01$, $^{**} p < 0.0005$ and $^{***} p < 0.0001$)

	Before operation							
	n	Q1	Q2	Q3	n	CSF-TT improvement, %	n	3 months post-op improvement, %
Walking 25 m (sec)	76	22	35	89	36	9***	60	30***
Walking 25 m (steps)	73	41	65	129	34	9***	59	25***
Walking 5 m forth and back including turning (sec)	45	11	17	26	24	8***	40	24***
Walking 5 m forth and back including turning (steps)	44	21	28	40	24	7***	40	17***
Climbing stairs (sec)	40	10	17	24	22	12***	39	26***
Turning in bed (sec)	70	12	22	105	33	4***	58	30***
Supine-sitting (sec)	72	4	7	32	36	6***	58	43***
Knee 90°-0-90°×10 (sec)	44	10	13	17	19	4***	40	8***
Hand knee-chin-knee × 10 (sec)	44	8	10	15	18	14***	38	19***
Finger-nose × 10 (sec)	34	9	13	20	17	20***	40	20***
Romberg's test (sec)	45	1	6	60	20	253***	43	1132***
One-legged stance (sec)	27	0	5	11	14	−20*	25	285***
Standing sec (cm)	15	1	2	18	8	1440*	18	3633**

3-month examination, 6% were wheel-chair bound, compared with 16% before shunt surgery. The number of patients walking without support increased from 45% to 60% (Table IV). At the 3-month examination the correlation between improvement in different tests measuring walking and transfers in bed was good ($p < 0.01$) (Table V). Improvement at the CSF-TT (more than 10% in tests 1–7) was followed by improvement after shunt surgery in 20 patients. The CSF-TT was false-positive (defined as >10% improvement after CSF-TT but <10% improvement 3 months after shunt surgery) in 4 of 27 patients and false-negative (<10% improvement after CSF-TT but >10% improvement after shunt surgery) in 3 patients. The best predictive tests in the CSF-TT were number of steps needed to walk 5 m backwards and forwards including turning around and climbing 6 steps up and down. The correlations with the improvement after shunt surgery were, for these two tests, $r = 0.70$, $p < 0.003$ and $r = 0.78$, $p < 0.0004$ respectively.

DISCUSSION

In this study we clearly show that patients with NPH who undergo ventriculo-peritoneal shunt surgery improve not only in gait but also in trunk and extremity motor functions. Further, a dramatic improvement in postural functions was seen. Our results strongly support the results of Soelberg

Table III. *Velocity (m/sec) and cadence (steps/min) at fast walking before and 3 months after a shunt operation and after lumbar tap of 50 cc CSF (CSF-TT) in patients with NPH*

n indicates number of patients, Q1, 2 and 3 the quartiles and mean ± SD the mean value and standard deviation

	n	Q1	Q2	Q3	Mean ± SD
Velocity, m (sec)	76	0.28	0.71	1.16	0.80 ± 0.61
Cadence, steps (min)	73	84	106.90	123.00	99.8 ± 35.7
After CSF—Tap Test					
Velocity, m (sec)	36	0.47	0.91	1.37	0.97 ± 0.68
Cadence, steps (min)	34	99.8	118.90	136.50	110.1 ± 38.6
3 months after operation					
Velocity, m (sec)	60	0.73	1.00	1.54	1.12 ± 0.56
Cadence, steps (min)	59	102.00	116.50	131.60	113.4 ± 27.2

Table IV. *The need for walking aids by patients with NPH before shunt surgery and 3 months postoperatively; numbers in figures and %*

	Before op.		3 months post-op.	
	n	%	*n*	%
No support	34	45	38	60
One cane	5	6	6	10
Bimanual support	13	17	15	24
Aided	12	16	0	0
Wheel-chair	12	16	4	6
Total	76	100	63	100

Sörensen et al. (9) and Tromp et al. (11) and there is therefore accumulating evidence to support the hypothesis that the motor impairment in NPH is generalized and not limited to gait.

Our patients were included consecutively and the number of patients was sufficiently large to exclude any selection bias. The distribution of different etiologies for our NPH patients' state was also in accordance with the literature (8, 14). So far, we have been able to follow 30 of the patients up to a 12-month control, but no further improvement has been found.

The improvement in motor function at 3 months was in the rather narrow range of 8–46%, mean 24% and 29% respectively, while the improvement in Romberg's test was much more pronounced (1132%) (Table II). This could be due partly to the measuring procedure itself but it could also be that the postural functions in NPH patients showed a real improvement to a greater degree than other functions. This discrepancy, and the lack of, or only weak, correlation between postural and motor functions could indicate that the two groups of signs may be caused by two different pathophysiological mechanisms involved in NPH. Our impression is that the balance problems are probably of major importance for the gait disturbance in many patients.

In this first investigation, we wanted a rapid, simple method that was easy to handle, inexpensive but still reproducible. We did not evaluate the intra and interobservation coefficients of the method but all the tests were performed by the same investigator (E.B.) and each procedure was repeated to optimise the method. Our method of measuring the motor and postural functions is neither optimal nor sophisticated. We feel, however, that it was sufficiently refined for the purposes of our preliminary investigations.

Romberg's test, a clinically widely used test of balance, was maximized to 60 s. As many patients managed this limit, a more sensitive test of balance would be valuable. Our one-legged stance test was of little value in most elderly patients, as performance was closely dependent on the strength of muscles acting round the hip (3). It would probably be of greater value to measure the mean of three trials with the preferred leg only (1). Arm and leg movements were tested to see whether the increased muscle tone, paratonic rigidity, could be evaluated. Paratonic

Table V. *Cross-table of correlation coefficients of improvement at the 3-month control between various motor and balance functions in 63 patients with NPH*

The tests are explained in the text

Walking 25 m (sec)												
Walking 25 m (steps)	***0.91***											
Walking 2 × 5 m (sec)	***0.85***	***0.70***										
Walking 2 × 5 m (steps)	***0.69***	***0.76***	***0.83***									
Climbing stairs (sec)	***0.79***	***0.53***	***0.76***	***0.58***								
Turning in bed (sec)	***0.73***	***0.74***	***0.71***	***0.66***	***0.68***							
Supine-sitting (sec)	***0.71***	***0.67***	***0.54***	0.43	***0.63***	***0.58***						
Knee 90-0 (sec)	***0.55***	***0.46***	0.43	0.44	0.48	***0.57***	***0.53***					
Hand knee-chin (sec)	***0.59***	***0.60***	0.38	0.42	0.35	***0.56***	0.36	***0.43***				
Finger-nose (sec)	***0.46***	0.37	0.47	0.27	0.48	***0.59***	0.21	0.47	***0.69***			
Romberg (sec)	***0.51***	***0.45***	0.49	0.46	0.54	***0.64***	0.39	0.38	0.24	0.27		
1-legged stance (sec)	0.13	0.14	0.19	0.37	0.10	0.01	0.15	0.36	0.19	0.07	0.01	
Standing sec (cm)	0.50	0.53	0.71	0.49	0.10	0.18	0.31	0.38	0.33	0.04	0.59	n.d.

$p < 0.01$. Bold: *not significant*, n.d. = not done

rigidity is accepted as an important component of these patients' symptoms and signs. Although the speed of the movements increased, we cannot definitely conclude that the paratonic rigidity had decreased: a more specific and objective method of evaluation of muscle tone has to be applied.

We have earlier pointed out the predictive value of a lumbar puncture with tapping of a relatively large amount of CSF. This study clearly shows that the improvement after CSF-TT correlates with the improvement after shunt surgery and that the post-tap improvement is approximately one-third of the post-surgery improvement. In conclusion, the methods for evaluating balance and muscle tone are somewhat coarse and more objective methods are needed. However, the 25% improvement in motor functions and more than 1000% improvement in balance functions, as measured by Romberg's test, are striking. All groups of NPH patients improved equally. After CSF-TT the improvement was significant and equalled approximately 30% of the improvement seen after surgery.

ACKNOWLEDGEMENTS

This study was supported by grants from the Section for Neurology of the National Association of Registered Physiotherapists, and from the Renée Eanders Foundation.

REFERENCES

1. Berg, K., Wood-Dauphinée, S., Williams, J. I. & Gayton, D.: Measuring balance in the elderly: preliminary development of an instrument. Physiother Can *41:* 304–311, 1989.
2. Graff-Radford, N. R. & Godersky, J. C.: Normal-pressure hydrocephalus. Onset of gait abnormality before dementia predicts good surgical outcome. Arch Neurol *43:* 940–942, 1986.
3. Iverson, B. D., Gossman, M. R., Shaddeau, S. A. & Turner Jr, M. E.: Balance performance, force production and activity levels in noninstitutionalized men 60 to 90 years of age. Phys Ther *70:* 348–355, 1990.
4. Knutsson, E. & Lying-Tunell, U.: Gait apraxia in normal-pressure hydrocephalus: Patterns of movement and muscle activation. Neurology *35:* 155–160, 1985.
5. Larsson, A., Moonen, M., Bergh, A.-C., Lindberg, S. & Wikkelsö, C.: Predictive value of quantitative cisternography in normal pressure hydrocephalus. Acta Neurol Scand *81:* 327–332, 1990.
6. Larsson, A., Wikkelsö, C., Bilting, M. & Stephensen, H.: Clinical parameters in 74 consecutive patients shunt operated for normal pressure hydrocephalus. Acta Neurol Scand *84:* 475–482, 1991.
7. Larsson, A., Bergh, A.-C., Bilting, M., Ärlig, Å., Jacobsson, L., Stephensen, H. & Wikkelsö, C.: Regional cerebral blood flow in normal pressure hydrocephalus: diagnostic and prognostic aspects. Eur J Nucl Med *21:* 118–123, 1994.
8. Petersen, R. C., Mokri, B. & Laws, E. R.: Surgical treatment of idiopathic hydrocephalus in elderly patients. Neurology *35:* 307–311, 1985.
9. Soelberg Sörensen, P., Jansen, E. & Gjerris, F.: Motor disturbances in normal-pressure hydrocephalus. Special reference to stance and gait. Arch Neurol *43:* 34–38, 1986.
10. Sudarsky, L. & Simon, S.: Gait disorder in late life hydrocephalus. Arch Neurol *44:* 263–267, 1987.
11. Tromp, C. N., Staal, M. J. & Kalma, L. E.: Effects of ventricular treatment of normal pressure hydrocephalus on psychological functions. Z Kinderchir *44,* Suppl 1: 41–43, 1989.
12. Wikkelsö, C., Andersson, H., Lindberg, S. & Blomstrand, C.: "Shuntography"—a radionuclide scanning method for evaluation of cerebrospinal fluid shunt patency. Nucl Med Com *4:* 88–93, 1983.
13. Wikkelsö, C., Andersson, H., Blomstrand, C., Lindqvist, G. & Svendsen, P.: Normal pressure hydrocephalus: Predictive value of cerebrospinal fluid tap-test. Acta Neurol Scand *73:* 566–573, 1986.
14. Wood, J. H., Bartlet, D., James, A. E. & Udvarhelyi, G. B.: Normal pressure hydrocephalus: Diagnosis and patient selection for shunt surgery. Neurology *24:* 517–526, 1974.

Address for offprints:

Elisabeth Blomsterwall, RPT
Department of Physiotherapy
Sahlgren's Hospital
S-413 45 Gothenburg
Sweden