Relationship between Amount of Daily Movement Measured by a Triaxial Accelerometer and Motor Symptoms in Patients with Parkinson's Disease

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Abstract: The aim of this study was to analyze the association between the amount of daily movement measured with a triaxial accelerometer (MIMAMORI-Gait) and motor symptoms in patients with Parkinson's disease (PD). The subjects were 50 consecutive patients with untreated PD free of dementia. The amount of overall movement over 24 h was measured with the portable MIMAMORI-Gait device and its association with the modified Hoehn and Yahr stage and UPDRS part II and III scores was analyzed. In patients with PD, the amount of overall movement measured with MIMAMORI-Gait was significantly associated with the UPDRS part II score ($\beta = -0.506$, $p < 0.001$) and part III score ($\beta = -0.347$, $p = 0.010$), but not with the modified Hoehn and Yahr stage. The amount of overall movement measured with MIMAMORI-Gait can potentially be used for evaluation of motor symptoms and ADL in PD patients.

Keywords: triaxial accelerometer; MIMAMORI-Gait; amount of daily movement; Parkinson's disease

1. Introduction

Parkinson's disease (PD) is a typical neurodegenerative disorder characterized mainly by motor symptoms. Similar to other countries, the number of patients with PD in Japan is rising as the elderly population increases [1]. PD is a heterogeneous disorder, and accordingly the clinical course and responsiveness to levodopa vary among individual patients depending on the age at onset and motor and nonmotor clinical symptoms and signs. Thus, treatment of PD requires adequate assessment of the status of patients as well as consideration of the effects of the disease on their daily lives and social activities. Although several methods for assessment of PD motor symptoms are available, two are widely used in daily clinical practice—the Unified Parkinson's Disease Rating Scale (UPDRS) [2] and the Movement Disorder Society-sponsored revision of UPDRS (MDS-UPDRS) [3]—which allow comprehensive assessment of motor symptoms and difficulties in activities of daily living (ADL). However, evaluation by an expert in the examination room and assessment of the ADL based on patient self-reports have several limitations. In fact, the on–off state is often difficult to assess in routine clinical practice, especially in patients with motor fluctuations.

In recent years, new technology-based methods for the assessment of PD have been proposed and developed [4–9]. Some employ wearable sensors, such as accelerometers, gyroscopes, magnometers, barometers, light sensors, and global positioning systems [10]. In fact, some of these new technologies are currently being used in clinical laboratory examinations. Although careful validation is necessary,

these sensors have enhanced our understanding of the physical function and activity in daily living that could not be captured previously by clinical observations. Thus, wearable sensors provide new opportunities to gain knowledge with regard to health and function [10].

It has been postulated that the degree of impairment in daily activities correlates with the severity motor performance deficits, quantified by wearable devices only and not by UPDRS part III, including elemental motor symptoms, such as rigidity and tremor [11]. However, this correlation remains to be investigated.

In Japan, the portable gait rhythmogram (MIMAMORI-Gait; LSI Medience Corporation, Tokyo, Japan) equipped with a triaxial accelerometer has been approved for health insurance reimbursement by the Ministry of Health, Labor, and Welfare. This device is mainly used for the assessment of the amount of overall movement and gait in patients with PD and other neurodegenerative disorders [12–15]. The amount of overall movement measured with MIMAMORI-Gait is assumed to quantify akinesia/bradykinesia, composite symptoms, combined with elemental motor deficit [12–15].

Using the MIMAMORI-Gait, the present study was designed to determine whether the amount of overall movement in PD patients correlates with UPDRS part II-estimated impairments in daily activities. The study also served to examine the correlation between the amount of overall movement measured by the device with the clinical score of elemental motor symptoms, Hoehn and Yahr (mH&Y) stage and UPDRS part III.

2. Methods

2.1. Participants

Among previously untreated patients with idiopathic PD who visited the Outpatient Clinic of the Department of Neurology, Tokyo Medical University Hospital, between July 2009 and March 2016, those meeting the following criteria were included in this study: (1) age <80 years; (2) Mini-Mental State Examination (MMSE) score ≥24; and (3) provided written consent to participate in the study. On the other hand, patients meeting the following criteria were excluded: (1) patients with other concurrent neurodegenerative disorders; (2) those with history of stroke; and (3) those with concurrent arthralgia or spinal diseases that interfere with the ADL. PD was diagnosed according to the criteria set by the United Kingdom Parkinson's Disease Society Brain Bank [16]. All patients underwent head magnetic resonance imaging to confirm the absence of stroke, idiopathic normal pressure hydrocephalus, and other degenerative disorders.

In this study, 15 healthy volunteers (9 men and 6 women; age, 67.9 ± 4.7 years; mean ± SD, height, 1.58 ± 0.07) were also examined under the same standards as the patients with PD, and served as the control group.

The study protocol was approval by the Medical Ethics Committee of Tokyo Medical University Hospital and a signed consent form was obtained from each subject.

2.2. Equipment

MIMAMORI-Gait (LSI Medience Corporation, Tokyo, Japan) is a small device (size, 8 × 6 × 2 cm; weight, 80 g) that measures, in three dimensions (a_x, a_y, a_z), the acceleration caused by limb and trunk movements, and that induced by step-in and kick-off during gait [12,17–19]. The device was secured with a belt to the front and center of the subject's waist. When standing in the anatomical position, the orientations of the X-, Y-, and Z-axes were medial/lateral, vertical, and anterior/posterior, respectively. Positive X values correspond to leftward acceleration, positive Y values to upward acceleration, and positive Z values to forward acceleration. Deficits in motor activities during the night can be the cause of falling when the patient wakes up to go to bathroom during the night. For this reason, the MIMAMORI-Gait device was designed to provide continuous 24 h monitoring including nighttime recording of motor activity. The subjects were instructed to wear the device at all times during the 24 h period, except when changing clothes or taking a shower/bath. MIMAMORI-Gait records at a

sampling rate of 10 ms. The sensor resolution is approximately 0.16 m/s^2. Data are automatically stored on a micro-SD card.

When recording is completed, the absolute value of acceleration vectors (a; $a^2 = a_x{}^2 + a_y{}^2 + a_z{}^2$) is automatically computed and displayed graphically on the PC monitor. A fully charged MIMAMORI-Gait can record continuously for 40 h [12,17–19]. In order to reinforce physical activities, the results of analysis were subsequently reported to the individual patient.

2.3. Procedure Applied for Minimization of Interday Variability

To minimize interday variability, we asked the patients to adhere to their ordinary routines and avoid exceptional physical activities, such as shopping and exercising outside of home. The 24 h continuous recording started from 10 to 12 am.

2.4. Calculation of Amount of Overall Movements

After continuous recording for more than 24 h, the accelerations induced by all movements were averaged every 10 min of recording, and the data were displayed graphically (Figure 1). Based on the assumption that the curve fits the gamma distribution, the mean value of the distribution was calculated mathematically. The gamma distribution is defined by the following formula.

$$f(x) = x^{k-1}e^{-x/\theta}/\Gamma(k)\theta^k \text{ for } x > 0$$

The mean value was named the amount of overall movement per 24 h, representing an index of akinesia/bradykinesia [13,15].
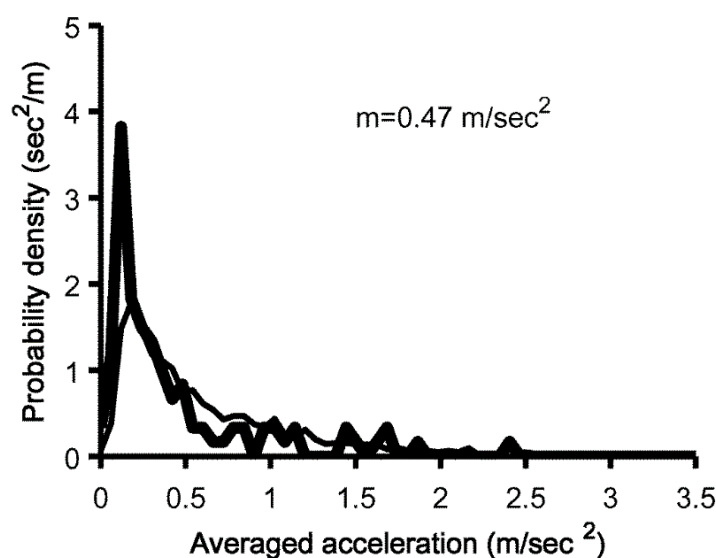

Figure 1. Probability distribution of the averaged acceleration per 10 min, obtained from continuous 24 h recording. Thin lines: distribution curve of 15 healthy volunteers, thick line: distribution curve of a representative 72-year-old man with Parkinson's disease.

2.5. The mH&Y Stage and UPDRS

The motor symptoms and clinical severity of PD were assessed by the mH&Y stage and UPDRS II and UPDRS III scores. The selection of these two parameters was based on their reliability and frequent use in many large-scale clinical trials [20–22].

2.6. Statistical Analysis

The data of all normally distributed clinical parameters (e.g., age, height, disease duration, and MMSE) were expressed as mean ± standard deviation. The Kolmogorov–Smirnov test was performed to verify the normality of the data. The Student's *t*-test was used to compare the amount of overall movement measured with MIMAMORI-Gait between patients with PD and healthy controls. We also examined the association between the amount of overall movement with the mH&Y stage and UPDRS score in patients with PD using multiple linear regression analysis and calculated the standardized partial regression coefficient after adjustment for age, sex, and disease duration. Statistical significance was set at $p < 0.05$. All statistical analyses were performed by using SPSS (version 22, IBM Japan Ltd., Tokyo, Japan).

3. Results

3.1. Clinical Features of Patients with PD

This study included 50 consecutive patients (29 men and 21 women). Table 1 lists the mean age, mean disease duration, mean MMSE score, mean mH&Y stage, mean UPDRS part II score and the mean UPDRS part III score. All patients with PD were independent with regard to ADL.

Table 1. Clinical features of patients with Parkinson's disease (*n* = 50).

Age (years)	65.7 ± 6.5
Male/female (n)	29/21
Height (m)	1.61 ± 0.09
Disease duration (years)	1.4 ± 0.9
Mini-Mental State Examination	28.0 ± 2.0
Modified Hoehn and Yahr stage	2.2 ± 0.7
Unified Parkinson's Disease Rating Scale part II score	7.9 ± 4.5
Unified Parkinson's Disease Rating Scale part III score	15.6 ± 8.7

Data are mean ± standard deviation.

3.2. Comparison of Overall Movement per 24 h between PD and Controls Measured with MIMAMORI-Gait

In patients with PD, the amount of overall movement per 24 h (0.43 ± 0.12 m/s^2) was significantly lower than that in healthy controls (0.65 ± 0.22 m/s^2) (Figure 2).
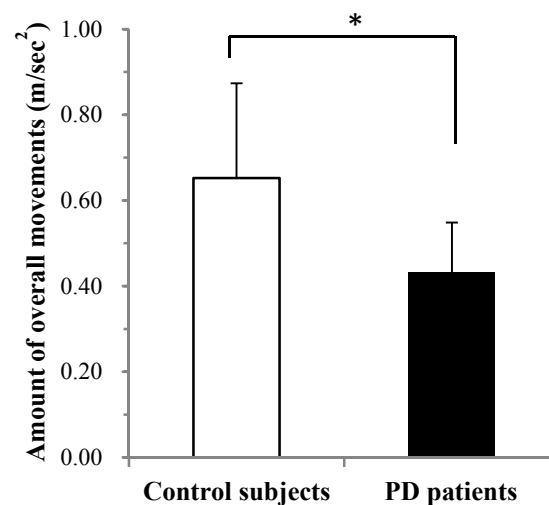

Figure 2. Amount of overall movement over 24 h measured by the portable MIMAMORI-Gait device in patients with Parkinson's disease (PD) and healthy control subjects. Data are mean ± SD. * $p < 0.01$.

3.3. Association between Overall Movement per 24 h Measured with MIMAMORI-Gait and UPDRS Scores

In patients with PD, the amount of overall movement measured with the MIMAMORI-Gait was significantly associated with the UPDRS part II score even after adjustment for age, sex, and disease duration ($\beta = -0.506$, $p < 0.001$). The association between the amount of overall movement and the UPDRS part III score was also significant, though weaker ($\beta = -0.347$, $p = 0.010$). No significant association was observed between the amount of overall movement and the mH&Y stage (Table 2).

Table 2. Association of the amount of overall movement measured by MIMAMORI-Gait with the modified Hoehn and Yahr stage and UPDRS scores based on models adjusted for age, sex, and disease duration.

Assessment of Motor Symptoms	B (SE)	β	p Value
Modified Hoehn and Yahr stage	$-0.044(0.023)$	-0.260	0.059
Unified Parkinson's Disease Rating Scale part II score	$-0.013\ (0.003)$	-0.506	<0.001
Unified Parkinson's Disease Rating Scale part III score	$-0.005\ (0.002)$	-0.347	0.010

B (SE), unstandardized regression coefficient (standard error); β, standardized regression coefficient.

4. Discussion

The level of ADL and quality of life of patients with PD are not only determined by the severity of motor symptoms, but also affected by concurrent nonmotor symptoms, such as cognitive impairment and psychiatric symptoms [23,24]. Thus, treatment of PD requires a comprehensive and objective assessment of both motor and nonmotor symptoms. However, no such assessment method has been established. Instead, examinations are often performed through interviews with the patients and their families, consultation with specialists, and questionnaires. Unfortunately, assessments performed in the examination room or based on patient self-reports are of limited value. The motor symptoms of PD vary according to the mental status of the patient and the surrounding environment at the time of assessment. Particularly, gait disturbance (e.g., freezing of gait) may often appear to be alleviated under the effects of attention and other factors during assessment at a hospital visit, and tends to be underestimated. Assessments based on patient self-reports are marred by the fact that patients often do not recognize their own symptoms. In fact, although bradykinesia and gait disturbance greatly affect ADL, some patients are less likely to recognize those symptoms compared with tremor [25]. With regard to motor fluctuation (e.g., wearing off), because patients subjectively perceive on–off changes, data obtained from the PD home diaries are often dissociated from the actual status. Considered together, the above background highlights a deficiency in the clinical assessment of PD at present and stresses the need for objective assessment of the status of PD patients during ADL and the response to treatment.

The MIMAMORI-Gait is a portable motion recorder designed for long-term continuous measurement, and has been approved in Japan for clinical assessment of gait disturbance and the amount of movement in patients with various diseases—such as PD, progressive supranuclear palsy, and vascular parkinsonism—and has been confirmed to be useful clinically [12–15,26]. The present study was carried out to determine the association between the amount of overall movement over the 24 h measured by the MIMAMORI-Gait and motor symptoms of patients with PD assessed at the outpatient clinic by the UPDRS.

We selected patients with untreated PD in this study to exclude problems related to diurnal variations in symptoms and motor complications due to antiparkinsonian agents. The results showed that the amount of overall movement measured with MIMAMORI-Gait was significantly associated with the scores of clinician-monitored motor evaluation and patient self-evaluation of ADL with UPDRS.

In addition to the motor status, the amount of movement of patients with PD is also influenced by several other factors, such as cognitive function, psychiatric symptoms (e.g., depression and apathy), and autonomic symptoms. In this study, the amount of overall movement measured by MIMAMORI-Gait was more strongly associated with the UPDRS part II score than the part III score. In other words, the finding suggests that measurement with this device reflects the overall level of ADL rather than the severity of elemental motor symptoms. Thus, the amount of overall movement measured by the MIMAMORI-Gait seems to be potentially useful parameter in patients with PD for objective assessment of the degree of health-related quality of life.

The results of the present study showed that the amount of overall movement was significantly lower in patients with PD, even during the early stage of the disease (mean disease duration of approximately 1.9 years), than healthy subjects. This result suggests that the amount of overall movement measured with MIMAMORI-Gait may help in the diagnosis of early PD.

Methodologically, there are some open questions. First, the amount of overall movement measured with MIMAMORI-Gait might not reflect accelerations induced by movements of the upper limbs. The device used in this study is a single-sensor-type accelerometer attached to the lumbar region. Thus, the amount of overall movement measured with this device mainly reflects the movement of the body axis and differs from the amount of movement of the whole body, including the upper limbs. We should carefully interpret the results, although a single-sensor-type device imposes only a slight burden on the patient during long-term continuous recording; thus, it seems to be useful for monitoring activities in the actual daily lives of patients.

Second, the effects of external acceleration (e.g., vehicles) may influence the measurement of movements. In this study, the patients were instructed to continue with their usual lifestyle patterns, and therefore the effect of external acceleration (e.g., prolonged transportation) was considered minimal. However, it is important to distinguish between acceleration of the patients themselves and external acceleration, and develop algorithms to exclude such influence.

Third, the sensitivity of MIMAMORI-Gait needs to be further examined. While we have determined the high sensitivity of our device for detection of gait-induced accelerations [17–19], we have not checked its sensitivity in the detection of overall movement-induced accelerations. In other words, a control study that includes simultaneous recordings using the MIMAMORI-Gait and other devices is needed before clinical application.

In spite of the lack of a control study for assessment of the amount of overall movement, our algorithm can be a potentially useful tool for quantitative assessment of motor symptoms of PD. The algorithm used in MIMAMORI-Gait for assessment of gait disorders has been validated in a series of studies from our laboratories [12–14,17–19]. The present results confirmed that the algorithm can accurately assess impairment of ADL and gait disorders in PD.

Fourth, the duration of monitoring should be examined. Daily activity levels vary among individual patients. Normally, a proper analytical procedure may be to take several measurements and use the mean value as the amount of movement. However, in this study, the amount of overall movement per 24 h was determined by using one measurement in each patient. In this study, the patient was asked to select a day when no special events—such as travel—were scheduled for the measurement, and they were also instructed beforehand to spend the day as usual with regard to physical activities.

In a related issue, the present study included untreated patients with PD and healthy control subjects, and the results allowed objective assessment of these patients. However, the study design did not include evaluation of the device in differentiating patients at the initial stage of the illness from those at advanced stage, based on the amount of overall movement over 24 h. It is also not clear at this stage whether the device can be used to evaluate the PD stage of patients under treatment to determine the response to such treatment. Further large-scale studies are needed to evaluate the suitability of the MIMAMORI-Gait device for the above purposes.

In summary, the present study measured the amount of overall movement over 24 h using the portable MIMAMORI-Gait device in patients with untreated PD. The associations between the recorded parameters and UPDRS scores were analyzed. The results showed that the 24 h amount of overall movement measured with MIMAMORI-Gait was significantly associated with the scores of clinically-monitored motor evaluation and patient self-evaluation of ADL with UPDRS, suggesting that the device is potentially suitable for objective assessment of motor status of PD patients. Further assessment of the device is needed to confirm its suitability for clinical evaluation and response to treatment.

Author Contributions: Hiroo Terashi and Hiroshi Mitoma conceived and designed the study; Mitsuru Yoneyama analyzed the data; Hitoshi Aizawa is supervisor of the group; Hiroo Terashi wrote the manuscript.

Conflicts of Interest: The authors report no conflict of interest associated with this study.

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