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Gait

## RESEARCH ARTICLE

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# Objective Assessment of Gait in Normal-Pressure Hydrocephalus

## ABSTRACT

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**Objectives:** Gait abnormalities are an early clinical symptom in normal pressure hydrocephalus (NPH), and subjective improvement in gait after temporary removal of CSF is often used to decide to perform shunt surgery. We investigated objective measures to compare gait before and after CSF drainage and shunt surgery.

**Design:** Twenty patients and nine controls were studied. Quantitative gait measures were obtained at baseline, after 3 days of controlled CSF drainage, and after shunt surgery. Decision to perform surgery was based on response to drainage, and patients were assigned to shunted or unshunted groups for comparison.

**Results:** There was no improvement after CSF drainage in the unshunted group ( $n = 4$ ). In the shunted group ( $n = 15$ ) velocity, double-support time, and cadence improved significantly after drainage, and improved further after shunt surgery. The degree of improvement after drainage significantly correlated to the degree of improvement postshunt for velocity, double-support time, cadence, and stride length.

**Conclusions:** There are significant, quantifiable changes in gait after CSF drainage that correspond to improvement after shunt surgery for patients with NPH. Use of objective gait assessment may improve the process of identifying these candidates when response to CSF removal is used as a supplemental prognostic test for shunt surgery.

**Key Words:** Normal-Pressure Hydrocephalus, Gait, Hydrocephalus Shunts, Diagnosis

**N**ormal-pressure hydrocephalus (NPH) is an uncommon, treatable disorder of the elderly that is recognized by a characteristic symptom triad of gait apraxia, dementia, and urinary incontinence resulting from ventricular enlargement, and associated with normal cerebrospinal fluid (CSF) pressure assessed by lumbar puncture.<sup>1,2</sup> Gait impairment is considered the earliest and predominant symptom in NPH,<sup>3-6</sup> and the term *gait apraxia* has been used to describe gait in NPH in the absence of demonstrable sensory or motor weakness.<sup>7</sup>

Typical complaints include “poor balance, off balance, unsteady, wobbly, staggering, difficulty on stairs and curbs.”<sup>1,3,8</sup> Short, shuffling steps; frequent falls; freezing during walking; and difficulty with turns or initiating walking characterize progression of the disorder. Falling is a serious problem, and most patients require the use of an assistive device for ambulation. Gait impairment in the elderly can result in deterioration of functional status and quality of life.<sup>9,10</sup>

Improvement in gait after temporary removal of CSF is often influential in the decision to proceed with shunt surgery,<sup>11-14</sup> but there has been little objective assessment of changes in gait, either after CSF drainage or shunt surgery in NPH. Quantitative measurement of gait has the potential to improve the ability to predict shunt responsiveness in NPH. We hypothesized that there are quantifiable and reversible gait abnormalities in NPH, and used objective gait measures to compare function before and after CSF drainage and shunt surgery. Objective measures were compared with expert clinical assessment, which was used to select subjects for shunt surgery.

## METHODS

### Patients

Twenty-two consecutive patients referred for evaluation of possible NPH were assessed in this prospective IRB-approved pilot study. Informed consent was obtained. The inclusion criteria were (1) clinical and radiographic evidence of hydrocephalus by CT scan or MRI, and (2) symptoms of gait impairment with either urinary incontinence or cognitive impairment. Exclusion criteria were prior or existing shunts; large cerebral or cerebellar infarction; small cerebral arterial infarctions (lacunae) if associated with hemiparesis; cerebellar signs or neurological deficits precluding motor assessment; intracerebral hemorrhage; traumatic brain injury; brain tumor; definite diagnosis of Parkinson or Alzheimer disease; functional blindness; or any musculoskeletal condition precluding assessment of gait.

Diagnostic criteria for NPH and for shunt sur-

gery have been previously described and are consistent with the INPH Consensus Guidelines published in 2005.<sup>11,12</sup> A temporary spinal catheter was inserted for 72 hrs of continuous CSF drainage at approximately 10 ml/hr. Patients were examined clinically for their response at least once daily. Response to drainage was defined as objective improvement in gait, cognition, or bladder control. The results of the GaitRite testing were not known by the clinical examiner (MAW) and were not used to make diagnostic decisions.

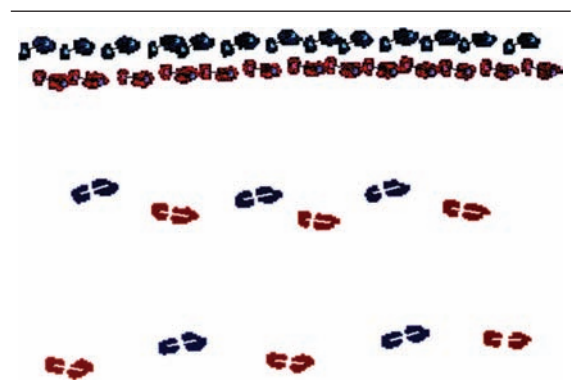
The control group ( $n = 9$ ) consisted of age-matched spouses or partners of the patients who had no clinical evidence of hydrocephalus.

### Instrumentation

Quantitative measures of gait were obtained with the GAITRite Portable Walkway and Gait Analysis System (CIR Systems, Inc., Havertown, PA). The system automates the acquisition, analysis, and reporting of the objective spatial and temporal gait parameters. The application software processes the raw data into footfall patterns (Fig. 1), and computes real-time parameters along with their coefficients of variation (CV). The system allows use of assistive or ambulatory aids, including crutches, canes, or walkers.

### Protocol

At the time of testing, each subject's medical condition and use of assistive devices were noted. The height, weight, and leg lengths were measured. Subjects were tested wearing their normal shoes and using their usual assistive devices, if any. For safety, subjects wore gait belts, and if they were unstable, an assistant walked alongside holding the gait belt. Subjects ambulated the length of walkway for five trials. The first walk was used for familiarization; the last four trials were averaged for data analysis. Gait assessment was performed under three conditions: before and after controlled CSF drainage (baseline and after drainage), and after



**FIGURE 1** Footfall patterns for subject 6 recorded by gaitrite at baseline (top), after drainage (middle), and after shunt (bottom).

**TABLE 1** Demographic characteristics of subjects and controls

Group	Males/Females	Age, yrs	Height, cm	Weight, lbs
Shunted ( <i>n</i> = 15)	11/4	73 ± 8	166 ± 12	168 ± 30
Unshunted ( <i>n</i> = 4)	3/1	76 ± 2	176 ± 7	183 ± 27
Controls ( <i>n</i> = 9)	2/7	69 ± 7	164 ± 10	150 ± 29

Values are means ± standard deviation.

shunt surgery (after shunt). The control group was tested at the same interval as the subjects, but had no diagnostic or therapeutic intervention.

### Study Variables

- (1) Velocity [VEL]: meters per minute; also known as self selected walking speed [SSWS].
- (2) Mean normalized velocity [MNV]: vel divided by the subject's leg length.
- (3) Stride length [SL]: distance in meters from heel strike of one foot to the next heel strike of the same foot (right and left).
- (4) Coefficient of variance of stride length [CVSL]: statistic obtained by dividing the standard deviation (SD) by the mean of the stride length of any subject. [CVSLL-left], [CVSLR-right].
- (5) Step length [StL]: perpendicular distance in meters from the geometric heel center of the (current) footfall to the geometric heel center of the (previous) footfall (StLL-left; StLR-right).
- (6) Cadence [CAD] (steps/min): number of steps taken in one minute.
- (7) Double-support time [DST] (secs): period during which both feet are in contact with the mat.
- (8) Base width [BW] (cm): perpendicular distance between heels at each heel strike.
- (9) Functional ambulation profile [FAP]: a comprehensive gait performance score ranging from 0 (no walking ability) to 100 (optimal performance). factors considered include bilateral asymmetries, assistance given, velocity, and others.<sup>15</sup>

### Statistical Analysis

Data were obtained by averaging the results of the series of four walks obtained at each test condition. Based on the results of the diagnostic protocol, subjects were assigned to two groups: the shunted group if they were diagnosed with NPH, and the unshunted group if they were not. Regression analyses, the mixed-effects model, and non-

parametric tests (Mann-Whitney *U* and Wilcoxon) were used to analyze study data within and between the groups using SAS (version 9.1.3) and SPSS (version 12.0). *P* values ≤0.05 were considered statistically significant.

## RESULTS

### Demographics and Diagnostic Results

The demographic data are in Table 1. Twenty-two subjects were enrolled, of whom two were withdrawn because of medical complications related to CSF drainage. Sixteen subjects were diagnosed with NPH and were advised to receive a shunt, of whom 15 had shunt surgery (shunted group, *n* = 15). Four subjects were not diagnosed with NPH and did not receive a shunt (unshunted group, *n* = 4).

### Gait Results

#### Control Group

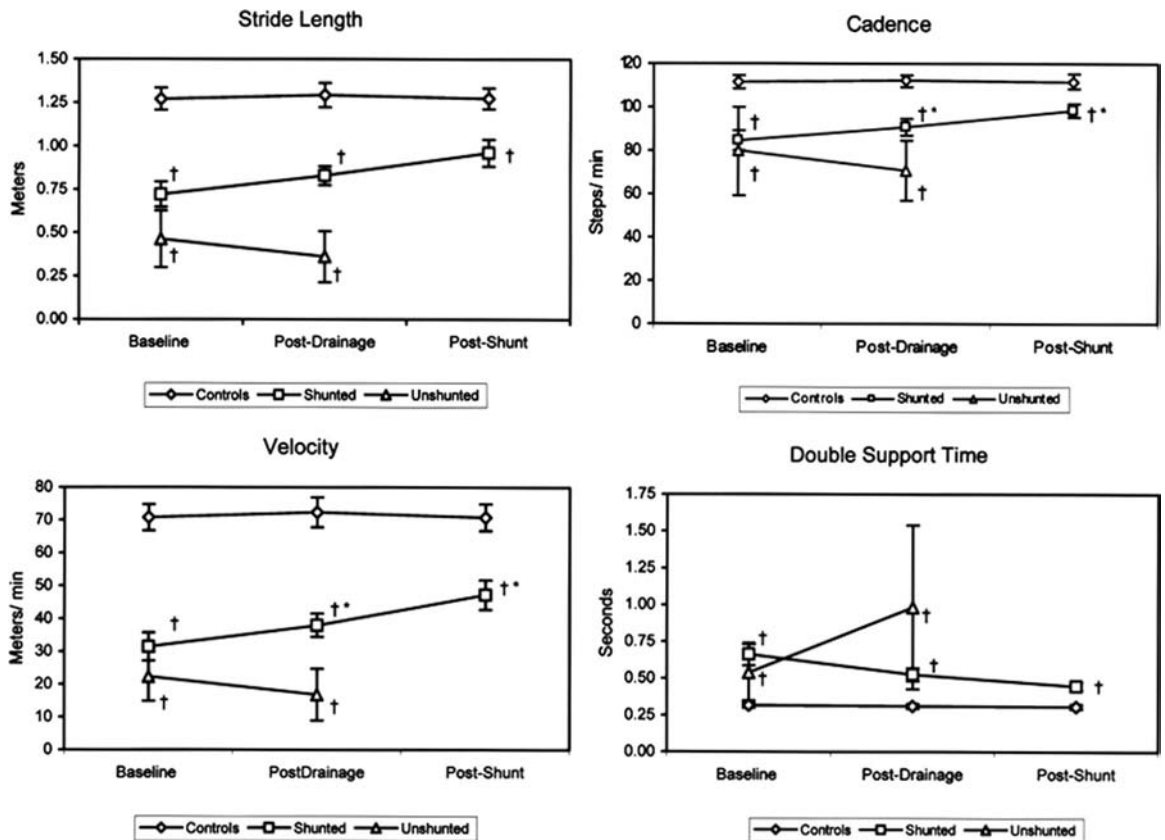
As expected, all variables for the control group were normal and did not change over time (Fig. 2).

#### All Subjects (Shunted and Unshunted Groups)

The duration of gait impairment was 36 ± 20 mo before baseline. The interval between baseline and postdrainage was 4.5 ± 0.99 days (range 4–7 days), and the interval between baseline and postshunt was 214 ± 202 days (range, 105–793 days). Postshunt testing for subjects 10 and 15 were delayed until 793 and 612 days after baseline, respectively, because of difficulty traveling. In each instance, they reported initial symptomatic improvement; however, they had experienced subsequent worsening by the time of evaluation. Their data are included in the analyses.

#### Shunted Group

At baseline, all variables were significantly worse than the control group, and did not differ from the unshunted group (Fig. 2). From baseline to postdrainage, the velocity, mean normalized velocity, DST, and cadence improved significantly. After shunt, all gait variables were significantly improved in comparison with baseline (*P* ≤ 0.05),



**FIGURE 2** Comparison of variables for the control, shunted, and unshunted groups. Positive slope indicates improvement, except for DST, in which negative slope indicates improvement.

including increases in velocity (50%), mean normalized velocity (49%), stride length (33%), FAP (27%), and cadence (16%), and a significant decrease in DST (33%) and base width (12%). The individual scores for velocity and FAP for all shunted subjects are shown in Figure 3. Whereas the coefficient of variance of stride length of individual subjects in the shunted group did not differ significantly between baseline and postdrainage, it did improve significantly between baseline and postshunt. The same was true for other gait variables such as FAP, stride length, and base width.

The degree of response to CSF drainage correlated significantly to the degree of response after shunt surgery for DST ( $r^2 = 0.737$ ;  $P < 0.001$ ), velocity ( $r^2 = 0.455$ ;  $P = 0.0058$ ), cadence ( $r^2 = 0.349$ ;  $P = 0.0203$ ), and stride length ( $r^2 = 0.477$ ;  $P = 0.004$ ) (see Table 2).

### Unshunted Group

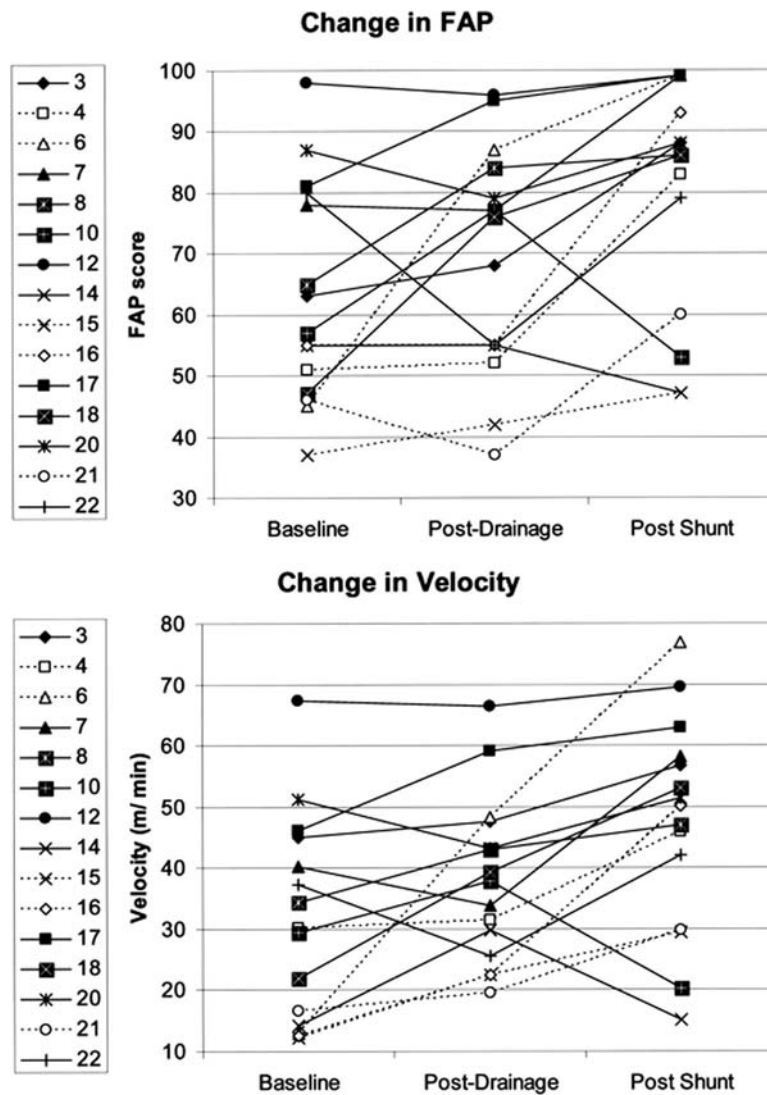
At baseline, all variables were significantly worse than the control group, and did not differ from the shunted group (Fig. 2). After drainage, none of the variables improved.

### DISCUSSION

Recent work has shown that improvement in gait after a trial of controlled CSF drainage is

highly predictive of response to shunt surgery in normal-pressure hydrocephalus.<sup>11,12,14</sup> Our study demonstrates that the changes after CSF drainage are significant and quantifiable, and they correspond to the improvement in gait after shunt surgery. In fact, the improvement in gait after shunt surgery far surpassed that seen after CSF drainage, a finding of important prognostic and functional significance. Quantitative gait analysis corroborates the selection of patients for shunt surgery by a clinician with extensive experience, and may be an important method for assisting the clinical evaluation of health care professionals who evaluate fewer patients for NPH.

The gait abnormalities at baseline were not different between subjects who were eventually selected for shunt surgery and those who were not, suggesting that it is, indeed, necessary to evaluate the response to CSF drainage to identify candidates for shunt surgery. This supports the clinical paradigm that many different disorders can produce NPH-like symptoms, and that it is difficult to diagnose NPH on clinical presentation alone. Although the shunted and unshunted groups were significantly worse at baseline, there was a wide range of individual gait impairment at baseline (Fig. 3), which suggests either that subjects were evaluated



**FIGURE 3** Individual functional ambulation profile and velocity scores for the 15 shunted patients at baseline, postdrainage, and postshunt.

at different stages of progression of NPH, or that there is wider variability in the gait difficulties of NPH than is commonly appreciated.

Our results support previous studies that report low speed, short stride length, and a wide base in NPH.<sup>6,16,17</sup> As reported by others, we found prolonged DST,<sup>6,18</sup> which, along with the slow speed, are compensatory mechanisms that reflect instability in walking.<sup>19,20</sup> Not all studies find prolonged DST in NPH.<sup>17,21</sup>

Our finding that the coefficient of variance (CV) of stride length was lower postshunt compared with baseline is consistent with work showing that the CV of variables such as step length or base width is a marker of the variability of gait, and a probable marker of the instability of gait.<sup>22,23</sup> Although we did not assess balance directly, the decrease in base width and CV of stride length, and the increase in FAP suggest that balance was improved after shunt surgery. The find-

ing that most subjects were willing to walk without an assistive device following shunt surgery suggests that they felt more secure and confident.

Some patients who were selected for shunt surgery on the basis of the clinical protocol had no significant change in gait variables after CSF drainage. This reflects the fact that gait is only one component of NPH that can respond to CSF drainage, and may also speak to more subtle findings that led to the decision for shunt surgery. Indeed, all but two patients who received a shunt had improved postshunt velocity whether they had improved after CSF drainage or not. This has also been reported by Fisher,<sup>3</sup> who emphasized that even patients who do not respond to CSF tap test can improve after shunting.

Both the criteria for selecting patients for shunt surgery for NPH and the outcomes of shunt surgery have varied widely.<sup>24-30</sup> Marmarou et al.<sup>14</sup>

**TABLE 2** Correlation of degree of improvement from baseline to after drainage and from baseline to after shunting in shunted group (n = 15)

Gait Variable	Correlation of Baseline-to-Postdrainage Response to the Baseline-to-Postshunt Response
FAP	$R = 0.59, P = 0.02, R^2 = 0.348$
Stride length	$R = 0.69, P = 0.004, R^2 = 0.477$
Velocity	$R = 0.68, P = 0.006, R^2 = 0.455$
Mean normalized velocity	$R = 0.50, P = 0.058, R^2 = 0.25$
Double-support time	$R = 0.86, P = 0.00004, R^2 = 0.737$
Cadence	$R = 0.59, P = 0.020, R^2 = 0.349$
Base width	$R = 0.48, P = 0.072, R^2 = 0.227$
CV stride length	$R = 0.50, P = 0.056, R^2 = 0.25$

VEL, velocity (m/min); SL, stride length; CAD, cadence (steps per minute); MNV, mean normalized velocity; DST, double-support time; BW, base width; FAP, functional ambulatory profile (combined scores for overall quality of gait); CVSL, coefficient of variance of stride length (left or right); StL, step length: distance (m) from heel center of one footfall to the heel center of the next footfall (left or right).

used steps per minute and descriptive assessment of gait (e.g., shuffling, wide-based, difficulty in turning) by an independent observer who viewed videotapes of gait. The gait assessment described by Sorensen et al.,<sup>17</sup> and Stolze et al.,<sup>6</sup> requires laboratory equipment not readily available in the clinical setting, where formal gait evaluation can be difficult. In our previous studies, gait assessment was primarily subjective or semiquantitative, based on the impression of the physician, patient and family,<sup>12</sup> and including the use of the Tinetti score, which is unlikely to detect small differences.<sup>14,31,32</sup>

Ideally, gait assessment in NPH requires a method that combines the simplicity and speed of use necessary for clinical practice with quantitative, reproducible data collection necessary for research. The GAITRite system used in our study is portable and can be used in outpatient and inpatient settings. The validity and reliability of the system in measurement of both averaged and individual temporospatial gait variables has been established.<sup>33,34</sup> The combination of the GAITRite system for gait analysis and assessment of gait before and after CSF drainage may prove to be an economic, reliable and valid method of selecting patients for shunt surgery.

Although our study is limited by a small sample size, the magnitude of improvement in gait after CSF drainage and shunt surgery indicates that the results are meaningful and robust. Furthermore, we used a prospective study design with controls, and made the diagnosis of hydrocephalus by use of controlled CSF drainage, which is considered the most accurate method for identifying shunt responsive idiopathic NPH.<sup>11</sup> Further study of a larger cohort may reveal further insight into baseline differences, if any, between subjects with and without NPH, and into the speed and characteristics of recovery after lumbar puncture, con-

trolled CSF drainage via spinal catheter, or shunt surgery.

In summary, objective improvement of gait variables in response to controlled CSF drainage is predictive of response to shunt surgery in patients with suspected NPH, and corroborates the selection of such patients on the basis of semiquantitative scoring systems or expert clinical judgment. The GAITRite system used in this study provides a combination of objective measurement and ease of use that may make it a suitable technique for use in the clinical environment. Further evaluation of this method in large cohorts of patients is needed.

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