TIMETABLE OF GAIT CYCLE EVENTS IN PARKINSON'S DISEASE

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Abstract : The study used an algorithmic method to measure fluctuations in the timetable of gait cycle events in patients with Parkinson's disease (PD) . Subjects with severe PD (n=10; age 63.6 ± 10.1 years; Hoehn & Yahr [H & Y] disability score 3 or 4) , mild PD (n=10; age 65.5 ± 4.3; H & Y ≤ 2) , and normal controls (n=10; age 65.1 ± 13.3) were studied. A camera was mounted on the trunk, and the subjects walked in a self-selected manner. Overhead images of the foot path were analyzed to geometrically describe motion in terms of displacement and velocity. The timing of three gait events, i.e.,[1] feet adjacent,[2] maximum speed of swinging foot, and[3] the trunk climbing to its highest point in mid-stance, was determined for extracted steps during steady-state gait. In severe PD, 74.9 ± 21.7% of steps was timetabled so that the swinging leg and the stance-phase leg became side by side before the trunk rose to its highest point to achieve 'foot clearance'. This pattern was significantly less prevalent in mild PD and controls. An altered timetable of gait cycle events may provide quantitative indices of gait disability during steady-state walking in patients with PD.

Key words : timetable, gait cycle, Parkinson's disease, overhead image, foot path

1.INTRODUCTION

Gait disturbance is one of the major symptoms in Parkinson's disease (PD) but is not necessarily easily quantifiable in routine clinical examination [1-3]. During past decades, well-trained researchers have biomechanically analyzed gait under controlled conditions in fully equipped laboratories in individuals with or without gait disturbances [4-7]. However, it remains uncertain if the results of these studies can explain real-life gait problems occurring in PD patients. Complex procedures and use of specialized equipment are seldom possible in routine clinical practice. To overcome these limitations and expand the ability to differentiate pathological from normal variations, an easy and reliable procedure for the quantification of gait problems is required.

This study aimed to identify quantitative indices of gait disability in PD patients walking in a natural manner. For this purpose, a velocity-based algorithm was used to measure small fluctuations in the timetable of high-speed gait events during steady-state gait

2. MATERIALS AND METHODS

2.1. Subjects. Patients with idiopathic PD were rated according to the Hoehn & Yahr (H & Y) disability score [8] and tested while clinically on. Patients with an H & Y score of 3 or 4 (n=10; age 63.5 ± 5; onset age 55.7 ± 6; disease duration 7.9 ± 2.4 years) who had postural instability and were physically independent were classified as having severe PD, while those with an H & Y score of 2 or less (n=10; age 65.5 ± 8; onset age 59.7 ± 6; disease duration 5.8 ± 3.1 years) without impairment of balance were classified as having mild PD. Ten subjects without motor disturbances (n=10; age 65.1 ± 6 years) served as controls. The Nara Medical University Ethics Committee approved the study, and informed consent was obtained from all participants before study entry.

2.2. Gait cycle event analysis. The subjects were instructed to mount a camera on the ventral aspect of the trunk and to walk at their own pace for 10 meters or more (Fig. 1A) . The system used in this study collected kinematic data at a frame rate of 240 Hz. Overhead images of foot paths were analyzed to geometrically describe motion in terms of displacement and velocity, using DIPP-Motion Pro2D software (Ditect Co., Tokyo, Japan) . Test steps were extracted from steady-state walking, and the swing phases of the legs and displacements of the foot path were recorded (Fig. 1B, 1C) . The frame in which the feet were closest, concurrently evaluated by visual inspection was labeled 'feet adjacent' (FA or fa) (Fig. 1D) . Fig. 1E. shows the velocity-based algorithm of the gait cycle and the annotation Q (or q) refers to the time of the maximum speed of the left (or right) swinging foot. The right (or left) foot during the

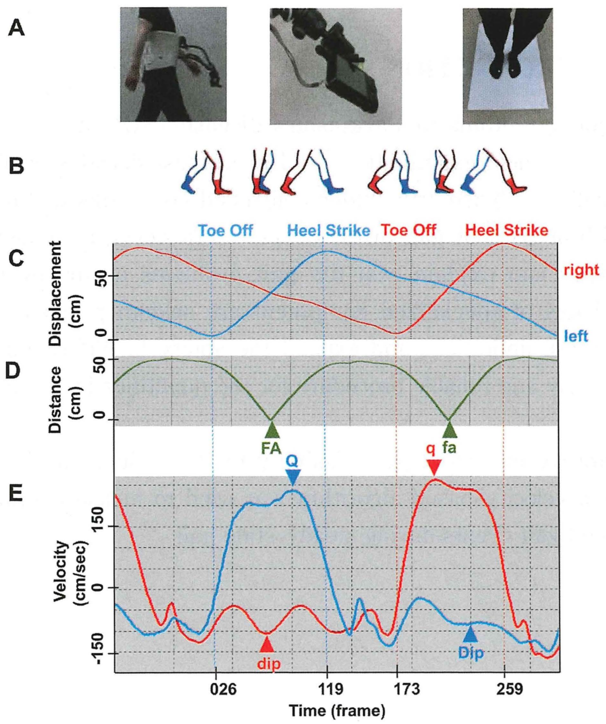

Fig.1. Overhead view of foot motion in a 59-year-old healthy man.

A. A digital camera is attached to the man. The camera (EX-FC200S, Casio Computer Co., Ltd., Japan) is mounted using a flexible camera tripod (GorillaPod Camera Tripod Focus, Ballhead X, Ballhead, JBOY, San Francisco, CA) . Color markers on the forefeet and a square calibration sheet (4 control points, 60 X 84 cm) were used for geographic analysis.

B. Consecutive swing phases of the left and right legs.

C. Displacement of foot path.

D. The side-to-side distance between the feet. The frame in which both feet were closest was labeled 'feet adjacent' (FA or fa) .

E. Velocity-based algorithm of the gait cycle. The annotation Q (or q) refers to the time of the maximum speed of the left (or right) swinging foot. During the swing phase of the left foot, 'dip', FA, and Q occurred in this order. During the swing phase of the right foot, q, fa, and 'Dip' occurred sequentially.

stance phase shows a double hump, which results from the forward speed of the body during early stance. There is a transitional reduction in forward speed as the body moves over the leg in mid-stance, and a second peak, resulting from the body's forward speed in late stance. That transitional reduction termed 'dip' (or 'Dip') corresponds to the time around which the trunk climbs to its highest point, for 'feet adjacent', of the foot swing phase [3, 9, 10]. Fig. 2 shows the step timetable on an x, y coordinate system. Negative X values mean that the swinging leg and the stance-phase leg are side by side before rising of the trunk. Positive Y values mean that the swinging foot attained its highest speed before 'feet adjacent'.

2.3. Statistical analysis. For continuous variables, results are expressed as means ± SD. Scheffé post-hoc tests were used to compare mean age and prevalence of steps in each quadrant among the three groups. The onset and duration of disease were compared between the severe PD group and mild PD group with the use of the Mann-Whitney test. All statistical analyses were performed with Stat View-J 5.0.

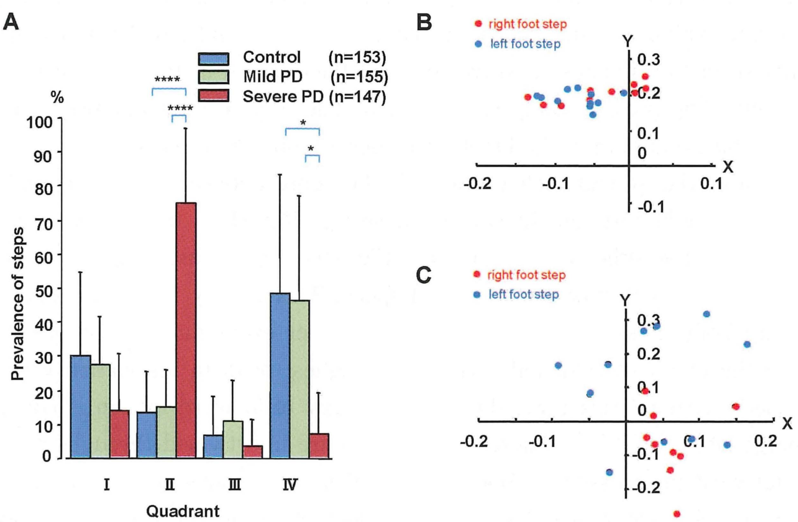

Fig. 2. Step timetable on an x, y coordinate system.

X and Y coordinate values of left steps were calculated using the following two equations:

X = (FA - dip) / left foot swing period,

Y = (FA - Q) / left foot swing period.

For the right foot swing period, q, fa, and 'Dip' were used instead. Frame number was used as a temporal unit. The interval between frames corresponds to 4.17 milliseconds.

A. Prevalence of steps taken in each quadrant by patients with severe PD, patients with mild PD, and normal controls. Data are means ± SD. *p<0.05, ****p < 0.0001 by Scheffé post-hoc-tests.

B. Step quadrant profile of a 68-year-old man with severe PD (H & Y score 4) . 17 of 21 steps were located in the second quadrant.

C. Step quadrant profile of a 68-year-old man with mild PD (H & Y score 1) . 16 of 19 steps were located in the first or fourth quadrants, and only 3 of 19 steps were located in the second quadrant.

3. RESULTS

The severe PD group showed a significant increase in the prevalence of steps in the second quadrant as compared with the control ($p < 0.0001$) and mild PD ($p < 0.05$) groups (Fig. 2A) . Negative X values were −0.13 ± 0.07 for severe PD (n=97) , −0.09 ± 0.07 for mild PD (n=26) , and −0.05 ± 0.03 for control (n=23) . The calculated lag thus showed that the trunk is significantly delayed in rising to its highest point at 'feet adjacent' in severe PD as compared with mild PD ($p < 0.05$) or control ($p < 0.0001$) . In representative patients with severe or mild PD, presentation of steps in terms of quadrants clearly demonstrated step profiles characterized by incoordination, asymmetry, or step-to-step variations. (Fig. 2B, 2C)

4. DISCUSSION

The present study was designed to identify a quantitative index that could be used to evaluate gait problems in PD patients while walking as naturally as possible. It was potentially important that steady-state walking reduced intra-subject variability, and 240 Hz kinematic collection provided high-resolution images sensitive to small fluctuations in the timetable of high-speed gait cycle events. The present study provides a unique way to interpret the timetable of gait events by applying event data in the kinetic interplay of foot movements.

As a temporal marker of gait cycle events, FA (fa) represents the time of 'feet adjacent' when the body's entire weight rests on the stance-phase leg (Fig. 1D) . In addition, a velocity-based algorithm identified two other event markers (Fig. 1E) : one was Q (q) , the time at which the swinging foot attained maximum forward speed. This energy movement likely affects the axis supporting body mass and body gravity. The other event marker was 'Dip' ('dip') , the time at which the trunk transitionally rises to its highest point in association with a reduction in forward speed. Around this time, the kinetic energy of forward motion is converted to the potential energy of height [2, 9, 10]. These three events are intertwined throughout steps and are involved in forward progression of body weight over the stance-phase foot, as well as limb advancement and 'foot clearance'. Estimation of fluctuations in the timetable of events might thus provide quantitative indices of gait disability during steady-state walking.

In the patients with severe PD (H & Y score 3 or 4) , 74.9 ± 21.7% of steps were timetabled so that the two feet rapidly became adjacent before the trunk transitionally rose. Consequently, the swing leg is unable to smoothly pass the stance leg (Fig. 2A, 2C) . As shown in the representative patients, an x, y coordinate system facilitates understanding of walking problems such as asymmetry, incoordination, and step-to-step variations in individual subjects (Fig. 2B, 2C) . Previous studies have reported that the trunk climbs to 20 mm above its mean level in mid-stance, and the toes normally clear the ground by very little, with a mean clearance of 14 mm around the time the feet are adjacent [9, 10]. An identical timetable was significantly less prevalent in mild PD (15.2 ± 10.0%) and controls (13.6 ± 11.9%) , and most steps were located in the first and fourth quadrants when trunk climbing preceded 'feet adjacent' (Fig. 2A, 2B) . There was considerable variation in the timing of the highest speed of the swinging foot among individuals. The lack of significant differences in current age, age at disease onset, and disease duration between the severe and mild PD groups (Mann Whitney test) indicated that timetable fluctuations represent pathological and not normal aging processes.

Taken together, our results suggest that the altered timetable of 'feet adjacent' and trunk rise underlie walking difficulty in PD patients. The present algorithmic analysis provides a way to screen for and to quantify gait disability and expands the possibilities to differentiate between pathological and normal variability of the gait-balance control system in PD patients.

CONFLICT OF INTERESTS

The authors have no conflict of interests.

REFERENCES

1) Giladi, N., McMahon, D., Przedborski, S. , Flaster, E. , Guillory, S. , Kostic, V. and Fahn, S.: Motor blocks in Parkinson's disease. Neurology **42**: 333–339, 1992.
2) Morris, M. E., Iansek, R., Matyas, T. A., and Summers, J. J.: The pathogenesis of gait hypokinesia in Parkinson's disease. Brain **117**: 1169–1181, 1994.
3) Perry, J.: Gait Analysis Normal and Pathological Function. Slac 1992.
4) Hausdorff, J. M.: Gait dynamics in Parkinson's disease: common and distinct behavior among stride length, gait variability, and fractal-like scaling. Chaos **19**: 026113, 2009.
5) Nieuwboer, A., Dom, R., De Weerdt, W., Desloovere, K., Janssens, L., and Stijn, V.: Electromyographic profiles of gait prior to onset of freezing episodes in patients with Parkinson's disease. Brain **127**: 1650–1660, 2004.
6) Hass, C. J., Waddell, D. E., Fleming, R. P., Juncos, J. L., and Gregor, R. J.: Gait initiation and dynamic balance control in Parkinson's disease. Arch Phys Med Rehabil **86**: 2172–2176, 2005.
7) Moore, S. T., MacDougall, H. G., and Ondo, W. G.: Ambulatory monitoring of freezing of gait in Parkinson's disease. J Neurosci Methods. **167**: 340–348, 2008.
8) Hoehn, M. M., and Yahr, M. D.: Parkinsonism: onset, progression, and mortality. 1967. Neurology **51**: S11–26, 2001.
9) David, L., Richards, J., and Whittle, W. M.: Whittle's Gait Analysis. Elsevier Limited. Oxford, 2012.
10) Murray, M. P.:Gait as a total pattern of movement. Am J Phys Med **46**: 290–333, 1967.