Article published online: 2023-08-25

https://doi.org/10.1590/0004-282X20180037

ARTICLE

Gait in normal pressure hydrocephalus: characteristics and effects of the CSF tap test

Marcha na hidrocefalia de pressão normal: características e efeitos do tap-test

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ABSTRACT

Normal pressure hydrocephalus (NPH), described by Hakim and Adams in 1965, is characterized by gait apraxia, urinary incontinence, and dementia. It is associated with normal cerebrospinal fluid (CSF) pressure and ventricular dilation that cannot be attributed to cerebral atrophy. **Objectives:** To evaluate gait characteristics in patients with idiopathic NPH and investigate the effect of the CSF tap test (CSF-TT) on gait. **Methods:** Twenty-five patients diagnosed with probable idiopathic NPH were submitted to the CSF-TT. The procedure aimed to achieve changes in gait parameters. **Results:** Fifteen gait parameters were assessed before and after the CSF-TT. Five showed a statistically significant improvement ($p < 0.05$): walking speed ($p < 0.001$), cadence ($p < 0.001$), step length ($p < 0.001$), *en bloc* turning ($p = 0.001$), and step height ($p = 0.004$). **Conclusion:** This study demonstrated that gait speed was the most responsive parameter to the CSF-TT, followed by cadence, step length, *en bloc* turning, and step height.

Keywords: gait; normal pressure hydrocephalus.

RESUMO

A hidrocefalia de pressão normal (HPN), descrita por Hakim-Adams em 1965, caracteriza-se por apraxia de marcha, incontinência urinária e demência e está associada com pressão normal do líquido cefalorraquidiano e dilatação ventricular não atribuída a atrofia cerebral. **Objetivos:** Avaliar as características da marcha em pacientes com HPN idiopática e o efeito do "tap-test" (TT) na marcha. **Métodos:** Vinte e cinco pacientes com o diagnóstico HPN idiopática provável, foram avaliados com o TT. O procedimento tem como objetivo causar mudanças nas características da marcha. **Resultados:** Quinze parâmetros da marcha foram avaliados com o TT. Cinco mostraram melhora estatisticamente significativa ($p < 0,05$): velocidade da marcha ($p < 0,001$), cadência ($p < 0,001$), comprimento do passo ($p < 0,001$), giro em "bloco" ($p = 0,001$) e altura do passo ($p = 0,004$). **Conclusão:** Este estudo demonstrou que a velocidade da marcha foi o parâmetro que mais respondeu ao efeito do TT, seguido da cadência, comprimento do passo, giro em "bloco" e altura do passo.

Palavras-chave: marcha; hidrocefalia de pressão normal.

Normal pressure hydrocephalus (NPH), described by Adams et al.[1] in 1965, is characterized by a classic triad of symptoms, consisting of progressive gait apraxia, urinary incontinence, and dementia. They are associated with normal cerebrospinal fluid (CSF) pressure and ventricular dilation that cannot be attributed to cerebral atrophy[1].

A transient improvement in NPH symptoms following removal of CSF by lumbar puncture (LP) was first reported by Adams et al.[1]. However, Wikkelsø et al.[2] refined the technique with quantitative methods to assess gait and cognition. The test has now gained widespread acceptance and is referred to as the CSF tap test (CSF-TT)[2]. The TT is important for diagnosing NPH[3,4] as well as predicting clinical postoperative outcomes[3,4]. The volume of CSF removed can vary between 15 to 50 mL, according to different authors[5,6]. According to Japanese guidelines, the CSF-TT should be the first invasive test indicated[3] when NPH is suspected; it has a positive predictive value of between 72% and 100% and a low rate of complications[7].

Gait disturbance is considered the first and main symptom in NPH[8,9]. Close observance of any changes in gait is fundamental for early diagnosis of the disease, as this

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Conflicts of interest: There is no conflict of interest to declare.
Received 22 November 2017; Received in final form 01 February 2018; Accepted 14 February 2018.

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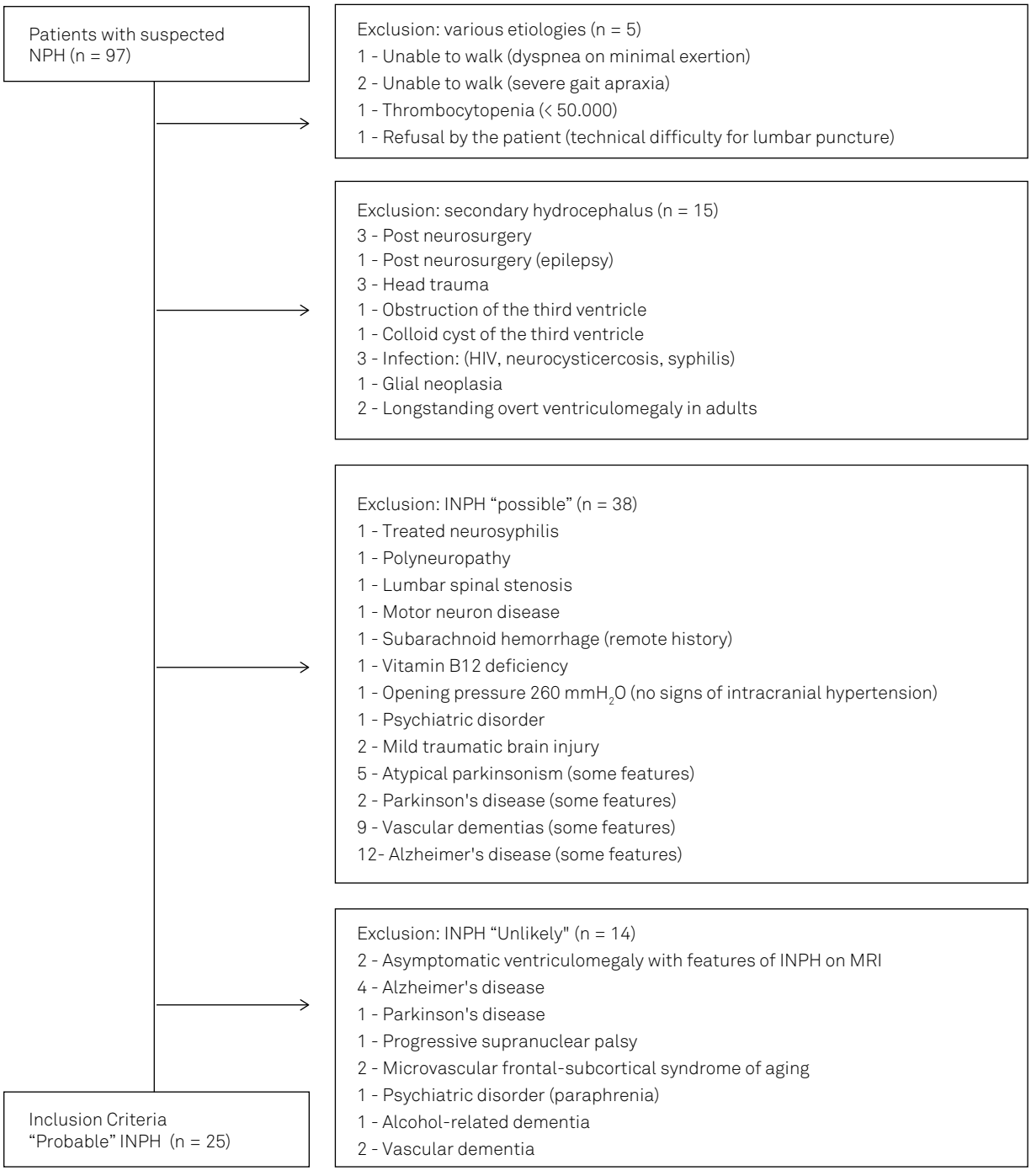
ensures a more favorable outcome for ventriculoperitoneal shunting[3]. Identification of gait changes also enables the CSF-TT to differentiate NPH from other diseases that mimic it. Correct diagnosis avoids unnecessary surgical procedures, including complications that may occur in up to 50% of patients[10].

The aim of this study was to identify gait impairment and parameters that respond to the CSF-TT in patients with probable idiopathic NPH (INPH), according to diagnostic criteria in the American-European INPH guidelines[4].

METHODS

We prospectively evaluated 97 patients with suspected NPH at the Curitiba Institute of Neurology from January 2006 to January 2011. Informed consent was obtained from all patients, and the study was approved by the local regulatory board.

Criteria for INPH diagnosis are those from the American-European guidelines, which classifies INPH into "probable", "possible", and "unlikely"[4]. Of 97 patients selected, 72 were excluded from the study and 25 met the inclusion criteria, characterizing our sample (Figure 1).



INPH: idiopathic normal pressure hydrocephalus; HIV: human immunodeficiency virus.

Figure 1. Patients with suspicion of normal pressure hydrocephalus: inclusion and exclusion criteria.

The inclusion criteria were based on proposed guidelines for the diagnosis of probable INPH according to Relkin et al.[4]: 1) insidious onset of symptoms after 40 years of age, with a duration longer than six months, and progression over time; 2) slow progressive gait dysfunction; 3) and the gait/balance disorder must be present, plus one other area of impairment in cognition, urinary symptoms, or both. Cognitive impairment was screened using the Mini-Mental State Examination test, adapted to our environment and adjusted for the educational level of the population[11]. The criteria to diagnose dementia were from the Diagnosis and Statistics Manual of Mental Disorders[12]; 4) urinary incontinence not attributed to primary urological disorders; 5) ventricular dilatation demonstrated by CT scan or MRI of the brain, not entirely attributable to cerebral atrophy or congenital enlargement (Evan's index > 0.3); and 6) normal CSF opening pressure in the range 70–245 mmH_2O determined by LP.

Exclusion criteria were: 1) a diagnosis of possible and unlikely INPH[10]; 2) secondary hydrocephalus, as a consequence of head trauma, intracerebral hemorrhage, and meningitis/encephalitis; 3) serious clinical or laboratory contraindication for the procedure (blood dyscrasias not amenable to correction); 4) brain imaging findings associated with any of the following: ventricular dilatation caused by macroscopic obstruction to CSF flow, and evidence of severe cerebral atrophy (score 3) sufficient potentially to cause ventricular enlargement. Simple rating scales were used to quantify the degree of global cortical atrophy. The four-step scale[13] classifies cerebral atrophy from score 0 = no atrophy to score 3 = severe atrophy, or the presence of structural lesions that may impact ventricular size, such as gliosis secondary to stroke and/or the presence of extensive vascular white matter lesions (Fazekas grade 3). The Fazekas scale[13] quantifies cerebral white matter lesions and how they develop over time. The scale ranges from 0 to 3, where 0 = no lesions or a single punctate lesion, 1 = multiple punctate lesions, 2 = confluent lesions, and 3 = extensive confluent lesions; 5) the patient is unable to walk or is severely demented and incapable of understanding the commands required to do a certain task; 6) musculoskeletal disorders that could interfere with gait analysis, such as rheumatoid arthritis or polyneuropathy; 7) chronic obstructive pulmonary disease and/or heart failure with dyspnea on minimal exertion; and 8) other causes of dementia.

Tap test

The test involved removal of CSF with a disposable Quincke needle for LP to gauge gait changes (clinical improvement). On the first day of the test, the patients were assessed for their baseline gait (Figure 2). On two consecutive days, LP was performed with an interval of 24 hours between procedures. Patients were in a lateral recumbent position during the LP and while the opening pressure was measured. A total of 30 mL of CSF was removed during each LP. The CSF collected was sent to the onsite clinical laboratory for analysis. Three hours after the LP, the patient's gait was recorded to determine whether the TT had resulted in any improvement.

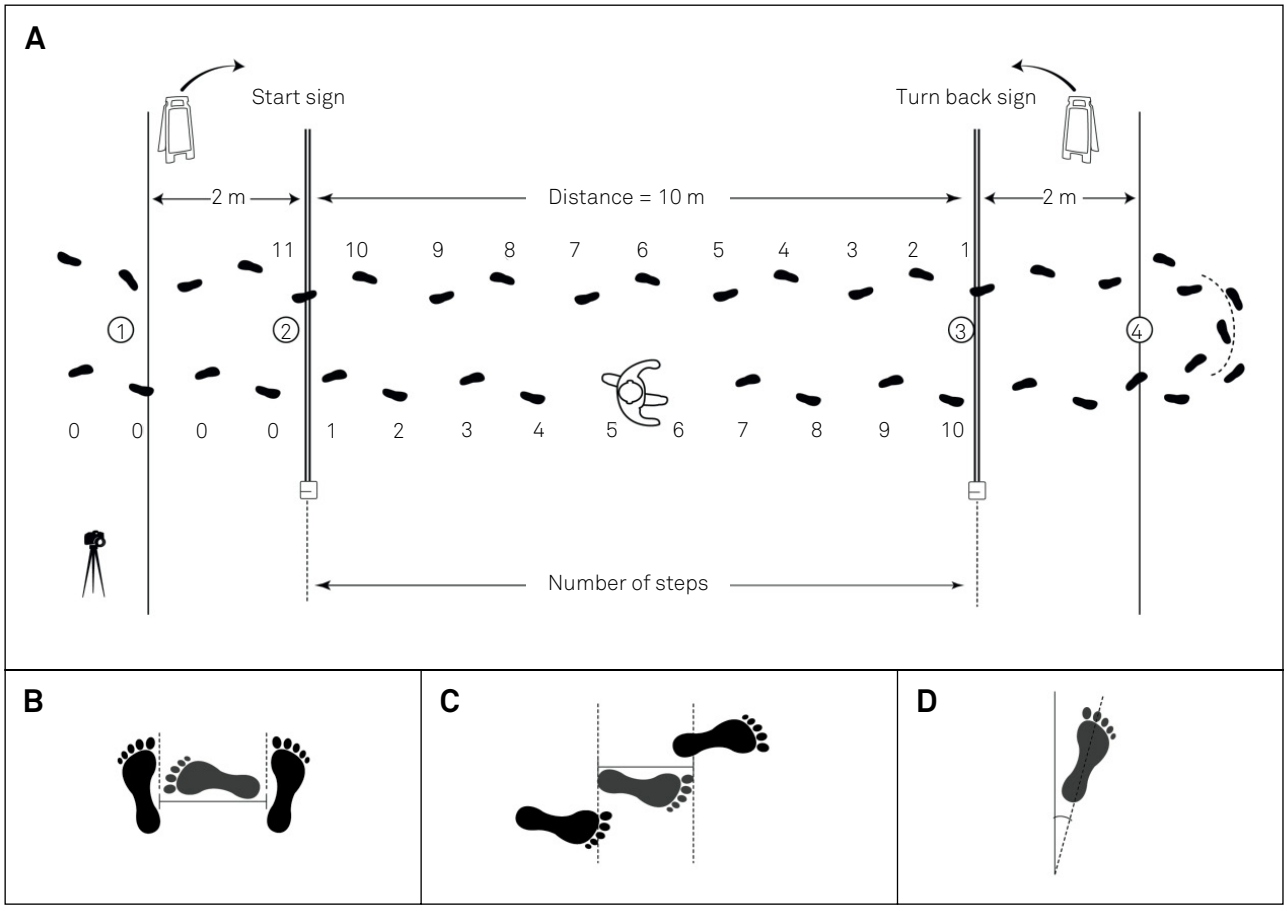
Gait analysis

Gait characteristics were assessed during free walking on a 10 meter (m) predesigned path. The study consisted of filming the patient walking on a 20 m path (10 m in one direction, turning, and then 10 m back to the starting point) during two trials, totaling 40 m of free walking (Figure 2). Gait velocity and step length were calculated as the mean values during the two trials. Patients were asked to walk and were also given these instructions: "follow this path", "go to the location indicated", "turn around", and then "return to the starting point" and "walk as fast as you can, with no running" (Figure 2). Tests were always carried out during the early afternoon to avoid possible time-related fluctuations.

Patients were filmed while walking, and data were transferred to a desktop computer, so that gait and posture could be analyzed. This was always done by two physicians (the first author and another member of the medical staff in the neurology department). Criteria used to evaluate gait and posture[4,14,15,16,17,18,19,20] are described in Table 1. The patient's gait speed was considered reduced when the time spent to traverse 10 m was greater than 11 seconds (s).[21] Stolze et al.[19] adopted a result greater than 20% as indicative of an improvement in gait velocity, while Damasceno et al.[8] considered an improvement as any result greater than 5%. In our study, an intermediate value was adopted. An improvement greater than 9% after the CSF-TT was considered the cut-off value for a gain in gait velocity. The following formula was used in percentages to evaluate if there was improvement in gait speed with the TT: 100 X (result before LP – best result after LP) / result before LP[14].

Statistical analysis

The results are expressed as means ± SD, or frequencies and percentages when appropriate. The results were analyzed using the Statistical Package for the Social Sciences, version 22.0 (Armonk, NY, USA). Each of the gait variables (gait speed, broad-based gait, *en bloc* gait, decreased step length, lateral flexion of the trunk, postural reflex, festination, hesitant gait, *en bloc* turning, imbalance, freezing, decreased cadence, trunk flexion, and toes turned outwards on walking) were classified qualitatively as "changed" or "unchanged" based on the evaluation of the researchers during the pre- and post-CSF-TT period. The McNemar Test was used for the analysis of these variables. The Wilcoxon test, a non-parametric test, evaluated the quantitative results obtained before and after the CSF-TT, and the time taken to traverse the 20 m path. Values of $p < 0.05$ were considered significant.



Source: Authors.

Figure 2. (A) Schematic viewed from above for the evaluation of gait parameters in patients with IHPN, (B) broad-based gait, (C) decreased step length, (D) toes turned outward.

RESULTS

The mean age of the cohort was 76.2 years (range 65–84 years, SD = 5.8) with 10 males and 15 females; all were right-handed; two were Afro-Brazilian and 23 were Caucasian. Three patients were illiterate and 22 had a formal education. The latter were divided into four groups according to the length of their formal education: eleven patients (1–4 years); two patients (4-8 years), two patients (9–11 years); and seven patients (> 11 years).

General sample characteristics

The term gait apraxia was defined to describe the features of a frontal gait disturbance such as: disequilibrium, impaired postural reflexes, and gait ignition with start hesitation, which could not be attributed to any motor, sensory, or psychiatric deficits[20]. The complete triad described by Adams et al.[1] was present in 22 of our patients (88%). Gait disturbance and dementia were detected in all patients; however, three had no urinary incontinence. A gait matching the classic description of "gait apraxia" was found only in four patients.

The average time between onset of symptoms of INPH and the CSF-TT was 22.9 months (range 3–60 months, SD = 13.2).

On neurological examination, dysarthria and supranuclear vertical upgaze palsy were observed in three patients, while frontal release signs were observed in five. The mean score on the Mini-Mental State Examination was 22.3 (SD = 5.2). The most commonly-associated condition was arterial hypertension in 20 patients (80%), followed by 11 patients with dyslipidemia (44%), 10 patients with diabetes mellitus (40%), seven with psychiatric diseases (28%) (anxiety in one and depression in six), five patients with hypothyroidism (20%), three patients with cardiac diseases (12%), one with hyperuricemia and one smoker (4%).

Gait features

Fifteen gait variables were studied (Table 2 and Figure 3), and abnormalities were found in 14 of them. A festinating gait was not observed in any of the patients. Of the 25 patients evaluated, 19 improved more than 9% in walking time with the CSF-TT. Only one patient had a gait within normal values, but there was improvement of more than 9% after the CSF-TT. The average time taken to traverse the 20 m path was 45.3 s pre-CSF-TT vs. 35.2 s post-CSF-TT, corresponding to an improvement of approximately 10 s (28.7%) post-CSF-TT ($p < 0.05$). Gait variables responsive to the CSF-TT are shown in Table 2 and Figure 3.

Table 1. Classification of gait and posture[4,14,15,16,17,18,19,20].

Parameters		Description	
En bloc turning		Requiring three or more steps for turning 180 degrees.	
Dynamic balance or imbalance		Patient is asked to walk 8 steps putting one foot in front of the other (tandem gait). Imbalance was considered to be present when correction steps were needed on two or more attempts.	
En bloc gait		Reduced rotation of the pelvic and scapular girdles and decreased mobility of the upper limbs.	
Festination		Accelerated gait at least once in the total path.	
*Postural Reflex	Score	Shoulder tug test	
	0	Patient stands without taking a step	
	1	Patient takes a step and remains stable	
	2	Patient takes more than one step and keeps his/her balance	
	3	Patient takes several steps and needs to be held	
	4	Patient falls backward without taking a step	
Freezing		Characterized by at least one episode of sudden deceleration or a break (feet almost stuck to floor) in gait during free walking.	
Hesitant gait		Hesitation at the beginning and end of the course.	
"Magnetism" or shuffling gait		Step height decreased during free walking.	
Broad-based gait		Distance between toes > 1 own foot length. (Figure 2 B)	
Decreased step length (*petit pas*)		Distance from heel of front foot to toes of rear foot < 1 own foot length. (Figure 2 C)	
Foot angle		Toes turned outward on walking. (Figure 2 D)	
Trunk flexion		A healthy person remains standing upright with his/her head up, chest out and abdomen held in.	
Lateral flexion of the trunk		Flexion of the trunk to one side while walking spontaneously.	
Gait cadence (Reference value for normality)	Gender	Age: 60–69 years	Age: 70–79 years
	Female	148 steps per minute (SD ± 23.07)	129.5 steps per minute (SD ± 21.79)
	Male	**Not given	119.4 steps per minute (SD ± 11.07)

*Assessment of postural reflexes. The examiner must stand behind the patient, pull the patient's shoulders suddenly and briskly and then analyze if there is retropulsion. The examiner should always be prepared to hold the patient when performing this test, otherwise, a person with a loss of postural reflexes may fall. The patient must be informed of the details of the test beforehand. A score of higher than 1 was considered impaired postural reflexes; SD: standard deviation; ** value for females was used; Gait cadence: number of steps per minute; Reference normality values of the preceding decade were used for patients older than 80 years.

Table 2. Evaluation of gait characteristics before and after the tap test.

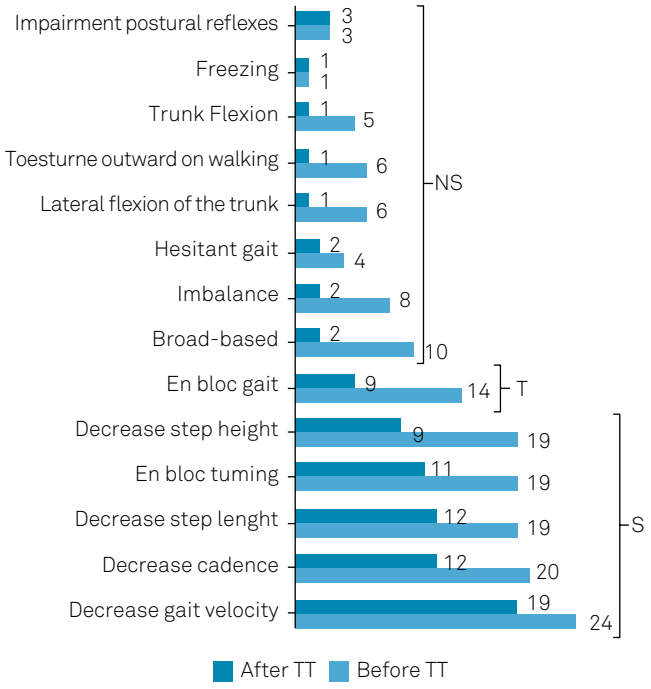
Before TT / After TT	Unchanged / Unchanged		Changed / Changed		Changed / Unchanged		Unchanged / Changed		p-value*
Characteristics Gait	Freq.	%	Freq.	%	Freq.	%	Freq.	%	
Speed gait	0	0	6	24	19	76	0	0	< 0.01
Broad-based	14	56	8	32	2	8	1	4	1.0
En bloc gait	11	44	9	36	5	20	0	0	0.063
Decreased step length	6	24	7	28	12	48	0	0	< 0.01
Decreased step height	6	24	10	40	9	36	0	0	< 0.01
Lateral flexion of the trunk	19	76	5	20	1	4	0	0	1.0
Postural reflex	22	88	3	12	0	0	0	0	1.0
Festination	25	100							-
Hesitant gait	21	84	2	8	2	8	0	0	0.50
En bloc turning	6	24	8	32	11	44	0	0	< 0.01
Imbalance	17	68	7	28	1	4	0	0	1.0
Freezing	24	96	0	0	1	4	0	0	1.0
Decreased cadence	5	20	8	32	12	48	0	0	< 0.01
Trunk flexion	20	80	4	16	1	4	0	0	1.0
Toes turned outward on walking	19	76	5	20	1	4	0	0	1.0

* McNemar test, $p < 0.05$

DISCUSSION

In this study, the classic triad of INPH was found in 88% of patients. The incidence of the classical triad is unknown; however, the presence of three concomitant symptoms has been reported in approximately 60% of cases[3], although the triad is not required for a diagnosis of INPH[3].

Ishii et al.[22] and Kang et al.[23] reported that the presence of parkinsonism characteristics was frequent in patients with INPN. However, consistent with findings from another



TT: tap test; }: the graphic signal expresses the statistical result with the effect of the TT; NS: not statistically significant; T: trend; S: statistically significant.

Figure 3. Evaluation of gait characteristics before and after the tap test based on results shown in Table 2.

study[14], our results indicate that parkinsonian signs are unusual. A possible explanation for these different outcomes was that the aforementioned authors did not discuss whether patients with "probable" and "possible" INPH were included in their criteria. Due to the inclusion of "possible" patients, those with atypical parkinsonism may have been included in the cohort. We included only "probable" patients, similar to the Bugalho and Guimarães study[14]. On the other hand, in the present study, specific scales to assess parkinsonism, such as the Unified Parkinson's Disease Rating Scale, were not used.

Gait disturbance in INPH is classically described as slow and broad-based, which is associated with imbalance (tandem gait) and *en bloc* turning[24]. Stolze et al.[19] also described, magnetic gait, and broad-based gait. Another study demonstrated that slowness, loss of balance, and short stride were the most frequent features in NPH patients[14]. The gait pattern triad characteristic in INPH consists of a small-stepped gait, magnetic gait, and broad-based gait[3]. In our patients with INPH, the main gait disturbances included velocity, cadence, step height, step length, *en bloc* turning, and *en bloc* gait, present in approximately 80% of patients. Ten patients (40%) had a broad-based gait, while eight patients (32%) had imbalance. Jankovic et al.[16] classified gait dysfunction in frontal gait and subcortical hypokinetic gait. Frontal gait dysfunction was characterized by decreased step length and height, imbalance, leg apraxia, freezing, abnormal stance (broad-based > narrow base), abnormal postural reflex, trunk/leg stiffness and frontal release signs, whereas the subcortical hypokinetic gait dysfunction presented with decreased step length and height, festination, start hesitation, freezing, *en bloc* turning, narrow base, abnormal postural reflex, shuffling, and parkinsonian signs. Gait disturbances observed in our patients with INPH suggest involvement of systems that modulate the cortical and subcortical regions, according to the classific

Gait velocity was found to be the feature that improved the most with CSF removal. Similarly, other studies have also shown gait speed to be the parameter most sensitive to the CSF-TT[5,6,14]. Measuring gait velocity requires only a stopwatch and no other specific or costly equipment[6]. In addition to improving gait velocity with the CSF-TT, cadence, step length, *en bloc* turning, and step height were the features most affected by the CSF-TT. The *en bloc* gait showed a marginal improvement after the CSF-TT, a trend that perhaps could become significant if studied in a larger cohort.

Surprisingly, in the present study, cadence was the second parameter most altered, showing a significant improvement after the CSF-TT. However, the results of several studies are less consistent regarding cadence, which was found to be unchanged[6,19] or higher[25] with the effects of the CSF-TT.

En bloc gait was present in 14 patients, and improved in 9 cases after the TT. Typical *en bloc* gait was also observed, and it is believed to act as a compensatory mechanism to reduce a lack of gait balance[26]. In other words, the decrease in mobility of the pelvic and scapular girdles and of the upper limbs occurs to avoid displacement of the gravity center and to maintain a safe balance during gait. The improvement in gait speed (step length and increased height) and *en bloc* turning suggests an improvement in functions related to the anatomy of subcortical regions. These findings support the hypothesis of secondary involvement of subcortical circuits in INPH and the hypothesis that impairment of these structures can be reversed by removing CSF, corroborating the findings of Mocco et al.[27]. No statistically significant improvement in other gait variables was observed following the CSF-TT. According to some authors, imbalance is a feature that does not improve after a CSF-TT[5,19]. This was supported by our own findings, as no improvement in balance was observed. Ravdin et al.[5] found that trunk balance (*en bloc* gait) showed a trend towards improvement, similar to our study.

We found outward rotation of the feet in 6 patients (24%) and a broad-based gait in 10 patients (40%), which is a less common feature of idiopathic Parkinson's disease[19]. These findings can assist in the differential diagnosis of INPH[19]. However, another study reported that gait in Parkinson's disease and NPH are similar; therefore, it is not possible to differentiate between both, based solely on gait pattern[25].

Yamada et al.[28] observed that patients with the shortest disease course had a better response to CSF-TT. In our work, the duration of the disease showed no relation to the response to the CSF-TT. The results of the present study, which used semi-quantitative visual analysis of posture and gait parameters, did not differ significantly from those of other studies in the literature that used quantitative analysis[6,19]. This type

of gait analysis, with infrared markers, requires expensive equipment and a specific location where the assessment can be conducted (i.e., gait laboratory) and, therefore, is not easily affordable. The semi-quantitative approach in this study proved to be effective in identifying gait characteristics and any changes in these after CSF removal; it also had the advantage of being more affordable. However, it requires the presence of an experienced neurologist to recognize subtle changes in NPH.

The complication rate of the test in our series was very low. The only complication observed after removal of CSF was not serious (headache) and occurred in only one patient (4%). A similar complication rate was reported by Malm et al.[7]. Thus, the CSF-TT can be considered safe and, as stated, should be the first invasive test indicated when INPH is suspected[3]. The main limitation of the study was the small sample size, due to the strict exclusion criteria.

In short, this study demonstrated that gait speed is the most sensitive parameter assessed after CSF-TT, followed by cadence, step length, *en bloc* turning, and step height. Further investigation is warranted to gauge changes in gait speed after ventriculoperitoneal shunting.

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