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The effect of CSF drainage on ambulatory center of mass movement in idiopathic normal pressure hydrocephalus

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ABSTRACT

Background: Although gait and balance disturbances are core symptoms of idiopathic normal pressure hydrocephalus (iNPH), the ambulatory center of mass (COM) movements in patients with iNPH remain unclear. We aimed to clarify the ambulatory COM movements using an accelerometer on the patients' lower torsos and to investigate the changes in COM movement after cerebrospinal fluid tap tests (TT) and shunt surgeries (SS).
Methods: Twenty-three patients with iNPH and 18 age-matched healthy controls (HCs) were recruited. A triaxial accelerometer was fixed with a belt onto each participant's torso at the L3 vertebra level. We assessed each patient's 10-m gait before TT, 3 days after TT, and 1 week after SS.
Results: Compared to the HCs, the patients exhibited decreased gait velocities, increased step numbers, and increased step times. Their movement trajectory amplitudes (i.e., the COM movements) were increased in the medial/lateral direction and decreased in the vertical direction. They also exhibited greater variability (measured as coefficients of variation) in step time and movement trajectory amplitude in both the medial/lateral and vertical directions. The patients' gait parameters were significantly improved after TT and SS.
Significance: Our results suggest that iNPH-associated gait disturbances could cause abnormal ambulatory COM movements and that these disturbances are mitigated by TT and SS.

1. Introduction

Idiopathic normal pressure hydrocephalus (iNPH) is a condition of enlarged brain ventricles under a normal cerebrospinal fluid (CSF) pressure, and it is characterized by a clinical triad including gait disturbance, cognitive impairment, and urinary incontinence [1]. Gait disturbances are the most common triad symptom, affecting 94–100% of patients [2,3]. The patients characteristically present with slowness; small-stepped, decreased foot-to-floor clearance; and wide-based gaits [4–6]. Additionally, iNPH-associated balance disturbances with disequilibrium [6,7] occur as a result of central and/or peripheral vestibular dysfunctions [8–10] and proprioceptive dysfunction [8]. iNPH-associated gait and balance disturbances are likely to increase the risk of falling [6–9].

Center of mass (COM) movement is the main element of gait because it reflects the whole body's movement [11,12]. COM stabilization during gait is explained by a simple rule called the inverted pendulum model [13,14]. Under this model [13,14], reduced foot placement precision results in wider strides, but this effect can be mitigated by walking with a faster cadence. This model illuminates how slowness, short strides, and disequilibrium may influence ambulatory COM movements in the case of iNPH-associated gait and balance dysfunctions. However, greater motor variability also implies that slowness, short strides, and disequilibrium may constitute a compensation strategy for prolonging motor independence [15]. In any case, clarifying the features of ambulatory COM movement in iNPH may help explain the patients' gait and balance disorders and elucidate the appropriate diagnostic and treatment strategies, which may include exercise therapy. Objective gait assessments in patients with iNPH have examined various gait parameters such as temporal and spatial parameters [4–6,8,10,16–19], but the ambulatory COM movements in iNPH remain unclear.

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Several studies have reported that a waist-mounted wearable accelerometer can easily record ambulatory COM movements [20,21]. We therefore aimed to clarify the characteristics of iNPH-associated ambulatory COM movement using waist-mounted accelerometers on patients and healthy controls (HCs) and to investigate the changes in patients' gait variabilities and COM movements after CSF tap tests (TT) and shunt surgeries (SS). We hypothesized that ambulatory COM movements in patients with iNPH would be larger and more variable than those in HCs and that CSF drainage would reduce COM movement abnormalities in patients with iNPH.

2. Methods

2.1. Participants

Twenty-three patients with iNPH (age [mean ± standard deviation]: 76.9 ± 5.7 years; 19 men and 4 women) and 18 HCs (age: 74.3 ± 3.4 years; 12 men and 6 women) participated in this study. The Osaka Medical College's ethics committee approved this study protocol (No. 1555), and all participants provided written informed consent. The study was performed in accordance with the Declaration of Helsinki. The patients had probable diagnoses with positive TT results according to the iNPH diagnostic criteria [22]. They underwent lumboperitoneal or ventriculoperitoneal SS 1 month after TT. A Codman–Hakim programmable valve with a siphon-guard (Codman and Shurtleff, Raynham, MA) was implanted in each patient, and the initial pressure settings were decided according to the patient's height and weight using Miyake's quick reference table [23]. The HCs were recruited from senior community service clubs. Table 1 shows the participants' demographics. Patients were excluded for (1) additional neurological or orthopedic disorders interfering with gait or (2) an inability to walk unassisted for at least 15 m. Each patient's cognitive function was examined using the Mini-Mental State Examination (MMSE) before TT, and the history of falling within the past 6 months was recorded.

2.2. Gait assessment procedure

Each participant had a triaxial accelerometer (MG-M1100-HW, LSI Medience, Tokyo, Japan; size: 7.5 × 5 × 2 cm^3; weight: 120 g) attached to the lower torso at the L3 vertebra level with a belt. This device can measure ambulatory COM movement [20]. Acceleration data were recorded at a sampling rate of 100 Hz.

The walkway was a 15-m straight path with 3-m acceleration and 2-m deceleration sections at the beginning and end, respectively. The participants walked twice at their normal, comfortable speed without assistance. We assessed the patients' movements before TT, 3 days after TT [17], and 1 week after SS.

Table 1
Demographic data of the HCs and patients with iNPH.

	iNPH (n = 23)	HC (n = 18)	*p*-Value
Age (years)	76.9 (5.7)	74.3 (3.4)	0.079[a]
Gender (male/female)	19/4	12/6	0.238[b]
Height (cm)	159.1 (7.9)	160.7 (8.5)	0.548[a]
Weight (kg)	60.7 (9.7)	58.0 (9.7)	0.516[a]
MMSE score (preTT)	25.0 (3.6)		
History of falls (%)	78.3	0	0.000[b]
Surgery type (LP/VP)	21/2		

Values are mean (SD); [a] *p*-value of independent-t test; [b] *p*-value of Chi-Square test.
MMSE: Mini Mental State Examination; TT: tap test; LP: lumbo-peritoneal shunt; VP: ventriculo-peritoneal shunt.

2.3. Data analysis

The acceleration data were imported into dedicated software (MG1100-PC, Gait View, Tokyo, Japan). The data from the 10-m section between the acceleration and deceleration zones were analyzed to calculate velocity, number of steps, and step time [20]. Step time was defined as the interval between acceleration minima. To calculate movement trajectory amplitudes that reflect COM movements, the acceleration signals in the medial/lateral (ML) and vertical (VT) directions were integrated twice in the time domain and high-pass filtered with a moving-window average [20]. Relative displacement in the anterior/posterior direction was not calculated this way because it can easily be calculated for participants walking forward at a constant speed. The ambulatory movement trajectory amplitudes for 1 participant are shown in Fig. 1. Gait variability was assessed as the percent coefficient of variation (CV = standard deviation/mean × 100) [24] of step time and movement trajectory amplitudes. Each participant's CVs were calculated based on acceleration data from the 10-m section between the acceleration and deceleration sections. All gait parameter variables are presented as an average of 2 trials.

2.4. Statistical analysis

Data are expressed as means ± standard deviations. Statistical analyses were conducted using JMP Pro v. 12.0 (SAS Institute, Cary, NC). To compare the characteristics and gait parameters (pre-TT for the patients) of the patients and HCs, significant intergroup differences were tested for using independent *t*-tests. The patients' gait parameters at different timepoints (i.e., pre-TT, post-TT, and post-SS) were compared using 1-way repeated-measures ANOVA. When significant differences were observed, multiple comparisons corrections were performed with the Bonferroni method to confirm significance. Furthermore, to quantify effect sizes, we calculated Cohen's d–based standardized mean differences (SMDs) [25] and confidence intervals (CIs) [25] for gait comparisons data. We defined statistical significance as $p < 0.05$.

3. Results

3.1. Participants

Table 1 shows the participants' demographics. The patients and HCs were comparable in age, sex, height, and weight. The patients had normal cognitive function as measured with MMSE scores (25.0 ± 3.6). Eighteen patients (78.3%) had a history of falling.

3.2. Gait analysis

Compared to measurements in the HCs, pre-TT measurements in the patients revealed significantly slower velocities (SMD: 1.98, 95% CI: −0.66 to −0.36 m/s, $p < 0.001$; Fig. 2a), significantly more steps (SMD: 1.18, 95% CI: 8.85 to 24.71 steps, $p < 0.001$; Fig. 2b), significantly longer step times (SMD: 1.01, 95% CI: 0.02 to 0.07 s, $p < 0.001$; Fig. 2c), and significantly larger step time CVs (SMD: 1.38, 95% CI: 4.7% to 11.11%, $p < 0.001$; Fig. 2d).

Compared to the movement trajectory amplitude measurements in the HCs, pre-TT measurements in the patients revealed significantly larger ML amplitudes (SMD: 2.03, 95% CI: 2.01 to 3.64 cm, $p < 0.001$; Fig. 2e) but significantly smaller VT amplitudes (SMD: 2.45, 95% CI: −2.17 to −1.31 cm, $p < 0.001$; Fig. 2f). The patients' CVs of movement trajectory amplitudes were significantly larger in both the ML (SMD: 0.79, 95% CI: 0.43% to 3.28%, $p = 0.011$; Fig. 2g) and VT directions (SMD: 1.58, 95% CI: 11.28% to 23.61%, $p < 0.001$; Fig. 2h).